

Buenstorf, Guido

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# PAPERS on Economics & Evolution



MAX-PLANCK-GESELLSCHAFT

# 0617

**Is Academic Entrepreneurship Good or Bad  
for Science? Empirical Evidence from  
the Max Planck Society.**

**by**

**Guido Buenstorf**

The *Papers on Economics and Evolution* are edited by the  
Evolutionary Economics Group, MPI Jena. For editorial correspondence,  
please contact: [evopapers@econ.mpg.de](mailto:evopapers@econ.mpg.de)

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Max Planck Institute of Economics  
Evolutionary Economics Group  
Kahlaische Str. 10  
07745 Jena, Germany  
Fax: ++49-3641-686868

## **Is Academic Entrepreneurship Good or Bad for Science? Empirical Evidence from the Max Planck Society**

**Guido Buenstorf\***

**Max Planck Institute of Economics  
Evolutionary Economics Group  
Kahlaische Strasse 10  
07745 Jena (Germany)  
Fax: (+49) 3641 68 68 68  
email: buenstorf@econ.mpg.de**

### Abstract:

Based on new data, this paper studies invention disclosure, licensing, and firm formation activities of Max Planck Institute directors over the time period 1985-2004, and analyzes their effects on scientists' publication and citation records. The results are consistent with prior findings that inventing does not adversely affect research output. More mixed results are obtained with regard to academic entrepreneurship. The analysis raises questions vis-à-vis earlier explanations for positive relationships between inventing and publishing. It finds little evidence that inventors learn from interacting with firms. Likewise, license revenues do not enable scientists to step up their research activities.

**Key words:** Basic science, academic entrepreneurship, innovation, licensing, firm formation.  
**JEL classification:** I23, M33, O31.

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## **Is Academic Entrepreneurship Good or Bad for Science? Empirical Evidence from the Max Planck Society**

### ***1. Introduction***

Scientists do not operate in a vacuum. They are affected by the demands and restrictions that society poses on their work. Over the past decades, Western societies have increasingly come to expect public research to generate “useful” results that can be put to practical applications in the private sector. This enhanced emphasis on knowledge transfer from public research shows in policy measures such as the Bayh-Dole Act in the United States, which was followed by analogous policy changes in many other countries, and likewise in the policy support given to university spin-offs. It is largely motivated by the intention to make best use of the substantial funds that society expends for public research (cf. Mowery et al., 2001; Egelin et al., 2002). In addition, technology transfer provides a potential source of income for universities and other public research organizations, which promises to reduce their dependency on public funds.

In a way, success in academia has always required scientists to exert entrepreneurial attitudes and behavior. With its reward structure that puts extremely high values on first discovery or “priority” (Dasgupta and David, 1994; Stephan, 1996), academic research has some similarity to competition in highly innovative markets and industries. The reward structure of public research exposes the individual scientist to substantial degrees of uncertainty, primarily as regards her reputation, but also in terms of future income and career opportunities. To compete successfully, large investments of time and effort are typically required whose pay-off cannot be assessed in advance. Being a successful scientist moreover requires alertness and creativity in identifying interesting problems as well as suitable methods for solving them. In essence, then, scientists have to behave like Schumpeterian entrepreneurs, coming up with new combinations of disciplines, theories, concepts, methodologies, and data, to attain novel findings and get the attention of their peers as well as potential providers of funding.

Albeit important in practice, this more traditional “scientific entrepreneurship” (Franzoni and Lissoni, 2007) is not at the center of interest in the present study. Rather, the study focuses on the new, more “commercial” entrepreneurial roles for scientists that arise

out of the enhanced emphasis on technology transfer. Given the incentives faced by universities and other public research institutions in many countries (including the U.S. and Germany), these institutions encourage their scientist employees to make and disclose inventions, which can then be patented and licensed to commercial firms, and/or to organize spin-off firms. Most institutions have set up technology transfer offices to support the scientist in these activities, but the scientist's active involvement is nonetheless required in the disclosure, patenting and commercialization of inventions. As a consequence, the inventing scientist is encouraged to also become an innovator and/or spin-off founder. It is the ensuing activities for commercializing academic inventions through licensing or spin-off formation that are understood as academic entrepreneurship, and analyzed empirically, in the present study.

The increased emphasis on this "commercial" academic entrepreneurship is a relevant issue to study because detrimental side effects on the scientists' ability and willingness to fulfill their traditional duties research and teaching cannot be ruled out on *a priori* grounds. Indeed, while policy makers and much of the broader public have hailed the policy changes for enhanced technology transfer and commercialization, skeptics have pointed out a number of potential hazards to the scientists' academic performance: competing demands on their time, increased secrecy, shifts in research interests and the like. These arguments will be presented in more detail in section 2 below.

A substantial empirical literature has emerged in the past years to assess the relevance of these concerns. Given limited availability of data, most studies have focused on patents and their relationship to individual research output (measured by publication and citation counts). Thus, these studies have focused on the effects of academic invention rather than academic entrepreneurship, even though the latter is more relevant from a societal perspective. An important exception is Lowe and Gonzalez-Brambila (2005) who analyze the research output of spin-off founders. The present paper goes one step further and utilizes a broad set of indicators for academic invention and entrepreneurship: disclosed inventions, successful licensing and license revenues, as well as spin-off formation with different forms of scientist involvement in the new venture. The relationship between these indicators on the one hand and publication / citation counts on the other are analyzed at the level of the individual researcher. To the author's knowledge, no comparably broad investigation into the effects of academic entrepreneurship, including both the Schumpeterian notion of entrepreneurship as innovation and the popular notion of entrepreneurship as new firm

formation, has been conducted before. By providing evidence on academic entrepreneurship in a non-university public research organization, and on licensing activities from European public research, the study moreover helps to close important gaps in the existing empirical record (cf. Geuna and Nesta, 2006).

The empirical analysis is based on longitudinal data for the top echelon of researchers employed by the Max Planck Society, Germany's largest non-university public research organization focusing on basic science. For a variety of reasons the Max Planck Society is well suited to study the relationship between research performance and academic entrepreneurship. First, it is large, covers a broad spectrum of disciplines, and follows a consistent strategy focusing on basic research. Second, the Max Planck Society has been subject to the same intellectual property rights (IPR) regime since the 1970s; a regime that moreover anticipated the emerging global model of organizing property in university inventions. Third, it has a well-established tradition of organized technology transfer, having established a dedicated technology transfer subsidiary in 1971. Accordingly, long time series data on inventions and licensing exist, Systematic support of spin-offs was taken up in the early 1990s.

The remainder of the paper is structured as follows. In section 2, theoretical considerations on the relationship between academic entrepreneurship and the research productivity of scientists in public research are presented. Section 3 reviews the existing empirical literature. Section 4 presents the institutional setup of the Max Planck Society and its intellectual property rights (IPR) regime. In section 5, the data underlying the econometric analysis are described. Section 6 presents the methods and results of the analysis, which is discussed in section 7. In section 8 some concluding remarks are made.

## ***2. Academic research and entrepreneurship: competing or complementary?***

In the past years, numerous conjectures have been put forward about the research performance of academic inventors. Most of the discussion has focused on university patenting. However, the theoretical arguments can generally be extended to academic entrepreneurship, and the conjectured effects can even be expected to be stronger for innovators and spin-off founders than for mere inventors.

*Negative effects of academic entrepreneurship*

The skeptical view on academic invention suggests that research and inventive activities are competing for the scientist's limited time, which implies that more inventing comes with less research output (cf., e.g., Markiewicz and DiMinin, 2004, and Breschi et al., 2005, for summaries of the arguments). This substitutive relationship between inventions and publications would not be expected only if inventions were purely joint products of research activities (e.g., instruments originally designed for research purposes) or if the same results can both be published and be used as the basis of useful products (as is the case, e.g., in some fields of the life sciences where "patent-paper pairs" are commonplace; cf. Murray and Stern, 2005). In any case, additional time is required to obtain patent protection for the invention.

Moreover, even if patentable, academic inventions are often far from being marketable, and substantial further innovative effort is required to turn them into commercial products. Frequently, successful commercialization hinges on the personal involvement of the inventor who possesses in-depth (tacit) knowledge about the technology (Jensen and Thursby, 2001; Lowe, 2003). Scientists involved in the formation of spin-offs in addition face organizational and management challenges in setting up the spin-off. According to this line of reasoning, academic entrepreneurship should therefore have stronger adverse effects on individual research activities than inventions.

Two further potential hazards of academic inventing are closely related to the above point: delays in publication and shifts in interests from basic to more applied work. Delays in publication may result from the legal requirements of the patent application process (Stephan et al., 2005). For academic entrepreneurs, an additional incentive for postponing publications stems from the need to safeguard first-mover advantages vis-à-vis potential competitors (of licensees or spin-offs). To the extent that applied work is more easily turned into commercial products, researchers may also be induced to focus on this kind of research. This is a problem to the extent that it compromises the generality and relevance of their work, which would show up in reduced citation rates. Again, this effect should be stronger for scientists intent on commercializing their technologies, and yet stronger for spin-off founders who will aim at broadening the technology base of their fledgling firm.

These considerations all imply adverse effects of entrepreneurial activities on individual research productivity. They can be summed up in the following hypothesis:

*Hypothesis 1 (crowding-out): Academic entrepreneurship has adverse effects on researchers' publication activities and citation rates. These effects are stronger than those of inventive activities for which no commercialization efforts are documented; they are stronger for scientists involved in spin-off formation than for those who license their inventions to pre-existing firms.*

*Positive effects of academic entrepreneurship*

Even though research and entrepreneurial activities may compete for a scientist's time, the relationship between these activities need not be negative if they have mutually beneficial side effects. In line with this consideration, several factors causing positive effects on publication rates have been suggested for academic inventions (cf., e.g., Stephan et al., 2005; Breschi et al., 2005). These factors are even more relevant for the research output of academic entrepreneurs than that of academic inventors.

Enhanced interaction with private-sector firms, opening up potentials for learning and access to complementary skills and assets, constitutes a potentially powerful benefit of academic invention and entrepreneurship. Contacts to firms help researchers to identify relevant issues for their research as well as approaches to tackle them. In addition, the skills and equipment available in firms are often complementary to those found in public research labs. Finally, firms may have access to networks that the researcher herself is not part of. All these effects of interaction with firms enable researchers to learn and to enhance their capabilities for doing research. They have been proposed before as benefits of academic invention, but they can be expected to arise in even stronger form from academic entrepreneurship, as commercialization necessarily involves private-sector interaction. Negotiations with licensees or involvement in spin-off activities is more likely to create opportunities for learning from private firms than academic inventing alone, which can in principle proceed in isolation. Accordingly, we expect to find stronger effects of learning for academic entrepreneurs than for academic inventors. This is expressed in the following hypothesis:

*Hypothesis 2 (learning): Interactions with private-sector agents provide learning opportunities for scientists that result in enhanced research output. The learning effects are strongest for researchers involved in spin-off formation, and they are stronger for inventors*



*of licensed and commercialized technologies than for inventors of technologies for which no commercialization efforts are documented.*

In addition to the learning opportunities generated by contacts to the private sector, academic entrepreneurs can also benefit more directly: through the financial pay-offs of their entrepreneurial activities. These activities often generate flows of income not only for the scientist personally, but also for her laboratory, which provides opportunities to step up her future research activities.<sup>2</sup> License revenues and patent sales provide direct sources of income from academic inventions. Spin-offs similarly are a source of funding for future research, at least those spin-offs that license technology from the scientist's employer institution. Additional income is often generated through direct funding of research provided by private firms, frequently based on research collaborations. Finally, researchers may benefit from in-kind transfer of resources, for example when private firms pay for specific items of laboratory equipment.

Including data on financial pay-offs from academic entrepreneurship in the empirical analysis allows for distinguishing the learning effects (hypothesis 2) from the resource effects. If academic entrepreneurs only benefit from the financial returns of their activities, then controlling for the financial pay-off should eliminate any positive relationship between inventions/innovations/spin-off formation on the one hand, and research output on the other. This is expressed in the following hypothesis:

*Hypothesis 3 (funds): Income flows from the entrepreneurial activities of academic researchers (commercialization through licensing and spin-off formation) have a positive effect on their future research output. This effect is not dependent on the inventive and innovative activities per se, but on the amount of income they generate.*

Table 1 summarizes the predicted effects of academic inventions and entrepreneurship on individual research output implied by the alternative hypotheses 1-3.

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<sup>2</sup> As will be detailed in the next section, in the Max Planck Society one third of all licensing income goes directly to the inventor's institute, where it is used to fund research activities.

**Table 1: Expected effects of inventions and entrepreneurship on research output**

Hypothesis / activity	Effect on research output
Hypothesis 1 (crowding-out)	
• <i>invention</i>	–
• <i>innovation</i>	– –
• <i>spin-off formation</i>	– – –
Hypothesis 2 (learning)	
• <i>invention</i>	+
• <i>innovation</i>	++
• <i>spin-off formation</i>	+++
Hypothesis 3 (funds)	
• <i>income</i>	+
• <i>invention</i>	o (controlled for income)
• <i>innovation</i>	o (controlled for income)
• <i>spin-off formation</i>	o (controlled for income)

*Individual heterogeneity*

A positive correlation between individual entrepreneurial activities and research output need not be caused by systematic complementarities between both activities, as is implied by hypotheses 2 and 3. Instead, it may simply reflect uncontrolled heterogeneity among researchers. It has been suggested that differences in both inventive activities and research output may be caused by the same variations in individual skills, effort, serendipity and luck – i.e., by having the “right stuff” for being a successful scientist, as Stephan et al. (2005) put it. If this conjecture holds, scientists coming up with more inventions are also likely to be superior researchers, as similar traits are required for both activities. In this case, a positive correlation between academic inventions and research output does not reflect a causal relationship between both variables.

Some of the factors underlying the (spurious) correlation can be derived from the economics of science (cf. Stephan, 1996). For example, lifecycle effects have been found to systematically affect individual research productivity. Not all heterogeneity among researchers will be observable, though, if only because some degree of luck is involved in

making important discoveries and inventions. In addition, differences in individual specializations by discipline and field of research can be expected to translate into differences in both inventions and publications. If fields with higher average propensities of publication were at the same time fields where scientists are more likely to make inventions, then a positive relationship between both activities at the individual level may reflect this positive correlation at the level of the field of research. Again, an analogous line of reasoning may be also hold for academic entrepreneurship: better researchers may also be more likely innovators and firm founders because they are more talented, more ambitious, or simply have more luck.

In the subsequent empirical analysis, the conjecture of heterogeneity in the talents of scientists will not be tested directly. Rather, econometric models are selected such that potential factors underlying the heterogeneity are included in the analysis as best possible, and the remaining unobserved heterogeneity can be controlled for by the model specification.

### ***3. Prior empirical findings on academic inventors and entrepreneurs***

A number of recent empirical studies have helped to clarify the relationship between academic inventions and individual research output. Most existing work is based on U.S. data, in particular university patents, but new studies using European data have been forthcoming lately. The existing empirical evidence strongly suggests complementarities between academic invention and individual research productivity. In contrast, very little prior work exists that investigates the effects of academic entrepreneurship rather than academic inventing.

A pioneering study by Agrawal and Henderson (2002) analyzes technology transfer from engineering and computer science departments at MIT. The authors find that the number of patents held by individual faculty members is uncorrelated with their numbers of publications, but positively correlated with the citation rates of their papers. These findings indicate that academic inventors do not publish more, but more relevant, work than their non-inventing peers. A broad sample of U.S. university faculty based on the *Survey of Doctorate Recipients* is utilized by Stephan et al. (2005). The econometric analysis indicates that on average, patenting researchers are more prolific authors than the members of the non-patenting control group. Markiewicz and DiMinin (2004) analyze a longitudinal panel

containing annual publication and citation rates of 150 faculty inventors as well as a matched control group of non-patenting scientists. In line with the results by Stephan et al. (2005), inventors are found to publish more and to have more citations to their work. Publication rates moreover go up significantly after a researcher's first patent. Azoulay et al. (2006) similarly identify a positive relationship between individual patenting and publication activities. Their study is noteworthy both for the size of the sample, which encompasses 841 academic inventors from the life sciences, and for the elaborate efforts taken to control for unobserved heterogeneity. Finally, Thursby and Thursby (2005) differ from the other studies of academic inventors in that their study is not based on patent data, but on inventions disclosed by U.S. university scientists to their employers. For this alternative, more encompassing measure of academic inventions, the finding of a positive relationship to publication output is reproduced.

Recent studies of European academic inventors indicate that their inventions do not affect research output in fundamentally different ways than observed in the U.S. Carayol (2005) and Van Looy et al. (2005) find positive relationships between patenting and publication counts for samples of scientists working at individual French (ULP Strasbourg) and Belgian (KU Leuven) universities, respectively. Carayol (2005) moreover finds that scientists publishing in journals with higher impact factors are more likely to patent, and the results obtained by Van Looy et al. (2005) indicate that the interests of patenting researchers do *not* shift toward more applied work. Finally, Breschi et al. (2005) analyze the broadest dataset available for European academic inventors. These authors study the patenting and publication records of 296 Italian university faculty, and a non-patenting control group of equal size, over a 22-year period. Consistent with the results from other countries, patenting is found to have positive affect on the subsequent publication output (as well as the citation record) of the Italian scientists.

To the author's knowledge, only a single paper has been dedicated to investigating the effects of academic entrepreneurship on individual research productivity. Lowe and Gonzalez-Brambila (2005) study a sample of 141 U.S. faculty entrepreneurs, defined as university researchers founding spin-off firms to commercialize own inventions previously disclosed to their employers. They find that faculty entrepreneurs are generally more prolific authors than either their graduate school peers or their coauthors. In addition, organizing a spin-off is found to have positive effects on the scientists' subsequent publication and citation records. If spin-off founders are further distinguished by discipline, these effects turn

insignificant for those disciplines (biomedical and chemical research) where founders are mostly senior scientists.

#### ***4. The Max Planck Society and its intellectual property rights regime***

Unlike the U.S. system, but similar to other continental European countries such as France and Italy, universities do not fully dominate basic research in Germany. The Max Planck Society, whose roots go back to the early 20<sup>th</sup> century, is Germany's largest non-university public research organization for basic research. Organized as a private not-for-profit association, the society employs some 4,000 researchers in 78 institutes located throughout the country.<sup>3</sup> It gets more than 80 per cent of its budget from public, institutional funding (Max Planck Society, 2005).

Research at the Max Planck Institutes is complementary to the university system in that the Max Planck Society is to take up large-scale, interdisciplinary, or particularly innovative activities that are beyond the reach of individual Germany universities. Its research activities encompass the whole spectrum of the sciences and the humanities, with the individual institutes organized into three sections: the biomedical section, the chemistry, physics and technology section, as well as the humanities and social sciences section. Within the institutes, the key organizing principle of the Max Planck Society – known as the *Harnack Principle* – is to put the “directors” of Max Planck Institutes, i.e. the highest-level researchers, in a particularly autonomous and powerful position. Depending on their size, individual Max Planck Institutes have from two to about ten directors. Currently, there are roughly 260 active directors in the entire Max Planck Society. Max Planck directors each lead their own research group; they jointly manage the institute. Directors are selected from particularly successful researchers of both German and foreign universities. Their mission is research-oriented, with substantial institutional funding and relatively small teaching loads and administrative burdens. As scientific members of the Max Planck Society, the directors are also involved in its strategic decision making.

Academic inventions and technology transfer activities from the Max Planck Society have historically been treated differently from those of German university researchers. All

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<sup>3</sup> In addition, there are three institutes located outside Germany. They all belong to the humanities and social sciences section and are disregarded in what follows.

employees of German firms are subject to the *Arbeitnehmererfindungsgesetz*, which mandates that employees must disclose their inventions to the employer, and grants the employer the ownership in employee inventions. University researchers used to be exempt from this law; they retained the intellectual property rights (IPRs) in whatever inventions emerged from their research (the so-called *Hochschullehrerprivileg* or “professors’ privilege”). In 2002, the privilege was abolished, and German universities became the legal owners of the inventions made by their researchers. The universities are now responsible for patent applications and the licensing of technologies, in particular they have to cover the cost of the patenting process. The inventing researcher is entitled to 30 per cent of the gross licensing revenues from her invention.

The new IPR regime for inventions by German university researchers essentially replicates the rules that Max Planck researchers have always been subject to. They are required to disclose all their inventions to the Max Planck Society, which can then claim the ownership in the technology. In this case, the Society organizes the patent protection for the technology (if possible and deemed adequate) as well as the sale and administration of licenses. The inventing researcher receives 30 per cent of all revenues from licenses and patent sales, and the Max Planck Institute employing the researcher gets an additional third of all income.

To organize the patent application and the marketing of Max Planck technologies, the Society in 1970 established a legally independent technology transfer subsidiary named Garching Innovation GmbH (Garching, a Munich suburb, is the location of a prominent Max Planck research campus). In its early years, Garching Innovation engaged in the construction and sale of prototypes based on Max Planck inventions. These activities were little successful, and for the past three decades the firm has consistently focused on patenting and licensing activities. Garching Innovation staff members regularly visit the Max Planck Institutes to inform scientists about its technology transfer activities and solicit the disclosure of new inventions. Working with external patent attorneys, Garching Innovation administers the application for patents on promising technologies. The technologies are subsequently marketed to domestic and foreign firms. In the early 1990s, the active support and counseling of spin-off activities was also taken up.

Since 1979, Garching Innovation has closed some 1,500 license agreements (Max Planck Society, 2005). Total returns from the licensing activities amount to some € 180 million, with the bulk of income resulting from a small number of highly successful

“blockbuster” technologies. Annual license revenues contribute 1 to 2 per cent to the Max Planck Society’s overall budget.

## 5. Data

The inventions, licenses and spin-off databases of Garching Innovation provide the principal sources of data for the present study. Disclosed inventions are taken as the key units of observation. In the database, each disclosed invention is documented, and the underlying inventions can be identified for both patents and license agreements. Adopting disclosed inventions as the units of analysis both helps to avoid double counting, as frequently multiple patents and license agreements pertain to the same invention, and also allows for including non-patented inventions that can nonetheless be licensed and commercialized (e.g., know how and software). In total, the inventions database contains some 3,000 inventions disclosed since 1970. Disclosure does not imply that patents ensuing from the inventions (if any) are necessarily assigned to the Max Planck Society. Therefore, an additional advantage of using disclosed inventions as the basic unit of observation is that problems of identifying inventions of Max Planck employees in patent databases are avoided.<sup>4</sup>

To identify innovations based on the inventions of Max Planck researchers, additional information from the licenses and spin-off databases was utilized. For all inventions it was recorded whether a license contract or similar form of agreement with a private-sector firm (such as an option for a license, often based on an initial research collaboration or third-party funding) was concluded. Licensee names were matched with the list of Max Planck spin-off firms to identify inventions licensed to spin-offs. In addition, all payments resulting from the contracts were deflated to year 2000 Deutsche Mark equivalents and aggregated into *AllResources*, a measure of actual income flows from the commercialization of inventions and contacts to private firms.<sup>5</sup> (In cases of license agreements and payments pertaining to multiple inventions, the payments were equally distributed among the inventions.)

Spin-off activities are identified in the data in three different ways. First, Max Planck researchers who want to commercialize inventions in spin-off firms are nonetheless required

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<sup>4</sup> Geuna et al. (2006) argue that most patents based on academic inventions in Europe are not assigned to the inventor’s employer but to private firms. This implies that patent ownership is a weak measure of academic inventing, necessitating the identification of inventors in patent data.

<sup>5</sup> The database does not contain information on direct payments from private firms to individual institutes that are not administered by Garching Innovation.

to disclose these inventions to the Max Planck Society, and the spin-off then has to obtain a license from the Max Planck Society. The licenses database therefore contains information on inventions licensed to spin-offs. Second, Garching Innovation's spin-off database contains more detailed information on the involvement of Max Planck researchers in the spin-off firms. Spin-off founders, operative managers, board members and consultants from the Max Planck Society are all identified in the database. The data provide useful information on what organizing a spin-off does (and does not) imply for the senior scientists considered in the present analysis. None of the directors listed as spin-off founders actually joined the operative management of the new venture, but most of them are listed as board members and/or advisors.

For the present study, only those inventions are further considered that have at least one Max Planck director among their inventors. Practically, the list of inventor names on all inventions disclosed to Garching Innovation was matched with a list of all Max Planck directors active since then, which is based on official publications (Henning and Ullmann, 1998; Max Planck Society, 2000) and updated to 2004. By restricting attention to the group of Max Planck directors, a straightforward control group exists for evaluating the impact of academic entrepreneurship on the director's research output. In the subsequent analysis, the publication and citation records of all Max Planck directors in the biomedical section and the chemistry, physics and technology section are used, beginning in 1985 and excluding directors for whom less than 5 annual observations exist. The humanities section is not taken into consideration because the entrepreneurial activities of its researchers are negligible. The total number of individuals fulfilling these criteria is 319. Among these, 142 (44.5%) have disclosed at least one invention to the Max Planck Society.

Using non-inventing directors as the control group is justified because the group of directors is homogeneous in various aspects. All Max Planck directors are experienced scientists selected on the basis of proven prior achievements. They all face similar working conditions and are evaluated against the same criteria of success, which emphasize the individual contributions to the respective fields of basic research. In addition, the selection process by which new directors are nominated is not only identical throughout the Max Planck Society, but the current directors are also involved in the selection of their future peers. Given the characteristics of Max Planck directors, the study analyses a highly selective subset of experienced first-tier scientists in Germany. The sample includes 10 Nobel laureates.



In total, the study is based on 854 director-invention pairs disclosed since 1985. There are a small number of joint inventions co-disclosed by two directors, which are treated as individual inventions for both directors. Counts of inventions by each Max Planck director are recorded by year. Their number is highly skewed, with 87.3 per cent of the observations equal to zero and the maximum being 11 disclosures in a single year. 245 inventions were licensed to firms (this includes options and patent sales). For 67 inventions there is conclusive evidence of successful commercialization, because there are positive payments based on variable elements of the license agreement. Since not all contracts have provisions for variable payments, this number provides only a lower bound to the successful commercialization of technologies invented by Max Planck directors. Finally, 153 inventions were licensed to spin-offs. There are 34 instances of Max Planck directors being listed as spin-off founders, and 45 cases of listings as organ members or consultants (these numbers include a small number of repeated spin-off involvement by individual scientists).

The objective of the study is to evaluate the impact of inventions and entrepreneurial activities on the research output of the inventing researcher. Two alternative measures of research output are utilized: annual publication counts and annual citation counts. These were obtained from the ISI Science Citation Index (Web of Science online edition) by counting all publications that name the respective researcher in the list of authors. To minimize errors from including non-Max Planck employees with identical names, all searches were performed specifying “Max Planck” in the address field and limited to the individual years of tenure as Max Planck director. The first years of individual tenures were disregarded because the data suggest that publications from those years are not reliably attributed to the Max Planck affiliation. Citations are used as a quality measure of publications. Accordingly, they were attributed to the publication years of the cited works, irrespective of the year of the actual citation. Both publication counts and citation counts are highly skewed and exhibit overdispersion (Figures 1 and 2). For 12.1 per cent of all director-years, no publications are listed in the Science Citation Index (citations: 13.5 per cent). The maximum number of publications (citations) per year recorded for a single researcher is 76 (6229). For publications, the mean is 8.4 and the standard deviation is 8.9; for citations, the mean is 266.4 and the standard deviation is 444.9

Fixed effect specifications are used below to control for cross-sectional heterogeneity across researchers. Accordingly, no time-invariant control variables need be included in the models. To account for the well-known life cycle effects in research output (Levin and

Stephan, 1991), the year PhD or MD completion was recorded for all individuals, and the time span between PhD year and year of observation is included in the model specifications. In addition, a set of 10 dummy variables was included that denote single years of tenure as Max Planck director. They control for the buildup of resources and reputation once a scientist assumes a directorship position at the Max Planck Society (The individual variables indicate, respectively, the second through tenth years of tenure, as well as all further years.)

Some of the specifications use weighted regression models (see section 6 for a detailed description). To construct the weights for these estimations, institute-level aggregates of cumulated inventive and entrepreneurial activities are used. Specifically, the numbers of inventions, licensing agreements, as well as spin-off activities by all employees of the respective institutes were retrieved from the Garching Innovation database, beginning in 1970 or the (later) year that the institute was founded. In addition, a dummy variable was constructed that indicates directors of institutes in the biomedical section, as well as three cohort dummies denoting directors nominated before 1981, between 1981 and 1990, and after 1990, respectively.

In a cross-sectional perspective, the data suggest that inventions and entrepreneurial activities are associated with above-average research performance. Directors who have disclosed at least one invention during their tenure have on average 10.7 publications per year, whereas non-inventors have 6.6. Similarly, directors who have disclosed at least one licensed invention record an average of 11.7 annual publications (directors without licensed inventions: 7.7). Directors who have at least one invention licensed to a spin-off on average have 12.9 annual publications (non spin-off inventors: 7.9).

## ***6. Econometric analysis***

### *Methods*

The general approach of the present study is to model a researcher's output  $y_{it}$  (proxied by annual counts of publications or citations) as a function of her innovative/entrepreneurial activities in the same period  $x_{1it}$ , (time-varying) personal characteristics  $x_{2it} \dots x_{nit}$ , as well as individual fixed effects  $c_i$  to capture unobserved heterogeneity.

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \dots + \beta_n x_{nit} + c_i + u_{it}$$

Including the fixed effects implies that the results of the estimations are driven by the within-individual time series variation. This specification is accordingly well-suited to deal with the challenges arising from factors such as differences in talent or in the publication cultures across fields and disciplines.

A sequence of models is estimated utilizing alternative proxy variables  $x_{lit}$  to assess the effects of inventions and entrepreneurial activities. In addition, the analysis employs two alternative econometric approaches. First, a series of conditional negative binomial models of annual publication or citation counts is estimated, with fixed effects controlling for time-invariant unobserved heterogeneity across researchers (Hausman et al., 1984). The negative binomial specification is required because the dependent variables exhibit overdispersion.

The fixed effects models cannot account for time-variant individual heterogeneity. It has been suggested, however, that this kind of heterogeneity is relevant in the present context (Azoulay et al., 2006). Over time, researchers who become more successful publishers, for example because they made an important discovery, may also become more likely inventors and/or entrepreneurs. In turn, past inventions and entrepreneurship may affect future research output, and output measures can no longer be assumed to be independent from earlier invention (entrepreneurship).<sup>6</sup>

Following Azoulay et al. (2006), the methodology of inverse-probability-of-treatment-weighted (IPTW) estimation is adopted to account for these interdependencies. This approach was originally developed in biostatistics to control for the effects of time-varying confounders. It is based on assigning to each subject  $i$  and period  $t$  a weight that equals the inverse of the conditional probability that  $i$  received her own treatment history up to  $t$  (Fewell et al., 2004). Thus, individuals with “unlikely” treatment histories are assigned bigger weights, which serves to counteract the confounder’s effect on the selection into treatment. Effectively, a “pseudopopulation” (Robins et al., 2000) of subjects is constructed for which the observed characteristics no longer predict selection into treatment. The weights are then used in weighted fixed effect regressions of (logarithms of) annual publication or citation counts.

The weights are derived as follows (cf. Fewell et al., 2004): Using logistic regression, the researcher’s probability of treatment at time  $t$  (denoted as  $p_t$ ) is estimated as a function of the time-varying confounder as well as other explanatory variables. In line with earlier work

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<sup>6</sup> This form of heterogeneity is also compatible with the “Matthew effect” suggesting that the publications of successful scientists get more attention (Merton, 1968).

on academic inventors (Breschi et al., 2005; Azoulay et al., 2006), the logistic regression includes publication output in  $t-1$  as an explanatory variable, as well as section and cohort dummies and a count variable measuring the stock of inventions (licenses, spin-off activities) accumulated at the specific Max Planck institute where the respective researcher is employed. If the researcher was indeed subject to treatment in the respective period,  $p_t$  directly enters the calculation of the weights; otherwise the probability of non-treatment ( $1 - p_t$ ) is utilized. The product of these probabilities, multiplied over all prior periods in which the researcher was under observation, is then used as the denominator of the weight. Finally, to prevent extreme weights for individual observations, the numerator of the weight is calculated analogously to the denominator, except that the count of publications in  $t-1$  is not included in the logistic regression.

IPTW estimation is unbiased provided there are no unmeasured time-varying confounders (Robins et al., 2000). This is a strong and untestable assumption. However, referring to prior work in labor economics, Azoulay et al. (2006) suggest that the method performs well if the estimated probability of treatment is based on a large set of explanatory variables, subjects are drawn from similar labor markets, and outcomes are measured similarly for treatment and control groups. These conditions are fulfilled in the present context.

In addition to these two alternative econometric approaches, two different types of model specifications are utilized below, which reflect different assumptions as to how inventions or entrepreneurial activities affect the researcher's output. In the initial set of models, these activities are interpreted as a permanent treatment. In the period of a researcher's first invention/entrepreneurial activity and all following periods,  $x_{lit}$  is assigned the value one, and the subsequent development of research output is compared between individuals who are or are not subject to the treatment. In these models, initial invention/entrepreneurship is accordingly assumed to have a lasting effect on the scientist's subsequent publication and citation record, which is moreover independent of the level of these activities. Alternatively, a set of fixed effects binomial models is estimated that assume the effect of inventions or entrepreneurial activities to be limited to the current period. These models moreover use counts of inventions (innovations, spin-off involvement) as measures of the respective activities. In contrast to the treatment models, thereby taking into account that the extent of inventive and entrepreneurial activities differs among individual researchers.

*Results: (Permanent) treatment models*

The models assuming permanent treatment are estimated first, beginning with fixed effects negative binomial regressions. The initial model (Model 1 in Table 2) utilizes an indicator variable to characterize the “inventor” state of an individual researcher. All researchers are in the “non-inventor” state before disclosing their first invention. If and when they disclose an invention, they switch to the “inventor” state and remain in it until leaving the sample. This specification is used both with publication and with citation counts as the dependent variable. Accordingly, the model measures whether inventing researchers publish more or less frequently, and more or less well, after their first disclosure. The dynamics in the research output of non-inventing researchers are adopted as the benchmark (difference-in-difference specification). To control for life cycle effects, the number of years elapsed since PhD completion are included both linearly and squared. The full set of tenure year controls is also included.<sup>7</sup>

The estimations show that in post-invention years, academic inventors publish more, and are more extensively cited, than their non-inventing peers. The coefficient estimates for both effects are sizeable and significant at the .01 level. In line with earlier results, the analysis furthermore indicates the presence of significant, non-linear life cycle effects. The coefficient estimates suggest that publication activities increase until 31 years after PhD completion and then begin to taper off. To control for the possible effects of time-varying confounders, the same models are re-estimated using IPTW-weighted fixed effects regression (Models 1c-d in Table 3). This reduces the coefficient estimate measuring the effect of inventing on subsequent publication output by almost 20%, but does not affect its significance. In contrast, the coefficient estimate measuring the effect of inventing on subsequent citation rates is reduced by some 40 %, and it is only significant at the .05 level.

Next, a series of analogous models is estimated where the indicator variable denoting individuals in the “inventor” state is replaced by alternative indicator variables denoting the various forms of academic entrepreneurship. In Model 2, the effect of becoming an innovator is analyzed, which is measured by the disclosure of the first invention that is subsequently licensed to a firm. In Model 3, the “entrepreneur” state of an individual is determined by the first invention of a technology that is subsequently licensed to a spin-off. In Model 4, researchers assume the “entrepreneur” state by being first listed as a spin-off founder in the

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<sup>7</sup> In the estimations, ten (twelve) subjects are disregarded because their publication (citation) count is zero in all years of observation.

Garching Innovation spin-off database. Again, these models are estimated using both negative binomial and IPTW-weighted estimations, and adopting publication or citation counts as dependent variables.

Regarding publications, positive effects of inventing licensed technologies are found, both in general and for inventors of technologies licensed to spin-offs. While highly significant for the set of all licensed inventions (Models 2a and 2c), the effects are not (Model 3c) or only marginally (Model 3a) significant for the subset of inventions licensed to spin-offs. Significantly negative effects are found for researchers listed as spin-off founders (Models 4a and 4c). When citations are adopted as the dependent variable, there are more pronounced differences between the alternative methodologies. In the negative binomial estimations, significantly positive effects of inventing technologies that are subsequently licensed are found both for the general case and for spin-off licensees (Models 2b and 3b, respectively). The analogous IPTW estimations find a smaller and only marginally significant positive effect of innovation (Model 2d), whereas the effect of inventing a technology licensed to a spin-off is (insignificantly) negative (Model 3d). Finally, for spin-off founders, sizable and significantly negative effects on subsequent citations are found in both settings (Models 4b and 4d).

Taken together, the evidence on the effects of entrepreneurial activities is mixed. While there seem to be positive effects of inventing commercially useful technologies, actually becoming a spin-off founder appears to come at a cost in terms of both publication quantity and quality. The results are moreover informative with regard to the proposed accounts for the positive effects of academic inventions. Relative to the initial Model 1 measuring the effects of becoming an inventor, all coefficient estimates obtained for the various proxies of entrepreneurship are smaller. If the above conjecture is correct that inventors of technologies that are licensed or become the foundation of spin-offs are in closer contact to private firms than inventors of non-licensed technologies, then the results for Models 2 and 3 suggest there are no discernible benefits of this contact. Accordingly, they are not consistent with the learning effect postulated in Hypothesis 2.<sup>8</sup>

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<sup>8</sup> This interpretation is corroborated by experimenting with a (non-reported) variation to Model 1 where indicator variables denoting inventors of licensed technologies, and of technologies licensed to spin-offs, were added to the variable indicating inventors. The additional variables did not improve the explanatory power of the model. Their coefficient estimates were small and insignificant, while the effect of becoming an inventor (which remained significant at the .01 level) was reduced by 15 % with publications as the dependent variable and by less than 5 % for citations.

*Results: Annual invention / entrepreneurship counts as explanatory variables*

Finally, a set of fixed effect negative binomial regressions utilizing annual counts of inventions/ entrepreneurial activities as explanatory variables, and assuming transitory effects of these activities on only the current period, is estimated (Models 5 to 9 in Table 4). Compared to Models 1-4, the only other modification in Models 5-9 is that the variable denoting current resource flows from licensing and commercializing inventions, *AllResources*, is included in the specification. This allows for a direct test of the resource effect postulated in Hypothesis 3.

Model 5 includes annual counts of disclosed inventions. Its results indicate that inventive researchers have significantly more and better (i.e., more extensively cited) publications in the years of invention disclosures. In Model 6, only those inventions that resulted in licenses are included in the count of innovations. Again, a positive effect on the number and quality of publications in the same period is found, with the coefficient estimates being substantially larger than in Model 5. Model 7 uses the counts of inventions licensed to spin-off firms as a measure of academic entrepreneurship. The coefficient estimates thus obtained are slightly higher than those for the measure of inventions in Model 5, but substantially smaller than those in Model 6. In contrast, there is no systematic effect on research output when entrepreneurial activities are measured by the listings of spin-off founders (Model 8). Finally, in Model 9, entrepreneurial activities are proxied by the listings of spin-off board members and advisors.<sup>9</sup> For this measure, a positive but insignificant effect on publication output is found (similar to Model 8a), whereas the effect on citations is significantly positive.<sup>10</sup>

Throughout Models 5 to 9, the coefficient estimates obtained for *AllResources* are insignificant and virtually indistinguishable from zero. This can be interpreted as a rejection of the (narrowly defined) resource effect conjectured in Hypothesis 3; it indicates that the research output of academic inventors and entrepreneurs is not boosted by the flow of licensing income. All models also reproduce the nonlinear life cycle effects on publication

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<sup>9</sup> No analogous treatment models were analyzed above, because the treatment variable corresponding to the entrepreneurship measure used in Model 9 is indistinguishable from the one used in Model 4.

<sup>10</sup> Analogous IPTW estimations were experimented with. Specifically, weights for individual observations were derived by assuming transitory (one-period) effects of treatment. These weights were then used in weighted fixed effects regressions, adopting counts of inventions/entrepreneurial activities as the explanatory variables of interest. These estimations yielded smaller and generally insignificant coefficient estimates that were qualitatively in line with those of the binomial regressions. The estimates were moreover sensitive to variations of the model specification.

and citation records that were already found in the negative binomial models assuming permanent treatment.

The findings based on using annual counts of inventions and entrepreneurial activities as explanatory variables help to put the earlier results into perspective. The negative effects of becoming a spin-off founder obtained in the treatment models are not reproduced in this model setting. In addition, the ranking of coefficient estimates is consistent with the interpretation that complementarities with research are stronger for academic entrepreneurs than for mere inventors. However, the confidence intervals of the alternative coefficient estimates overlap, and the additional effect of entrepreneurial activities on research output may not be systematic even in the case of licensed inventions (Model 6).<sup>11,12</sup>

## 7. Discussion

In the present study, a number of different model specifications and proxy variables have been adopted to analyze the relation between academic inventing and entrepreneurship on the one hand and individual research productivity on the other. The empirical investigation was based on a rich dataset on Max Planck directors. Working in a non-university public research organization that focuses on basic research and strives for excellence at a globally competitive scale, these researchers constitute a distinctive subset of Germany's top-tier scientists.

The evidence confirms previous findings that inventive activities of academic researchers are associated with increases in research output. Thus, a first implication of the study is that the earlier findings generalize to a sample of senior researchers employed in a non-university setting that is unusually homogeneous in terms of selectivity, prior experience, and working conditions, and that has consistently been subject to a Bayh-Dole-like

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<sup>11</sup> Compared to Model 5, including both counts of licensed inventions and counts of all inventions in the same model reduces the effect of inventions by less than 20 %. It remains highly significant for both publications and citations as dependent variables. The coefficient estimates obtained for the effect of licensed inventions are of similar size as those for all inventions, but they are insignificant (for publications) or only marginally significant at the .10 level (for citations). The explanatory power of the model is not significantly increased.

<sup>12</sup> As an additional robustness check, all model specifications were re-estimated with lagged independent variables to reflect possible publication lags. This modification yielded similar results to those reported above. In particular, the relative size of the alternative proxy variables was generally preserved. The only qualitative difference was that the (transitory and mostly insignificant) positive effects of founding or becoming involved with a spin-off in Models 8 and 9 were eliminated, instead finding insignificantly negative effects.



institutional framework. Also, to the author's knowledge, the present findings are the first results of this kind that have been obtained for Germany.

Adding to the prior literature, there is substantial evidence for positive effects also when only licensed inventions are considered, or only inventions licensed to spin-off firms. These findings lead us to reject the presumption of a "crowding-out" relationship between commercially valuable inventions and publications underlying Hypothesis 1. There does not seem a fundamental incompatibility between being a prolific author of relevant scientific work and doing research that can successfully be commercialized.

In contrast, the effects of being involved in spin-off activities are less straightforward. The permanent treatment specifications suggest that founding a spin-off may be detrimental to the quantity and quality of a researcher's subsequent output. This result contrasts with the earlier findings by Lowe and Gonzalez-Brambila (2005) who interpret entrepreneurship as a transitory treatment and find positive effects. It is noteworthy because none of the scientists in the sample entered into the operative management of a spin-off. Moreover, the effects of inventing spin-off technologies are mostly positive, and no short-term negative impact of spin-off involvement is found in the model specifications analyzing effects of current activities. These patterns are puzzling, since substantial efforts are normally required to develop academic inventions into commercially viable technologies. They would in part be expected to fall into the time period following the invention but preceding the actual spin-off formation, which frequently lasts for several years. If such efforts affect research output negatively, they should already show up in the aftermath of the invention, not only after the actual organization of the spin-off. One possible explanation for the results is that, due to the time lag between invention and spin-off formation, spin-offs are often started at a late stage of the scientist's career. The declining subsequent research output may thus reflect adverse life cycle effects that are not fully controlled by the life cycle variables.

Finally, the present findings raise questions regarding the conventional accounts given to explain apparent complementarities between research and academic inventions. If interactions with private-sector firms result in important learning effects, as was conjectured in Hypothesis 2, then academic innovators and entrepreneurs should benefit more than "mere" inventors. However, the empirical analysis found sizeable and robust positive effects of being an inventor, irrespective of whether or not the invention was successfully commercialized. In the series of models assuming permanent treatment, these effects diminished and even turned negative as the proxy variable of entrepreneurship was

successively restricted to researchers likely to engage in close private-sector interaction. Moreover, while the results of the models assuming transitory effects are more easily reconciled with the conjecture of learning from private-sector interaction, there is only weak evidence in favor of learning effects even in these models. Taken together, the empirical evidence suggests that benefits of private-sector interaction are short-lived at best, and of secondary importance in accounting for the performance of academic inventors. Finally, there is no evidence whatsoever that the flow of income drawn from licensing and commercialization of inventions is positively associated with the quantity and quality of publications produced by researchers, as was posited in Hypothesis 3.

## ***8. Concluding remarks***

Using a new and original dataset, this study found strong evidence suggesting a positive relationship between the inventive activities of scientists on the one hand and their performance as researchers on the other. Positive effects are also identified for inventors of technologies that are subsequently licensed to private-sector firms, while the evidence on the impact of spin-off involvement is mixed. At the same time, the present results are not easily reconciled with earlier attempts to explain the research performance of academic inventors. There is at best weak evidence that inventors learn from the interaction with firms, while a resource effect based on licensing income could be squarely rejected. Thus, the primary implication of this study may be that further work is required to understand the determinants of research productivity and the impact of invention and entrepreneurship.

It is important to interpret these results in their broader context. Most importantly, the above analysis was restricted to the individual level. It provides no information on the potential effects that IPR policies and enhanced emphasis on technology transfer have on the strategies, staffing decisions, and performance of universities and public research organizations (cf. Geuna and Nesta, 2006, for some potential concerns). Likewise, it is possible that IPR protection of research-relevant technologies has a negative impact on the advance of science if it restricts the access to equipment and research tools. Indeed, there is some evidence suggesting (modestly) adverse effects of this kind (Murray and Stern, 2005; Sampat, 2004). Both institution- and system-level effects cannot be identified based on the kind of individual-level evidence utilized above.

Finally, in spite of the recent attention given to university licensing and spin-off formation out of public research, these are only two out of a variety of channels of technology transfer, and they do not even seem to be the most significant ones (Bozeman, 2000; Zellner, 2003; Sampat, 2006). In this context, it is noteworthy that the aggregate volume of license revenues generated from the inventions of Max Planck directors from 1971 to 2004 generated little more than the equivalent of 33 million Deutsche Mark (in year 2000 prices). (Note that some of the best-selling technologies in the Max Planck Society's portfolio have no directors among their inventors.) Furthermore, studies of firm performance have found that spin-offs from public research are not necessarily the most successful new ventures in an industry. For example, both in the U.S. and the German laser industries, new laser producers whose founders came from public research tended to perform significantly worse than entrants with other backgrounds, including pre-existing firms diversifying from related industries and spin-offs from industry incumbents (Sleeper, 1998; Buenstorf, 2005). These findings suggest that in spite of the recent wave of interest in technology transfer and academic entrepreneurship, we still have much to learn on these issues.

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**Table 2: Fixed effects negative binomial regression models – permanent treatment**

	Model 1		Model 2		Model 3		Model 4	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	<b>Publication counts</b>	<b>Citation counts</b>	<b>Publication counts</b>	<b>Citation counts</b>	<b>Publication counts</b>	<b>Citation counts</b>	<b>Publication counts</b>	<b>Citation counts</b>
Inventor	.235*** (.045)	.433*** (.045)						
Innovator			.186*** (.048)	.341*** (.053)				
Spin-off inventor					.114* (.068)	.209*** (.078)		
Spin-off founder							-.280*** (.061)	-.181** (.084)
Years since PhD	.075*** (.015)	.080*** (.018)	.072*** (.015)	.074*** (.018)	.070*** (.015)	.077*** (.018)	.077*** (.015)	.079*** (.018)
Years since PhD <sup>2</sup>	-.001*** (.000)	-.002*** (.000)	-.001*** (.000)	-.002*** (.000)	-.001*** (.000)	-.002*** (.000)	-.001*** (.000)	-.002*** (.000)
Tenure year controls								
Constant	.250 (.205)	-1.226*** (.237)	.292 (.205)	-1.150*** (.236)	.301 (.206)	-1.183*** (.235)	.190 (.206)	-1.216*** (.236)
No. observ. (individuals)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)
Log-likelihood	-7678.613	-17868.084	-7684.959	-17892.538	-7691.051	-17908.742	-7681.219	-17909.726
P > chi <sup>2</sup>	.000	.000	.000	.000	.000	.000	.000	.000

included

Notes: standard errors in parentheses; \*significant at .10 level; \*\*significant at .05 level; \*\*\*significant at .01 level.

**Table 3: Weighted fixed effect regression models (inverse probability of treatment weights) – permanent treatment**

	Model 1		Model 2		Model 3		Model 4	
	(c)	(d)	(c)	(d)	(c)	(d)	(c)	(d)
	Log publication counts	Log citation counts	Log publication counts	Log citation counts	Log publication counts	Log citation counts	Log publication counts	Log citation counts
Inventor	.193*** (.051)	.264** (.121)						
Innovator			.168*** (.056)	.229* (.131)				
Spin-off inventor					.009 (.067)	-.209 (.156)		
Spin-off founder							-.390*** (.074)	-.931*** (.183)
Years since PhD	.081*** (.019)	.023 (.047)	.076*** (.019)	.014 (.047)	.077*** (.019)	.028 (.047)	.087*** (.018)	.049 (.046)
Years since PhD <sup>2</sup>	-.001*** (.000)	-.002** (.001)	-.001*** (.000)	-.001* (.001)	-.001*** (.000)	-.002*** (.001)	-.001*** (.000)	-.002*** (.001)
Tenure year controls								
Constant	.050 (.244)	4.106*** (.629)	.120 (.245)	4.230*** (.630)	.101 (.247)	4.037*** (.631)	-.068 (.243)	3.709*** (.624)
No. observ. (individuals)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)
Adj. R <sup>2</sup>	0.695	0.582	0.699	0.582	0.698	0.586	0.705	0.591
P > F	.000	.000	.000	.000	.000	.000	.000	.000

included

Notes: robust standard errors in parentheses; \*significant at .10 level; \*\*significant at .05 level; \*\*\*significant at .01 level.

**Table 4: Fixed effects negative binomial regression models – effects of current activities**

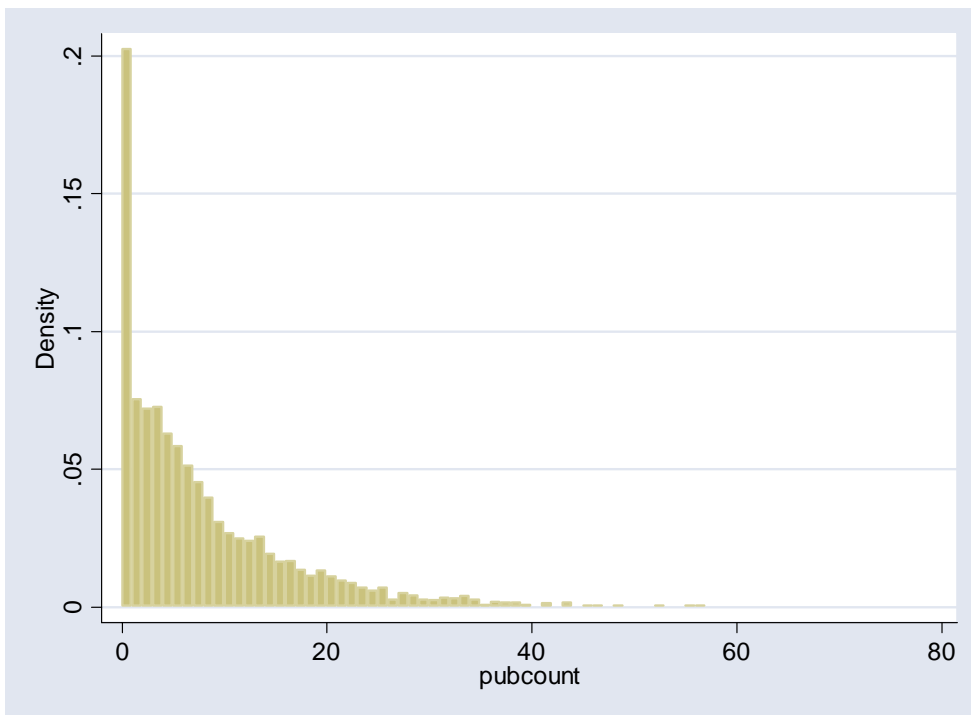
	Model 5		Model 6		Model 7		Model 8		Model 9	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Invention counts	.040*** (.012)	.083*** (.018)								
Innovation counts			.063*** (.023)	.152*** (.036)						
Spin-off inventions			.046* (.025)		.093** (.037)					
Spin-off formation						.119 (.082)	.165 (.143)			
Spin-off involvement									.101 (.071)	.300** (.120)
Current resource flow	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)
Years since PhD	.071*** (.015)	.077*** (.018)	.072*** (.015)	.078*** (.018)	.079*** (.018)	.071*** (.015)	.077*** (.018)	.072*** (.015)	.072*** (.015)	.077*** (.018)
Years since PhD <sup>2</sup>	-.001*** (.000)	-.002*** (.000)	-.001*** (.000)	-.002*** (.000)	-.002*** (.000)	-.001*** (.000)	-.001*** (.000)	-.001*** (.000)	-.001*** (.000)	-.002*** (.000)
Tenure year controls										
Constant	.287 (.205)	-1.181*** (.236)	.267 (.207)	-1.203*** (.236)	.263 (.206)	-1.206*** (.236)	.273 (.205)	-1.184*** (.236)	.267 (.205)	-1.184*** (.236)
No. observ. (individuals)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)	3431 (309)	3409 (307)
Log-likelihood	-7686.340	-17902.246	-7688.613	-17904.954	-7690.498	-17909.619	-7690.999	-17911.528	-7691.050	-17909.438
P > chi <sup>2</sup>	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

included

Notes: standard errors in parentheses; \* significant at .10 level; \*\* significant at .05 level; \*\*\* significant at .01 level.



**Figure 1: Histogram of publication counts, 1985-2004.**



**Figure 2: Histogram of citation counts, 1985-2004**

