Is it the prominent scientist the one who becomes an inventor?
A matching of Swedish academic pairs in nanoscience to examine the effect of publishing on patenting

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Abstract

Nanoscience is an innovation intensive interdisciplinary field, where science and technology are closely related during development. Sweden represents an interesting setting to examine how they are related, because a high fraction of the total Swedish academic patents can be classified as Nanoscience. Combining bibliometric data from Web of Science, patent data from EPO and data from Swedish universities, this paper identifies all authors and all inventors listed on patents who work at universities, within nanotechnology in Sweden. The main question we address is if prominent academic scientists in terms of scientific publications are also the ones who become academic inventors. Publications are examined in terms of published articles and invention in terms of patents. The paper uses a novel semi-parametric technique, namely a conditional regression in a matched sample, in order to isolate the effect of publishing on patenting. The novelty of this paper is that it applies a conditional logistic regression in matches of academic pairs in order to isolate the relationship between patenting-publishing in nanoscience. The empirical results show that academics who both publish and patent have on average more publications as well as more citations. Furthermore, having a higher number of citations can increase the probability of having a patent. Thus, by isolating the effects of publishing on patenting, this paper contributes by demonstrating that scientific prominence, indicated both by number of articles and citations, positively impact the propensity to take patents.

1. Introduction

Key foci of public policy and research in recent years is to understand, and change, the role of the university system. Much of the debate concerns whether the university system faces complementarities or trade-offs in achieving the two goals of delivering scientific excellence and contributing to economic growth through industrial invention. Scientific excellence is equated more with basic research whereas academic engagement in industrial invention is more related to technology, applications and applied research. In terms of proxies, science is often measured through scientific excellence through publications and invention through patents. Much of this debate has focused on whether there is a trade-off between basic and applied research, or whether these are complementary activities. In other words, should scientists focus solely upon either scientific excellence or industrial invention, or does excelling in one of them also stimulate the other? This paper therefore addresses the question of trade-offs and complementarities, by investigating the specific links between scientific excellence and industrial invention. The study is based upon a conditional logistic regression in matches of academic pairs, using a micro-data approach to all the individual university employed academics who publish and patent in the emerging field of nanoscience in Sweden.

Scientific excellence is a concept usually measured through scientific publications, while the relevance of academia to industrial invention is indicated through patents and start-up companies. In the emerging fields of life sciences and nanotechnology, previous research suggests that there are close relationships between basic research as in scientific excellence and applied research as in industrial invention (Genet et al. 2012; Mangematin and Walsh 2012; McKelvey 1996; Martin Meyer 2000; M. Meyer 2006; Meyer-Krahmer 2000; Rothaermel and Thursby 2007; L. G. Zucker et al. 2007). Close relationships have been identified at the institutional, organizational or individual levels. One line of recent research tries to disentangle the effect of publishing on patenting in general as compared to the effects of when individuals publish highly cited papers. This paper follows this line of research, including citations as independent variables.

Whether scientists focus upon scientific excellence or invention is also related to their perceptions of the role and relevance of universities to society. There is some evidence that academics who consider science as a public good will be less likely to commercialize (Krabel and Mueller 2009). Other studies suggest that scientists as a group are changing their perceptions about their roles in the society (Jain et al. 2009; Tuunainen and Knuuttila 2009). In the traditional form of universities, scientists are perceived as independent, who work for the sake of the whole society and thus emphasize public benefits. However, this appears to be changing. Critics suggest that entrepreneurial universities may work against open science culture, and hence the privatization of knowledge through invention may prioritize private instead of public benefits. Therefore, in this interpretation, there are trade-offs between science and invention. These two different roles of the researcher and the entrepreneur are seen to be contradictory with each other, and generate tensions for academics (Tuunainen and Knuuttila 2009; Vestergaard 2007). Vestergaard (2007) argues that for academics, it is very difficult to integrate these two roles and therefore he argues that the researcher and entrepreneur roles should be separated, also to enable entrepreneurial universities.

In contrast, Gulbrandsen (2005) and Fogelberg and Lundqvist (2012) argue that entrepreneurial scientists can combine these two separate roles of scientist and entrepreneur. Jain, George et al. (2009) suggests a continuum. He suggests that there is a range from the 'pure scientist' pursuing Mertonian ideals of science (Merton 1959), to 'entrepreneurial scientist' who are strongly engaged with industry. Most scientists would thus be situated at different points on this scale from pure to entrepreneurial scientists. However, one rationale for combining the roles of scientist and entrepreneur comes from the 'star scientist' literature, which suggests strong complementarities. This research argues that the star scientists have relevant intellectual capital and they are more likely to move into commercial involvement than are the marginal colleagues in terms of science, as demonstrated in biotechnology (L. Zucker and Darby 1996; L. Zucker et al. 1998). Previous research can also be a signal to obtain more resources (Allison et al. 1982).

For this study, we have developed a database of academic inventors, by pooling from multiple new and existing databases to create micro-data of individuals. The article analyzes the phenomenon at the individual level, and holds the technological field and the national institutional level constant – by focusing upon university scientists active in nanotechnology in Sweden. Scientific excellence is investigated through the number of scientific publications (e.g. peer-reviewed articles) and through citations to these articles as a proxy for quality. Industrial invention is investigated through patents, defined as university scientists who are inventor on at least one patent.

The methodology is based upon matched pairs, e.g. those who publish and those who both publish and patent. In order to compare the two categories of 'author' and 'author-inventor', we use an elaborate matching methodology, which allows us to isolate "twin" authors and author-inventors and then compare their respective records. We use control variables such as discipline, university and individual characteristics which could affect the delivery of patents and publications. Therefore, we are able to isolate and match the author-inventors with a control group of authors who do not invent. Next, we compare the productivity scores of the two groups and the population in terms of publications and citations and we apply a conditional logistic regression.

One problem with empirical studies in the field is endogeneity, because both patenting and publishing have many common factors influencing performance, with variables such as prestige, life cycle, educational endowments, social networks and institutional background (J. Long and McGinnis 1985; J. S. Long et al. 1993). In order to mitigate this bias, this paper uses a matching technique as in the paper by Fabrizio and Di Minin (2008). This matching technique is used in order to get robust results and a *ceteris paribus* effect of publishing on patenting. A conditional logistic regression and a conditional poisson regression are then run in the matched pairs. These models were used because they fit the data and have to our knowledge have not been used before in this stream of literature.

Patenting-Publishing in Nanotechnology and hypotheses

Because our empirical setting is the emerging field of nanoscience/nanotechnology, we need to first delineate the field. Nanotechnology can be described as research related to understanding, controlling and manipulating matter at the nanoscale which equals to one billionth of a meter. Many different disciplines are involved, and only a few universities have dedicated departments. Therefore the definition of scientists active in the field is generally done by counting those researchers that have at least one publication in the field, rather than by focusing upon dedicated departments (Kostoff et al. 2007; Porter et al. 2008; Zitt and Bassecoulard 2006).

Nanotechnology appears to be a field with strong complementarities, where, new advancements often emerge at the interfaces between science and technology (Roco and Bainbridge 2002). Recent studies provide evidence for the idea that the boundary between science and technology is quite fluid in research related to nanotechnology. For instance, Hu, Chen et al. (2007) analyze patents filed at the USPTO related to nanotechnology from 1976 to 2004, and they find that 60 percent of these patents have on average 18 academic citations. The citations to academic articles within patent documents have increased faster in this period for the nanotechnology field as compared to other technical fields.

Moreover, nanotechnology has been characterized by intensive patenting activity, involving both universities and firms. the worldwide annual growth rate measured as the number of nanotechnology patent applications in the period from 2000 to 2008 is higher than the rate of increase in the number of Science Citation Index nanotechnology articles (Dang et al. 2010). Moreover, in addition to firms, the research universities are the leaders of nanotechnology patents (Islam and Ozcan 2013; Li et al. 2007; D. C. Mowery 2011). Wang (2007) points out that the average annual growth rate in industrial nanotechnology patents in the period from 1990 to 2005 was 12 percent and in university nanotechnology patents was 30 percent. At the same time, established companies have been involved in nanotechnology innovations already in the early stages of the field (Mangematin and Walsh 2012; Rothaermel and Thursby 2007). The involvement of firms at this early stage suggests that there is little or no time lag between scientific research on the one hand, with technological advancements and commercialization.

Furthermore, public policy through science and technology policies have supported research projects with industrial impact, and promoted the linkages between universities and firms (McCray 2005; Sá 2011). For example, NNI (National Nanotechnology Initiative) in the USA is seen as a convergence between science and technology policy and industrial policy because its aim is not only to support basic research and development of related technologies but also increase commercialized industrial products (Motoyama et al. 2011). In addition, an analysis of patents taken by American universities in nanotechnology for the period between 1996 and 2007 by Jung and Lee (2014) reveals that knowledge inflows (where the number of backward citations made to industry nanotechnology was used as a proxy for knowledge inflows) have significantly increased between university-industry.

Thus, the aforementioned findings about nanotechnology support the complementarities argument and thus are at odds with the opposing argument that there is a trade-off between basic and applied research (Blumenthal et al. 1996; Blumenthal et al. 1997; Campbell et al. 2002). In fact the literature suggests that the existence of a trade-off or not may depend upon the technological field. Specifically, academic patenting is highly skewed in favor of science-based fields such as pharmaceuticals and chemicals (Harhoff et al. 2003), and this skewness is an indicator of the increasing role of knowledge in technological advancements (Narin et al. 1997). The increased industrial interest in knowledge-based fields of academic research has also led to the expansion of academic patenting in the fields of biomedicine and biotechnology (Henderson et al. 1998; David C Mowery et al. 2001). Furthermore, studies from Europe confirm the evidence of a proportionally higher increase of academic patenting in biotechnology (Balconi et al. 2004; Martin Meyer 2003). Nanotechnology is an interdisciplinary field with similar characteristics with the biotechnology, when it comes to knowledge intensity (Thursby and Thursby 2011).

Therefore, existing literature would lead to a prediction that the trade-off between basic and applied research is weak. Moreover, we may assume complementarities, and a positive link.

When we focus more specifically within nanotechnology field, some evidence can be found to support the linkages between patenting and publishing. Bonaccorsi and Thoma (2007) investigate the relation between science and technology and find that a significant majority of nanotechnology patents have at least one inventor that is also an active scientist (i.e. having a published article). Meyer (2006) uses American patent data and SCI (Science Citation Index) database for publications and finds that author-inventors account for a relatively large share among nano-inventors, albeit differs by country of origin, it ranges between 27 and 40 percent. This study also indicates that author-inventors apparently outperform their non-inventing peers in terms of both publication and citation frequencies.

The literature suggests not only that the trade-off between publishing and patenting is relative to the technological field but that patent ownership also matters. Breschi, Lissoni et al.(2007) in a study of Italian academic inventors reveal a positive correlation between patenting and publishing but interestingly the effect is significant when the patents are owned by business partners instead of university or the inventor. In our empirical setting, the vast majority of academic patents in Sweden are owned by firms (Lissoni 2012). The study points towards a positive correlation between publishing and patenting which is statistically significant when the patent owners are firms. Based on this positive link we suggest a set of hypotheses that test the effect of high numbers of publications on becoming an inventor at first and becoming a serial inventor afterwards. We then move to the analysis of the effect of the quality of publishing as measured by citations.

Our hypothesis coincides with the literature which suggests that researchers with numerous and well-cited publications, so-called start scientists, are more likely to get involved in commercialisation (L. Zucker and Darby 1996; L. Zucker et al. 1998).

The literature suggests that academic author-inventors publish more and better papers than their non-patenting colleagues (Perkmann et al. 2012). Azoulay et al. (2007) find that patenting activity has also a positive effect on the pace of publications and their quality (Azoulay et al. 2007). In contrasts, Fabrizio and Di Minin (2008) find that the average citations decrease for serial inventors.

There are however also studies, which do not find a significant correlation between publishing and patenting but do find a significant correlation between patenting and author's citations instead (Agrawal and Henderson 2002).

The above papers suggest that publication quality is positively correlated with patenting even in some cases where publication number has not shown significant effect.

Due to the combined effects of disappearing boundaries in nanoscience between science and technology, the heightened interdisciplinary nature of nanoscience making patenting and publishing more common in tandem, the successfulness of the push effect of policy towards commercialization and collaboration between universities and firms, and the fact that firm ownership is the norm in Nanoscience patenting in Sweden, we suggest the following hypotheses, which route back to the positive links between science and technology found in the academic patenting literature presented above:

Hypothesis 1a. Academics with larger number of publications have higher probability to become inventors (with at least one patent).

Hypothesis 1b. Academics with larger number of publications have higher probability to become inventors with a larger number of patents.

Hypothesis 2a.. Academics with higher cited publications have higher probability to become inventors (at least one patent).

Hypothesis 2b. Academics with higher cited publications have higher probability to become inventors with a large number of patents.

3. Research strategy: Data and methodology

Data and variables

The data collection steps include identifying all publications in nanotechnology with at least one Swedish author; identifying researchers who publish in nano, which we call academic authors if they only publish; identifying researchers who publish and who are also inventor of at least one academic patent, which we call academic author-inventors; and gathering relevant control variables at individual and university levels.

Defining emerging scientific fields with contributions from various disciplines leads to the well-known problems of identification of disciplinary boundaries. Given that nanotechnology is an emerging and interdisciplinary technology, these methodological difficulties in defining the field must be addressed. The initial attempts to delineate the field started with looking for "nano-" prefix in articles. Later, other methods employing text mining techniques and trying to find out the keywords which best describe the field of nanotechnology have been proposed. Zitt and Bassecoulard (2006), Porter et al. (2008) and Kostoff et al. (2007) are the most prominent of these studies.

In this paper we followed the methodology proposed by Porter et al. (2008) for the delineation of the nanotechnology field in Sweden. We used a list of queries including keywords proposed by Porter et al (2008) to find out the articles published by researchers working at Swedish universities in the journals included in ISI Web of Science-Science Citation Index (expanded) database. The queries were run on 12 April 2014 for a twelve years period from 2000 to 2012. A total of 14317 articles were found. Full bibliometric records of these articles were exported as a text file from ISI WoS. These records were reformatted into a Microsoft Access 2003 database using a Visual Basic script. Each of these articles was given a unique number from 1 to 14317 and all the other variables (i.e. authors. institutes. addresses. titles and keywords) were linked to each other through this unique identifier. Data processing was performed by creating tables and queries in this database. We could then create a list of Swedish nanotechnology authors called NANO AUTHORS.

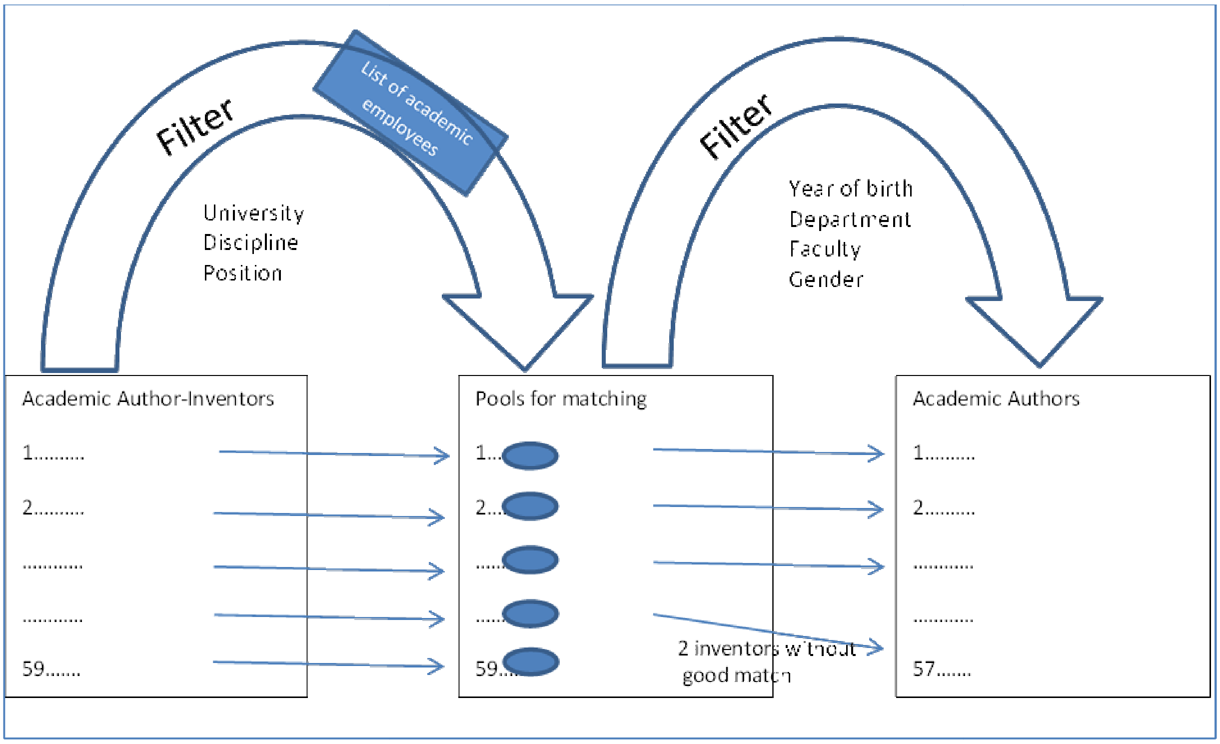
The data for the Swedish academics come from the database SWEDISH ACADEMICS 2011, a database created by the authors as a part of the EU project KEINS project of academic inventors in Europe. We have to mention here that in Sweden there is no centralized database with the academic employees because each university has administrative autonomy and therefore different structure in their databases. In previous research, we have collected the lists of employees from each university separately and then unified them into one database containing the following information about all the employees in Swedish universities: Name, Surname, Birthday, Address, Position, University, Discipline, Faculty, Department, and Division. The database includes all the employees, 48237 in number, in 27 Universities, which corresponds to all the universities which according to the Swedish National Agency for Higher Education (Högskoleverket) at that time had the right to grant an degree at a doctoral level. In the collected lists of employees, in our variables Position, Faculty and Department, and Discipline there is a high degree of heterogeneity across the different universities since no unique national system of taxonomy is used. In this database, we have manually normalized the variable Discipline across all universities according to the "Standard for Swedish classification of research areas 2011", a normalized classification's guide published by the Swedish National Agency for Higher Education (HSV 2011).

Another database that our research team has developed in past years on Swedish academics was used in order to identify the academic inventors in nanoscience in Sweden. The KEINS/APE-INV database contains data about the academics that are registered as patent inventors in the European Patent Office's (EPO) register. This database was expanded by the authors, in the APE-INV project, by matching the SWEDISH ACADEMICS 2011 to EPO applications. The methodology used largely corresponds to the one employed for constructing the KEINS database. This resulted to a dataset of 1020 academic inventors employed by a Swedish University (KEINS/APE-INV 2011-SWEDEN).

At the final stage, in order to identify which academic inventors have been publishing within nanoscience we combined the NANO_AUTHOR database with the KEINS/APE-INV 2011-SWEDEN database on names and surnames. The initial match of names-surnames resulted in 95 people. However, because of the large homonymy problem in Sweden, as well as duplicated matches, we proceeded with a manual check and cleaning of the data which resulted into 59 academic author-inventors in nanotechnology. Having the 59 identified nano author-inventors as a treatment group, we then identify a control group of twins which are as "similar" as possible in terms of defined characteristics (variables) but who are only authors of nanotechnology articles. The method used is a combination of exact and nearest neighbour match. The criteria for the exact matching were: university, discipline, position (title), gender, age, and department.

See in Figure 1. below the matching procedure at the individual level, conceptualised as matched pairs

Figure 1. Matching Author-Inventors to Authors



After having the two lists of nanotechnology only authors and nanotechnology author-inventors, we collected bibliometric data for each of these 114 researchers. Publication data for these researchers was retrieved from ISI WoS for each individual researcher; the time limitation for publication was set to 2012. The same homonymy problem also occurred at that stage, and so for these cases, the publications were checked with the list of publications in the researcher's CVs and university web pages. Finally we had a data file for these 114 researchers which include the number of publications, the number of citations and the number of co-authors for publications.

In the SWEDISH ACADEMICS 2011 database, there is a high heterogeneity in the data across universities regarding position, faculty and department. For example there are different titles for the position according to the university's policy of employing (guest professor, professor employed as lector, professor employed as chief physician, research assistant, researcher, etc.). In a traditional econometric model the use of these categorical variables would be still limited, for example in the case of discipline, the disciplines are expanded in different levels according to the level of specialization we could identify and we end up with a high variation in 3 different levels, while nanotechnology is highly interdisciplinary as mentioned. The problem of missing values is also present as we did not manage to get all the required information from all universities. In order to overcome the above difficulties we chose a semi-parametric technique. We created a model based on the matching techniques and the treatment effect analysis. The technique overcomes the bias problems that a traditional regression model will suffer by in our dataset, because of the lack of control variables. The control variables will be used as matching criteria in order to overwhelm the heterogeneity and the high variation within the control variables. For example, the high variation in the variable discipline will not affect the outcome as each "twin" we will compare will belong into the same discipline category. Thus, that the treatment effect analysis, which follows, was considered the best option for our data.

Dependent variables

We use two dependent variables in our regressions:

a) The variable "patenting" which is a binary variable indicating if the individual has at least one patent or not according to the EPO register.

b) The variable "Npatents" which is a count variable indicating the number of patents of the individual according to the EPO register.

Independent variables

There are two independent variables in this study:

a) "Publications" which is a count variable indicating the total number of publications per individual found in Web of Science database.

b) "Citations" which is a count variable indicating the total number of times cited for the publications identified per individual, as found in Web of Science database.

Control variables

Since we have used a matching technique, we have controlled for the following factors in the matching process in ascending order:

a) University: The pairs were selected by people belonging to the same university.

b) Discipline: The pairs were selected by people working in the same discipline, according to the categorization by the National Agency for Higher Education in Sweden.

c) Position (title): The pairs were selected controlling for the academic title of the individual. (Each university uses its own variation of academic titles, but since we were choosing pairs within same university, we selected pairs having the same title as well).

d) Gender: The pairs were formulated with individuals of same gender.

e) Age: The pairs were selected with the minimum age difference between the “twins”.

f) Department: People from same/adjacent departments were selected in the pairs.

g) Links: In the regression models the number of co-authors per publications was used as a control variable for the academic network.

The regression models

In matched case-control studies, conditional logistic regression is used to investigate the relationship between an outcome of being a case or a control and a set of prognostic factors. When each matched set consists of a single case and a single control, the conditional likeli-

$$\prod_i (1+\exp(-\beta^T(x_{i1}-x_{i0})))^{-1}$$

hood is given by

where xi1 and xi0 are vectors representing the prognostic factors for the case and control, respectively, of the ith matched set. This likelihood is identical to the likelihood of fitting a logistic regression model to a set of data with constant response, where the model contains no intercept term and has explanatory variables given by di = xi1 - xi0 (Breslow 1982).

A matched design requires a matched analysis (Rothman et al. 2008) and therefore we use a conditional logistic regression.

We employed four econometric models employed in order to analyze our data. It should be noted here that the “treatment” variable, that is patenting, is used as the dependent variable (which seems counterintuitive) in the conditional logistic regression since the models transforms the dependent variable into “1” for all the observations and then calculate the different probability scores for the two groups of the matched pairs. In the case of the conditional Poisson regression, the relative "risk ratio" is calculated for the two groups.

In model (1), we run a logit regression for the binary variable "patenting" on the three independent variables. In model (2) we perform a conditional logistic regression, a model that recognizes the dataset as a matched paired dataset.

In model (3) and (4) we use "Npatents" as the dependent variable and the same independent variables as before. We perform a poison regression in the third model since the dependent variable is a count variable. In the fourth model we perform a conditional Poisson regression which is a simulation of the technique applied in the case of conditional logistic regression found in the literature, with only difference that it is now applied in a count variable and the Poisson regression.

4. Results

Descriptive statistics: Author-inventors in nano

The descriptive statistics focus first upon author-inventors in nanotechnology. This group of 59 author-inventors has been identified by combining matching the databases, as described above in previous section.

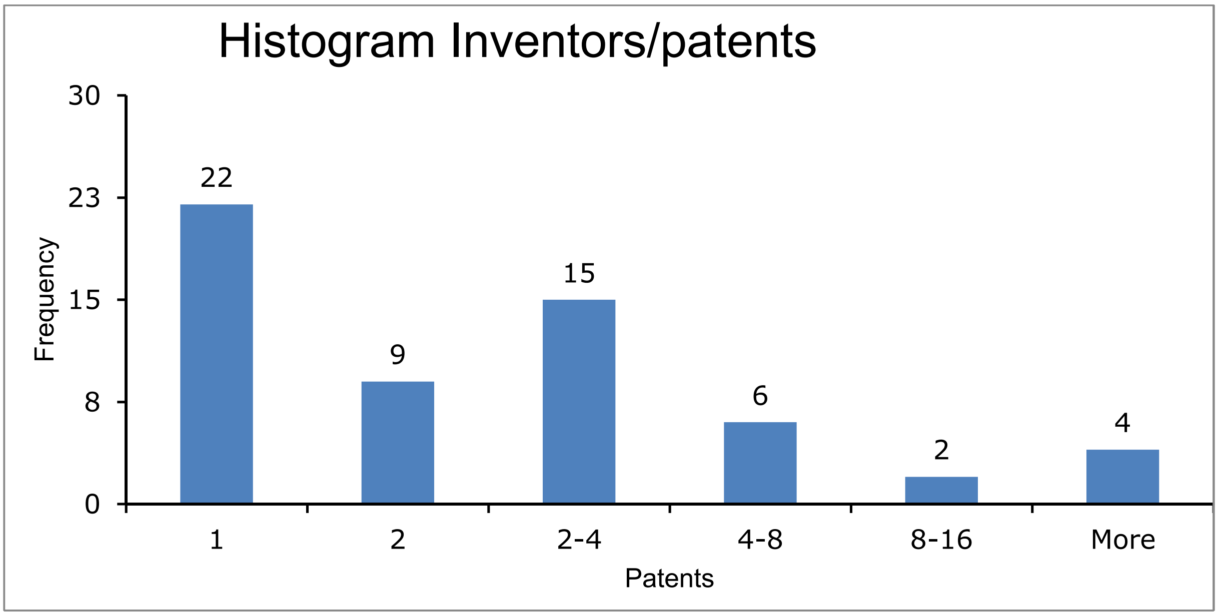
Table 1 presents the descriptive statistics, listed by academic position (title). The individuals are active in both scientific research as well as in patents. We notice that 54% of the author-inventors are professors and these professors produce 72% and 74% of the publications and the patents respectively.

Table 1 Number of inventors, publications and patents by position for author-inventors

Position	Number of author-inventors	Total number of publications	Total number of patents
Professor	32	435	179
Docent	2	7	4
Associate Professor	5	44	21
PhD student	3	9	5
Researcher / Research assistant	11	81	23
Senior lecturer	5	29	9
Project manager	1	3	1
Total	59	608	242

The distribution of inventors over the number of patents is skewed to the right, as shown in the histogram in Figure 2. The majority of the inventors (22) have only one patent. Four individuals have more than 16 patents.

Figure 2 Frequency Inventors/number of patents for author-inventors



The next step is to compare descriptives between the author-inventors with authors, e.g. university scientists who are only authors in nanotechnology. When comparing the differences in the summary statistics between the two groups, there are differences. Thirty-three author-inventors of 57 (58%) produce more publication than their matched pairs of authors. Moreover, while average number of publications for the author-inventor group is 36.2, it is 25.6 for the group of authors. The differences between the matched pairs have a high variance. There is one pair were the author-inventor has 339 more publications than the non-inventor author. However, note that 23 of the non-inventor authors have a better publication performance than their matched pairs; and at most, an author had published 128 articles more than their paired author-inventor.

The group of author-inventors has on average a higher number of citations as well, as visualized in Figure 3.

Figure 3 Citations for the 57 Author-Inventors and the matched Authors

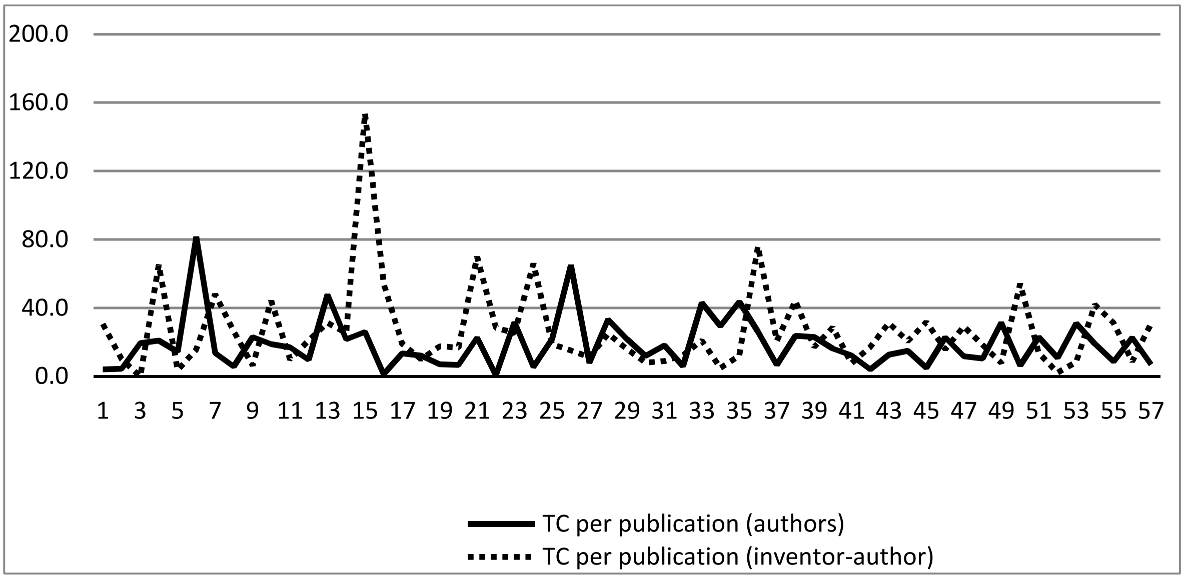
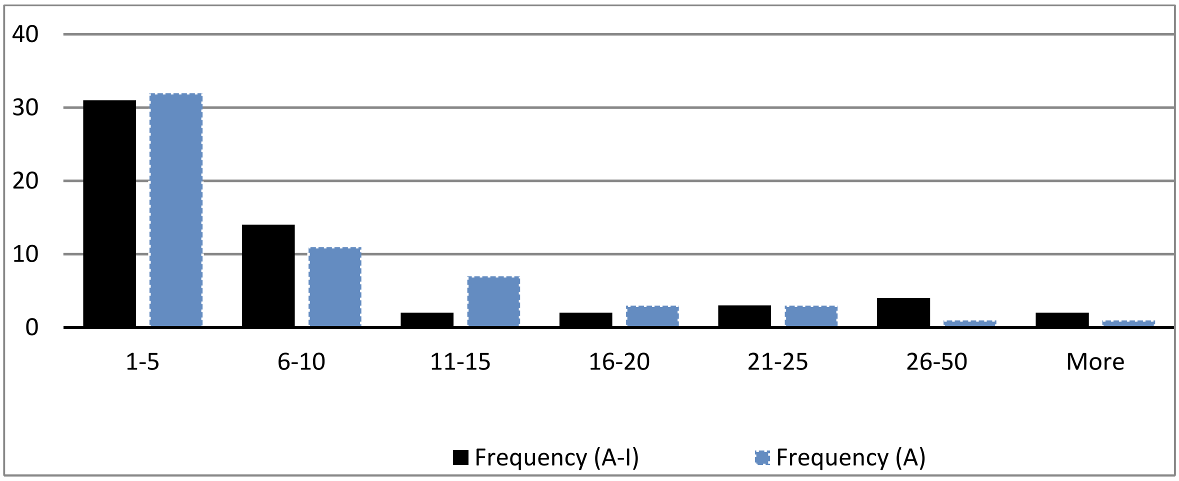


Figure 4 presents the frequency histograms of publications for the two groups, the author-inventors and the control group, the authors.

Figure 4 Histogram of publications for the two groups



As shown in Figure 4 the majority of the academic scientists have between 1-5 publications and the distributions between the matched groups follow a similar pattern and are both skewed to the right.

Figures 5 and 6 illustrate the differences in the average publications and average citations between the two groups. The average number of publications is 41.4 percent higher for the Author-Inventors and the average number of citations is 95.5 percent higher.

The t-statistics show that the difference is significant at the 10 percent level for the differences in citations but it is not significant for the differences in publications.

Figure 5 Average publications in the two groups

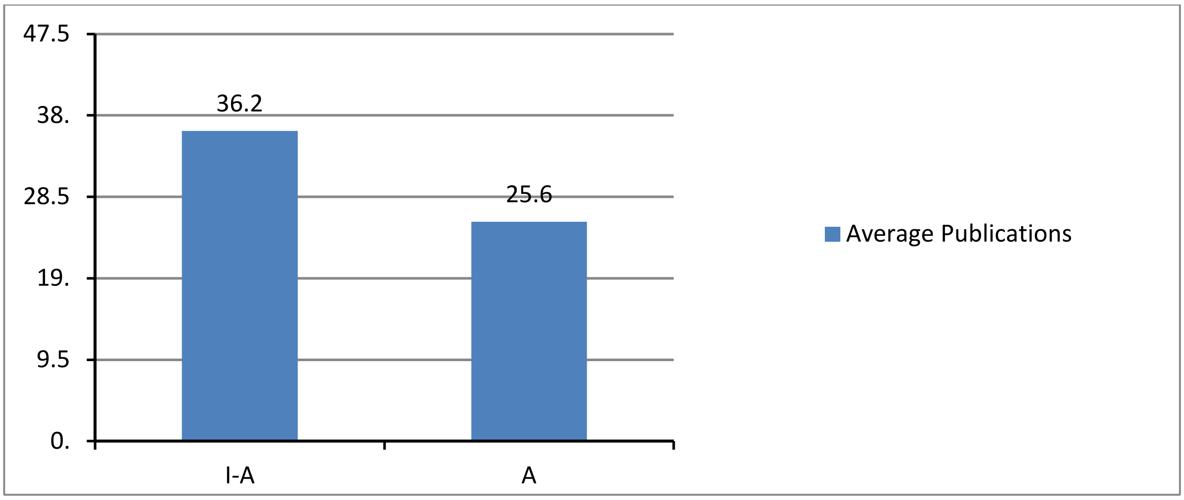
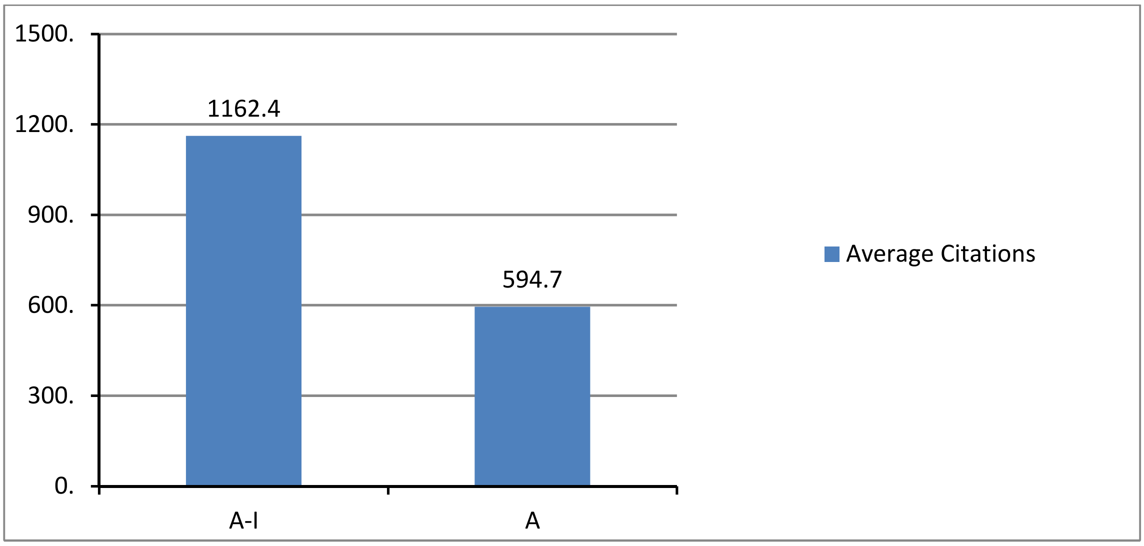


Figure 6 Average citations in the two groups



Econometric results

This section provides and describes the econometric results. As discussed in the method section, the regression is applied to already matched data. Consequently the most relevant control variables were used in the matching process, and therefore, no additional control variables are used in the econometric analysis.

In the first model, we run a logistic regression without conditioning for the matched pairs. In the second model, the regression is conditioned on the matched pairs and should provide more robust results. The results of the first model are also presented for comparison.

(Insert Tables A1-A4 around here)

In model 1 and 2 the variable "citations" is significant at the 10 % level of significance. The magnitude does not change dramatically from model 1 to model 2, thus indicating similar results.

In the first and the second model the number of publications and the "links" are not significant in either model 1 or 2, (see Table A1 and Table A2).

The dependent variable in models 3 and 4 is a count variable that contains more information as compared to the binary variably in models 1 and 2. They can therefore provide more illustrative results when it comes to the correlation of the independent variables with patent volume.

As previously, model 3 is used for comparative purposes. Model 4 with the conditional on the matched pairs regression is an unbiased model. Model 4 provides robust results in comparison to model 3 since it controls for all the matching factors and adjusts the regression to the matched pairs.

In model 3 citations are significant at the 1% level of significance comparing to the 10% level of significance in models 1 and 2. The number of links per publication is also significant at the 1 % level of significance with a negative sign. The number of publications is not significant, see Table A3.

However, the number of publications becomes significant at the 10% level of significance in model 4 with a small positive effect, see Table A4. Interestingly, the variable number of citations remains significant and with a higher effect in model 4, as compared to model 3. The number of links has now become significant only at the 10% level of significance, keeping the negative sign.

The econometric results show a clear effect of the scientific citations on the propensity to patent, an effect which become stronger for serial patentees. The number of publication was not significantly correlated with patenting in the unconditioned model, but in the most developed model where we used the count variable for the number of patents as dependent variable, the number of publications becomes significant as well. Interestingly, in the last model, the number of links is negatively correlated with the number of patents. The summary of the econometric results is presented in Table 2 below.

Table 2. Hypothesis testing results

	Model	**Support**
Hypothesis1a	2	not supported
Hypothesis 1b	2	supported
Hypothesis 2a	4	supported
Hypothesis 2b	4	supported

5. Conclusions

Nanotechnology encompasses research carried out in multiple disciplines such as physics, chemistry, biology, materials science and engineering (Shapira et al. 2011). This multidisciplinary knowledge area provides a good opportunity to observe and scrutinize the emergence of a scientific discipline and especially the dynamic links between science and technology, and between basic and applied science.

The modern role of the university and the academic includes entrepreneurial actions, such as patenting or engaging in start-up of a company, which could theoretically affect the direction of the scientific research. Much research suggests a potential trade-off between basic and applied research, which has been tested in several studies through the patenting-publishing relationship.

The publishing-patenting literature has provided mixed results (Blumenthal et al. 1996; Bourelos et al. 2012; Gulbrandsen and Smeby 2005; Van Looy et al. 2004; Van Looy et al. 2006), though these results are generally in favor of the "star-scientist" argument that patenting and publishing are complementary. However, the multi -factor nature of academic performance makes the analysis of patenting-publishing vulnerable to bias and there is still a lack of studies that can solidify the links and the direction within patenting and publishing. Our study attempts to correct for some of this bias.

In this study, we used a sample of academics in nanoscience, as an indicative field, and with a matching procedures which isolates "twin" individuals we tested the effects of publishing on patenting. The results revealed that academics with highly cited publications have higher probability of becoming inventors as well as "serial" inventors, confirming what was previously found by Agrawal and Henderson (2002) who found a significant correlation between patenting and research paper's citations. When it comes to the amount of publications, it had a less significant effect but still a positive effect on the probability of being an inventor with large number of patents.

Our contribution is primarily methodological to isolate effects, by applying a conditional logistic regression and a conditional Poisson regression in the area of patenting analysis. The results show that the patenting-publishing relationship needs to be studied in the micro level and with high scrutiny because there the more the detailed the analysis, the greater the difference in the results. Thus, the distinction between the effects of publications and citations is noticeable, and our results are at odds with Fabrizio and Minin (2008) study which is uses the US patent data, and finds that there is a complementary effect between publishing and patenting but the average citations for repeated patentees decreases over time. In the same direction of our results, in a study of academic life scientists, Azoulay, Ding et al. (2007) find that patenting has a positive effect on the rate of publications but a weaker effect (still positive) on the quality of these publications (Azoulay et al. 2004).

Our results are interesting for various reasons. First, they present a clear positive relationship between publishing and patenting in a field of applied science and technology with many patents . Therefore, these results provide evidence that there is no trade-off between basic and applied research. There are instead complementarities. Second, they come from a matched dataset where similar academics are compared and we are able to control for many other factors. Third, because they reveal important and clear differences between the effects of publications and citations and these effects are differentiated between being an inventor and a "serial" inventor.

To conclude, in nanoscience there are few academics that have managed to become very successful inventors with many patents. Most of these inventors have also been successful researchers with highly cited publications. Further research can focus more and identify specific indicators within these highly cited papers that can predict an upcoming inventor. Moreover, the pattern of highly cited papers and patents needs to be analyzed over a time period to see the trends within a time series data analysis.

Appendix

Table A1.

		(1)
Model 1	VARIABLES	patenting

patenting	publications	0.00572
		(0.00569)
	citations	0.0238*
		(0.0124)
	Links	-0.0743
		(0.0919)
	Constant	-0.366
		(0.442)
	Observations	114

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A2.

		(1)
Model 2	VARIABLES	patenting
patenting	publications	0.00678
		(0.00671)
	citations	0.0222*
		(0.0120)
	Links	-0.0813
		(0.0917)
	Observations	114

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A3.

		(1)
Model 3	VARIABLES	Npatents

Npatents	publications	0.00119
		(0.00140)
	citations	0.0161***
		(0.00333)
	Links	-0.105***
		(0.0318)
	Constant	0.727***
		(0.140)
	Observations	114

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A4.

		(1)
Model 4	VARIABLES	Npatents
Npatents	publications	0.00538*
		(0.00315)
	citations	0.0258***
		(0.00553)
	Links	-0.106*
		(0.0569)
	Observations	114
	Number of id	57

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

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