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Effects on academia-industry collaboration of extending university property rights

Finn Valentin · Rasmus Lund Jensen

Abstract Several recent studies show European university scientists contributing far more frequently to company-owned patented inventions than they do to patents owned by universities or by the academic scientists themselves. Recognising the significance of this channel for direct commercialisation of European academic research makes it important to understand its response to current Bayh-Dole inspired reforms of university patenting rights. This paper studies the contribution from university scientists to inventions patented by dedicated biotech firms (DBFs) specialised in drug discovery in Denmark and Sweden, which in this respect share a number of structural and historic characteristics. It examines effects of the Danish Law on University Patenting (LUP) effective January 2000, which transferred to the employer university rights to patents on inventions made by Danish university scientists alone or as participants in collaborative research with industry. Sweden so far has left property rights with academic scientists, as they also were in Denmark prior to the reform. Consequently, comparison of Danish and Swedish research collaboration before and after LUP offers a quasi-controlled experiment, bringing out effects on joint research of university IPR reform. In original data on all 3,640 inventor contributions behind the 1,087 patents filed by Danish and Swedish DBFs 1990–2004, Difference-in-Difference regressions uncover notable LUP-induced effects in the form of significant reductions in contributions from Danish domestic academic inventors, combined with a simultaneous substitutive increase of non-Danish academic inventors. A moderate increase in academic inventions channelled into university owned-patents does appear after LUP. But the larger part of the inventive potential of academia, previously mobilised into company-owned patents, seems to have been rendered inactive as a result of the reform. As a likely explanation of these effects the paper suggests that exploratory research, the typical target of joint university-DBF projects in drug discovery, fits poorly into LUP's requirement for ex ante allocation of IPR. The Pre-LUP convention of IPR allocated to the

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industrial partner in return for research funding and publication rights to the academic partner may have offered more effective contracting for this type of research. There are indications that LUP, outside the exploratory agenda of drug discovery, offers a more productive framework for inventions requiring less complicated and uncertain post-discovery R&D.

Keywords University technology commercialization · Research collaboration · Biotechnology

JEL Classifications I23 · L65 · O31 · O34 · O38

1 Introduction

Advanced economies are giving increasing attention to the *direct* contributions from universities to industrial competitiveness. As an important part of this trend a number of countries, inspired by the American Bayh-Dole act of 1980, have been giving their universities a more active role in taking out patents emerging from academic research, and in pursuing their commercialisation.

While more countries are adopting Bayh-Dole inspired policies and developing the administration for their implementation (Technology Transfer Offices, special venture capital programs, etc.) an increasing body of research is beginning to question the consequences of the added emphasis on university property rights (Cohen, 2004; Mowery, Nelson, Sampat, & Ziedonis, 2004; Jaffe & Lerner, 2004; Leaf, 2005). While this literature largely has focused on the role of universities as patentees, less attention has been given to *effects on academia-industry collaborative research*.

Previous studies (Balconi, Breschi, & Lissoni, 2004; Crespi, Geuna, & Nesta, 2005; Meyer, 2003; Valentin & Jensen, 2003) suggest that inventions originating from this collaboration tend to be assigned predominantly to the industrial partner, constituting a modus which, when seen from the academic perspective, could be referred to as ‘‘unappropriated collaboration’’. It seems to be a more widespread mechanism by which university science contributes to commercial technology than is the mechanism by which universities pursue their own patenting for subsequent licensing to industry. It matters, therefore if the modus of unappropriated collaboration is negatively affected by Bayh-Dole inspired legislation.

This paper examines if such negative effects have appeared in Denmark, which in January 2000 enacted Bayh-Dole inspired legislation in the Law on University Patenting (LUP). LUP transferred to universities ownership of patents on inventions made by Danish university scientists, be it as a result of their separate effort or as an outcome of joint research with industry. Sweden so far has refrained from reforming academic property rights along the lines of LUP, leaving Swedish academic property rights with the academic inventors the way they also were in Denmark prior to LUP.

Consequently, systematic comparison of patent related university-industry collaboration in Denmark and Sweden before and after LUP offers a quasi-controlled experiment, bringing out effects on joint research of regulation affecting its IPR framework, reformed in one case, maintained in the other. These effects have implications not only for understanding the impact of Bayh-Dole inspired legislation on national science-based competitiveness. They also may deepen our understanding of university-industry collaboration per se, and of its particular role in the broader science-technology relationship (Agrawal & Henderson, 2002).

Biotech drug discovery firms offer a useful focus for this comparison. Not only is this one of the most patent-intensive industries, it also relies heavily on academic research. Furthermore, Denmark and Sweden are quite similar in this field of activity. The paper uses inventions from Dedicated Biotechnology Firms (DBFs), specialised in drug discovery research, as a case to allow comparisons to be made within the same sector in the two countries.

Our findings indicate a LUP-induced decline in collaborative drug discovery research in Denmark. This constitutes an unintended side effect of LUP, the core objective of which was to induce universities into a more active role in commercialising the inventive potential of their scientists. It is conceivable, therefore, that university-owned patents, subsequent to LUP, provide outlet for academic inventor contributions, substituting for their reduced contribution to DBF-owned patents. Although no full-scale study of this substitution is offered, the paper does present findings indicating distinctly incomplete substitution.

The main objectives of the paper therefore are to examine (1) if, in the field of drug discovery research, a systematic shift appears in academia-industry collaboration associated with the implementation of LUP in 2000, (2) if university-owned patents emerge to offer a substitutive outlet for academic inventor contributions and (3) and to consider causes that may account for empirical findings.

The paper is structured as follows: the next section briefly considers the causes behind the increase in academia-industry collaborative research, presents the methodology with which we study these trends, and summarises findings from previous studies using methods similar to the one used here. Section three compares the DBF sectors of Sweden and Denmark, identifying similarities and differences relevant for assessing the specific impact of the LUP reform in Denmark. The reform itself is summarised in Sect. 4, with an emphasis on the mechanisms by which it affects university-industry research collaboration, the empirical extent of which is examined in Sect. 5. Section 6 studies whether the decline in academic inventor contributions to industry-owned patents after LUP has ‘‘reappeared’’ as university-invented and -owned patents after LUP. A discussion of findings is offered in Sect. 7.

2 Industry-university collaboration as observed in patent data: metrics and trends

Direct relationships between private and academic science is part of a broader trend of increasing inter-organisational collaboration in R&D. Over the previous two decades strategic alliances and collaborative arrangements have come to play a growing role in the organisation of R&D in all high-tech industries (Calvert & Patel, 2003; Hagedoorn & van Kranenburg, 2003). This increase in inter-organisational R&D collaboration has several causes. Technological opportunities have expanded as a result of maturation of basic science-driven inventions and of new, general purpose technologies (Helpman & Trajtenberg, 1998). As a result, individual companies often experience increase in opportunities beyond what they can accommodate in internal R&D. At the same time competition intensifies as a result of globalisation and new more effective tools for design and product development (Dodgson, Gann, & Salter, 2005; Thomke, 2003). Collaborative R&D has emerged as a response to these conflicting pressures, allowing firms to access a broader pool of skills, and to respond to competitive pressures faster and across a broader frontier of opportunities (Chesbrough, 2003). Nowhere is this confluence of trends more apparent than in biotechnology. The number of collaborative arrangements has grown steadily through the 1980–1990s (Allansdottir et al., 2002), and the particular significance for biotech firms of collaboration with, and direct knowledge transfer from, academic science has been documented in a number of studies (Fuchs, 2003; Liebeskind, Oliver, Zucker, & Brewer, 1996; Powell, 1998; Santos, 2003).

Consequently, the possibilities of specific nations or regions for effective networking into academic science substantially affect the competitiveness of their biotech sectors. It is useful, therefore, to find methodologies allowing systematic observation of trends and configurations in this field of industry-academia collaboration. Since inventions in biotechnology to a large extent are filed for patent protection, one possibility for systematic observations is offered by information from patents on the contribution of university scientists to inventions.

Patents based on such contributions are assigned either to the university employing the inventor scientist (university owned patents) or to a third party typically the company sponsoring the research leading to the invention (university invented—but not university owned—patents).[1] Several studies of separate European countries demonstrate that university invented patents are far more prevalent than university owned patents, e.g. Italy (Balconi et al., 2004), Finland (Meyer, 2003), Germany (Schmoch, 2000). The same pattern is identified for single large universities, e.g. University Louis Pasteur (Llerena, Matt, & Schaeffer, 2003; Saragossi & van Pottelsberghe de la Potterie, 2003). A recent study offers a useful overview of these findings (Crespi et al., 2005) and presents results from a large analysis of 9,000 EPO patents across six European countries, identifying one inventor in each. The sample also includes a small segment of 294 inventor contributions from university scientists, which gave rise to only 85 university assignments.

Another study focuses on biotechnological modification of a micro-organism of particular significance in food processing (lactic acid bacteria). Analysis of 180 key patents in this field reveals that it develops through the 1980–1990s largely through university-industry research collaboration (Valentin & Jensen, 2003). The 200 assignments and the 320 inventor participations found in these patents reveal that firms and universities balance these two roles in very different ways. Companies, in no case contribute inventor capacity without also being assigned the patent. Scientists from universities and Government Research Institutes on the other hand, contributed 198 inventor participations, for which they earned 46 of the total of 200 assignments. The latter, in other words, contribute as co-inventors four times as frequently as they obtain assignee status, roughly the same rate observed in the study by Crespi et al., whereas the country studies referenced above report considerably higher rates of patents invented by, but not assigned to, universities.

This pattern, referred to in the introduction as "unappropriated collaboration", in European countries comes out as a far more prevalent mode of academic contribution to technological invention than is the mode in which universities are assigned patent rights. For the overall contribution of academia to the technological performance of Europe it emerges as an important issue if that contribution is negatively affected by Bayh-Dole inspired legislation, and if, in that case, adequate new mechanisms appear as substitutes.

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[1] An additional small share of patents are assigned to the inventor, or remain unassigned (Balconi et al., 2004; Meyer, 2003).

Furthermore this pattern of the highly uneven assignment to companies and to university scientists of patents, to which both parties have contributed as inventors, indicate that academics do not collaborate on inventions motivated by the wish to obtain patent rights. Their other motives are discussed in Sect. 7.

The above studies vary in their procedures for tracking the host organisation of inventors, which on patent front pages are identified by name and address only. Since the present study has it focus on the strongly science-based field of biotechnology, our procedure takes advantage of the papyrophilic traces left by scientific research. E.g. publications of inventors are often cited in the patent to which they have contributed. We used this and similar information as a point of departure for search in various bibliometric sources, and established the organisational affiliation of inventors at the time of invention (defined as the application date of the patent) with considerable accuracy.[2] Patents based on bio-scientific research often involves multiple inventors, and each inventor team now may be characterised by the composition of organisations collaborating in specific inventions, e.g. by shares of inventors coming from academia or from industry. While this methodology for enriching patent-based inventor data is time consuming, it offers considerable advantages for systematic observation and analysis. Entire technology areas, or countries, may be characterised by their inventor compositions (for an example see Valentin & Jensen, 2004).

For the present paper we focus on inventors listed in the patents filed by Danish and Swedish drug discovery DBFs. Denmark has 51 DBFs, of which 48 have filed patents. In Sweden 41of the total of 44 DBFs have filed patents. Together these Danish and Swedish 89 DBF have filed 1,087 patents, listing a total of 4,028 inventor participation, of which 90.4% were successfully identified in the procedure summarised above. That leaves us with the net population of 3,640 inventor participations, on which the analysis of this paper is based.[3]

3 Danish and Swedish academic inventors in biotech

The quasi-controlled experiment attempted in this paper benefits from a number of characteristics shared by Denmark and Sweden. First, each country is internally homogeneous in the sense that regulations of university IPR uniformly affect all its academic research, unmodified by country-internal variations between, e.g. private versus public universities, or by variations at lower levels of government (länder or states). Second, as demonstrated in this section, our focus on drug discovery DBFs delimits a sector in which the two countries are remarkably similar.

Figure 1 shows how the sector of DBFs was established in the two countries over the past 15 years, presenting the entry of new firms in each year. Similarities are apparent, early entry of firms beginning, and remaining at a low level in the first half of the 1990s, until the entry level in both countries picks up from 1997. A slightly

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[2] In previous studies of biotech patents the authors applied this procedure and obtained identification of 85–90% of inventors. Subsequent validation, based on direct confirmation from inventors, revealed identification errors for less that 5% of inventors.

[3] Data for this paper was extracted from the *Scanbit Database,* established and continuously updated by *Research Centre on Biotech Business* at Copenhagen Business School. The database brings together patent information with a number of other metrics and indicators on drug discovery DBFs in Denmark, Sweden and Norway (Dahlgren, Jensen, & Valentin 2004; Valentin et al., 2007).

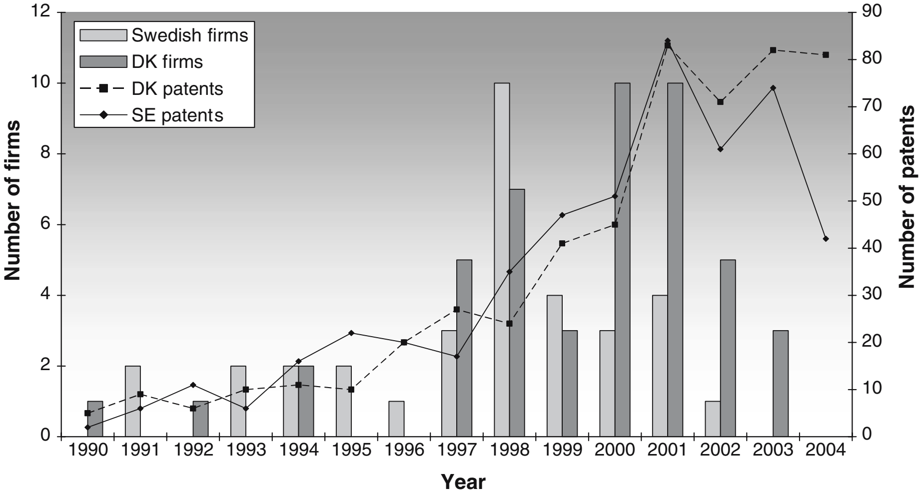

Fig. 1 Number of drug discovery DBFs established in Denmark and Sweden and their number of patent applications for each year 1990–2004

higher entry level is seen for Sweden until 2000 when Danish entries for four consecutive years remain higher, so that the present Danish DBF industry on average is younger. No entries are recorded in 2004 in either country.

The decline in entry of new firms after 2001 is linked to the crisis in venture capital financing in 2001, which spread from the bursting IT bubble to other high-tech sectors. This crisis is clearly brought out in Fig. 2, which for each of the years 1996–2004 presents the total number of Danish Kroner invested in DBFs in the two countries, along with the number of investment rounds by which infusion of new capital took place. Invested sums drop notably after 2001, but do so in parallel reductions in the two countries.

Figure 1 also presents the number of patent applications filed each year by DBFs in the two countries. Reflecting the gradual rise in firm entries, parallel trends are seen until 2003. The decline and discrepancy between the two countries in 2004 is a data artefact, caused by the delay in patent registrations, leaving us with incomplete observations for that year when data for the paper was collected in the fall of 2005.

These are the patents for which we have identified a total of 3,640 inventors. Their distribution on employer organizations, at the time of invention, is presented in Table 1, which shows almost 2/3 of Danish inventors being employed by the firm behind the invention (i.e. the party to which the patent is assigned). That is the case for about a quarter of the Swedish inventors, where also the share of university scientist is twice as high as in Denmark, and the share of inventors from other companies is three times higher. The overall composition of Danish inventor teams, in short, is considerably more introvert, and relies less on academic science.

These country differences in the involvement of academic scientists relate to the issue examined in this paper and must be examined so as to better understand effects specifically related LUP.

From previous examination of the same data we know that Danish firms have a larger share of DBFs specialised in small molecule drug discovery, whereas a larger

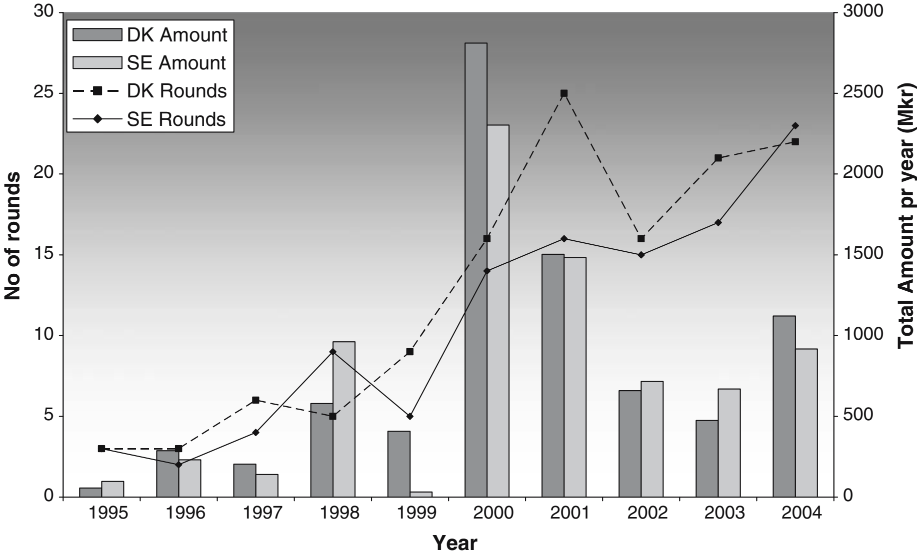

Fig. 2 Invested Danish Kroner and number of investment rounds in Danish and Swedish DBFs in each year 1995–2004

specialisation in biopharmaceuticals is found among Swedish firms (Valentin, Jensen, & Dahlgren, 2007). A number of studies have shown the latter to be more directly related to the scientific revolution in molecular biology, and hence with its basis in academic science (Cockburn, Henderson, Orsenigo, & Pisano, 1999). We therefore examine, in a simple OLS regression, if the higher Swedish involvement of academic inventors is affected by a larger share of patents from firms specialised in biopharmaceutical discovery, as distinct from patents from firms specialised in small molecule research.

More specifically, we define a dependent variable, calculated for each quarter, as the share of domestic Swedish university scientist of all Swedish inventors, and a similar share for the portion of Danish university scientists of all Danish inventors. The ratio of Swedish shares divided by Danish shares (labelled SE/DKUni_ratio)

Table 1 Distribution of inventors by types of host organisations

Types of inventor host organisations	Affiliation of inventors			
	In Danish DBF patents		In Swedish DBF patents	
	N	Share of total (%)	*N*	Share of total (%)
Assignee company	1162	66.55	530	27.98
Other companies	123	7.04	477	25.18
PRO[a]				
Universities	368	22.11	819	43.24
Government research institutes	75	4.29	68	3.59
SUM	1738	100.00	1894	100.00
Not identified (% of all)	186	9.63	202	9.64

[a] Public research organisations, including also non-domestic organisations

expresses, for each quarter, differences between the two countries in levels of involvement of academic inventors.

As independent variables we calculate, for each quarter, the ratio of patents filed by biopharmaceutical DBFs over patents filed by small molecule DBFs (labelled BioPharm/SM_ratio), and as a control variable we enter the total number of patents filed in each quarter. A log transformation of the dependent variable is applied. As in all other models presented in the paper the data is truncated to begin in the first quarter of 1994 (1994:1), due to the very low number of observations in years up to that point. Definitions of variables and their associated labels are summarised in Table 2, which also includes all other variables used in subsequent models in the paper. Tables 3 and 4 presents descriptive statistics for the three variables used in the models presented in Fig. 4.

The significant estimate for BioPharm/SM_ratio of 0.665 implies that a unit increase of this ratio is associated with 66% increase of the ratio by which Swedish academic shares exceed Danish academic shares. It refers, in other words, to a notable part of the actual difference between the two countries observed in Table 1, but the R^2 of 0.22 at the same time demonstrates that only a moderate portion of total variation in the Danish-Swedish difference is explained by this factor.

The estimate of –0.023 for the control for the number of patents indicate, as a tenuous trend (significant at the 10% level only), that with increasing numbers of patents the academic involvement in Denmark increases slightly relative to the Swedish counterpart. Whereas it could have been conjectured that the comparatively smaller Danish university system more easily would run short on inventor contributions as the number of patent-related collaborations increases, actually the opposite is the case. Later in the paper we shall interpret a decline in the academic involvement in Danish inventions after 2001 when the volume of patenting stabilizes notably above its previous level (comp. Fig. 1), so it is useful to have this indication that academic inventor shortage is an unlikely explanation.

The lower involvement of academic scientists in small molecule drug discovery requires us to consider specific effects from the higher entry rate of new Danish firms from 2000 onwards. It cannot be ruled out that these entries, with a larger concentration of small molecule DBFs, could be the cause of declining relative involvement of academic scientists on the Danish side, i.e. the very same effect which otherwise could be attributed to the introduction of LUP in January 2000.

Table 2 Variables applied in regressions

Label	Description
EV	A binary dummy variable for the event data, quarters after 2000:1
DKSE	A binary dummy variable denoting the origin of the observation in Denmark (=1) or in Sweden (0)
Npat	Number of patents by application date
DuniS	Share of domestic university scientists of total number of inventors listed on patent front pages, pooled by quarter
Non-DuniS	Share of non-domestic university scientists of total number of inventors listed on patent front pages, pooled by quarter
BioPharm/SM_ratio	A ratio of patents assigned to Biopharmaceutical companies in a given quarter divided by patents assigned to small molecule companies in the same quarter.
SE/DKUni_ratio	Swedish DUniS divided by Danish DuniS for each quarter

Table 3 Descriptive statistics for the model in Table 4

Name of variable	N§	Mean	SD	Min	Max
Ln(SE/DKUni_Ratio)[a]	41	1.294	1.163	-0.764	4.063
BioPharm/SM_ratio	41	1.006	0.689	0.071	3.000
Npat	41	22.537	14.079	4.000	59.000

[a] One percentage point has been added to the baseline to avoid loss of observations in the log transformation

Table 4 Standard OLS regression of SE/DKUni_ratio

Independent variables	Dependent variable : Ln(SE/DK Uni_Ratio) Model 1
Intercept	1.139** (0.521)
BioPharm/SM_ratio	0.665*** (0.246)
Npat	–0.023* (0.012)
Model *F*-test *P>F*	0.0035
R-square	0.2204
DF	40

Robust standard errors are given in brackets

Three outliers removed, their values two times above the standard deviation, based on less than five patents

Stars denote the level of significance: *** <1%, ** <5% and * <10%

Tests of LUP effects, in other words, must control for simultaneous effects from increasing shares of small molecule firms in Denmark.

To summarise: DBF sectors in the two countries are similar on a number of dimensions, including their size, history of emergence through the 1990s, response pattern to the 2001 high-tech bubble, their number of inventions, and in the amount of inventors mobilised to bring the inventions about. They differ primarily in the larger share of academic scientist among Swedish inventors. Part of this difference is explained by a stronger concentration of small molecule DBFs among Danish firms. At the same time, the entry of new firms after 2000 is much steeper in Denmark, which cannot be ignored as a potential cause behind subsequent downward shifts in academic involvement. The implication for the main issue of this paper is that specific effects of LUP should not be tested without controlling for simultaneous effects of an increasing share of small molecule DBFs in Denmark.

4 The law on university patenting and its potential implications for collaborative research

Legislation from 1949 in Sweden and from 1955 in Denmark transferred the right to inventions to employers. In both cases an exception was made for teachers and scientists at universities and other institutions of higher learning. This so-called ‘‘teacher’s exception’’ has been maintained in Sweden, and has been argued to be particularly beneficial for academia-industry collaboration in biotechnology (McGguire, 2004), but is currently i.e. Spring, 2006, being reconsidered (SOU, 2006).

The Danish law in 1955 was directly influenced by the 6 years older Swedish legislation, and the two countries remained in this respect homogenous until Denmark, effective as of 1 January 2000 implemented ‘‘Act on inventions at public research institutions’’, commonly referred to as the ‘‘LUP’’. The act has the purpose of (§1) ‘‘...ensuring that research results produced by means of public funds shall be utilized for the Danish society through commercial exploitation.’’[4] Its key instrument lies in allocating to universities ownership of an invention made as part of the work of employees (§7). That also pertains to inventions resulting from collaborative work with third parties (e.g. firms), but in these cases the university may (§9) ‘‘...upon prior agreement with the party concerned, renounce, in full or in part, the right to the inventions made by the project’’.

How did Danish academic scientists prior to LUP handle intellectual property to inventions to which they had contributed? The general tendency in Europe for university scientist to refrain from claiming patent rights to their inventions, documented in Sect. 2 above, was probably even more pronounced in Denmark. No exhaustive study is available of patents assigned to Danish university scientists, but available sources, consistent with studies of other European countries referred to in Sect. 2, indicate extremely low levels of patents assigned to university scientists (Davis & Lotz, 2006; Valentin & Jensen, 2003). Interviews we have made with research managers and with university scientists with long records of industrial collaboration, indicate that collaboration typically would be based on contractual allocation of ownerships rights to the firm and publication rights to involved academics. As part of, or related to this contract, the industrial partner would make resources available in the form of, e.g. PhD funding or give access to the firm’s research capabilities for purposes specified in the contract.[5] It was up to the two parties to assess if this package of exchanges and joint activities would justify the commitment required for the collaboration, and property rights rarely were a high priority issues for the academic partners. This stylized version of the ‘‘package’’ is consistent with quantitative studies summarized below in Sect. 7.

The elemental change introduced by LUP is to replace this bilateral quid pro quo with a trilateral arrangement, in which the university ex ante holds all rights to results. If universities under LUP are allowed to renounce these rights, why might they nevertheless introduce critical complications for academic-industrial collaboration? These complications, we argue, grow out of the uncertainty whether or not the university in a particular case will exercise its rights to IPR. Even though Danish universities in many cases seem to conclude their deliberations on this option by renouncing their rights, the process to reach that conclusion may entail critical complications.

These complications may come from delays required for the TTO to reach a decision, which may be hazardous in the context of patent races, or from firms being required to negotiate ownership rights in conflict with their concern for confidential aspects of their knowledge and expectations. Probably the most serious complication

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[4] The ‘‘Act on inventions at public research institutions’’ of 2 June 1999 may be accessed at http://www.videnskabsministeriet.dk/cgi-bin/doc-show.cgi?doc_id=14206&leftmenu=LOVSTOF. An English translation is available at http://www.videnskabsministeriet.dk/cgi-bin/doc-show.cgi?doc_id=20047&doc_type=22&leftmenu=1.

[5] These terms correspond well the typical set-up for industry sponsorship of academic life-science research as identified in more comprehensive surveys, when we correct for the inclusion in the latter also of more short-term research issues (Blumenthal, Causino, Campbell, & Seashore, 1996).

introduced by LUP comes from the fact that ex ante distribution of ownership rights squares uneasily with discovery oriented research because it often gives rise to findings and insights not explicitly covered by, but still related to, activities and objectives specified in its contract. Whereas such related inventions previously were considered part of the residual rights of the company funding the collaboration, LUP turns them into residual rights for the university. As an effect firms may now be met with property claims not only to the direct results of the collaboration, but also to related inventions, potentially affecting their overall IPR position beyond what they intended when they entered the collaboration.

While these complications do not preclude academia-industry collaboration altogether, they restrict its scope to joint research amenable to ex ante allocation of IP ownership. Joint research directed at issues close to full grown technological innovations offers this amenability because it is easier to anticipate not only its outcome but also its market potential and the volume of R&D required to translate the invention into an innovation. Conversely, joint *exploratory* research with greater difficulty lends itself to ex ante allocation of IPR. Some pharmaceutical firms refer to their activities in this early front-end of the R&D spectrum as "pre-discovery" or "project generating" research, and as a rule of thumb they expect less than 1% of such projects to translate into new drugs. That translation goes via a complex sequence of further investments and combinations with subsequent efforts the costs and success of which cannot be foreseen. As a consequence, companies cannot predict the manner in which specific pieces of front-end research may become commercialised, nor the costs required to take it that far (David, Mowery, & Steinmueller, 1994; Slowinski & Sagal, 2006). That defines what may be a core dilemma for firms confronted with LUP regulations: firms cannot invest in these complex subsequent processes of translation without having secured their patent rights to initial results. On the other hand they cannot with TTOs negotiate acquisitions of single pieces of this front-end research, since their separate values defy ex ante calculation. Therefore if firms cannot collaborate with academic scientists on exploratory research without assigning rights to results, wholly or partially, to the university, or if in advance they do not know whether the university will exercise or renounce their rights, their response could be to withdraw from this type of joint research.

It is essentially the same argument as is normally advanced to explain why many inventions in biotechnology, and in other science-based technologies, are left unexploited and undeveloped in the "valley of death", not because they are known to lack potential, but because they are too immature to be assessed by venture capital for their commercial possibilities. And the same type of market failure most likely is part of the difficulties, which most TTOs, in Denmark and elsewhere, experience in commercialising their patent portfolios.

The implication of this argument is that collaborative drug discovery research, along with other areas of front-end, exploratory investigations, could be negatively affected by LUP. In that case, subsequent to LUP, we should expect drug discovery collaboration to decline, but not to disappear altogether. By the same argument, we should *not* expect a similar reduction in joint academia-industry research addressing issues closer to technological innovation in more finalized forms. But we should take notice of studies indicating that it is in their exploratory research that science-based companies particularly benefit from collaborating with academic science (Calvert & Patel, 2003; Meyer-Krahmer & Schmoch, 1998; Valentin, 2000).

5 LUP effects examined

This section examines if LUP empirically has affected joint drug discovery research as conjectured above. First, comparing Denmark with Sweden we use Difference-in-Difference (DD) regressions to test for shifts before and after LUP in shares of university scientists among inventors contributing to patents assigned to DBFs. We tests separately for shifts in shares of *domestic* scientists (i.e. Danish university scientists contributing to patented inventions assigned to Danish DBF, and similarly for Sweden), since only domestic contribution to Danish patents would be affected by LUP.

Next, we test separately for shifts in the shares of non-domestic university scientists, for the following reason: If Danish DBFs, in response to complications in joint discovery research introduced by LUP, reduce their collaboration with domestic university scientist, and if at the same time they find academic contributions indispensable for their inventions, conceivably they could step up collaboration with non-domestic academic scientists. According to the literature summarised in Sect. 2, scientists in a number of other countries seem less restricted by *actual* university practices in this respect, irrespective of general legislation on employers' ownership rights. On this basis, an increasing post-LUP share of non-domestic academic inventors behind Danish DBF patents, coinciding with a decrease in the share of domestic academic inventors, would further support the interpretation that LUP introduces critical complications in the involvement of Danish university scientists. We therefore test, again using DD regression, for a post-LUP shift in the contributions from non-domestic university scientists to patents assigned to DBFs in each of the two countries.

Next, to enhance interpretation of DD findings, we test for shifts in trends, before and after LUP, again in the same shares of domestic and non-domestic university scientists. Both sets of tests are made with the data presented above, for which the following should be noted:

- The share of university scientist is based only on the total number of inventors listed on patent front pages. In most cases one or several inventors comes from the company to which the patent is assigned, but the assignee organisation as such is not included in the basis for calculation of shares.
- Shares are calculated for all inventors pooled within each quarter.
- Quarters are truncated to begin 1994:1, prior to which quarterly patents become too scarce, and ends 2004:4, when patents started to be only incompletely available in Derwent World Patent Index in the fall of 2005, when data was collected.
- The event date is the start of 2001, defining a lag of 1.5 years for effective implementation of LUP. Collaborative arrangement with industry commenced prior to 1 July 1999 are respected by LUP (§19.3). The duration of these projects (according to interview information) is in the range of 1–2 years, suggesting turn of the year 2000–2001 as the point in time when LUP actually could begin to affect patterns of collaboration.

The DD regressions below uses the share of domestic Danish university scientists as test group and the Swedish counter part as control group, so that the simple DD estimator is equal to:

$$\begin{aligned}\delta =&\{[S(DKSE=1,\ EV=1)-S(DKSE=0,\ EV=1)] \\ &-[S(DKSE=1,\ EV=0)-S(DKSE=0,\ EV=0)]\},\end{aligned} \tag{1}$$

where: S(DKSE, EV) is the share of domestic university scientist of a given patent, with DKSE = 1 denoting a Danish patent DKSE = 0 a Swedish patent, EV = 1 denoting application date after 2000 and EV = 0 before 2001.

The simple DD δ coefficient from Eq. 1 is equal to the δ_1 coefficient in the simple pooled regression of Eq. 2 where Y(unishare) is denoting the share of domestic university scientists.

$$Y(\text{Unishare}) = \beta_0 + \beta_1\ \text{DKSE} + \beta_2\text{EV} + \delta_1\ \text{EVDKSE} + \varepsilon. \tag{2}$$

For reasons explained in Sect. 3 the ratio of biopharmaceutical over small molecule patents is entered as control variable. Descriptive statistics for the two sets of DD regression are presented in Table 5, showing non-domestic inventor shares having a notably lower overall average (8%), compared to the 22% average for domestic academic shares. The overall average for the biopharm/small molecule ratio is close to 0.949, but drops notably to 0.399 after the event, indicating a steep increase in the share of small molecule patents.

DD regressions of domestic university shares are presented in Table 6. The control for the biopharm/small molecule ratio is entered in Model 2, to which is added its post event values in Model 3, in both cases bringing non-significant estimates. A structural shifts towards a larger Danish share of small molecule patenting, in other words, turns out not to affect the share of university scientists given the context of the other variables, all of which emerge as significant. The negative estimate (Model 3) of –0.168 for DKSE confirms the lower level in the entire 1994–2004 decade of academic involvement in DBF inventions for Denmark, as compared to Sweden, which also was clearly discernable in Table 1. The significant estimate for EV*DKSE signifies that a decrease of 12.6% appears, specifically attributable to the event, in the share of Danish academic inventors as compared to the share in the Swedish control group. The positive estimate for the event indicates the overall increase in academic inventor shares for the two countries. I.e. the negative effect of LUP on Danish academic inventor involvement takes places in a context of overall increasing involvement for the two countries together. The regressions bringing together these three independent variables form a strongly significant model, explaining 57% of the variation in the overall involvement of academic scientists as inventors.

DD regressions for corresponding shares of non-domestic academic scientists are presented in Table 7. The Biopharmaceutical/small molecule ratio again is entered as control, but remains insignificant both before and after the event. The event obtains a significant negative estimates, i.e. the overall share of non-domestic academic scientists declines moderately after the event, partially mirroring the corresponding increase in domestic shares identified in Table 6. The overall Danish level is moderately below the Swedish level. However, the event alters this pattern, producing a, significant increase of 13.7% in the average involvement of non-Danish university scientists, as compared to the Swedish control group.

Further characterisation of these effects may be obtained from testing, using the same data, for pre- and post-LUP trends in the involvement of domestic and non-

Table 5 Descriptive statistics for models in Tables 6 and 7

Name of variable	*N*§	Mean	SD	Min	Max
DuniS	80	0.219	0.164	0.000	0.667
Non-DuniS	80	0.082	0.091	0.000	0.333
BioPharm/SM_ratio	80	0.949	0.661	0.071	3.000
EV*BioPharm/SM_ratio	80	0.399	0.595	0.000	2.222
EV		38.75% (1)			
DKSE		55.00% (1)			
EV*DKSE		20.00% (1)			

Table 6 Difference-in-difference OLS regression comparing shares of domestic university inventors in Denmark and Sweden before and after LUP

Independent variables	Dependent variable : share of domestic university scientists		
	Model 1	Model 2	Model 3
Intercept	0.268*** (0.030)	0.256*** (0.036)	0.259*** (0.037)
EV	0.173*** (0.039)	0.170*** (0.039)	0.149*** (0.053)
DKSE	–0.168*** (0.038)	–0.168*** (0.038)	–0.168*** (0.038)
EV*DKSE	–0.128** (0.052)	–0.127** (0.052)	–0.126** (0.052)
BioPharm/SM_ratio		0.013 (0.021)	0.009 (0.025)
EV*BioPharm/SM_ratio			0.020 (0.042)
Model *F*-test $P > F$	0.0001	0.0001	0.0001
R-square	0.5719	0.5748	0.5759
DF	79	79	79

Robust standard errors are given in brackets

Eight outliers removed, values two times higher than the standard deviation in quarters with less than five patents

Stars denote the level of significance: *** <1%, ** <5% and * <10%

domestic academic inventors in Danish DBF patents and comparing them with their Swedish counterpart. Time series for domestic shares are presented in Fig. 3, and for non-domestic shares in Fig. 4, in both cases as two-quarter moving averages. The generally higher involvement of domestic academic scientists in Swedish inventions is apparent in Fig. 3. And the generally lower level of non-domestic academic scientists in both countries also is immediately apparent from comparing Figs. 3 and 4.

Tests are made with OLS regressions with successive quarters as independent variable and domestic academic inventor shares (DuniS) and non-domestic shares (Non-DuniS) for Denmark and Sweden as dependent variables. Each dependent variable is tested separately, with the event introduced as a 0–1 dummy-variable. Table 8 presents descriptive statistics and Tables 9 and 10 present regressions for domestic, respectively, non-domestic academic inventor shares.

Model 1 in Table 9 identifies an increasing pre-event trend in shares of Danish scientists in Danish patents of about 1.9% per quarter (significant at the 5% level). The post-event trend develops much steeper, at a *declining* rate of 6.9% per quarter (significant at the 1% level). The event itself brings a notably higher level of academic involvement. Together the three trends form a model explaining 18% of total variance, significant below close to the 1% level. Model 2 for the Swedish data offers no systematic trends for any of the three independents variables. These results

Table 7 Difference-in-difference OLS regression comparing shares of non-domestic university inventors in Denmark and Sweden before and after LUP

Independent variables	Dependent variable share of non-domestic university scientists		
	Model 1	Model 2	Model 3
Intercept	0.132*** (0.028)	0.115*** (0.033)	0.107*** (0.035)
EV	–0.084*** (0.031)	–0.088*** (0.031)	–0.047 (0.052)
DKSE	–0.085*** (0.031)	–0.086*** (0.029)	–0.086*** (0.029)
EV*DKSE	0.137*** (0.037)	0.139*** (0.038)	0.138*** (0.038)
BioPharm/SM_ratio		0.019 (0.017)	0.028 (0.019)
EV*BioPharm/SM_ratio			–0.039 (0.036)
Model *F*-test $P > F$	0.0064	0.0063	0.0022
R-square	0.1795	0.2022	0.2176
DF	79	79	79

Robust standard errors are given in brackets

Eight outliers removed, values two times higher than the standard deviation in quarters with less than five patents

Stars denote the level of significance: *** <1%, ** <5% and * <10%

demonstrate that Denmark, from an initial much lower level of academic involvement through the 1990s *converges* towards the generally higher Swedish level. That takes the overall Danish post-event involvement to a level above that of its entire pre-event period, accounting for the positive estimate of the event-dummy in Model 9:1. However, within the higher post-event level a distinct downward trend is identified.

Table 10 presents parallel tests for the share of non-domestic university scientists, with a log transformation applied to the dependent variables. Significant estimates are obtained for the Danish data, but should be disregarded as far as the pre-event estimate is concerned, since too many data points disappear in the transformation or are removed as outliers, which also renders the significant shift associated with the event unreliable. What remains is the significant, quite steep post-event estimate of 0.51. Although results from only 16 data-points require cautiousness, they do suggest a trend, which is consistent with findings from the DD regressions. Recalculating the number of non-domestic inventors to annual shares gives the following results for each of the four post-event years: 2001 = 4.9%; 2002 = 7.2%; 2003 = 9.5%; 2004 = 11.0%. These increases, appearing in a total of 1,016 post-event Danish inventor participations, confirm a sharply increasing post-LUP trend in the involvement of non-Danish university scientists in Danish DBF patents.

Bringing together results from the DD regressions and trend analyses the following picture emerges.

- Since the mid-1990s the number of DBF patents in Sweden and Denmark as a whole has increased steeply, as has the number of academic scientists contributing to inventions not only in absolute number. An increase also is observed in academic inventors as a share of all inventors.
- Throughout the 1994–2004 period, the academic involvement in Swedish patents is notably above what is seen in Danish patents. However, the Danish pattern, until the event, quite systematically *converges* towards the higher Swedish level.

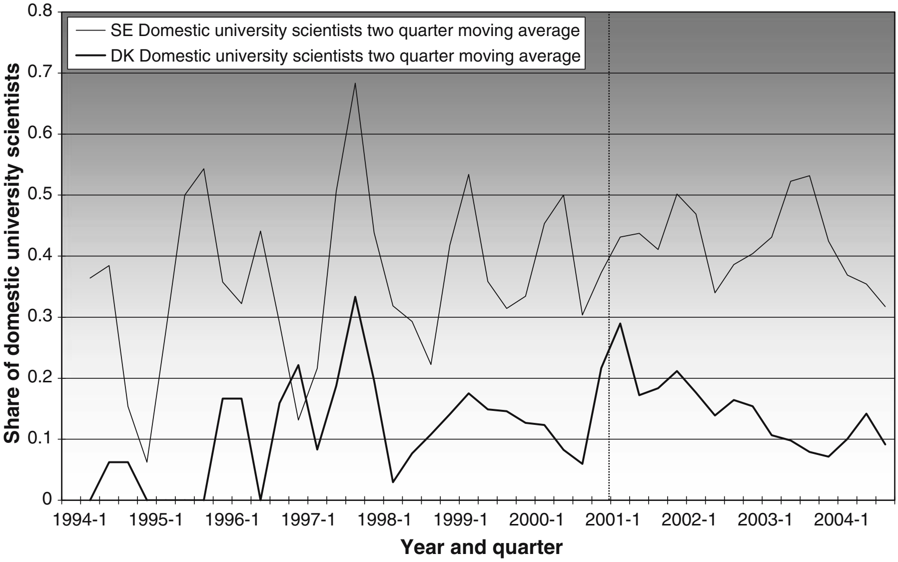

Fig. 3 Share of domestic university inventors in Sweden and Denmark for each quarter 1994–2004

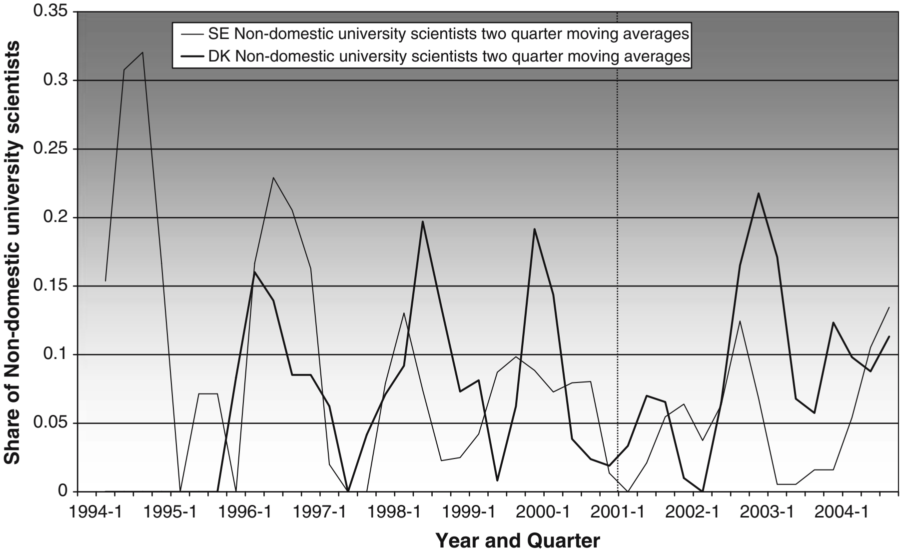

Fig. 4 Share of non-domestic university inventors in Sweden and Denmark for each quarter 1994–2004

- Compared to the Swedish control group, the DD regression identifies a drop of 12.6% in the share of domestic academic inventors behind the Danish patents, specifically attributable to the event. In the trend analyses this appears as a *reversal* of the previous convergence towards the higher Swedish level into a sharp *downward* trend.

Table 8 Descriptive statistics for models in Tables 9 and 10

Name of variable	*N*§	Mean	SD	Min	Max
Share of Danish university scientists	42	0.1245	0.1045	0.0000	0.3619
Share of non-Danish university scientists	25[a]	-2.4572	0.8089	-4.1109	–1.6094
Share of Swedish university scientists	44	0.3835	0.1671	0.0000	0.7000
Share of non-Swedish university scientists	25[a]	-2.5143	0.9619	-4.5109	–1.0986
Event	42	38.10% (1)			

[a] One percentage point has been added to the baseline to avoid loss of observations in the log transformation

Table 9 Regression of the shares in total inventor participations of Danish (Model 1) and Swedish (Model 2) university scientists as a function of time by quarters

Independent variables	Dependent variable: share of domestic university scientists	
	Model 1 Danish university scientists	Model 2 Swedish university scientists
Intercept	–0.050 (0.079)	0.2428* (0.1316)
Quarter	0.0194** (0.009)	0.0137 (0.0153)
Event	0.893*** (0.297)	0.5185 (0.5102)
Quarter × Event	–0.069*** (0.226)	–0.0384 (0.0386)
Model *F*-test $P > F$	0.0144	0.4451
Adj- *R*-sqaure	0.1799	-0.0064
DF	41	43

Robust standard errors are given in brackets

Two outliers removed, values two times higher than the standard deviation in quarters based on less than five patents

Stars denote the level of significance: *** <1%, ** <5% and * <10%

Table 10 Regression of the shares in total inventor participations of non-Danish (Model 1) and non-Swedish (Model 2) university scientists as a function of time by quarters

Independent variables	Dependent variable Ln (share of Non Domestic University scientists)	
	Model 1 Danish University scientists	Model 2 Swedish university scientists
Intercept	0.2019 (1.2336)	0.3564 (0.7603)
Quarter	–0.2926** (0.1322)	–0.2949** (0.0807)
Event	–5.8596** (2.4825)	0.8392 (4.9397)
Quarter × Event	0.5082** (0.2026)	-0.0262 (0.3711)
Model *F*-test $P > F$	0.0974	0.0012
Adj- *R*-sqaure	0.1481	0.4252
DF	24	26

Robust standard errors are given in brackets

Four outliers removed among pre-event observations, values two times higher than the standard deviation in quarters based on less than five patents

Stars denote the level of significance: *** <1%, ** <5% and * <10%

- Non-domestic inventors on the whole are involved with notably lower shares as compared to domestic inventors, and also in this respect the Danish level is below Sweden. However DD regressions identify a significant increase in Danish non-domestic shares of 13.7%, as compared to the Swedish control group, specifically attributable to the event. The trend analysis in this case offers only tenuous results, but they suggest a steep increase in the Danish post-event involvement of non-domestic inventors. The latter is confirmed by consistent yearly increases, over the four post-event years bringing the level from 4.9 to 11% of all Danish inventor contributions.
- When put together these findings strongly indicate a Danish pattern, significantly distinct from the Swedish counterpart, of a post-event decrease in the involvement of domestic academic scientists, compensated by a substitutive increase in the involvement of non-Danish university scientists. The overall share of 22% of academic inventors in Danish DBF patents reported in Table 1 implies that this substitution is no marginal phenomena. Subsequent to the event, non-domestic university scientists to a notable extent substitute for their domestic counterpart in Danish inventor teams.

Beyond reasonable doubt LUP may be assumed to be the event producing these shifts in Danish–Swedish differences. The two sectors are otherwise (1) exposed to the same external conditions, such as the expanding opportunities for drug discovery offered by the unfolding biotech revolution, (2) simultaneously affected by the collapse of the high-tech bubble, and (3) strikingly similar in terms of emergence and growth since 1990, with the primary difference of a larger share of small molecule firms, demonstrated to be unrelated to event effects.

To this may be added that the event generates effects not when LUP was formally enacted, but at the very point in time when actual effects reasonably may be assumed to appear. Furthermore, effects are identified not by shift in a single indicator, but by simultaneous, opposite shifts in both domestic and non-domestic inventor contributions. I.e. whatever other factor should be considered as an alternative candidate for the event mechanism should explain not only why domestic inventor shares decline, but also why, at the same time a preference emerges in Danish DBFs for substituting this decline with an increase in its non-domestic counterpart.

6 University-owned patents as substitutive outlet for academic inventive potential

The results from the previous section substantiate the argument that LUP has negatively affected the contribution of university scientists to the inventions of Danish biotech firms. To assess the implications of that finding we must take into account if new channels for academic inventiveness have emerged as replacement, above all in the form of university owned patents, as was indeed the intent of LUP. Therefore we identify the number of domestic academic inventor participation in university-owned patents filed subsequent to LUP (consistently using 2001:1, as the date argued above to best distinguish effective implementation of LUP). Next we calculate the number of participations ''lost'' as an effect of the decline, estimated in the models above, in domestic academic inventor contributions to company-owned patents for the same period, and then compare the two.

Table 11 Patents assigned to 5 Danish universities 2001–2004 by category of invention

Invention category	Number of patents	Share of total (%)
Drug discovery	14	25.45
Other pharma-medico related[a]	26	47.27
Physics etc	15	27.27
Total number of patents	55	100.00

[a] Diagnostics (eight patents), Drug Delivery (one patents), Genetic method/Technique (two patents), Measuring or testing processes (ten patents) and Medical instruments (five patents)

The five major Danish universities involved in pharma related research (including their research hospitals),[6] until 2005 applied for a total of 72 patents, of which 55 were filed subsequent to 2001:1. There is no question, in other words, that LUP has induced a notable increase in university-owned patenting. To identify comparable figures among the 55 university-owned post-LUP patents we identify those relating to drug discovery. This identification was made on the basis of their main International Patent Classification and their abstracts, producing the categorisation presented in Table 11.

The 14 patents in drug discovery identified in Table 11 list a total of 66 inventors, 11 of which were non-academic. That leaves 55 inventor contributions from university scientists as relevant for comparison with the decline in academic inventor contributions to DBF-owned drug discovery patents.

To calculate the number of academic inventor contributions missing as an effect of LUP estimates from either two approaches applied in the Sect. 5 may be used. From the DD regressions the LUP-specific effect on Danish academic inventor shares of –0.128 (from Table 6, Model 1) translates into a deficit of 130 inventor contributions, equivalent to an average decline of 0.41 academic inventors per post-LUP Danish DBF patent. That is not too different from results obtained from extrapolating the pre-LUP upward trend by which the Danish domestic academic shares converge towards the higher Swedish level. Extrapolating this trend of 0.0194 in quarterly increases (from Table 9, Model 1) through 2001–2004 to get expected shares, from which actual shares are subtracted, returns an estimated deficit of 160 inventor contributions.

Preferring the lower DD-based estimate of 130 inventor contributions missing from DBF patents as an effect of LUP, and relating it to the 55 academic inventor contributions to post-LUP university-owned patents identified above, we observe a substitution in inventor contributions of 42%.

It must be added, however, that the 55 inventor contributions identified in post-LUP university-owned patents in drug discovery should *not* be compared to patents filed *only* by Danish DBFs. The post-LUP decline in academic involvement affects also other Danish firms engaged in the type of advanced drug discovery relying on university collaboration. That is the case not least for the two largest Danish pharmaceutical firms of Novo Nordisk and Lundbeck.

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[6] University of Copenhagen, University of Southern Denmark, Technical university of Denmark, University of Aarhus, The Royal Danish School of Pharmacy.

From 2001 to 2004 these two firms applied for a total 380 new patent families in drug discovery,[7] i.e. exceeding the 317 patents concurrently filed by all 49 Danish DBF. Inventor identification has not been undertaken for these 380 patents, but one assumption could be that they mobilize the same number of inventors per patent as found in the Danish DBF patents, have them similarly distributed on company and on academic inventor contributions, and have the latter similarly reduced as an effect of LUP. Under that assumption we may apply the average post-LUP decline of 0.41 academic inventors per patent also to the 380 Novo and Lundbeck patents, which equals an expected loss of 158 academic inventor contributions. More conservatively their decline in academic participations could be assumed to average only half the rate observed for DBFs (0.205), equivalent to a post-LUP loss of 79 academic contributions.

The first assumption brings the combined post-LUP absence of academic collaboration in drug discovery inventions for Danish DBF and the two pharmaceutical firms to a total of 288 university inventor participations, for which the 55 academic inventor contributions to university-owned patents represents a substitution of 19%. The second assumption produces a combined absence of 209 academic participations, for which university-owned patents substitute 26%.

Even when consistently preferring conservative estimates in the above calculations we reach the conclusion that university-owned patents are very far from providing a substituting outlet for the inventive potential of university scientists previously mobilised for company-owned drug discovery patents.

Yet another possible outlet to consider is if the inventive potential of academia resides particularly in those university scientists who later on spin out to form companies of their own, relevant not least for the steep increase in the formation of new DBFs in 2000–2001 observed in Fig. 1. The argument behind this conjecture would be that this steep increase in entry of new firms involved a migration of university scientists to the role of start-up founders to such an extent that a significant part of the inventive potential at this juncture moved from academia to industry, hence possibly inducing a part of the decline in academic inventor contributions after 2001.

We examine this conjecture by identifying all Danish academic scientists who appeared as inventors prior to 2001 and who *also* spun out as founders of new firms in the steep increase of entries in 2000–2001.[8] That turned out to be only three academics, and they delivered only 2.5% of academic inventor participations before they became founders of start-ups, and a similar share of 2.5% afterwards. In other words, the migration of inventive talent from academia to start-up founder teams specifically associated with the 2000–2001 wave of entries is much too small to be attributed any significant role in explaining the shifting trends in academic inventor contributions identified above.

To sum up, neither university-owned patenting, nor university spin-outs, substitute to any substantial extent for the inventor contributions estimated missing as an effect of LUP. *By far the largest part of this academic inventive potential simply seems to have been rendered inactive as an effect of LUP.*

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[7] I.e. excluding patents in process technologies, tools, devices etc. comprising an additional large number of patents particularly from Novo Nordisk.

[8] This information is extracted from SCANBIT, which comprises a full identification of the founder teams behind Scandinavian DBFs engaged in drug discovery.

7 Discussion

The two previous sections have shown that domestic academic contributions to Danish DBF patents notably declined as an effect of LUP, and that only a minor part of this decline has reappeared as inventive capability in university-owned patenting or in the formation of university spin-outs. These findings beg the question why the academic inventive potential previously mobilized for company assigned patents fail to reappear in subsequent university-owned patenting. In this final section, we draw on extant literature to piece together at least a partial answer to this question.

A useful point of departure is to look into the motives driving academic scientists to join the kind of collaborative research, which as one of its outcomes may turn them into inventors credited on industry-owned patents. A recent study obtained responses from 4,300 UK academics[9] in the UK on their *types of relationships* with industry, including collaborative research, along with consultancy, conference attendance, joint PhD supervision, etc., on a menu of nine different types of relationships (D'Este & Patel, 2005). The first finding to note from this study, is that factor analysis of the nine types of relationships brings out ''joint research'' as a separate, highly robust factor. In other words, more than any of the other relational types, joint research is sui generis in the way academics connect to industry. Furthermore academics engage in joint research for purposes that are distinctly different from the motivations driving them in other types of relationships with industry. Citing the response categories from the survey, academics do joint research predominantly for the purpose of ''keeping abreast of research in industry''; ''increasing the applicability of university research'' and ''getting access to research expertise in industry''. So whereas academics may engage in other relational types for a variety of reasons, they participate in joint research so as to better anticipate the technological frontier, and to access expertise of a kind less easily found within academia. To put it differently: in stead of seeing joint research with industry as a detour temporarily diverting them from their core scientific agenda, collaboration is perceived as having intrinsic, i.e. epistemic, value for this agenda.

This understanding is supported by another recent study, which identifies higher overall scientific publication performance of 299 Italian university scientist credited as inventors in EPO patents in the 1978–1999 interval, compared to a matched sample of academics without inventor contributions (Breschi, Lissoni, & Montobbio, 2005). Superior performance is attributable partly to the well-known phenomenon that a segment of academics delivers a disproportionately high share of publications. So while it is not surprising that this segment has its higher productivity expressed in *both* patenting and publications, it also means that industry recruits its academic inventive potential particularly within this high-performing segment. Higher performance, however, also is a result of the projects in which academics have contributed to patented inventions, because academics in these projects access extra resources for their research. For the same reason the beneficial effects of inventor contributions on subsequent publication rates turn out to be much stronger for inventions patented by firms as compared to academic inventions patented by universities. An equally interesting finding in this study is that this beneficial effect on

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[9] Sampled from the total of 25,400 university scientists who had received grant from the Engineering and Physical Research Council between 1999 and 2003.

academic performance does not imply a shift towards more applied research. On the contrary, it is particularly strong when it comes to publications in *basic* science journals.

Collaboration with industrial partners may fit into particular issues of academic research in ways that benefits its progress (Rosenberg, 1994, 2000), e.g. by offering opportunities to experiment on a larger scale, or under more realistic conditions. Academic scientist exhibit increased presence in industry collaboration precisely during the stage when new agendas emerge for industrial research, arguably because that is when collaboration with industrial R&D is particularly fruitful for the advancement of scientific knowledge (Valentin & Jensen 2003).

Therefore, despite differences in their objectives, industrial R&D and academic science may find issues for collaborative research offering complementarities and synergies benefiting either party. Consequently, when left with sufficient possibilities for self-organising behaviour, university scientists and firms are likely to select issues for collaboration offering, at one and the same time, opportunities for epistemic and technological advances, even if technological intensions at this early stage are quite unspecific. The defining characteristic of such collaboration is a research agenda representing *a duality of epistemic and technological objectives*.

The pre-LUP framework was conducive for such dual-objective collaboration, because it allowed the industrial partner to appropriate its technological results (patents), while the university scientist from the enhancement it brought to her research, via publications could build academic reputation in the pattern referred to above as ‘‘unappropriated collaboration’’. In this arrangement perhaps the most important control either party had to their respective outcomes referred to their residual rights (i.e. those rights not explicitly specified in the contract), so that in this context they became ‘‘partitioned residual rights’’. Much hinges, we submit, on exactly this principle, since partners in joint research do not look upon their collaboration only from a static perspective as an exchange of information and activities. Rather they see the project and its outcome more as a type of good offering *generative* potential, capable of bringing about further benefits when combined with additional activities or assets separately controlled by the partners. Contracts with high tolerance for partitioned residual rights are helpful for joint efforts directed at such generative goods, because they incentivize partners to invest in their creation, at the same time handling their concern that they cannot ex ante specify claims on outcomes.

These contractual principles for academia-industry collaboration in important ways are affected by LUP, which introduces the university (as represented by its TTO) as an actor looking for potential revenues to the university. That is quite different from the pre-LUP version of university interests, which were represented through academics looking for intellectual synergy combined with industrial funding. In this sense TTOs are not simply as a more formal representation of the interests of academic scientists. More correctly they could be seen as building a tri-partite contractual space involving the TTO, the academic scientists, and the company.

In many cases complementarity of interests between all three parties allows joint research to be undertaken, based on ex ante agreement about resultant IPR. It was argued above that research objectives closer to technological innovation typically would form such cases, while exploratory, front-end joint research often will fit into this tri-partite framework with much greater difficulty (Laroia & Laroia, 2005; Slowinski & Sagal, 2006).

In other cases, the industrial partner and the academic scientists may have a complementarity of interests not shared by the TTO. In exploratory research firms and academic scientists often find interest complementary sufficient to motivate collaborations, as witnessed by the hundreds of inventor contributions to patents documented above. Mutual recognition of ‘‘partitioned residual rights’’ was an effective contractual form for their pursuit of this complementarity. The requirement introduced by LUP that IPR be allocated ex ante, on the other hand, often will fit inadequately into this complementarity. The inadequacy of this fit will tend to grow with increasing technological immaturity of the inventions emerging from exploratory research, rendering remaining R&D costs and the eventual market value increasingly difficult to asses.

These complications, we submit, are the most plausible reasons why Danish biotech firms, after the implementation of LUP withdraw from collaborations with Danish university scientists, increasingly substituting them with non-Danish academics, presumably operating under less restrictive regulation.

To what extent should academic inventive potential rendered inactive by LUP regulation, be expected to reappear in university-owned patents, invented solely by academic scientists? It should be remembered that pre-LUP regulation offered *stronger* incentives for academics to invent and patent. When nevertheless they rarely did so, it was not only because they preferred the resources they could obtain from the collaborative arrangements in return for the IPR assigned to the industrial partner. It was also because on their own they lack the information, the heuristics, and the experience in drug discovery and development, which the industrial partner brings to the table in collaborative research. Without this complementarily of insights, originating in both commercial and in academic drug discovery research, university scientists are not likely to maintain the rate of invention which they obtained in collaborative research. On their own university scientists should be expected to appear les frequently as inventors on patents, compared to their pre-LUP appearance in company assigned patents.

This disadvantage in inventiveness on part of academic science to some extent grows out the discipline-based organisation of university research. A recent study of the early history of modern US biotechnology indicate much stronger commercialisation from university research which had been reorganised to bring the more basic science of the molecular biology department into direct exchange with departments in the same university focused on applied and clinical research. The gradual diffusion across US research universities of such interdisciplinary organisation of academic biomedical research probably ranks importantly among the reasons for the higher academic patenting activity observed in the US as compared to Europe (Jong, 2006). The larger mobility of scientists between industry and academia and the stronger inter-university collaboration observed for the US constitute additional mechanisms pulling in the same direction (Owen-Smith, Riccaboni, Pammolli, & Powell, 2002). These, and other related organisational features increase the exposure of US academic scientists to information and opportunities allowing them to a higher extent to produce inventions leading to university-owned patents. At the same time they rest on deep-rooted and far-reaching differences between Europe and the US not likely to disappear in the foreseeable future (Allansdottir et al., 2002).

The implication of this argument is that the US context in important ways plays into the effects, which the Bayh-Dole reform has had in stimulating university biotech patenting. Without this context Bayh-Dole inspired reforms in other countries may generate very different effects, as demonstrated by the Danish case presented in this paper. Lacking the specific advantages of the US context, the pre-LUP arrangement could very well have provided Denmark with a better framework for the broader objective of commercialising the inventive potential associated with academic *explorative* research.

Qualifying the argument as pertaining to exploratory research only is important. As argued above, university research operating in fields closer to technology, less demanding in terms of complex, post-discovery development, is better able to invent on its own, without relying on clues and information from industrial partners. And if such downstream issues are addressed in collaborative projects, they also lend themselves more easily to ex ante allocation of IPR.

Consistent with this qualification, Table 11 above identified almost 26 patents, invented and owned only by universities, in the category of ‘‘other pharma-medico related patents’’. Inventions in this category, comprising e.g. diagnostics and measuring and testing processes, have a shorter and less complicated road from invention to marketed innovation, as compared to drug discovery inventions, of which there only about half as many among university-invented and owned patents.

In other words, LUP is not uniform in its effects on joint university-industry research. Ceteris paribus, it will operate best for joint R&D on issues closer to commercial technologies. The extent to which academic engagement in this end of the R&D spectrum is consistent with the broader rationale and objectives of university science opens a set of issues beyond the scope of the present paper.

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