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THE ROLE OF PUBLIC RESEARCHER MOBILITY FOR INDUSTRIAL INNOVATION

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Abstract
Scientific knowledge is an important ingredient in the innovation process. Drawing on the literature on the relationship

between science and technology, organizational learning theory, and the absorptive capacity perspective, this paper scrutinizes the importance of mobility of university scientists for firms' innovative activities. Combining patent data and matched employer-employee data for Danish firms, we are able to detect nearly all labor mobility of R&D workers for an entire economy from 1999 to 2004. We find that firm joiners contribute more to innovative activity than stayers. We also observe that newly hired university researchers give a stronger contribution to innovative activity than newly hired recent graduates or joiners from firms, but only when firms have recent experience in hiring university researchers. Moreover, we find that firms' recent experience in hiring university researchers enhances the effect of newly hired recent graduates' contribution to innovation.

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THE ROLE OF UNIVERSITY SCIENTIST MOBILITY FOR INDUSTRIAL INNOVATION

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ABSTRACT. Scientific knowledge is an important ingredient in the innovation process. Drawing on the knowledge-based view of the firm and the literature on the relationship between science and technology, this paper scrutinizes the importance of university scientists' mobility for firms' innovative activities. Combining patent data and matched employer-employee data for Danish firms, we are able to track the labor mobility of R&D workers from 1999 to 2004. We find that new joiners contribute more to innovative activity in the focal firm than long-term employees. Among new firm recruits, we observe that newly hired university researchers contribute more to innovative activity than newly hired recent graduates or joiners from firms, but only if the firm has a high level of absorptive capacity in the form of recent experience of hiring university researchers. Moreover, we find that firms' recent experience of hiring university researchers enhances the effect of newly hired recent graduates' contributions to innovation.

KEYWORDS: Innovative activity, the science-technology relationship, labor mobility.

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ABSTRACT. Scientific knowledge is an important ingredient in the innovation process. Drawing on the knowledge-based view of the firm and the literature on the relationship between science and technology, this paper scrutinizes the importance of university scientists' mobility for firms' innovative activities. Combining patent data and matched employer-employee data for Danish firms, we are able to track the labor mobility of R&D workers from 1999 to 2004. We find that new joiners contribute more to innovative activity in the focal firm than long-term employees. Among new firm recruits, we observe that newly hired university researchers contribute more to innovative activity than newly hired recent graduates or joiners from firms, but only if the firm has a high level of absorptive capacity in the form of recent experience of hiring university researchers. Moreover, we find that firms' recent experience of hiring university researchers enhances the effect of newly hired recent graduates' contributions to innovation.

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Search is considered local when it applies to knowledge that is close to the focal organization's current knowledge base (Helfat, 1994). There are well-known advantages to organizations' conducting local searches in the course of their problem-solving activities—including problem-solving related to innovation—and there are good reasons why local search tends to be prevalent (Nelson and Winter, 1982; Fleming and Sorenson, 2004). However, local search can also potentially be damaging or fatal if organizations become too reliant on it (March, 1991; Levinthal and March, 1993; Tripsas and Gavetti, 2000; Levinthal and Rerup, 2006). An important way of overcoming such local search problems regarding innovation involves private firms' use of science. The role of science and scientists—"philosophers and men of speculation", as scientists once were described[1]—for distant search and consequent innovative activity was noted by Adam Smith as early as 1776 in his *Wealth of Nations*:

[1] See Pavitt (1991: 110).

> Many improvements have been made by the ingenuity of the makers of the machines, when to make them became the business of a peculiar trade; and some by that of those who are called philosophers, or men of speculation, whose trade it is not to do anything, but to observe everything, and who, upon that account, *are often capable of combining together the powers of the most distant and dissimilar objects* in the progress of society, philosophy or speculation becomes …the principal or sole trade and occupation of a particular class of citizens. (Smith, 1976: 10, emphasis added).

Fleming and Sorenson (2004) pointed out that it was not until the second half of the 20th century that researchers began testing this link empirically and developing it further from a theoretical point of view. An early empirical result in the innovation literature established that successful innovations show a closer coupling with the scientific and technological community in relation to the specific innovation project than unsuccessful innovations (Rothwell, Freeman, Jervis, Robertson, and Townsend, 1974).

Our study is concerned with the role of scientific skills in technological innovation in industrial firms. It is located within two streams of the research literature. The first is preoccupied with the role of science (and scientists) in industrial innovation; the second investigates labor mobility among organizational units in the context of innovation. The first the literature focuses on how science, and university scientists, contribute to the innovative efforts of private business firms (e.g., Gibbons and Johnston, 1974; Jaffe, 1989; Liebeskind, Oliver, Zucker, and Brewer, 1996; Cockburn and Henderson, 1998; Spencer, 2001; Fleming and Sorenson, 2004; Gittelman, 2007). Within this research, in a study of the extent of research and development (R&D) knowledge flows at US state level, Jaffe (1989) finds that corporate patenting responds positively to knowledge from academic research, providing evidence of the importance of geographical proximity for shaping the patterns of university-industry interaction. It suggests that the co-location of complementary resources may increase the opportunities for commercialization. Fleming and Sorenson (2004) point to the advantages of scientific thinking in technological search. They show that patents are more frequently cited if they contain references to scientific papers and if the frequencies of patent subclasses appearing in combinations with other subclasses on other patents are high (the authors refer to this as "coupling"). In the context of high levels of coupling, Fleming and Sorenson argue that scientific knowledge and methods can serve as a "map" that helps structure the search process more systematically.

The second strand in the literature focuses on labor mobility as a source of knowledge spillovers for innovative activity (e.g., Almeida and Kogut, 1999; Rosenkopf and Almeida, 2003; Song, Almeida, and Wu, 2003; Tzabbar, 2009; Corredoira and Rosenkopf, 2010; Kaiser, Kongsted, and Rønde, 2011; Singh and Agrawal, 2011). For example, Rosenkopf and Almeida (2003) examine pairs of firm and show that dyads involved in high levels of mutual labor mobility are involved also in larger knowledge flows. As a consequence, inter-firm collaboration through alliances, combined with inter-firm labor mobility might help to overcome the local search problem referred to above. Also, Tzabbar (2009) shows that the recruitment of technologically distant scientists is positively associated with firm-level technological repositioning. In a paper that uses the Danish register data employed in our study, Kaiser, Kongsted and Rønde (2011) study the mobility of workers across private sector employers. They find that workers who transfer to a new firm from a previous employer that was involved in patenting, contribute substantially to the new employers' stock of patents. They contribute more than joiners from non-patenting firms and immobile workers. Their main finding is, however, that workers who leave to a patenting firm also appear to contribute to the patenting activity of their previous employer.

While both of these streams of research have produced important insights, they have some major limitations. The contributions in the first strand of literature do not explicitly model the mechanisms by which industrial firms gain access to academic science and/or do not analyze how this access affects firm-level outcomes. The second strand of research explicitly models a mechanism (labor mobility), but typically looks at hirings from other industry firms, not from universities. Also, it looks at how labor mobility affects hiring firms' technological search processes (reflected in patent citations), not at how the innovative output of hiring firms is affected. Lastly, this literature predominantly relies on patent data for measuring mobility of R&D workers. This implies that only individual inventors whose names appear on patents registered before and after a move will be counted as mobile.

The present study should fill some of these gaps in the literature by analyzing the effect on private sector firm-level innovation of recruiting R&D workers from universities, controlling for inward mobility of labor from other types of organizations. To our knowledge, this paper is the first to study this effect. Empirically, we can trace all mobility of R&D workers for an entire economy, not just movements of persons appearing on patents before and after a move. The paper draws on the knowledge-based view of the firm and the literature on the relationship between science and innovation, to examine the importance of mobility of university scientists for firms' innovative activities. Using these elements, we build a theory whose basic proposition is that firms' hiring of university researchers can provide important support for boundary-spanning search that leads to more firm-level innovation. However, while university scientists often interact with private firms on the basis of aligned economic interests, they operate under very different incentive systems which reward the disclosure rather than the exploitation of knowledge (Dasgupta and David, 1994; Gittelman and Kogut, 2003; Breschi, Lissoni, and Montobbio, 2008). Therefore, there are significant initial costs involved in hiring university scientists. For this reasons we hypothesize that absorptive capacity reflected in experience of hiring university scientists in the past, is of central importance in order to benefit from such recruitment.

We use a unique register data set on the entire population of Danish firms and their employees for the period 1999 to 2004. These data allow us to measure the average innovation effects of public R&D workers moving to private firms. We link these data to the number of patent applications made by each firm to the European Patent Office (EPO), which we use as our innovation measure. The analysis focuses on firms that employ at least one R&D worker since these firms are more likely to patent. It is based on 16,531 observations for 5,714 firms. The econometric analysis takes account of state dependence—past innovative activity is likely to have an impact on present innovation, and unobserved firm-specific time-invariant heterogeneity—some firms may be inherently better at innovating than others, based, perhaps on better management of R&D. We investigate the extent to which science or engineering graduates who join a private firm after taking up a research position in a university after graduation ("university researchers") contribute to the innovative output of the firm they join. We also consider the effects of recent science or engineering graduates who join a private firm after graduation ("recent graduates"). We contrast these effects with the effects of R&D workers who either join from another firm ("firm joiners") or remain with the same employer ("stayers"). In line with the literature, we find that firm joiners contribute more to innovative activity than stayers, that is, in the context of innovation, firms can engage in explorative learning through inward mobility of researchers. More importantly, we find that newly hired university researchers make a bigger contribution to innovative activity than newly hired recent graduates or joiners from other firms, but only if the hiring firm has recent experience of hiring university researchers. In addition, we find that firms' recent experience of hiring university researchers enhances the effect of newly hired recent graduates' contribution to innovative activity.

EMPIRICAL AND THEORETICAL BACKGROUND

A long tradition in innovation studies (Schumpeter, 1912/1934; Nelson and Winter, 1982; Kogut and Zander, 1992; Fleming and Sorenson, 2004) proposes that innovation can be conceptualized as the result of the novel integration of previously separate bodies of knowledge that has commercial application. The knowledge-based view posits that a firm's competitive advantage depends on its ability to combine previously separate bodies of knowledge, and that this new knowledge can be fruitfully recombined into innovations through a learning process that depends on the level of the given firm's "combinative capabilities" to synthesize and apply current (firm-internal) and acquired (external) knowledge (Kogut and Zander, 1992). We build on this approach and examine the ability of firms to create new knowledge through the recombination of knowledge across organizational boundaries by using firms' existing knowledge combined with new knowledge acquired through worker mobility. In particular, we focus on the knowledge reconfiguration capabilities of firms by looking at the inward mobility of university scientists.

The starting point for our analysis is that human capital is mobile since employees are generally free to quit and take up a new job at will and will carry with them some part of the knowledge developed in the previous employer (Liebeskind, 1997; Agarwal, Echambadi, Franco, and Sarkar, 2004; Campbell, Ganco, Franco, and Agarwal, 2012). We assume also that university scientists and other R&D workers are willing to move. The reasons commonly cited for university scientists moving into employment in industry are higher salaries, and in some cases, better research funding opportunities (see e.g., Roach and Sauermann, 2010), although this is not a central concern in the present paper.

We adopt Nelson and Rosenberg's (1994) view that most research conducted in universities is basic research, aimed at understanding phenomena at a relatively fundamental level, although this is not to imply that such research is unaffected by the pull of important technological problems and objectives. Nelson and Rosenberg (1994: 346) suggest that a fruitful division of labor between universities and industry has emerged:

> Universities have taken the responsibility for training young professionals, most of whom will go on to work in industry. And they have performed much of the research that has led to theories, concepts, methods and data that are useful to industry in the development of new products and processes. In some fields this has involved developing and experimenting with pilot versions of radically new products and processes, as well as research into fundamental scientific questions relating to what is going on inside some particular industrial technology. But by and large it has not involved putting academics in the position of having to make commercial judgments.

They also suggest that the major share of industry R&D is directly to shorter term problem-solving, design and development, because the payoffs from basic research are long-run and difficult to appropriate. For these reasons, industry performs very little basic research and undertakes relatively little training of scientists to provide academic research skills. Given that science is concerned mostly with explorative learning, firms often find science and scientific skills extremely useful complements to internal capabilities in working on innovations, although these more academic skills can be problematic for profit-motivated firms for the reasons outlined below.

HYPOTHESES

Boundary-spanning through general labor mobility. Our first hypothesis can be considered a "baseline hypothesis" because it corresponds to what is implied in the innovation and labor mobility literature (Rosenkopf and Almeida, 2003; Song et al., 2003; Singh and Agrawal, 2011), although this literature focuses on the effect of mobility on knowledge flows, and not on the level of innovative activity, the focus of the present paper. Innovative activities are largely firm-specific, local and cumulative, making inter-organizational transfer of pertinent knowledge difficult (Dosi, 1988; Szulanski, 1996). However, as Dosi (1988) notes, this does not imply that the skills and tacit knowledge related to innovation are entirely immobile since "People can be hired away from one firm to another" (p. 1131), enabling their transfer.

The innovation literature (Pavitt, 1988; Cantwell, 1989; Helfat, 1994; Stuart and Podolny, 1996; Tripsas and Gavetti, 2000) suggests that initially, the members of an organization should search for innovative solutions for new processes, products, and services in areas where the organization already has expertise. Nelson and Winter (1982: 9-10) refer to organizations being "typically much better at the tasks of self-maintenance in a constant environment than they are at major change, and much better at doing 'more of the same' than they are at any other kind of change". In other words, learning is easier if it is restricted to the familiar (Cohen and Levinthal, 1990). The problem with firm-internal ("local") sources of inputs to the innovation process is that—on their own—they tend to provide limited inspiration and variety for resolving innovation-related problems; the local search environment is narrow in terms of the opportunities for the combination and recombination of knowledge (Rosenkopf and Nerkar, 2001;

Chesbrough, 2003; Fleming and Sorenson, 2004; Laursen and Salter, 2006; Rothaermel and Alexandre, 2009). Given that the previously stated definition of innovation involves the novel integration of previously separate bodies of knowledge, the availability of variety becomes central (Metcalfe, 1994). By definition, in-house sources of knowledge variety are limited, but beyond the boundaries of the focal organization are many. In terms of mobility of R&D workers, inward mobility offers the hiring firm access to parts of the organizational routines and knowledge bases of the previous employing organization, which most likely are different from those of the focal firm. These internal and external elements can often be fruitfully recombined to produce innovation (Kogut and Zander, 1992). In sum, we hypothesize that:

Hypothesis 1: Firm joiners contribute more to innovative activity than stayers.

The benefits of hiring university scientists for innovative activity. The literature on the role of university science for industrial innovation identifies several benefits (see, Pavitt, 1991; Salter and Martin, 2001). These benefits can be derived from hiring human capital in the form of university researchers since this arguably is an important channel for the transmission of science. Certainly, knowledge transfers in the context of the links between basic science and technology "are mainly person-embodied, involving personal contacts, movements, and participation in national and international networks" (Pavitt, 1991: 112). We can distinguish three major benefits: 1) that industry-employed scientists can play a direct and important role in technological problem-solving, based on their scientific knowledge; 2) that industry-employed scientists can exploit their social networks in the university system in the context of their technological problem-solving activities; and 3) that scientists can apply their general research skills and techniques to technological problems. Note that these benefits overlap, but for analytical reasons we consider them as separate.

Regarding the first benefit, and as indicated by Nelson and Rosenberg, given that science is basically concerned with explorative learning, scientific knowledge is often directly useful for technological problem-solving in private firms. For instance, the general principle related to a pharmaceutical drug may be scientific knowledge, but the artifact only becomes a commercial product after a process in which scientific and technological knowledge interact. In this context, Gibbons and Johnston (1974) found that a particularly important role played by scientists was that of "translating" information from scientific journals into a form meaningful to industry problem-solvers. In relation to the second benefit, industry-employed scientists formerly employed at universities can utilize their social networks in the university system when they engage in technological problem-solving activities. It may not be that the newly hired university scientists solve a difficult innovation-related problem through their own efforts: the inspiration for problem-resolution may come from former colleagues employed in a university. One of the respondents in Gibbons and Johnston's (1974: 238) study noted that:

> Whenever we had a knotty problem I knew I could always go up to the uni (sic) and talk it over with the electronics people I knew from the old days, and what's more use their equipment and library. I kept this quiet and I got a reputation as the man to see with a difficult problem.

In relation to the third benefit, the literature demonstrates that scientists can apply their general research skills and techniques to technological problems. Gibbons and Johnston (1974) found that when presented with a problem the scientist may be able to provide a direct solution, but more often will be to suggest alternative ways that the problem might be tackled, to reduce the range of considerations or to provide equipment and procedures to test the feasibility of an industry generated solution. At a more general level, Fleming and Sorenson (2004) argue that scientific knowledge can lead to very different types of searches than local technological search, by providing inventors with the equivalent of a map, or stylized representation of the area to be searched. Scientific knowledge differs from knowledge derived from technological practice predominantly because scientific activity most often involves generation and testing of theories. As Fleming and Sorenson (2004) explain, science attempts to explain why phenomena occur, providing a means for predicting the results of untried experiments and the usefulness of previously uncombined configurations of technological components. Having an understanding of the fundamental problem, or what Fleming and Sorenson describe as a map, likely alters inventors' search processes by leading them more directly to useful combinations, eliminating fruitless research directions, and motivating them to persevere even in the face of negative results.

We argue that, given the potentially major benefits to industry firms of combining scientific knowledge, skills and techniques with technological problem-solving activities, hiring university scientists should have a stronger effect on innovation activity than recruiting recent graduates and joiners from other firms. Recent graduates have much less scientific experience and poorer involvement in scientific networks than newly hired university researchers, and for those reasons, have less "science" to offer the firm. Joiners from other firms will contribute knowledge, skills and techniques that are mostly similar to those owned by the focal firm. As Song et al. (2003) note, researchers hired from other firms are likely to exhibit local search behaviors and attempt to innovate in technological areas close to their existing knowledge (i.e. the old firm's knowledge). These arguments suggest that:

Hypothesis 2: Newly hired university researchers make a larger contribution to innovative activity than newly hired recent graduates or joiners from other firms.

The costs of hiring scientists: Investments in absorptive capacity. While the benefits to industry firms of science and of recruitment of university scientists are evident, hiring scientists does imply some non-trivial costs on the part of the recruiting firm (in addition to the usual pecuniary costs of new hires). These non-trivial costs are related to the fact that it may be difficult for firms to integrate university scientists into the firm's local knowledge production. The costs involved in crossing the boundary between science and technology are related to fundamental differences between the structures of the knowledge production in these spheres. Science and technology are similar, in that they use similar inputs (scientists, engineers, laboratories) and produce similar outputs (knowledge) (Pavitt, 1991). In addition, there are famous examples of exceptional science performed in the laboratories of large industrial firms (Rosenberg, 1990). However, as Pavitt (1991) highlights, these observations neglect the very different nature and purpose of the core activities of university and business laboratories.

According to Dasgupta and David (1994), what fundamentally differentiates scientific and technological knowledge is the nature of the goals that are accepted as legitimate by the two communities of researchers, and the norms of behavior with regard especially to the disclosure of knowledge and features of the reward systems in place. Based on these goals, norms and incentives, academically trained scientists tend to have a strong "taste for science" and a preference for basic research, for freedom to choose research projects, and disclosure of research results through publications (Stern, 2004; Roach and Sauermann, 2010). In addition, while industry may often need scientific insights to resolve technological problems or to identify new ideas, firms do not gain directly from contributing to important scientific questions (Gittelman and Kogut, 2003; Lacetera, 2009). These observations suggest that employing university scientists in industrial settings may be challenging for profit-oriented business firms.

Certainly, industrial firms, in many cases, respond by allowing employees with academic backgrounds to be involved in academic activities, including publishing (Rosenberg, 1990; Cockburn and Henderson, 1998; Roach and Sauermann, 2010). Despite these efforts, integrating individual scientists into the innovative activities of for-profit firms can be difficult and reveal underlying tensions. Accordingly, the ability to utilize these potentially valuable knowledge inputs needs to be acquired through a laborious and painstaking process. In our setting this observation translates into firms requiring a certain level of absorptive capacity in order to assimilate university scientists and the important knowledge and skills they confer. Cohen and Levinthal (1990: 128) argue that a firms' absorptive capacity is "largely a function of the level of prior related knowledge." We use this argument to support the idea that firms that have recruited university scientists in the recent past are more likely to have learnt how to integrate them in the firm's knowledge production activity. Firms that have recruited scientists in the past are likely to have learnt to deal with the difficulties related to employees unaccustomed to the goals, norms and incentives of for-profit organizations. Thus, we hypothesize that:

> Hypothesis 3: Firms' recent experience of hiring university researchers enhances the effect of newly hired university researchers' contributions to innovative activity.

Hiring experience and recent graduates. In their review of the literature on the economic benefits of publicly funded basic research, Salter and Martin (2001: 522), conclude that "[m]any studies of the economic benefits of publicly funded research identify skilled graduates as the primary benefit that flows to firms" because new graduates entering industry bring knowledge of recent scientific research and also scientific skills and techniques. However, recent graduates inevitably have less scientific experience and are not so deeply embedded in scientific networks as newly hired university researchers. These shortcomings are less important if the hiring firm has also recently employed university scientists, who in their new employment out of academia can train the recent graduate recruits and include them in their professional scientific networks. In other words, we suggest there is a complementary relationship between industrial firms' recent university researcher hiring experience and their recruitment of recent graduates:

> Hypothesis 4: Firms' recent hirings of university researchers enhances the contribution to innovative activity from newly hired, recent graduates.

METHODS

Data

In this section we discuss the data sets from which we draw our final data, and how we define R&D active and inactive firms, R&D workers from non-R&D workers, and mobile workers and immobile workers.

Patent data. Our first set of data is all patent applications filed with the EPO, with at least one Danish applicant, since 1978 (the date when EPO was established). There data are taken from EPO's "Worldwide Patent Statistical Database" or "PatStat" database.[2] This data set is critical since our measure of innovation is patent counts. Although patent counts are clearly imperfect proxies for real innovative activity (Arundel and Kabla, 1998), they provide a proxy for the intermediary output, R&D, are representative of one specific invention (patent applications refer to single inventions) and can be related to patent value correlates (Trajtenberg, 1990). Patent counts are used extensively the management (Stuart and Podolny, 1996; Almeida and Kogut, 1999; Song et al., 2003) and the economics (Griliches, 1990; Blundell, Griffith, and van Reenen, 1995; Kim and Marschke, 2005) literatures. Our data end in 2004 due to lags in reporting at the EPO.

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[2] See http://www.epo.org/patents/patent-information/raw-data/test/product-14-24.html.

Matched employer-employee data. We use matched employer-employee information provided by Statistics Denmark. Note that our data set includes the whole population of Danish firms and workers not a selected sample. The database is acknowledged as a valuable resource for research in the social sciences (see for instance, Albæk and Sørensen, 1998; Sørensen, 2007; Dahl, 2011, as examples of prominent applications of the matched data). The matched employer-employee data are available from 1980. Information on all variables at firm level is available from 1999 onwards. A structural break in the recording of the unique firm identifiers used by Statistics Denmark prevents us from using pre-1999 information.

To create our data set we attached the unique firm identifiers from the firm-level data, to each of the patent applicants in our patent data. This allowed us to match 95 percent of applicants. The unmatched ones refer to firms that went out of business before 1999. These firms would have been lost excluded anyway since our firm-level information begins only in 1999. Since current patent counts are the result of past research efforts, we lag all R&D-related variables by one period as in Blundell et al. (1999). Therefore the effective starting date of the within-sample period is 2000; 1978-99 is a pre-sample period of information on patents used in the estimation (see below).

Using firm identifier numbers, it is straightforward to match patent application and firm-level data, which essentially constitute balance sheet information. We finally matched these data to our employee-level data. The most important pieces of information in that data set is highest level of education attained by an individual worker, and details of current occupation. We use this information to define our population of R&D workers. The employee-level data are aggregated at firm level before being merged. That is, in our estimations, we consider the total number of R&D workers for each firm. We do not use employee-level data in the estimations but we do use this in the descriptive analysis.

Definitions

R&D active firms. We do not consider the whole population of firms since it would be unlikely that firms with no R&D workers would patent (see findings in Kaiser et al. (2008) using similar data). We therefore impose the following restrictions to obtain our final data set: first, the data are restricted to firms with at least one R&D worker. R&D workers are individuals aged between 20 and 75, with a master's or PhD degree in technical sciences, natural sciences, veterinary sciences, agricultural sciences or health sciences, in a job function that requires a "high" (professionals) or "intermediate" (technicians and associate professionals) level of skills.[3] Second, we only include private sector firms (not operating in public service) (although we do consider labor mobility from the public sector). The main estimation results are based on 16,531 firm-year observations of 5,714 unique R&D active firms. A total of 292 different firms patented at least once within our five years 2000-2004.

Knowledge workers. We separate the population of R&D workers into *knowledge-intensive R&D workers* and *R&D support workers*, based on the skill level of their current occupation. The first group defines people working in positions requiring high levels of scientific and technological activity, and are the focus of this analysis. The second group defines workers in positions requiring an intermediate level of scientific and technological activity. R&D support workers are included in our estimations as control variables. We do not discuss them further.

Mobility. We further differentiate among knowledge-intensive R&D workers according to mobility status. We identify movement between non-affiliated firms, and between universities

[3] The information on job function skill levels was retrieved from the International Standard Classification of Occupations (ISCO) published by the International Labor Office, at http://www.ilo.org/public/english/bureau/stat/isco/isco88/publ4.htm

and firms. The types of workers we consider are: (i) *Stayers* who are employed in firm A at time *t* and time *t-1*; (ii) *Firm joiners* who are workers employed in firm A at time *t*, but are employed in firm B at time *t-1*; (iii) *Joiners* from universities are defined as workers employed in firm A at time *t* and at a university at time *t-1*; (iv) *Graduates* are defined irrespective of their previous employment status, and according only to time since graduation. *Graduate*s acquired their R&D-related education in *t-1* and were employed in a knowledge-intensive position at firm A at time *t*.; and (v) *Other joiners* who are employed at firm A at time *t* and whose employment status at *t-1* is unknown.[4] This last group of workers is constituted by R&D support workers who are included only as a control variable and are not differentiated by mobility. Having defined all the relevant worker types, the employer-employee link is used to aggregate the information at firm-level, and for each firm, to determine the share of each R&D worker type.

Recent experience in hiring university researchers: Hypothesis 3 and Hypothesis 4 both relate to firm *j* having "recently" hired a university researcher. We define firm *j* as having recent experience in hiring university researchers if firm *j* has hired at *t*-2. To test Hypothesis 3 we interact this dummy variable with the share of university researchers firm *j* hired at *t*. To test Hypothesis 4, we interact the dummy variable for past experience in hiring university researchers with the share of recent graduates.

Accounting for patent value. In order to account for the skewed patent value distribution (Lanjouw, Pakes, and Putnam, 1998; Harhoff, Narin, Scherer, and Vopel, 1999; Hall, Jaffe, and Trajtenberg, 2005), we weight each patent application by the number of citations received by the patent. More specifically, and following Trajtenberg (1990), we weight each patent by 1 plus the

[4] These are persons who previously were self-employed, were on leave of absence schemes, or entered the country (immigrants) between *t-1* and *t*.

number of citations to the patent within the three-years following the year of EPO publication.[5]

Variables. Our dependent variable is number of patent applications by firm *i* in year *t*. The main explanatory variables are the six different types of R&D workers defined above. We control also for a set of variables conventionally considered to be determinants of patent activity. First, we include the natural logarithm of total number of R&D workers. Second, we include capital stock, measured as the book value of physical capital. Third, we include a set of sector dummies defined according to the two-digit NACE Rev.1 industrial classification. Fourth, we control for regional effects and time-fixed effects using dummy variables. Fifth, we account for possible path dependence in patenting activity by including a dummy variable for patenting in *t-1*. Sixth, we control for firm *i*'s pre-sample patenting history by including the natural logarithm of firm *i*'s patent applications prior to 1999, and a dummy variable for applying for at least patent in the pre-sample period. We discuss the details of our empirical specification in the "Empirical strategy" section.

Descriptive statistics: firm-level data

Table 1 presents descriptive statistics of the dependent and explanatory variables at firm level. It differentiates firms with pre-sample patents, that is, firms with at least one patent application before 1999, and those with no pre-sample patent applications. Table 1 shows that the average firm in our sample applies for 0.29 citation-weighted patents per year. The related citation-unweighted figure is 0.12, which implies that the patents in our data receive an average of 2.4 citations. There are quite pronounced differences between firms with and without pre-sample patenting, with respect to within-sample patenting activity: the average number of patents is more than 36 times higher for firms that have at least one patent prior to 1999 compared to firms

[5] A 5-year time window is often used, but we chose a shorter time bcause our citation data end less than 4 years after the patent data. Our patent citation data are from the "EPO/OECD patent citations database", available from the OECD (Webb, Dernis, Harhoff, and Hoisl, 2005) and covers the period 1978-2006.

with no pre-sample period patent activity.

For the alternative worker shares we consider and for regional affiliation, the differences between firms with and without pre-sample patents are small. Stayers (63.1%) are by far the largest group of R&D workers. Next are support workers at 16.1 percent, then joiners from the private sector at 11.5 percent of total current R&D employment on average. Other joiners and recent graduates account for about 4 percent each of the R&D workforce, while joiners from university research constitute the smallest employment category at 0.8 percent of all R&D workers belonging to that group. The average firm in our data employs about seven R&D workers. Firms with patenting activity prior to 1999 employ 21 R&D workers while firms without pre-sample patents employ about 5 R&D workers. Firms with pre-sample patents also have substantially larger capital stock and tend to be active in more technology-intensive sectors, such as chemicals (including biotech), machinery and electronics.

[Insert Table 1 about here]

The Appendix Table displays the correlation matrix of our explanatory variables. It shows that the correlation between variables is low, a finding confirmed by the mean variance inflation factor (VIF) 1.67, which is well below the critical value of 10 suggested by Belsley et al. (1980).

Empirical strategy

Our empirical framework is a standard firm-level patent production function augmented by including our six alternative R&D worker types. It accounts also for feedback from past to present patenting activity, and for observed and unobserved firm heterogeneity.

The patent production function. We assume that the knowledge production function is Cobb-Douglas (Hausman, Hall, and Griliches, 1984; Blundell et al., 1995). Patent output P depends on labor input L, capital input K and a term A that captures a set of additional control variables.

Labor input is differentiated into joiners from firms, L_J, joiners from university research, L_U, recent graduates, L_G, other joiners, L_O, stayers, L_S and support workers, L_P;$L = L_J + L_U + L_G + L_O + L_S + L_P$. The six different types of R&D labor enter the patent production function as efficiency units as in Hellerstein et al. (1999) as well as in Galindo-Rueda and Haskel (2005). This enables us to estimate each labor type's relative patent productivity. We normalize marginal patent productivities of each labor type by the marginal patent productivity of stayers, L_S, and use natural logarithms to obtain:

$$lnP = \ln A + \beta \ln K + \alpha \ln L + \delta_J s_J + \delta_U s_U + \delta_G s_G + \delta_O s_O + \delta_P s_P, \quad (1)$$

where s_k denotes the share of labor type k, $s_k = L_k/L$, and stayers are the omitted reference category.

Count data models. The dependent variable is discrete and takes the values zero or a positive integer, making a count data model appropriate. The most popular model of this type is the Poisson regression (Cameron and Trivedi, 1986; Winkelmann, 2008) with an exponential mean function, as in Hausman et al. (1984). However, the Poisson model assumes equality between the conditional mean and the conditional variance, that is, equi-dispersion. This assumption is often violated when using patent data (Blundell et al., 1995; Cincera, 1997). This violation does not affect the consistency of the parameter estimates, but does affect estimation precision. The Negative Binomial model allows a more flexible relationship between the mean and the variance. Therefore, to allow for over dispersion in the data we use the Negative Binomial model. The Negative Binomial model is an extension of the more standard Poisson count data model. The Poisson model comes with the somewhat restrictive property that its conditional mean function is equal to its conditional variance which does not affect parameter estimates, but renders the corresponding variance-covariance matrix biased and inconsistent. Tests for equality of mean and variance clearly favor the Negative Binomial model over the Poisson model.

Unobserved heterogeneity. Our specification controls for firm-specific permanent heterogeneity in patenting activity, for example, due to differences in R&D management, different R&D investment appropriability conditions, or different technological opportunities. There are two ways that are commonly used to deal with this problem: fixed effects and random effects models. Random effects are not plausible in our setting since unobserved permanent heterogeneity will most likely be correlated with the regressors. Blundell et al. (1995; 1999) suggest a method to proxy for the unobserved permanent heterogeneity—the "fixed effect". Their "pre-sample mean estimator" is developed for count data models where the information on the dependent variable has a longer history than the information on the explanatory variables. This applies to the case of our data: Patent data start in 1978, but firm-level information (allowing for lags) starts only in 2000. The estimator uses the average of the dependent variable over the pre-sample period as a proxy for correlated fixed effects, for each firm. Hence the key assumption here is that the main source of unobserved permanent heterogeneity in patent productivity is the pre-sample patent stock.

The pre-sample mean estimator relies on stationarity of the dependent variable. However, there is a strong upward trend in number of patent applications; we therefore apply trend adjustment of the proxy variable as suggested by Kaiser et al. (2008). In the practical implementation of the fixed effects proxy variable, we follow Blundell et al. (1995; 1999; 2002) and include the natural logarithm of the pre-sample mean number of patent applications per firm. For firms with no pre-sample patent applications, we substitute an arbitrary small constant as in Blundell et al. (1999). To account for this non-linear transformation and for the patent count being 0 for most firms, we also include a dummy variable coded 1 if the firm has at least one pre-sample patent and 0 otherwise. An alternative way to control for the large share of firms with no pre-sample patents would be to use zero-inflated count data models. These models adjust for zeros by modeling an additional process describing whether the firm patents or not, using the Probit framework. However, this method requires "exclusion restrictions", for example, variables that affect the decision to patent at all, but not the number of patents for proper identification. Further, Staub and Winkelmann (2009) show that, unlike the Negative Binomial model, zero-inflation models are not robust to misspecifications of the data-generating process.

State dependence. We control finally for possible state dependence in patenting activity. Blundell et al. (1995) include firm *i*'s discounted patent stock as an explanatory variable. We follow the approach in Crépon and Duguet (1997) and introduce state dependence by including a dummy variable for patenting activity in *t-1* rather than patent stock, since this emphasizes recent patenting activity and circumvents collinearity problems by using fixed effects proxy variables.

RESULTS

Table 2 presents our estimation results. Note that the coefficient estimates relate to the R&D worker shares shown in Table 2 do not translate directly into marginal effects as in OLS models. What is directly interpretable, however, is their effect on patenting activity relative to the reference group of workers, R&D stayers. A positive coefficient of any of the five worker group shares included in the estimation indicates that the respective worker group contributes more to innovation than R&D stayers. Two of our hypotheses (1 and 2) imply multiple comparisons, and therefore need tests of joint significance. For example, Hypothesis 1 refers to three types of joiners (firm joiners, university researchers, university graduates) whose effect on patenting is compared to the contribution of stayers. We test separately for each of these mobile labor types' contribution to patenting compared to stayers, and apply joint tests for firm joiners, university researchers and university graduates contributing more than stayers.

The results from the joint tests of significance and the findings related to Hypothesis 2 (which compares university researchers with firm joiners as well as university graduates) are displayed in Table 3.

[Insert Table 2 about here]

Hypothesis 1 states that firm joiners contribute more to innovative activity than stayers. Table 2 Model I shows that the effects of joiners from firms, other joiners and university researchers are all positive and significantly different from the effect of stayers in affecting innovative output, while graduate joiners and support workers are not. When we look at the joint effect (stayers vs. the three different types of joiners; see Table 3), the hypothesis finds clear support because the joint test is significant at the 1 percent level. The results are also consistent with Hypothesis 2 that newly hired university researchers make a bigger contribution to innovative activity than newly hired recent graduates or joiners from (other) firms. First, the coefficient of share of university researchers is large and significant at the 1 percent level (see Table 2, Model I). Second, (see Table 3), the joint test for effect of hiring university researchers compared to the effects of newly hired recent graduates and joiners from firms is significant at the 5 percent level.

[Insert Table 3 about here]

We find support for Hypothesis 3 that firms' recent hiring of university researchers enhances the contribution of newly hired university researchers to innovative activity. Table 2, Model II, shows that the effect of the share of newly hired university researchers at *t-1* interacted with the share of recently hired university researchers at *t-2* is positive and significant at the 5 percent level. Note that the main effect of newly hired university researchers at *t-1*, disappears when the interaction term is inserted into the regression. Absorptive capacity hence matters greatly here. Hypothesis 4 proposed that firms' recent experience of hiring university researchers enhances the effect of newly hired recent graduates' contribution to innovative activity. Our results show strong support for this hypothesis: the interaction effect of newly hired recent graduates and the share of hired university researchers at *t-2* is positive and statistically highly significant. In contrast, the coefficient of the non-interacted graduate joiners is statistically insignificant in model II. This indicates that only firms with past experience of hiring university researchers are able to benefit from hiring university graduates, a finding that again highlights the importance of absorptive capacity.

We present marginal effects in Table 4. Marginal effects are the absolute change in the expected number of patent applications due to an increase of one in the number of workers from a particular skill group. The marginal effects are linearly dependent on the number of patents the a firm applies; thus Table 4 provides marginal effects for (i) all firms, (ii) firms with patents in the period under consideration, and (iii) firms with pre-sample patents. It also displays the marginal effects for the specifications with and without interaction with past university hires.

[Insert Table 4 about here]

Starting with the specification without interaction, Table 4 shows that university joiners make the largest contribution to firms' patenting. One additional university researcher leads to 0.09 additional patents, across all firms. The effect is substantially larger for firms with pre-sample patents (0.213 across all firms) and for firms with a patent in the period under consideration (0.361). Both Firm joiners and graduate joiners add 0.04 new patents; there is no statistically significant difference between these two types of workers. The marginal effect for support workers is 0.016. The marginal effects are statistically insignificant for other joiners and R&D stayers.

The marginal effects for the specification with previous hires of university researchers interaction reinforces our finding related to the importance of past hires for innovation. Table 4 shows that the marginal effect of university researchers is 0.201—five additional workers generates one additional patent for firms with past university researcher hires. In contrast, the marginal effect of university researchers is statistically insignificant for firms with no experience of hiring university researchers. We find similar results for recent university graduates. The marginal effect is 0.157 for firms with past university researcher hires and substantially larger than the effect for firm joiners at 0.042. However, firm joiners are the only group that statistically significantly adds to the patenting activity of firms without university researcher hires. The marginal effect is 0.051 for this type of worker across all firms.

Other results are that: (i) the total number of R&D workers and firms' capital stock are positively associated with patenting activity. The corresponding coefficients from Table 2 translate into elasticities: a 1 percent increase in capital stock is related to a 0.16 percent increase in the expected number of patents, and a 1 percent increase in the number of R&D workers is associated with a 0.26 percent increase in the expected number of patents; (ii) past patenting activity has a substantial effect on present patenting activity. The respective coefficient estimate suggests that a firm that patented in *t-1* is about 1.4 times more likely also to patent in *t,* which is evidence of substantial state dependence; likewise (iii) an increase in the number of pre-sample patents leads to an increase in the number of contemporary patents. The related elasticity is 0.34 which is larger than that for of capital stock and number of R&D workers.

ALTERNATIVE EXPLANATIONS AND ROBUSTNESS CHECKS

In this section we discuss whether there may be alternative factors driving our estimation results, and we run some alternative models to check whether our results hold if an alternative sample is considered. Overall, we can conclude that alternatives lead to more conservative estimates. In other words, in the absence of these alternatives, our results would be even stronger. For reasons of space, we do not report the robustness results or alternative explanations.

Alternative explanations for our results include differences in experience and education among worker groups. Mobile workers might be more experienced and better educated than immobile workers (related to Hypothesis 1), and the same might be true of joiners from university research versus recent graduates and joiners from other firms (related to Hypothesis 2); this would provide an alternative explanation for the empirical results we obtained. Regarding Hypothesis 1 detailed inspection of our dataset reveals that the reverse is actually true—mobile workers tend to be less experienced and less well educated than their immobile peers and this holds also for the comparison between recent graduates and joiners from firms.

In comparing joiners from university research and recent graduates, we find clear differences in experience and level of formal qualification, as we would expect. However, both differences can be regarded as integral to the predicted differences in the amount and quality of the scientific and technical human capital accumulated by workers in either group, and thus our descriptive findings are completely consistent with Hypothesis 2. In relation to the timing of moves between academe and industry it seems that most moves from university employment are the result of an unfavorable tenure decision and works against the effect of any positive selection after graduation.

We also observe that firm joiners on average are more experienced than joiners from university research. This effect should work in the opposite direction to our results and hence reinforces our interpretation based on the theoretical model. For the level of education, it is higher among joiners from university research, which is consistent with our interpretation that the differential effect between joiners from university research and firm joiners is driven by higher ability of university scientists to re-combine scientific skills and techniques as well as by a better access to social networks. These considerations all support Hypothesis 2. A final alternative explanation for our findings might be that university researchers and university graduates join particularly patent-intensive sectors. Based on detailed data inspection, this is clearly not the case.

We conducted robustness checks to see whether not applying citation weighting makes a difference to our findings and also to find out whether our results for the interaction model are driven by the small number of observations (1 year of data is lost in that analysis). Our results from the main model in Table 2 are fully supported if citation weights are not applied to our dependent variable although the corresponding coefficient estimates and marginal effects are slightly smaller compared to the specification with citation weights.

If we re-run the baseline specification in Table 2 without interactions, on the interactions data (e.g. we lose 1 year of data) we still find positive and statistically significant effects of university researchers and recent graduates as well as of firm joiners on the number of (citations-weighted) patents. The coefficient estimates for university researchers and recent graduates are almost identical quantitatively, and there is no statistical significance. We can speculate that the reason for this is that the coefficient of university researcher is no longer well identified by our data due to a further reduction in the (already small) number of firms employing university researchers.

This, in turn, would work against our findings regarding the interactions between past university hires and hires of university researcher and hires of recent graduates.

We analyzed to what extent particularly patenting active firms—which may be very relevant in a small economy such as Denmark—and the sector chemicals (which includes biotechnology) which is a particularly patent active sector, matter for the results. The results of this exercise show that neither the exclusion of very patenting active firms nor the exclusion of firms from the chemicals industry substantially affects our estimation results for the baseline model without interactions. The corresponding coefficient estimates and the marginal effects, however, are smaller than for the full data.

CONCLUDING DISCUSSION

This paper started from the proposition that firms' hiring of university researchers can be an important channel for supporting boundary-spanning search which leads to more firm-level innovation. Our empirical approach took into account of state dependence and unobserved firm-specific time-invariant heterogeneity. We found support for the general idea that inward mobility of researchers has a positive effect on the level of innovative activities in private business firms. More specifically, we have demonstrated that newly hired university researchers play a stronger role in affecting innovative activity than newly hired recent graduates or joiners from firms, but only if firms have recent experience hiring university researcher hirings. We observed also that firms' recent experience in hiring university researchers enhances the effect of newly hired recent graduates' contributions to innovative activity.

Our study extends previous research. First, we contribute by extending the theoretical and empirical underpinnings of the resource-based view (RBV) of the firm. The RBV suggests that variations in investment choices regarding resources, drive variations in firm performance.

However, the RBV suffers from an important limitation in that it says little about how firms can identify opportunities and make *ex-ante* investments that become valuable *ex-post*. Although proponents of the RBV acknowledge that recruitment from outside may enable firms to overcome the constraints to firm growth imposed by internal resources and capabilities (Penrose, 1959; Barney, 1991), the theory does not explain how such recruitment helps to generate innovation and value. The knowledge-based view can be seen as an extension to the RBV in stating that a firm's competitive advantage depends on its ability to combine previously separate bodies of knowledge, however, it is not precise about how these elements should be combined to create this competitive advantage. Although we do not solve these general problems, we make a contribution in this direction by providing a set of micro mechanisms that underpin how newly recruited human capital in the form of university scientists can provide important inputs to the innovation process in private business firms.

We contribute also to the organizational learning literature (Levinthal and March, 1993; Rosenkopf and Nerkar, 2001) by establishing theoretically—and corroborating empirically—that recruiting university researchers is an important way to overcome local search problems at firm level. We contribute also by explicitly addressing the important costs of this boundary-spanning search. Empirically, we found only positive effects from hiring recent graduates and university researchers provided that the focal firm has had recent experience of hiring university researchers: In line with the idea proposed by Cohen and Levinthal(1990) (and Rosenberg, 1990, in the context of private firms' absorption of the results of basic research), knowledge is not a public good and requires substantial and specific investment to be absorbed. It can be noted that the effect of absorptive capacity is likely to have been underestimated in our results. It seems likely that the positive effect of hiring the first university scientist is potentially higher than the effect from hiring the n^{th} scientist, given the high potential for knowledge recombination. All other things being equal, this would suggest a negative interaction effect of newly hired university researchers at *t-1* interacted with the share of recently hired university researchers at *t-2*. However, we found a positive effect, indicating that the ability to utilize these potentially valuable sources of knowledge, skills, and techniques needs to be learnt through a laborious and painstaking process. These positive interaction effects seem to matter most for particularly patenting active firms as well as for firms operating in the chemicals industry (which includes biotechnology).

Finally, we contribute to the literature on university-industry interaction. We show that the transfer of knowledge between universities and private business firms is not confined to formal research cooperation and joint research projects, as indicated in most of the literature. Public-private transfer of knowledge is also achieved through mobility of university researchers and recent graduates, which we have shown have economic sizeable and statistically highly significant effect on the innovative activity of private firms.

The findings from this study have implications for managerial practice. For example, the contribution of R&D stayers is small in both absolute and relative terms, which suggests that firms need to devise strategies to keep their worker stock up-to-date regarding recent science and engineering developments. This could include initiatives to facilitate the exchange of knowledge between academia and industry. Obviously, hiring workers from academia will help to reduce the adverse effects of knowledge decay. This prompts the question of there is not more mobility of scientists from university to industry given our finding that the *direct* contribution to patenting activity of stayers is much lower than that of mobile workers. We suggest that the reason might be related to "endogenous absorptive capacity" (Arora and Gambardella, 1990; Cohen and

Levinthal, 1990; Cockburn and Henderson, 1998; Zahra and George, 2002). Certainly, our results suggest that absorptive capacity is of central importance in this context: Firms without prior experience of hiring university researchers find it difficult to integrate them into their knowledge production.

This study has some limitations. As already noted, we model only one particular antecedent to absorptive capacity: Previous experience of hiring and integrating university researchers. While this approach has advantages in our context, future research could model more facets of the notion of absorptive capacity. Also, Fleming and Sorenson (2004) suggest that scientific thinking for performing technological search is more important when technologies are tightly coupled. New research could investigate whether hiring university scientists is more beneficial for firm-level innovative activity in firms working with tightly coupled technologies compared to firms engaged in less closely connected technologies. Insights from this research could provide guidance for management decisions about R&D worker recruitment, and which types of worker will provide the most benefits.

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TABLE 1
Descriptive Statistics

	All obs.		**Obs. w/o pre-sample patent**		**Obs. w/ pre-sample patent**	
	Mean	**Std. dev.**	**Mean**	**Std. dev.**	**Mean**	**Std. dev.**
# Patent applications, citations weighted	0.294	4.375	0.060	1.653	2.239	12.282
# Patent applications, citations unweighted	0.115	0.267	0.117	0.272	0.101	0.218
Dummy for patent at t-1	0.039	0.194	0.010	0.098	0.284	0.451
Share joiners from firms	0.115	0.267	0.117	0.272	0.101	0.218
Share "other" joiners	0.008	0.072	0.008	0.073	0.012	0.065
Share graduate joiners	0.044	0.178	0.046	0.184	0.023	0.111
Share university researchers	0.040	0.160	0.041	0.165	0.035	0.113
Share support workers	0.161	0.331	0.157	0.332	0.192	0.318
ln(capital stock) at t-1	15.170	2.845	14.890	2.744	17.493	2.586
ln(R&D workers) at t-1	0.790	1.079	0.703	0.980	1.516	1.503
ln(adj. # patents in 1990, citations weighted)	-11.119	1.228	---	---	-7.855	1.434
ln(adj. # patents in 1990)	-11.094	1.271	---	---	-7.624	1.229
Dummy for pos. patent stock in 1990	0.108	---	0.000	---	1.000	---
# obs.	16,531		14,750		1,781	

Note: Descriptive statistics for the entire set of observations, for observations of firms with pre-sample patents and those with no pre-sample patents.

TABLE 2
Main Estimation Results

	Model I W/o interactions			Model II W/ interactions		
	Coeff.	**Std. Err.**		**Coeff.**	**Std. Err.**	
Labor type shares (base: R&D stayers) at *t-1*						
Share joiners from firms	0.822	0.196	***	0.987	0.319	***
Share university researchers	1.959	0.504	***	0.382	1.156	
Share "other" joiners	0.267	0.401		-0.443	0.726	
Share graduate joiners	0.847	0.316	***	0.615	0.823	
Share support workers	0.297	0.220		0.273	0.252	
Interactions						
Dummy hired uni.res. at *t-2* * share uni. res. at *t-1*	---	---		3.980	2.044	**
Dummy hired uni.res. at t-2 * share grad. joiners at *t-1*	---	---		2.810	1.250	*
Dummy hired uni. res. at *t-2*	---	---		0.105	0.191	
Other innovative inputs						
ln(capital stock) at *t-1*	0.165	0.034	***	0.157	0.041	***
ln(R&D workers) at *t-1*	0.257	0.057	***	0.218	0.071	***
State dependence & dynamics						
Dummy for patent at t-1	1.394	0.172	***	1.444	0.197	***
ln(adj. # patents in 1990, citations weighted)	0.339	0.082	***	0.312	0.101	***
Dummy for pos. patent stock in 1990	0.222	0.304		0.423	0.419	
# obs. & # unique firms						
# obs.	16,531			10,585		
# unique firms	5,714			3,880		

Note: The dependent variable is the number of the firm's citations-weighted patent applications per year. The estimation results are generated by Pre Sample Mean Estimation. The asterisks and the symbol "†" denote marginal significance levels of 0.1, 1, 5 and 10% respectively. Two-tailed tests for controls, one-tailed tests for hypothesized variables.

TABLE 3
Hypotheses Tests

	W/o interactions			W/ interactions		
	χ^2	dof		χ^2	dof	
H1: firm joiners contribute more to innovative activity than stayers.						
H1a - firm joiners vs. stayers:	17.65	1	***	9.59	1	***
H1b - university researchers vs. stayers:	15.09	1	***	0.11	1	
H1c - university graduates vs. Stayers:	7.19	1	***	0.56	1	
H1 joint:	30.93	3	***	9.82	3	***
H2: Newly hired university researchers give a stronger contribution to innovative activity than recently hired recent graduates or joiners from firms.						
H2a - recent graduates:	4.96	1	**	0.26	1	
H2b - joiners from firms:	3.73	1	*	0.03	1	
H2 joint:	4.99	2	*	0.45	2	
H3: Firms' recent experience in hiring university researchers enhances the effect of newly hired university researchers' contribution to innovative activity.						
	---	---		3.79	1	*
H4: Firms' recent experience in hiring university researchers enhances the effect of newly hired recent graduates' contribution to innovative activity.						
	---	---		5.05	1	**

Note: "χ2" corresponds to a Wald test for (joint) significance. Asterisks and the symbol "†" denote marginal significance levels of 0.1, 1, 5 and 10% respectively. The test results are based on the estimation results displayed in Table 2. "dof" is degrees of freedom underlying the test.

TABLE 4
Marginal Effects at Means

	All obs.		Firms w/ at least one patent		Firms w/ at least one pre-sample patent	
	ME	*p*-val.	ME	*p*-val.	ME	*p*-val.
Specification w/o interaction with past hires of university researchers						
Joiners from firms	0.039	0.000	0.155	0.000	0.094	0.000
Joiners from university research	0.090	0.000	0.361	0.000	0.213	0.000
Other joiners	0.014	0.392	0.054	0.431	0.035	0.383
Recent graduates	0.040	0.002	0.159	0.002	0.096	0.002
Support	0.016	0.045	0.060	0.058	0.038	0.038
Stayers	0.002	0.378	0.006	0.583	0.007	0.219
Specification w/o interaction with past hires of university researchers						
Firms with university graduate hire in t-2						
Joiners from firms	0.042	0.009	0.150	0.016	0.093	0.011
Joiners from university research	0.201	0.016	0.786	0.018	0.460	0.016
Other joiners	-0.025	0.463	-0.120	0.386	-0.062	0.440
Recent graduates	0.157	0.001	0.610	0.001	0.358	0.001
Support	0.008	0.508	0.015	0.766	0.016	0.579
Stayers	-0.005	0.608	-0.037	0.291	-0.014	0.502
Firms without university graduate hire in t-2						
Joiners from firms	0.051	0.000	0.198	0.000	0.117	0.000
Joiners from university research	0.023	0.675	0.084	0.697	0.051	0.680
Other joiners	-0.016	0.630	-0.072	0.594	-0.038	0.621
Recent graduates	0.034	0.371	0.128	0.391	0.076	0.377
Support	0.018	0.072	0.063	0.107	0.039	0.081
Stayers	0.005	0.082	0.012	0.359	0.010	0.134

Note: Based on the estimation results in Table 2. The top panel refers to the specification without interactions with the dummy variable for past university hires, the two lower panels refer to the specification with interactions included. Marginal effects are evaluated at the means of the involved variables. E.g., 1 additional joiner from a private firm is related to 0.039 additional citations-weighted patents for the firms in the specification with no past university hires interactions.

APPENDIX TABLE
Correlations between the Explanatory Variables

		1.	2.	3	4.	5.	6.	7.	8.	9.	10.
1.	# Patent applications, citations weighted	1.000									
2.	Share joiners from firms	0.006	1.000								
3	Share "other" joiners	0.027	-0.025	1.000							
4.	Share graduate joiners	-0.022	-0.076	-0.020	1.000						
5.	Share university reseachers	0.010	-0.068	-0.001	-0.039	1.000					
6.	Share support workers	-0.002	-0.162	-0.045	-0.101	-0.103	1.000				
7.	ln(capital stock) at t-1	0.207	-0.010	-0.019	-0.061	-0.042	0.168	1.000			
8.	ln(R&D workers) at t-1	0.267	-0.029	0.004	-0.062	0.003	-0.029	0.330	1.000		
9.	ln(adj. # patents in 1990, citations weighted)	0.517	-0.017	0.020	-0.037	-0.009	0.020	0.295	0.295	1.000	
10.	Dummy for pos. patent stock in 1990	0.438	-0.018	0.020	-0.040	-0.013	0.033	0.284	0.234	0.948	1.000

Note: The specification includes sector, year and region dummies. For reasons of space, the correlations are not displayed here.