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What is the causal effect of R&D on patenting activity in a professor's privilege country? Evidence from Sweden

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JEL codes: C25, C26, I23, I28, O31, O32, O34, O38

Keywords: research and development, patenting, academia, knowledge production functions, the professor's privilege, Sweden

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We investigate the responsiveness of academic patenting to research and development (R&D) on the subject level at Swedish universities in panel data regressions. The general responsiveness to R&D is found to be higher than corresponding estimates found in US studies, especially when we adopt instrumental variable techniques that address endogeneity in the studied R&D-to-patent relationship. We also find that this responsiveness is not associated with lower quality of patents measured in terms of citations. A higher responsiveness from R&D to patenting is found in "Information technologies", "Chemistry (science)", "Electrical engineering, electronics & photonics" and "Chemical engineering", "Medicine" and in "Microbiology" than in other common patenting fields. Our main result, that academia in Sweden contributes well to inventive activity support the view that the professor's privilege may be a contributing factor.

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1 Introduction

Academic patenting is one of many dimensions related to entrepreneurial behavior of academics. Academic researchers rarely leave academia, especially not to start new firms, mainly due to a lack of job security outside academia and the satisfaction of 'solving research puzzles' at their current job, which compensates for relatively lower incomes (Åstebro et al. 2012; Stern 2004; Åstebro et al. 2015). Therefore, patents are an important channel to study in order to understand how academic research results are transferred into economic results.

A large literature examines different factors that affect university entrepreneurship broadly and patenting more specifically (Rothaermel et al. 2007; Foray and Lissoni 2010). In the

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literature on academic patenting, several topics have been discussed including factors on the individual level that stimulate involvement in commercialization; that of the appropriation behavior that can follow from ownership of intellectual property rights and ensuing tensions with a culture of open science. An important stream of research has focused on the role of the institutional regime, i.e. who should own the rights to commercializable research results. One important area has largely been ignored, however, namely how patenting responds to the level of resources available. Thus, while resources are normally geared towards producing research results, we have substantially less knowledge about how much commercial results can be expected. In this paper we address the question: How does patenting among academics respond to research funding?

This is an important research area for several reasons. Policy makers are increasingly interested in whether research and development (R&D) outlays result in commercializable results, but without even having estimates of such relationships, there are risks that policies go in the wrong direction. To give a few examples, policy officials tend to rhetorically claim that academia does not contribute 'enough' commercializable results.[3] This may easily be taken as 'evidence' to alter incentives for academics to research vs. to produce e.g. patentable results, with potentially disastrous long-term effects on basic science development. Policy may also as be tempted to fiddle with the intellectual property regime, following the popular trend in Europe to switch ownership to patents from the individual level to that of universities, although an emerging academic literature has become increasingly skeptical of such shifts.

To our knowledge, only two previous contributions study the relationship between R&D and patenting by also taking into account the heterogeneity of patenting that pertain to the field of activity of academic researchers and using a similar knowledge production function (KPF) approach as in this paper (Coupé 2003; Gurmu et al. 2010). Both these studies examine the United States, a country which has had a default university ownership of intellectual property for a long time. In this context it becomes important that we examine the case of Sweden, one of few countries in Europe, where individual ownership has been the law since 1949.

We give a causal interpretation to the R&D to patenting relationship by an instrumental variable approach. Two studies on the R&D-patent relationship also using US data exist (Whalley and Hicks 2014; Payne and Siow 2003). However, in contrast to the two KPF-studies, they pool fields and treat university patenting by year as their unit of observation. Our analyses utilize a new dataset on patenting by academics from the period 1995-2010, which we analyze over 32 sub-fields. We utilize government block grants and non-block grants by university in the broad field of science where a researcher is active, deducting the corresponding numbers for a subfield's own subject grants to use as our instrumental variables. Our investigation therefore add insights into a) whether the Swedish system, with the main characteristic of maintaining the professor's privilege, makes individuals contribute more or less to patenting for a given set of R&D-resources and, b) the causal effect of R&D to patenting, analyzed also on the field level.

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[3] "For instance, ex-minister of Industry Maud Olofsson stated "Normally the debate always revolve around two things: the so-called Swedish paradox, that we do a lot of research, but are lousy at entrepreneurship. Our patents and our research stays in academia or is taken over by foreign financiers and businesses." (*Veckans Affärer*, 27/4 2007; own translation).

We find that Swedish patenting responds more strongly to R&D resources than corresponding estimates obtained through US data, also after accounting for heterogeneity of inventive activity across fields and especially when we adopt an instrumental variable approach. This increase does not seem to affect patent quality, measured by citations. The estimated effects are strongest in what seems like specific Swedish strongholds in “Information technologies”, “Chemistry (science)”, “Electrical engineering, electronics & photonics” and “Chemical engineering”, “Medicine” and in “Microbiology”.

While we realize of course that our research question only addresses the link from R&D to patent and not subsequent contributions to new firms and job growth, we see it as a first step towards bringing more systematic knowledge about the causal effects of R&D to entrepreneurial activity. Thus, based on the findings of this paper, our recommendation is that policy makers do not abolish the professor’s privilege and instead realize that increasing R&D has a causal impact and high impact on patentable results, at least relative to the US, that does not come at the cost of the quality of patents.

2 Literature review

Patenting constitutes one of the mechanism that allow actors to benefit from a division of labor where academics can develop commercially viable inventions, but where firms with greater commercial skills may market and sell products derived from inventions (Arora et al. 2001). But patents remain controversial, especially those that come forward as a result of academic research. This is because such research is often publicly funded which raises normative issues regarding whether researchers or universities should at all be involved in intellectual property rights ownership and how this may conflict with the open science ideal of provision of a public good (Dasgupta and David 1994; Murray and Stern 2007; Washburn 2008).

Against this stands the important point that researchers are needed as translators of scientific knowledge into commercialization and that patents can provide one such compensatory mechanism for lost research time (Zucker et al. 1998a; Zucker et al. 1998b). Therefore, it remains an important research area to understand which behavioral determinants and institutional characteristics that can help academics contribute to innovation, e.g. through patents. This becomes no less important as individual-level data indicate that researchers who engage in commercialization, at least measured through patents, also become better researchers (Azoulay et al. 2009; Buenstorf 2009).

The factors that have been shown to influence academics’ patenting activity include gender, age, institutional norms and the patenting regime. It is well established that women researchers tend to spend less time engaging in commercialization activity, although the exact mechanism are not firmly established (Cole and Zuckerman 1984). Some possibilities include are a higher commitment towards family obligations, including a longer parental leave time that may erode the human capital base of an academic career (Mairesse and Pezzoni 2013). It is therefore not usual to observe that women in academia put stronger emphasis on publishing relative compared to commercialization activities, in order to demonstrate a convincing publication track record (Ding et al. 2006; Lissoni et al. 2013a).

Also age and advancement to senior status play important roles. One fundamental aspect of the academic career is the forward looking nature of research that augments the human capital base of researchers. This is one reason why many researchers' publication activity tend to go down as they approach retirement. This important life-cycle effect (Levin and Stephan 1991) also explains a shifting emphasis away from publishing towards commercialization where professors may want to 'cash in' on human capital accumulated over their careers or, arguably more positively, through increased responsibilities to attract research funding from a wider range of sources for their academic department (e.g. Toole and Czarnitzki 2010). Both being closer to retirement and advancement to professorship are therefore factors that can make individuals more willing to engage in commercialization.

Other aspects, such as culture and academic norms could be very important determinants of commercialization activity, but are less tangible. Huang et al. (2011) examine organizational and individual determinants of patent production from a US national survey conducted in 2010. They find that technology transfer offices established at the university (TTOs) may have an effect on individuals' patenting in the first place (cf. Coupé 2003, below), while rather department incentives and individual preferences shape the level of patenting. They argue that doctoral training programs entail a socialization process, whereby the proclivity towards patenting in different fields could be linked to open science arguments, i.e. to maintain research results public. But the role of TTOs also tend to differ by ownership regime. Sellenthin (2009) surveyed academic researchers Sweden and Germany and found that in Germany, where researchers had (then recently) lost ownership rights to intellectually property to universities, had much more contacts with the TTO. In Sweden, no obligations to use TTO services exist due to the default individual ownership rights to patents.

Universities and the IPR ownership regime

One of the rationales for the study we are undertaking is that the US case (on which much of the published work comes from) differs from many European countries where university researchers until recently held ownership to their inventions, commonly referred to as the professor's privilege. These changes were inspired by the US Bayh-Dole act of 1980, which transferred ownership rights to patents from federally funded research from the federal level to the university level. Observing a rise in US university patenting in the 1980s (Jaffe, 1998) that followed Bayh-Dole, many European countries changed ownership regime to the university level in the 2000s.

Several studies have investigated whether researchers are stimulated to invent under the two regimes, both from theoretical and empirical standpoints. However, David Mowery and associates showed that US academic patenting started to increase even before the act, and seem to have had more to do with the rise of biotech and the IT sector than the act itself (Mowery et al. 2001; Mowery and Ziedonis 2002). It could be noted that, whereas the US change involved a decentralization of ownership, the European case more or less invariably involves centralization.

Theoretically, university vs. individual ownership may both impede and raise the willingness to invent. Verspagen (2006) notes that universities may be efficient agents of commercialization under university ownership if they can pool knowledge and pick the best commercial actor to work with through skilled TTO interaction. An additional advantage of university ownership may rest in the alignment of interests between inventors and their universities, the former which may suffer from time-constraints due to involvement in administration and teaching, and the latter which may act to free up researchers' time to engage in commercialization. On the other hand, TTOs may also add a bureaucratic burden if ineffective, and if the researcher already knows the most expedient way to commercialize an invention.

These trade-offs are summarized in the model by Lowe (2006). Here researchers have the choice between commercializing their inventions themselves in a firm of their own or by contracting with another firm, which are analyzed under the two ownership regimes. In order to stimulate future inventor involvement, it is generally necessary to reward inventors by royalties or equity shares from future production (cf. Jensen and Thursby 2001). Without university involvement in the Lowe model, it is optimal for academic inventors to commercialize inventions through their own firms if their opportunity costs are sufficiently low and/or the degree of tacitness involved in invention is high. On the other hand, when universities are involved as intermediaries, royalty rates remaining for the inventor will lower the output below what the inventor can obtain without university involvement. Even though the university comes out as a winner in this situation, for society these gains are offset by lower total output because rewards are higher taxed; both for the inventor and university. The inventor also loses, because of the lower output and ensuing lower royalties and the fees shared with the university. A case could be made for university ownership when the university charges a fixed fee and is better at aggregating information to find prospective partners than inventors who may have difficulties collecting such information.

A recent model, accompanied by numerical analysis, was presented in Färnstrand Damsgaard and Thursby (2013) who compare the Swedish system of professor's privilege with that of the US system of university ownership. Comparisons are made with respect to the relative merits of faculty startups and established firm commercialization of university inventions. The Swedish system is found to be more conducive to entrepreneurship if established firms have an advantage over faculty startups. On the other hand, the average rate of commercialization is higher in the US system, except if there are search costs in finding an established firm, if the inventor has a preference for doing research, or if development efforts are subject to near constant returns to scale and/or combined with an advantage for established firms.

These models do not lend themselves to a clear theoretical prediction about which ownership regime is superior for influencing the rate of invention, although theory suggests that under a TTO system large universities may have better possibilities to pool resources and to efficiently guide academic inventors, provided that there are economies of scale and scope stemming from learning in commercialization over time. On the other hand, if universities are small, TTOs, lacking the necessary built-up competencies, may instead be blocking budding academic inventors.

Despite these theoretical considerations, policy has followed a simplistic behavior aimed at mimicking the US system.

Empirically, studying the role of ownership regime for stimulating patenting should ideally be done under experimental situations, where the behavior of academics could be observed under the two regimes. It may also be possible to study universities with different ownership regimes operating under otherwise similar institutional and economic conditions (Kenney and Patton 2011), or to see whether the rate of invention changes if a country changes ownership system (Lissoni et al. 2009; Lissoni et al. 2013b; Czarnitzki et al. 2015).

Kenney and Patton (2011) make a six-university comparison of spin-off formation at universities in North America, where the university of Waterloo in Canada is the only one to have a system of inventor ownership. They argue, based on the model by Lowe (2006), that inventive ownership should be associated with a higher rate of spin-offs, in relation to university ranking, to R&D expenditures, and patents per faculty, after conditioning by academic field. Waterloo excels in the rate of number of spin-offs in relation to R&D expenditures or faculty. Interestingly, the second best performing university is University of Wisconsin, Madison, which has an earlier history of inventor ownership.

Denmark was the first country in the recent wave to change ownership in 2000, and was studied by Lissoni et al. (2009). Unfortunately, the authors were unable to compile lists on professors before 2001, and therefore not much can be said about level effects of the IP rights change. The main observed difference seems to be that individual ownership of patents has now been replaced with university ownership.

In Italy, two major reforms influenced the rate of academic patenting (Lissoni et al. 2013b). First, in 1989 and through amendments in the 1990s, Italian universities were granted autonomy with respect to governance and funding. Second, in 2001 the country switched to a system of professor's privilege. The autonomy reform(s) had the effect of clarifying ownership to the universities of academic inventions, which prior to the reform had been outside the responsibilities of both universities and central government. The introduction of the professor's privilege came as a big surprise to technology managers at Italian universities, where few immediately complied and others made amendments in their internal IP-regulation to circumvent and maintain university ownership. Lissoni et al. (2013b) conclude that the actions of the universities effectively negated the introduction of the professor's privilege, and find a decline in the share of academic patents and a rise in the share of university ownership over time.

Probably the most convincing piece of evidence comes from Czarnitzki et al. (2015) who uses difference-in-difference estimations comparing university researchers' (who switched regime) patenting on the individual level with that of institute researchers (where no change took place) before and after the abolition of the professor's privilege in Germany. The results clearly indicate that patenting by university researchers dropped after introducing university ownership compared with institute sector researchers' rate of patenting activity.

Knowledge production functions in university patenting analyses

Knowledge production functions (KPF) were first introduced by Griliches (1979) to study the role of R&D in firm productivity. Some of the challenges discussed was that knowledge accumulated can only imperfectly be captured by current investments in knowledge, e.g. through R&D, and how to account for the fact that past investments lose importance over time, i.e. depreciation. This is further complicated by the fact that knowledge is more difficult to measure than physical capital investments. Nevertheless, a large number of studies exist on the effects of R&D on the firm level (see Wieser 2005; Hall et al. 2010 for surveys), mainly on productivity gauged by value added or production value or in some cases production costs. This literature has typically settled on a 15 percent depreciation rate of knowledge capital constructed from R&D. The most common approach is to start from a Cobb-Douglas production function, although a small number of studies use the more flexible translog production function and some studies also examine the effects of R&D on production costs (Hall et al. 2010). Other issues dealt with has been differences in cross-sectional estimates and those over time and how to identify causal effects rather than advanced correlations. The literature often uses GMM-estimators which exploits lagged variables as instruments to deal with the endogenous relationship between R&D and the studied productivity outcome.

In studies using patents as dependent variables, practical considerations become more pressing due to data availability constraints. Two classic papers, Hausman et al. (1984) and Hall et al. (1986) utilized linked patent-compustat firm data from the 1960s and 1970s and laid the foundation for the studies in this field. They recognized the strongly non-normal distribution of patents on the firm level whereby the vast majority, even among firms that conduct R&D, never patent and a few firms patent intensively. Such data therefore call for different estimation techniques, applying either Poisson or negative binomial regression methods.

Furthermore, some results concern the appropriate lag structure, where the original papers stressed the almost contemporaneous nature of the relationship from R&D to patents. Recent studies indicate that the time lag from R&D to patenting has become longer from the 1970s to the 1980s (Gurmu and Pérez-Sebastián 2008).

As we now move our attention to the corresponding analysis for universities, existing studies, of which there are only two, have used the standard approach, namely Cobb-Douglas production functions coupled with Poisson and negative binomial regressions to deal with the heterogeneous nature of the data. This is a natural first step, as it would allow for comparison of estimates between firms and universities, although nothing in principle would hinder a development towards e.g. translog production functions. However, in our analysis we use this standard approach because we are mainly interested in differences with earlier studies.

The two existing studies are Coupé (2003) and Gurmu et al. (2010) who use science fields at American universities as their unit of analysis and employ panel regression methods based on the KPF approach. They both find an elasticity of patenting with respect to R&D of about 0.3-0.4. Coupé (2003) adopts the KPF approach to university-wide data from the United States over time to estimate the link between resources for R&D and number of patents for 212 universities. He uses the full series of recorded R&D expenditures 1972-1994, i.e. the period both before and after the introduction of the Bayh-Dole act in 1980, which transferred ownership rights to patents from federally funded research from the federal level to the university level. The act was associated with the start of Technology Transfer Offices (TTOs) at many universities. The TTO-effect was found to be positive and increasing over time by Coupé (2003). Cross-sectional estimates from R&D in the study indicate unit elasticities in Poisson and Negative binomial regressions. Higher elasticities are found for chemicals and drugs than for computer sciences, electrical and mechanical. However, cross-sectional estimates neglect disciplinary and university unobserved effects. This is addressed by including disciplinary and in some specifications university dummies, which effectively lead to a fixed effect panel regression approach. The elasticity is then lowered to about 0.4. Pooled data over time suggest that there are increasing returns to scale, while fixed effect panel models suggest decreasing returns.

Gurmu et al. (2006) study the period 1985-1999 with university-fields as the unit of observation. Their sample consists of 172 universities belonging to the Association of University Technology Managers (AUTM). In comparison to Coupé (2003), this sample is probably somewhat more skewed towards universities with an interest in patenting. They apply the Negative binomial, random effects model and reach similar conclusions as Coupé (2003). They find an R&D elasticity of around 0.3 and also a significant TTO effect. The chemicals science field was found to be most inducive to patents. In addition they investigate if the rate of patenting depends on number of faculty, postdoc and PhDs. They find a somewhat higher semi-elasticity for postdocs than for other PhDs. They also find that the elasticity of postdocs on temporary visas have a lower semi-elasticity with respect to patents.

By Swedish law academics are expected to interact with society according to the so-called third mission. The law does not stipulate the extent of such interaction, which may also involve commercial interaction though such activities should not interfere with on-the-job activities or compete for the same funding. According to Swedish law the rights to invention also normally fall under the ownership of employers, but teachers are an exception. Hence, this is considered a “teacher’s exception” or with a more common label in the literature a “professor’s privilege”. Thus, while R&D resources would normally be expected to generate more publication, in some fields additional resource could stimulate patentable inventive activity.

3 Method and data

3.1 Data on Swedish academic patenting

Investigations of academic patenting typically starts from inventor records found on patent data and combines this with directories of university employees. The large-scale collection efforts by Lissoni and associates in the previous KEINS-project and the APE-INV project for European countries used university staff lists as the starting point, and then tried to find inventors on those staff lists.[4] This is also the process followed by earlier Swedish studies on academic patenting (Göktepe 2008; Ljungberg et al. 2013). There is already some evidence that Swedish academic patenting is high. Lissoni et al. (2008) report descriptive data on France, Italy and Sweden, complemented with data from the US on academic patenting and reach the conclusion that academia in Sweden contributes to about 6 percent of all patenting, just over the US figure. Ejermo (2012), using an earlier version of our data and independently collected data, reaches a similar level for Sweden.

[4] See for instance the special issue of Industry and Innovation published in 2013 (Lissoni 2013).

The data on academic inventors used here draw from a different approach than that of linking staff lists to patent records. From the outset we use a dataset compiled by collecting *all* inventors with Swedish address listed on European Patent Office (EPO) applications. From these, 83% of all inventors or about 27,000 unique individual were linked with their social security number and then to Statistic Sweden directories of employer-employee linked data (LISA) in a panel dataset. LISA gives us access to the basic individual characteristics we use in this paper regarding birth year and gender. This dataset is described on a high level of detail in Jung and Ejermo (2014). From the inventors we select the subset with an academic affiliation as their main work place found in ancillary university-employee databases. The latter source allows us to characterize position and subject field of inventors. We aggregate patents by fractional count on the university-field level by year. Our start year for the patent variable is 2001 as this is the first year that we have information on researchers' field of research. The final year is 2010 as later years would be subject to truncation.

Figure 1 shows the absolute level of patenting and its share in all patent applications to the EPO by Swedish residents that can be attributed to any university employee by main workplace in Sweden. As can be inferred, concomitant to a general increase in Swedish patenting, academic patenting has been rising from about 60 patents at the beginning of the period to about 140 in 2010. Its share of 5-7.5% is very close to earlier reported numbers (Lissoni et al. 2008; Ejermo 2012) and therefore, to some extent validates its use for our purposes.

INSERT FIGURE 1 ABOUT HERE

As our main explanatory variable, we compiled data on R&D expenditures by field from Statistics Sweden's public databases. We use the period 1993-2006. R&D data from before 2001 was used in order to construct lagged R&D variables. Unfortunately, R&D data before 1995 is only available on university level and not distributed by fields. Seeing as the distribution across field do no differ much, we solve this by using the distribution in 1995 to distribute the R&D level by field in 1993. Also, since R&D data is only available biennially (1995, 1997,…), we intrapolate data for intermediate years using the growth rate in surrounding years. All R&D data were deflated to 2011 year's price level using the consumer price index. We analyze only fields active in the broad fields of natural, technical, and agricultural sciences as well as medicine as mainly research in those areas can generate patentable results. Table A1 of the Appendix lists those fields, their respective sub-fields and patenting activity. We exclude from our analysis university-field combinations with zero recorded R&D, as fields without R&D are not likely to produce patents.

3.2 Empirical strategy

As a basis for our analysis we use the knowledge production function (KPF) approach originally developed for firm level analysis (Griliches 1979) to examine field level patenting as a function of R&D.

Our level of analysis is the field active at a particular university. The basic estimated relationship is:

$$P_{iu,t} = f(R_{iu,t-4}, X),$$

where $P_{iu,t}$ denotes patenting in field i, that takes place at university *u* in time *t*. $R_{iu,t-4}$ denotes "R&D" lagged four years. We follow Gurmu et al. (2010) in assuming a four-year lag in the R&D to patent relationship that is based on earlier studies on patent-publication pairs, and employ R&D stocks as our preferred explanatory variable. These stocks are a compound of R&D expenditures in *t-4, t-5, t-6* and *t-7*, depreciated by 15% on a yearly basis.[5] X is a set of control variables.

As is typical for patent data, our dependent variable has a skewed distribution with a large prevalence of zeros, see Table 1.

INSERT TABLE I ABOUT HERE

To take the skewed distributions that affect the level of patenting into account we therefore employ Negative binomial and Poisson regressions (Hausman et al. 1984; Cameron and Trivedi 2005). Furthermore, we use random-effects panel regressions and take field level heterogeneity into account. We do this by including field-level fixed effects, which captures field-related heterogeneity in patenting.

3.3 Instrumental variables

One important challenge for econometric analysis is typically the possibility of reverse causality or the omission of important explanatory variables.[6] Not accounting for such endogeneity will cause biased estimates. In our case, this could stem from several channels. Some examples include patenting units that are able to attract a lot of external funding because their research has shown commercial potential or similarly, that government wants to support a scientific field that shows commercial potential. Although one would think that lagging R&D might solve these issues, the length of time from R&D to patenting varies and the relationship may be subject to simultaneity in underlying processes. Furthermore, if there are measurement errors in our independent variable these will cause similar biases in estimates,

In order therefore to address this potentially endogenous relationship we looked at the literature that tries to examine the causal effects of R&D on publication outcomes. Using congressional alumni representation as an instrumental variable for federal R&D, Payne and Siow (2003) estimate an increase in 10 more articles and 0.2 patents of $1 million in federal R&D. In the Swedish case, decisions are usually not changed in the budget proposals to parliament. This would suggest that alumni representation on the government level itself could be a reasonable instrumental variable. We have not tried this approach as data were not

[5] We also ran our regressions using R&D expenditures (not stocks) lagged four years with very similar results. Those results are excluded to conserve space but can be obtained on request from the authors.

[6] For an introduction to instrumental variable regressions, see e.g. Kennedy (2008).

available. Moreover, proposals from the higher education minister to 'favour' his own university of graduation may be considered nepotism. Still, this could be an interesting undertaking for future research.

Whalley and Hicks (2014) instead use university endowment values that is interacted with stock market returns as a source of exogenous variation. They find an elasticity from R&D to publications of one but neither a significant effect on number of patents nor an effect on patent quality measured as citations per patent in their instrumental variable regressions. The Swedish case differs substantially from the US; most university assets are owned by the Swedish state, are not on the stock market, and proceeds from asset gains are not directly used to finance R&D. One issue with both Whalley and Hicks (2014) and Payne and Siow (2003) is that they do not distinguish between field effects.[7] Patenting propensity varies widely by field, as was recognized by Coupé (2003) and Gurmu et al. (2010) and therefore not distinguishing field differences could result in misspecification. Jacob and Lefgren (2011) used a regression discontinuity approach to distinguish a causal effect of obtaining federal R&D grants compared to those who did not obtain grants, but this approach is more suitable for examining the effects of a specific type of R&D rather than R&D spending in total.

We finally found for our purposes a highly promising approach in the paper by Rosenbloom et al. (2014) that inspired us. They examine the effects of R&D spending on publication output in chemistry. As their instruments for R&D at the university they use federally funded R&D *from a different field*, namely math and physics research allocated to the university. This instrument captures broad field-related conditions that vary arguably exogenously to their outcome variable, publications. Their second instrument is a variant, namely non-federally funded R&D expenditures for math and physics research. This instrument should capture changes in funding environment of a more applied character, e.g. how industry in the region finances research to a higher degree, major fundraising campaigns or faculty recruitment efforts. The variable could also reflect funding from research councils awarded on a competitive basis. We argue that the relative share of these sources could vary greatly. Their third variable is fall student enrollment numbers. The last instrument is intended to capture variations in tuition fees that could lead to faculty recruitment. Rosenbloom et al. find that $1 million in R&D funding increases publication output by 19 articles and also increase citations.

In the Swedish system, financing of universities' activities may be divided into three main categories: a) resources for research and teaching as base funding from the central government budget, i.e. block grants allocated by field to universities, b) resources for research that have other sources, such as competitive grant funds or local external funding, and c) resources for teaching, based on number of study seats. Student numbers are decided by central government through the allocation of study seats. Although this could be considered exogenous to some extent, we cannot find a clear link from such a variable to a specific field as many students take educational programs that spread over several fields rather than a specific one that we study.

Therefore, as we are interested in how the effects vary across different fields, we construct variants based on Rosenbloom et al.'s first two instruments as follows:

[7] This probably stems from the fact that they employ university-wide variables as instruments and therefore choose the university as their unit of analysis.

1. Government block grants for R&D to a university summed over the broad field of activity (e.g. natural sciences) deducting the own sub-field's (e.g. physics) contribution, lagged one year.

2. Non-block grants for R&D to a university summed over the broad field of activity deducting the own sub-field's contribution, lagged one year.

We also construct stocks of these variables similar to our explanatory R&D variables and use the result as our instruments. Our R&D-based variables are exemplified by Figure 2, which shows the development of R&D expenditures in one of our investigated university-fields, Information technology at Lund University. Panel a) depicts total R&D expenditures divided into funds from the central government in the form of block grants and non-block grants. Panel b) shows the R&D expenditures that form our instruments, namely block and non-block grants to the broad technology field at Lund University, minus block and non-block grants in information technology, i.e. what we see in panel a). The rationale for our instruments (the exclusion restriction) is thus that the patenting outcome of one field is not directly influenced by the R&D inputs from other fields.

INSERT FIGURE 2 ABOUT HERE

3.4 Control variables

Many potential control variables derive from a literature according to which individual level factors impact on commercialization behavior. Still, in our panel setting, it is only if these variables change over time that they gain significance. In fact, in our empirical results these seldom have a significant effect and will not be discussed any further.

We include the share of faculty which is the share of researchers on permanent contracts, i.e. senior lecturers and full professors, to control for the possibility that staff at different career stages engage differently in patenting. Cross-sectional data indeed suggest that professors are substantially more active in commercialization (Huang et al. 2011), although this may not have a causal interpretation; more able individuals active in both publishing and commercialization that make it to the professor's level may explain this finding. Ejermo (2014) finds that senior lecturers and especially professors as well as age factors and gender explain a lot of the cross-sectional variation for a host of commercialization indicators. We also include average age and the share of male researchers working in the field in order to control for life-cycle effects (Levin and Stephan 1991) and gender effects on patenting (Lissoni et al. 2013a).

4 Regression results

We first present estimates where we put all observations over different fields together. Table 2 presents linear panel regressions with random effects (LPRE), Negative binomial and Poisson regressions all without instruments and, in the fourth column, our IV-estimates. We vary these regressions by including field dummies. For our LPRE and IV regressions, we use log patent fractions as our dependent variable, but set log (zero) as zero and include a dummy variable that takes the value one for those cases (Bound et al. 1984; Payne and Siow 2003). This has the advantage of including zero patenting among the observations and still allows us to compare LPRE with IV estimates.

INSERT TABLE 2 ABOUT HERE

The results always yield a positive and highly significant coefficient for R&D. The lowest estimate elasticity is found for LPRE at about 0.11-0.13 depending on whether we include field dummies. On the other hand, for Negative binomial and Poisson regressions the estimates are much higher and the results are fairly much the same. When comparing our results with Gurmu et al. (2010), it is clear that our estimate is much higher, but when comparing with Coupé (2003, Table XI) our estimate is nearly identical. However, Coupé uses R&D expenditures, whereas we and Gurmu et al. use R&D stocks.

For the instrument variable regressions the first stage-estimations (Table A2 in Appendix) show that the first instrument based on block grants is positive and highly significant both when we include and not include field dummies. The other instrument based on non-block grants is, however, negative and highly significant when excluding field dummies and non-significant when including field dummies. Examination of the correlation coefficients reveals that, while each of the instruments have a correlation with the explanatory variable of 0.55 (block grant instrument) and 0.39 (non-block instrument), their internal correlation is as high as 0.81. Therefore, the negative estimate in the first stage should not necessarily be taken literally but be viewed as a moderating effect, which differs by field. An F-test very strongly rejects that the instruments are weak whether including field dummies or not. However, the Hansen J-test rejects the validity of the overidentifying restrictions in the model without field effects. Moreover, the Hausman specification tests (Hausman 1978) reveal that there are systematic differences between that LPRE and IV estimations, indicating that the relationship between R&D and patents indeed suffers from endogeneity. It is therefore clear that not taking the endogenous nature between R&D and patenting into account may severely bias the estimated effect. This makes the model with field effects using instrumental variables preferable. Thus, in this regression our estimate shows a higher elasticity by a factor of 2.3 compared to the LPRE estimate. The point estimate implies that a 1% increase in R&D raises patenting by about 0.3% on average.

Note that in the IV-models the estimates are much larger than the corresponding LPRE estimates. This is contrary to the story of more patent productive field-university combinations also receiving more funding. If that was the case we would expect the IV-estimates to be smaller than the LPRE estimates, since such a productivity bias would make us overestimate the effect of R&D to patenting (the units receiving a lot of grants are also the units that patent a lot). However, the results are consistent with a bias stemming from measurement errors in the R&D variable. Consider that not all funding for R&D are used for R&D, instead part of the funding goes to cover e.g. overhead costs. In that case we would rather underestimate the effect of R&D on patenting in the LPRE models and the IV models would take care of this downward bias.

Finally, we also examined, using citations per patent as our dependent variable, whether patent quality dropped using all of the above estimation methods.[8] Patent citations were measured within a five-year period after application. In order to avoid truncation issues, we dropped the observations for 2006-2010. We never found a significant effect, which combined with the earlier result suggests that patenting increases as a result of R&D without attaining lower quality.

4.1 Estimates across different fields

Table 3 shows the corresponding estimates for the top ten patenting fields in the Swedish university system. Clearly, the effects are very heterogenous. Again LPRE effects are the lowest, with an elasticity ranging from 0.07 (Physiology & pharmacology; not significant) to 0.492 (Microbiology). There is a dramatic shift upward in the estimated coefficient when we use estimation methods that more appropriately take into account the heterogenous distribution of patenting. Most fields exhibit a positive and statistically significant effect. The two estimation methods also point to similar coefficient estimates (Negbin/Poisson), with Medicine, Surgery, Information technologies and Chemical engineering showing the largest coefficients. A few differences can be observed where the most important are that Medicine obtains a more than twice as high estimate using the Poisson method, Physiology & pharmacology is insignificant using Poisson and Chemical engineering does not achieve convergence using Negbin (and hence no estimate can be reported). Compared to results reported by Gurmu et al.[9] using Negbin, they found the following coefficients: Electrical, Electronic and Mechanical (0.3958), Drugs & Medical (0.3638), Chemical (0.2833), Other Field (0.2508), and Computer & Communications (0.1600). These are clearly smaller than the estimates we obtain for high-patenting fields.

INSERT TABLE 3 ABOUT HERE

In the instrumental variable regressions, our first-stage estimates show that the block grant instrument is always positive and highly significant (Table A3, Appendix). Now, in addition the non-block grant instrument is also positive and highly significant in four fields: Medicine, Microbiology Physiology & Pharmacology and Surgery, and statistically insignificant in six cases. In all significant cases, this instrument shows a stronger positive effect than the block grant instrument. This points to differences in the relative importance of block vs. non-block funding in different fields. For the IV-estimates such differences are more correctly picked up by the first-stage coefficients that can adjust to field specificities, which supports our interpretation that the second instrument was "moderating" the first-stage effect when we analyzed all fields jointly.

In the second stage, for four out of ten subject fields we see higher estimates and statistically significant effects that are different from zero in our IV-estimations. These are Information

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[8] These results can be obtained upon request from the authors.
[9] They report this in Appendix B, Table B2 retrieved from http://www2.gsu.edu/~ecosgg/research/pdf/sbg_ei.pdf on April 10th, 2015.

technologies, Chemistry (science), Electrical engineering, electronics & photonics and Chemical engineering. The elasticities roughly double using IV and range from 0.32-0.63. For Medicine and Microbiology the coefficients remain positive and significant with roughly the same size estimate (0.21 for Medicine; 0.44 now for Microbiology) as the LPRE-estimates although they are now only significant on the 10 percent level. For Physics, Physiology & Pharmacology, Surgery and Chemistry (medicine) the estimates remain not significantly different from zero. Thus, as we suspected, our IV-estimates suggest that the causal effect we obtained as a general result in Table 2 actually derive from specific fields.

Furthermore, it can be noted the difference between the LPRE and the IV estimates are larger in some fields compared to others. For example, the difference in Information technologies is 0.472 (=0.626-0.154) while in Medicine the difference is just 0.005 (= 0.211-0.206). Thus, the extent of the bias stemming from a possible measurement error in R&D, due to e.g. overhead costs, seem to be larger in some fields. That the difference is smaller in the medical sciences is not surprising considering that much of the overhead costs here are covered by separate funding (so-called “ALF”-funds), which for example cover clinical research carried out at university hospitals. For medicine therefore the R&D-variables would tend to be more correctly measured. This is also consistent with the observation that much of the potential bias in R&D is stemming from measurement error.

5 Conclusions

To our knowledge, we provide the first systematic investigation of the relationship between R&D and patenting in Swedish higher education. In relation to existing studies, we add a causal interpretation that also takes field-specific effects into account. Our results show a strong positive effect of R&D on patenting in particular compared to earlier US studies, without seemingly compromising patent quality. What can explain this clear strength of the Swedish system? As was discussed earlier, one distinguishing feature of the academic system is the maintained professor’s privilege that an emerging literature indicates can be a positive factor for involving researchers in inventive activity (e.g. Czarnitzki et al. 2015). However, although there is mounting evidence that professor privilege systems may stimulate more inventive behavior of academics, we cannot rule out other possible explanations such as a strong inventive ‘culture’ at Swedish universities, which may pertain to specific fields. This does not rule out that Swedish academia may happen to be strong in fields that are particularly patent-prone. Of course, the professor’s privilege may in turn have been instrumental in fostering such strengths. A promising research direction would be to investigate whether the exchange from R&D to patenting changes as a result of an ownership regime and in general to examine this link across different sets of countries. In addition, although extensive (at least relatively) inventive results emerge from the Swedish system, it would be fruitful to further investigate the ultimate translation of patenting activity into e.g. innovation, spin-off activity and growth. The Swedish context is much more homogenous than that of the United States, as the university system is primarily the responsibility of one central government. In this study we therefore focused on field differences rather than trying to disentangle differences across universities. The latter may be more warranted should we reinvestigate this line of research by examining the effects of R&D on e.g. ensuing start-up activities that follow from patenting.

From a policy perspective, our results point in a completely different direction compared to what is commonly repeated among Swedish policymakers on the highest level. These have complained for decades about the lack of 'usefulness' of Swedish academic research in terms of applied outcomes. Our results suggest that those expectations may have been set overly high, possibly stemming from a lack of knowledge about the conditions and main driving forces of researchers that (usually) first and foremost seek to publish their research and only occasionally engage in commercialization activities, possibly to further improve financing for their research activities or their research group more broadly. It is for this reason important to emphasize that the great commercial drive will probably always comes from those graduating from university rather than those employed there (Åstebro et al. 2013).

The policymakers' expectations may also have formed from a frustration in the lack of economic growth combined with lacking knowledge about the international situation with respect to patenting, which is not surprising given that so many studies have developed in this area over the last decade. In any case, our results show that by international comparison Swedish academics contribute a lot to inventive activity. An earlier official government report (SOU 2005) recommended that Sweden should maintain its professor's privilege. We see no reason that such a policy recommendation should be overturned based on our results.

Figures and Tables

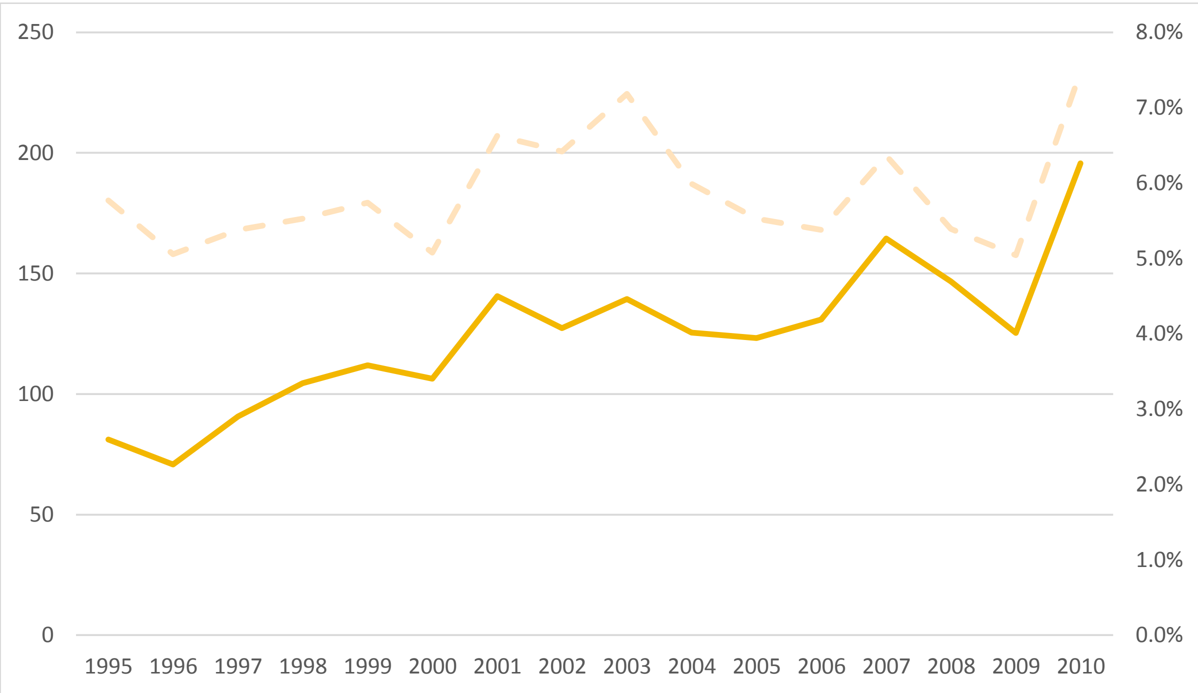

Figure 1. University patenting, absolute numbers (unbroken line, left axis) and relative to all patenting in Sweden (dashed line, right axis) as a share of all patenting in Sweden 1995-2010 in the database.

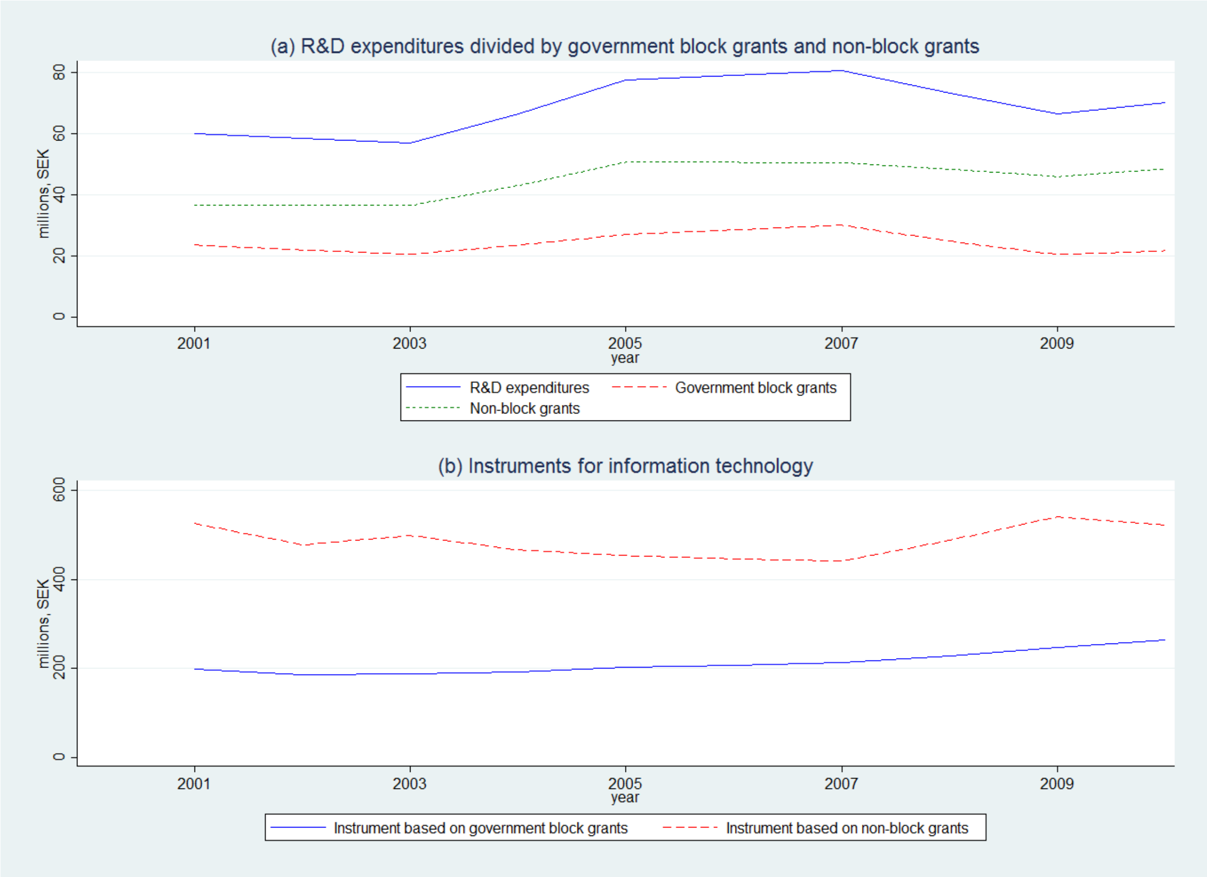

Figure 2. R&D funding to information technology at Lund University.

Table 1. Observations of patent fractions in our sample.

	Freq.	Percent	Cum.
0	1,152	60.41%	60.41%
0.05-0.5	226	11.85%	72.26%
0.51-1.0	179	9.39%	81.65%
1.1-2.0	149	7.81%	89.46%
2.1-4.0	141	7.39%	96.85%
4.1-21.3	60	3.15%	100.00%
All observations	1,907	100.00%	100.00%

Table 2. Panel estimations of patent production functions

	LPRE, dependent variable: patent fractions (log)		Negative Binomial, dependent variable: patent fractions		Poisson, dependent variable: patent fractions		IV, dependent variable: patent fractions (log)	
R&D-stocks, all funding (log)	0.112*** (0.0183)	0.134*** (0.0162)	0.856*** (0.0768)	0.912*** (0.0727)	0.893*** (0.0741)	0.914*** (0.0715)	0.219*** (0.0518)	0.311*** (0.0517)
F-statistic on instruments	.	.	.	.	.	.	173.14	205.56
Hansen's J-stat	.	.	.	.	.	.	8.426**	1.330
Hausman specification test	.	.	.	.	.	.	37.05***	65.89***
Field dummies	NO	YES	NO	YES	NO	YES	NO	YES
University-field combinations	231	231	231	231	231	231	184	184
Observations	1,765	1,765	1,765	1,765	1,765	1,765	1,574	1,574

Controls for share of faculty, average age and share of male researchers are included. Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3. Panel estimations of patent production function, by 10 most patenting scientific fields

	Information technologies	Chemistry (science)	Electr. engineering, electronics & photonics	Physics	Medicine	Microbiology	Physiology & pharmacology	Surgery	Chemistry (medicine)	Chemical engineering
LPRE, dependent variable: patent fractions (log)	0.154** (0.0604)	0.172** (0.0781)	0.297*** (0.0744)	0.0755 (0.0537)	0.211** (0.0920)	0.492*** (0.174)	0.0736 (0.0811)	0.367 (0.231)	0.171 (0.152)	0.162* (0.0874)
Neg. bin., dependent variable: patent fractions	1.481*** (0.242)	1.180*** (0.294)	0.879*** (0.137)	0.564*** (0.190)	1.470*** (0.480)	0.887** (0.382)	0.769*** (0.245)	1.548*** (0.481)	0.726** (0.298)	.
Poisson, dependent variable: patent fractions	1.481*** (0.242)	1.173*** (0.296)	0.806*** (0.147)	0.719*** (0.217)	3.475*** (0.831)	0.885** (0.383)	0.392 (0.353)	1.452*** (0.538)	0.541*** (0.206)	1.884*** (0.386)
IV, dependent variable: patent fractions (log)	0.626*** (0.185)	0.324** (0.131)	0.609*** (0.155)	0.168 (0.116)	0.206* (0.123)	0.439* (0.265)	-0.0958 (0.263)	0.221 (0.314)	-0.108 (0.186)	0.507*** (0.178)
Observations	198	160	129	143	68	65	72	66	60	89
Universities	24	21	18	20	8	8	11	7	6	12
Observations, IV	130	131	90	118	62	63	65	65	55	62
Universities, IV	16	14	13	15	7	7	8	7	6	8
F-statistic on instruments, IV	40.9	137.23	38.91	43.69	133.5	36.43	17.53	24.83	34.95	65.29
Hansen's J-stat., IV	0.142	0.433	0.413	0.002	0.101	0.590	2.790*	0.325	0.131	2.430
Hausman specification test, IV	10.19*	2.60	5.32	10.33*	.	.	0.83	0.67	4.11	8.68

Controls for share of faculty, average age and share of male researchers are included. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix

Table A1. Fields of science and subfields according to Swedish national research topics and corresponding patenting levels.

		Sum patenting 2001-2010
Social sciences/Humanities		9.36
	Religious studies/Theology	0.00
	History/philosophy	0.33
	Creative studies	0.50
	Linguistics	0.50
	Other humanities and religion	0.00
	Jurisprudence/Law	0.33
	Social sciences	0.44
	Economics and business	1.50
	Statistics, computer and systems science	5.58
	Other social sciences	0.17
Natural sciences		**231.20**
	Physics	88.53
	Chemistry	91.95
	Biology	33.73
	Earth Science	0.34
Engineering and Technology		**613.41**
	Information technology	174.99
	Engineering physics	34.89
	Electrical engineering, electronics & photonics	177.25
	Chemical engineering	67.65
	Biotechnology	50.18
	Engineering mechanics	32.08
	Technical material science	44.61
	Civil engineering and architecture	8.90
	Industrial engineering and economics	9.46
	Other engineering sciences	13.39
Agricultural sciences		**21.40**
	Soil science	2.00
	Plant production	9.12
	Livestock science	5.00
	Product research	4.89
	Landscaping	0.00
	Area technology	0.00
	Area economy	0.40
Medicine		**426.00**

	Surgery	69.30
	Morphology	30.97
	Medicine	120.43
	Physiology & pharmacology	51.59
	Social medicine	3.83
	Microbiology	87.81
	Chemistry	37.00
	Psychiatry	2.91
	Dentistry	4.70
	Pharmacology	13.37
	Veterinary medicine	4.08
Other/cross-disciplinary research topics		8.02
	Child studies	0.00
	Home economics and food science	0.00
	Health care in the community	0.00
	Communication between people	1.00
	Technology and social change	0.00
	Water in nature and society	0.00
	Caring Sciences	6.44
	Ethnic studies	0.00
	Gender studies	0.00
	Cultural heritage and cultural production	0.00
	Sport science	0.58
	Gerontology	0.00
	Other topics	0.00

Broad fields included in the estimations and sub-fields where at least one university always has positive R&D are marked in bold. Own translation of field names from Swedish.

Table A2. First-stage IV-estimations of patents production functions, dependent variable: R&D expenditure (log)

Block grant in the general field to R&D except for own sub-field, *t-1*	0.0608*** (0.00427)	0.0701*** (0.00413)
Non-block grant in the general field to R&D except for own sub-field, *t-1*	-0.0235*** (0.0106)	0.0039 (0.0129)
Field dummies	NO	YES
R-squared	0.418	0.597
Observations	1,574	1,574

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A3. First-stage IV-estimations of field-level patents production functions, dependent variable: R&D expenditure (log)

	Information technologies	Chemistry (science)	Electrical engineering, electronics & photonics	Physics	Medicine	Microbiology	Physiology & Pharmacology	Surgery	Chemistry (medicine)	Chemical engineering
Block grant in the general field to R&D except for own sub-field, *t-1*	0.05800*** (0.01411)	0.18016*** (0.01545)	0.07499*** (0.02251)	0.23322*** (0.02974)	0.10985*** (0.00933)	0.08051*** (0.01453)	0.04073*** (0.01154)	0.04638*** (0.00982)	0.13850*** (0.02190)	0.08309*** (0.01499)
Non-block grant in the general field to R&D except for own sub-field, *t-1*	-0.01303 (0.04056)	-0.03925 (0.08036)	0.06986 (0.06799)	0.02115 (0.13460)	0.13828*** (0.02403)	0.10874*** (0.03079)	0.18044*** (0.04318)	0.10366*** (0.02293)	0.03036 (0.06507)	-0.02513 (0.04432)
Observations	130	131	90	118	62	63	65	65	55	62

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

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