GOTHENBURG STUDIES IN INNOVATION AND ENTREPRENEURSHIP 1

Knowledge Creation and Technology Transfer

An Analysis of Swedish Academics

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To my grandmother,
who is no longer here

Abstract

This PhD thesis examines knowledge creation and transfer from universities into industry with a focus on academic patents. Academic patents are defined as patents with at least one academic inventor. The thesis presents empirical, methodological and theoretical contributions to the literature on research commercialization and university-industry interaction, focusing on academic inventors and knowledge transfer to the industry.

The modern university has been through a transformation to incorporate and expand the third mission in addition to the traditional missions of education and research. The third mission includes interaction with industry and society which will contribute to economic growth. The pressure on the university to adapt to this new role has brought new policies and practices within the areas of commercialization and university-industry interactions. Therefore, it is important to understand this transformation in order to create new public policies and university support structures that will stimulate these positive economic impacts. This thesis is a collection of papers which use quantitative methods. Data related to academic patents has been developed, and multiple quantitative methods used, in order to quantify commercialization and university-industry interaction.

One contribution is the creation of a database and methodology for identifying academic inventors in Sweden, combined with an overview of academic patenting across the Swedish universities. The database is used in combination with other data sources to test hypotheses related to the mechanisms of knowledge creation behind academic patenting as well as the ties academics build with industry.

The thesis investigates the factors affecting commercialization. The study revealed that academics have positive attitudes to commercialization and they have satisfactory commercialization output, measured as patents and start-ups. The results show that publishing is positively correlated with commercialization and that university support structures play an important role through technology transfer offices, courses in entrepreneurship and incubators.

One study focuses on academic scientists within nanoscience, and proposes a novel methodology to study the relation between patenting and publishing at the micro-level. An elaborate matching methodology was used in order to isolate and match author-inventors with "twin" authors who do not invent. The results show positive complementarities and higher number of publications for academic inventors.

A cross-sectional study on firm-owned academic patents provides an analysis of the relation between academic inventors, the technological profiles of firms and patent value. One finding is that academic patents have a short-term disadvantage, which disappears in the long term. The study introduces the technological profile of the patent as a control variable for the value of academic patents. Technological profile has been used before in order to classify patents belonging to the firm's core technologies. Our results show that patents belonging to firms' core technologies have significantly higher value, regardless of whether they are academic or non-academic patents.

Key words: University-Industry interaction, Commercialization, Academic patenting, Swedish academics, Nanoscience

Abstract in Swedish

I denna doktorsavhandling undersöks hur kunskap skapas och överförs från universitet och högskolor till näringslivet, med fokus på akademiska patent. Ett akademiskt patent definieras som ett patent med minst en akademisk uppfinnare. Avhandlingen ger ett empiriskt, metodologiskt och teoretiskt bidrag till litteraturen om kommersialisering av forskningsresultat och samverkan mellan universitet och näringsliv, med fokus på akademiska uppfinnare och kunskapsöverföringen till näringslivet.

Det moderna universitetet har genomgått en omvandlingsprocess för att till de traditionella uppdragen utbildning och forskning foga och vidareutveckla ett tredje: att samverka med näringsliv och samhälle för att bidra till den ekonomiska tillväxten. Pressen på universiteten att anpassa sig till denna nya roll har resulterat i nya strategier och metoder på områdena kommersialisering och samverkan universitet–näringsliv. Det är viktigt att förstå denna omvandling så att nya offentligpolitiska strategier och stödstrukturer för universiteten kan skapas som ska stimulera till den ekonomiska tillväxten.

Denna avhandling består av ett antal olika uppsatser där kvantitativa metoder har använts. Data som rör akademiska patent har tagits fram och multipla kvantitativa metoder har använts för att kvantifiera kommersialiseringen och samverkan mellan universitet och näringsliv. Ett av avhandlingens bidrag är den databas och den metodologi som har skapats för att identifiera akademiska uppfinnare i Sverige, tillsammans med en sammanställning av akademiska patent från svenska universitet och högskolor. Databasen används tillsammans med andra källor för att testa hypoteser som rör de mekanismer för kunskapsskapande som ligger till grund för akademisk patentering och de förbindelser med näringslivet som akademiker etablerar.

I avhandlingen undersöks de faktorer som påverkar en kommersialisering av forskningsresultat. Undersökningen visar att akademiker är positivt inställda till kommersialisering och att de också uppnår tillfredsställande kommersialiseringsresultat, mätt i patent och nyetableringar. Resultaten visar en positiv korrelation mellan publicering och kommersialisering och att universitetens stödstrukturer i form av tekniköverföringskontor, kurser i entreprenörskap och företagsinkubatorer har en viktig roll att spela.

I en studie om akademiska forskare inom nanovetenskap föreslås en ny metod för att studera kopplingen mellan patentering och publicering på mikronivå. En noga utarbetad matchningsmetod används för att identifiera och para ihop publicerad forskare som även är uppfinnare med sin ”tvilling” som inte ägnar sig åt uppfinningar. Resultaten visar på positiva komplementariteter och ett större antal publikationer för akademiska uppfinnare.

I en tvärsnittsstudie om företagsägda akademiska patent analyseras relationen mellan akademiska uppfinnare, företagens tekniska profiler och patentets värde. En observation är att akademiska patent har vissa nackdelar på kort sikt, men att dessa försvinner på längre sikt. I denna studie används ett patents tekniska profil som kontrollvariabel för ett akademiskt patents värde. Teknisk profil har tidigare använts för att klassificera patent som rör företagets centrala teknik. Våra resultat visar att patent som rör ett företags centrala teknik har betydligt högre värde, oavsett om det är fråga om ett akademiskt eller ett icke-akademiskt patent.

Acknowledgements

I would never have been able to accomplish this PhD thesis without the generous and precious help of my supervisors, colleagues and friends from academia. This help has not only influenced the present study but also had an impact on the way I think as a researcher and an individual. I am indebted to you all. During the last four years I had the opportunity to meet many notable researchers and inspirational people; I feel very lucky for that.

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This thesis is a collection of papers, and I was fortunate to work together with excellent researchers and wonderful people. Mats Magnusson's scientific excellence and creative ideas for our paper was a valuable experience for my career later on, and I am thankful for that. When I started the PhD, I met Daniel Ljungberg sitting behind a stack of books at his office in Chalmers in order to introduce me to the KEINS database. Two years later Daniel started to work in our institute, which was also destined to change my PhD thesis. Writing together with Daniel was a gift and a great learning experience. His charisma and precision in writing are priceless. I am indebted for all his comments and advice for this thesis, which added great value. Berna Beyhan was also a wonderful co-author to work with in quantitative data, and I am thankful for all her hard work and for covering my shortcomings wherever needed.

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Evangelos Bourelos

November, 2013

Appended papers

Paper I

Universities and their involvement in industrial invention as seen through academic patents. Co-authored with Maureen McKelvey and Olof Zaring. Book chapter presented at workshop and to be published in the book: McKelvey, M and Zaring, O. (2014 forthcoming). Below the Surface of the Swedish Paradox in Innovation and Entrepreneurship (Under ytan av den svenska paradoxen inom innovation och entreprenörskap). To be published in Swedish.

Paper II

Investigating the complexity facing academic entrepreneurs in science and engineering: the complementarities of research performance, networks and support structures in commercialisation. Co-authored with Maureen McKelvey and Mats Magnusson. Published in: *Cambridge journal of economics* (2012) 36: 751-780.

Paper III

Academic Inventors and Knowledge Technology Transfer in Nanoscience in Sweden. Co-authored with Berna Beyhan and Maureen McKelvey. An earlier version was presented at the Druid Academy 2013 conference, Aalborg, Denmark, January 16- 18, 2013.

Paper IV

Academic Inventors, Technological Profiles and Patent Value: An Analysis of Academic Patents Owned by Swedish-Based Firms. Co-authored with Daniel Ljungberg and Maureen McKelvey. Published in: *Industry and Innovation* (2013) 20: 473-487.

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1. Introduction

The importance of innovation in order to achieve growth in modern society has been highlighted in the literature for many years (Baumol, 2002, Schumpeter, 1934, Rosenberg, 1982). In the modern economy, knowledge has become a crucial element of innovation and economists claim that we are moving towards a "knowledge intensive capitalism" (Florida, 1995) or an "intellectual capitalism"(Granstrand, 2000). The increasing importance of knowledge has increased the expectations of the university and academic individuals.

The importance of universities for economic progress has been demonstrated in the literature (Mowery and Sampat, 2005, Etzkowitz and Leydesdorff, 2000). First, the university contributes through education, which became more important during the transition towards a knowledge-based economy (Stehr, 1994). Through education, the university transfers know-how to the industry (Salter and Martin, 2001), but education is not the only contribution. University research and academics play a crucial role in technological and economic change (Mansfield, 1991, Mansfield, 1998, Rosenberg and Nelson, 1994).

The shift towards a society which is becoming increasingly knowledge-based (Granstrand, 1999) has put pressure on the university to contribute to the industry and the society (Geuna, 2001, Salter and Martin, 2001). As a result of this pressure, the university explicitly introduced a third mission in addition to the two traditional missions of education and research. The third mission includes interaction with industry and society as well as commercialization of academic research which will contribute to economic growth (Etzkowitz and Leydesdorff, 2000).

The transformation of the university into an economic actor attracted the interest of economists and policy makers, especially in countries such as Sweden where academia relies heavily on the public sector (Granberg and Jacobsson, 2006, Jacob and Orsenigo, 2007). First, one vital question for researchers is whether the introduction of the third mission has a negative effect on the quality of education and research, based on the reasonable hypothesis that there is a trade-off between traditional and third mission activities (Larsen, 2011). Second, the university as an economic actor cannot be understood if its particular role as a provider of both public and private goods (Deiaco et al., 2012) is not taken into account in the analysis. Third, the third mission activities are complex and it is difficult to evaluate the output. Consequently, it is difficult to assess policies in order to promote economic activities within a public organization when at the same time there are critiques based on the Swedish paradox (Edquist and McKelvey, 1998). It is therefore a vital research task to study the economic impact and consequences of the third mission, to quantify and measure the output and to suggest effective public policies.

The first contribution of this thesis is the creation of the 2011 KEINS database which comes to fill the gap regarding academic patents in Sweden and complements the earlier database. The thesis later uses the data in combination with other data sources in order to evaluate the output of third mission and examine the relation between third mission activities and research. It also uses the data in order to scrutinize the dynamics of the collaboration between academics and the industry. The study combines an analysis of the macro data with descriptive statistics at the aggregate level and an analysis of the micro level with academic individuals and patents as units of analysis. It therefore addresses the following broad research questions: who are the academic inventors, which factors affect academic patenting and commercialization, how do the links between academic inventors and industry work and what is the relation between science and patenting? The answers and the analysis of the results in this PhD thesis have implications for public policy.

This PhD thesis contributes to the literature on research commercialization and university-industry interaction, two key areas within the third mission. The analysis is mainly based on data on academic patents, which are defined as patents with at least one academic inventor (Lissoni, 2012). In particular, it focuses on the role of academic patents and academic inventors as an output of knowledge creation and a vehicle of knowledge transfer from the universities to the industry.

Academic patents contain data on ownership and inventorship which can be used as proxy variables for elaborating the links and the type of collaboration between the university and the industry. An academic patent can be owned by a firm, and at the same time industrial researchers can be listed as co-inventors. Thus, academic patents can be seen as a result of university-industry (U-I) interaction (Ljungberg and McKelvey, 2012). U-I interaction can however take place in many formal and informal channels (Bekkers and Freitas, 2008). Therefore, this thesis uses different complementary variables in order to capture U-I links such as informal contacts with industry actors and academic experience working in firms.

Patents are often used as proxies for commercialization of university research in the literature (Henderson et al., 1998, Jaffe and Lerner, 2001, Pries and Guild, 2011, Zucker et al., 2002), and together with spin-offs are considered the most tangible assets of the entrepreneurial university (Klofsten and Jones-Evans, 2000, Rasmussen et al., 2006). Patents, according to EPO, "give holders the right to prevent third parties from commercially exploiting their invention". Not every invention necessarily becomes a commercialized innovation. In fact, innovation has been defined as an invention in use (Freeman, 1990, Garcia and Calantone, 2002, March, 1991). Patents are still a good proxy for commercialization for the scope of this thesis, even assuming that some patents are not in use, if we take into account that most patents in Sweden are owned by a few multinationals and thus are already in some use by the industry. This thesis also includes, however, the use of spin-offs as a proxy for commercialization in order to capture the two common variables defining commercialization of academic research (Rothaermel et al., 2007).

The topics within commercialization and U-I interaction have been addressed in the literature by other papers using academic patents as well. On the one hand, the literature on publishing-patenting has provided mixed and ambiguous results (Gulbrandsen and Smeby, 2005, Van Looy et al., 2004, Blumenthal et al., 1996), though these results are generally in favor of the "star scientists" argument that patenting and publishing are complementary (Zucker and Darby, 2007). On the other hand, the questions about the relative value of academic patents remain largely unanswered (Geuna and Rossi, 2011, Lissoni and Montobbio, 2012).

The data created for this thesis provided the opportunity to dig into specific nuances within patenting-publishing, the value of academic patents, and evaluation of U-I collaboration through academic patents.

The use of academic patents as a tool which enables quantitative research within the topic of U-I and commercialization has caused a surge in empirical papers focusing on academic patenting. The boom began in the US because better data was available earlier than in Europe. The differences between the legal systems and the heterogeneity of the European data created the need for better patent data across the European countries as well as a harmonization among the different countries' data.

Given the relatively new and fast growing number of patent studies and in particular academic patent studies, the lack of standardized patent databases becomes more significant. The available patent data is unexploited despite the rapid increase in the potential size of database storage which has boosted empirical research in adjacent fields within innovation. Take as an example the Community Innovation Statistics (CIS) database which has become the basic platform in innovation studies. The existing patent data in the European patent office (EPO) registers provided the raw material for patent datasets used in a significant number of quantitative papers. The need for a harmonized patent database across Europe led to the creation of the KEINS[1] database which compiles academic patent data in a number of European countries.

The Swedish setting

Sweden is a country where university policies have brought into the mainstream efforts to assist academic entrepreneurship and other ways of technology transfer (Henrekson and Rosenberg, 2001). Public policies in favor of strengthening the support structures in universities had already started some decades ago. In 1975 a third objective was added to the agenda of universities, namely to communicate to the surrounding society about results emanating from university research and how they can be applied. Gradually this third objective came to be interpreted more broadly as collaboration between universities, on the one hand, and private industry and the public sector, on the other. In the 1990s, the university went through reforms which increased autonomy (Jacob and Orsenigo, 2007). In the new regulation of the universities, effective from 1998 (SOU, 1998:128), this third objective is spelled out explicitly. The universities are encouraged to be open to influences from the outside world, to disseminate information about their teaching and research activities outside academia, and to facilitate the surrounding society to gain access to relevant information about research results (Henrekson and Rosenberg, 2001).

As a result of the new policies towards an innovative and entrepreneurial university, Vinnova, the Swedish Governmental Agency for Innovation Systems, was created in 2001. Vinnova continuously provides funding to academia, with its main aim being to boost innovation activities. In 2004 Vinnova launched the Vinn Excellence Center program. The Vinn Excellence Center is a form of cooperation between the business world, public sector, universities, and other research institutes and organizations.

Despite the early systematic efforts towards a third mission and the big support of universities by the state (Jacob and Orsenigo, 2007), the Swedish universities have failed to provide an undisputable output which would justify the efforts. The mismatch led to the conception of the paradox of high investment into R&D, but at the same time low returns in growth (Edquist and McKelvey, 1998). Later critiques on the European paradox (similar to the Swedish paradox) argued that it is a misconception based on an incorrect linear view from science to new products

[1] The KEINS database on academic inventors contains detailed information on university professors from France (Llerena), Italy (Lissoni), and Sweden (McKelvey), who appear as designated inventors on one or more patent application registered at the European Patent Office (EPO), 1978-2004 and was created in 2005 under the KEINS project. The data later expanded to include: Great Britain, Belgium and Germany.

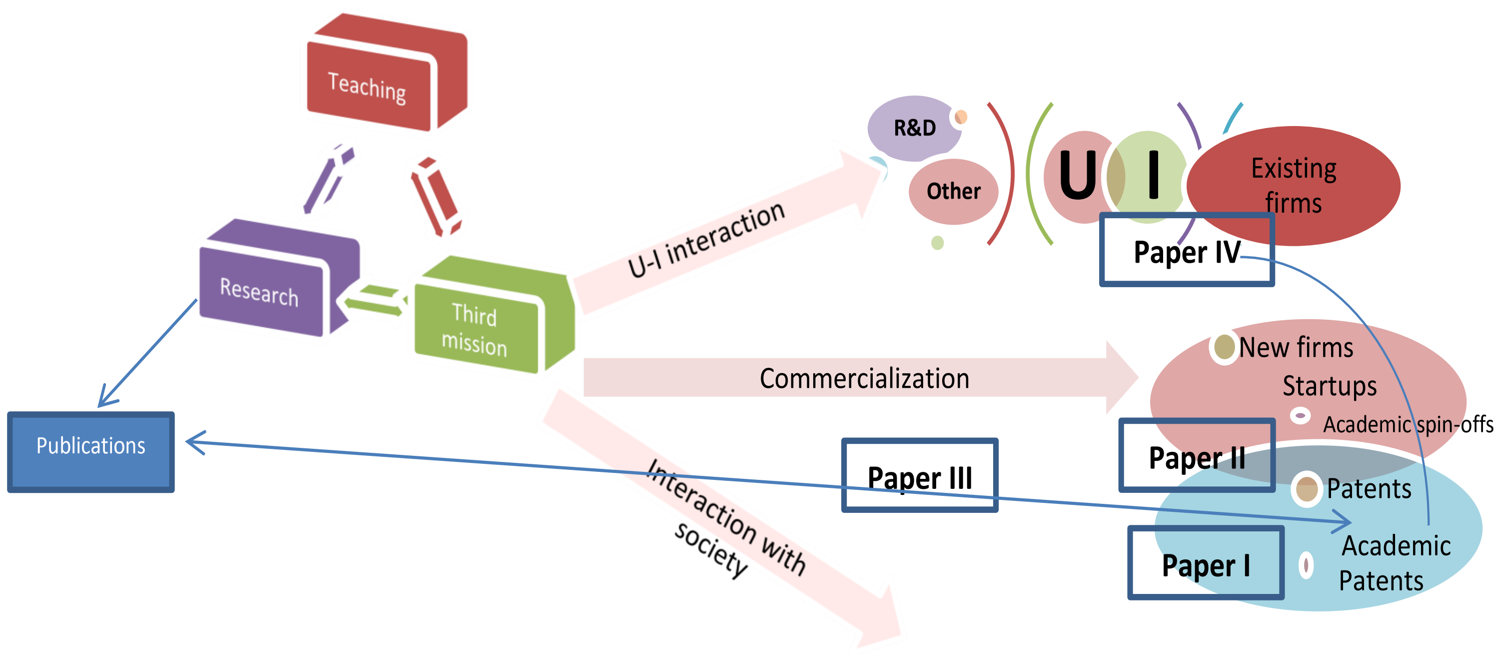
(Dosi et al., 2006). Another reason for the misconception is the lack of quantitative data to assess the output of universities.

In Sweden, an academic dataset within the KEINS project was created in 2005 but since then only very few papers have been published on academic patenting. In addition, irregular selection of data has not helped to proliferate the empirical studies on Swedish academic patents, which is at odds with the high accessibility and high standard of organized data that is characteristic in Sweden.

The theoretical framework in the next section will help the reader to understand the logic behind the hypotheses built in the appended papers. This section contributes a suggested theoretical model and a structured literature review within the topics of U-I interaction, commercialization and academic patenting. The theoretical model aims to explain the simultaneous transformation of the university and the individual towards an entrepreneur as an evolutionary process where the micro and the macro level are interconnected.

This PhD thesis consists of the current introductory chapter and four appended papers. The structure of the introductory chapter is as follows. The introduction is followed by a frame of reference in Section 2. Then comes the research design and methodology in Section 3 where the specific research questions and methods are described in detail. The summary of the appended papers is presented in Section 4 while Section 5 concludes with a discussion of the contributions and key findings as well as implications and future research.

Figure 2.1 Literature map – position of the appended papers



2. **Theoretical background and literature review**

This section presents the theoretical framework within the topics covered in this thesis. Figure 2.1 visualizes the theoretical framework and the relevant position of the appended papers. The starting point in this framework is the university and its three missions, and the analysis is performed from the university angle. The third mission actions are categorized here into three different channels as seen by the arrows stemming from the third mission box in Figure 2.1. The three channels are the U-I interaction, commercialization of knowledge and interaction with society. U-I interaction refers to the university's links with existing firms. Commercialization refers to the creation of new firms or academic patents or both. Academic patents can be a result of the commercialization process, but not all academic patents have to be (direct) commercialization of academic research, since there are academic patents which are not used. Academic patents are nevertheless used as a proxy for commercialization of university research in the literature (Henderson et al., 1998, Jaffe and Lerner, 2001, Pries and Guild, 2011, Zucker et al., 2002).

First, a theoretical model is developed which aims to explain the simultaneous transformation of the university and the individual towards an entrepreneur as an evolutionary process where the micro and the macro level are interconnected. The model is presented in order to suggest an underlying theory of the three missions and can also help in understanding the hypotheses and the results of this thesis later on.

The structured literature review focuses on three topics inside the three missions: U-I interaction, commercialization and academic patenting. The structured literature review was conducted in order to produce an overview with descriptive statistics at the aggregate level and at the same time to identify the most important papers and authors in the field.

The section is organized as follows. Subsection 2.1 presents a suggested theoretical model underlying the three missions. Subsection 2.2 discusses the three missions in the university, and subsection 2.3 presents the methodology and the results from the structured literature review. After the structured literature review, the literature within each of the three topics is discussed. Subsection 2.4 discusses U-I interaction, subsection 2.5 commercialization and subsection 2.6 academic patenting. Conceptually, the subsections move from the left to the right (from the general to the specific) within Figure 2.1 (2.1-2.2 on the three missions, 2.3-2.6 on U-I interaction-commercialization-academic patenting).

2.1 Invention: The backbone of evolution

This subsection presents a theoretical model developed by the author. The model was developed in order to better understand the dynamics within the three missions in relation to the role of the academic individual who incorporates them.

The model proposes that the transformation of the university towards a three-mission entity is an endogenous process. The backbone of this endogenous transformation is innovation and more specifically innovation's seed, invention. The analysis starts from the beginning of economic development and the evolution through inventions.

At the beginning of the science fiction film "2001: A Space Odyssey", a tribe of apes struggles to survive. While the other members of the tribe are hanging around pointlessly, the leader of the tribe finds the remaining bones of a dead animal. After experimenting with the bones, one of the apes realizes how to use bones both as tools and as weapons in order to defeat other ape tribes and to kill prey for their food. The central idea of this story is the evolution of humans from primitive apes to civilized human beings.

The stairway in this evolutionary process is innovation, and innovation's structural element, invention. In primitive human societies where education was not organized, the biological characteristics of the individual were probably responsible for whether that individual became an inventor or not. These characteristics could be combined with courage and aggressiveness in order to beat the fear of the unknown and an instinctual intelligence to choose the best possible combination. Courage is important because in order to invent you need to experiment, and in order to experiment you need to break the fear of the unknown. This fear comes from the dangers hidden by uncertainty, which can sometimes be lethal. Thus, the ape who was not afraid of getting injured by the bones, or the human who was not afraid of the fire, was probably the one who took the risk and managed to utilize these tools.

One can only speculate how many people burned their hands before they actually managed to handle the fire, but the fact that many languages[2] still include the expression "don't play with fire" is illustrative. Even though technology has advanced and invention is now a result of a more systematic and organized approach, uncertainty still hides its dangers and courage is still needed to invent. Take Marie Curie, as a modern example, who probably died as a consequence of her long-term exposure to radiation.

After invention, which can be explained as a natural result of the survival instinct, follows the process of learning. Going back to the previous example with the ape that used the first bone, the leader had to teach the other members of the tribe how to use the new weapon and they had to pass the knowledge to the next generation too. At this point, the need for education was created, a need which led humans to organize education systematically and create universities.

The next assumption of this model is that invention is also linked to the need for understanding. The argumentation of this assumption follows. The need for understanding comes from curiosity to understand the surrounding world and phenomena. Therefore, it is a need which can exist before and without invention. Curiosity however is also driven by the survival instinct, and the need to understand the surrounding world is connected with the struggle to survive. When an

[2] At least in Greek, Italian, German, English, Swedish, Dutch, and Turkish.

invention comes, two things happen. First, a new phenomenon becomes an object of observation attracting curiosity. Second, this invention might give competitive advantage to the inventor in the struggle to survive and thus "the new object of observation" is particularly interesting for the observer. It is at this time that the individual poses the question of why, and tries to understand the phenomena. Thus, these two arguments suggest that invention creates a need for understanding.

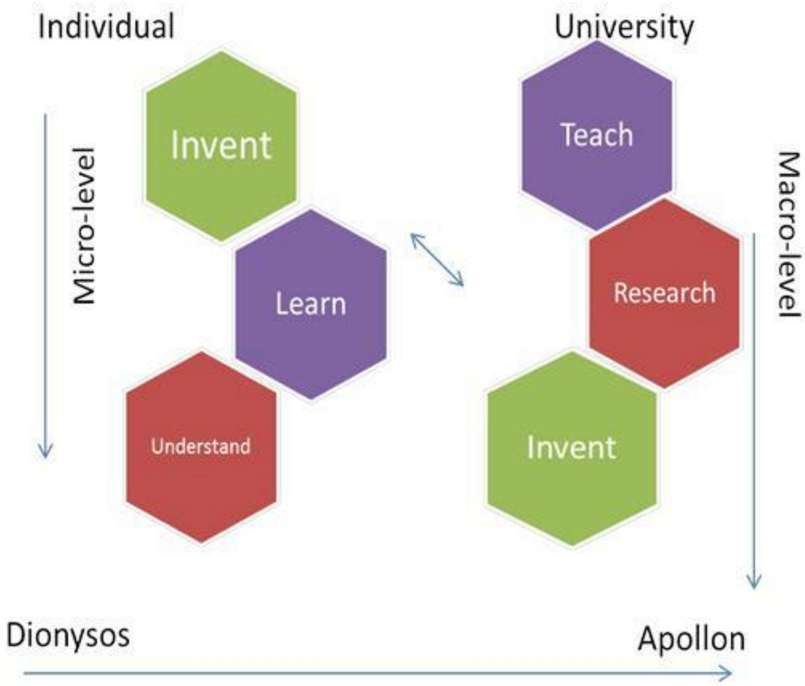
If all the assumptions above are valid, then the evolution which starts from invention at the individual level results in the following domino: invention → transfer of knowledge → understanding, or parallelized in other words: technology → education → science.

The transition from the micro-individual level to the macro-university level has its roots in the generation of the need for education. Since the knowledge had to be transferred from the individual inventor to the rest of society and the next generation, we gradually ended at the creation of the university as a response to the need for organized education. Education constitutes the first mission of the university.

The university transformed into an institution which combines research as a second mission and is gradually moving towards the inclusion of a third mission to contribute to economic development (Etzkowitz and Leydesdorff, 2000). The evolutionary process at the university took place in the following order: teaching, research, third mission. Third-mission activities are constituted of different components as analyzed previously. One component is academic patenting, which is based on invention and is the component extracted in this model to show the connection between the micro and the macro level. Then we can express the order differently, as education-science-invention or education-science-technology. Thus the evolutionary process of the university transformation breaks down into the same components as the evolutionary process of the individual, but in a different order. First comes the individual invention which generates the need to learn and understand. The need to learn then generates the need for education and the university. The university follows its own evolutionary process at the macro level, as shown in Figure 2.2, which ends when the three components from the individual level are completed.

So this model suggests that the transformation of the university into a three-mission entrepreneurial university is a self-fulfilling prophecy with its roots going back to the invention at the individual level. This evolutionary spiral movement connecting the micro and the macro level is depicted in Figure 2.2. Invention is the starting point and the ending point. It started as a primitive instinctive invention by the individual, but at the end when technology had evolved and there was a high demand on knowledge capacity in order to invent, the university was the place which fulfilled these prerequisites and we moved towards a knowledge-intensive invention which comes from organized science. So, according to this model the modern university is the collective and organized evolutionary product of human evolution from the primitive to the scientific nature, which traveled upon the vehicle of invention (see Figure 2.2). Consequently, the model clearly suggests that the three missions, presented in the next subsection, are complementary.

Figure 2.2 From the primitive towards the academic inventor



[3]

2.2 The three missions of the modern university

Traditionally, the main objective of the university was to transfer knowledge to society through education (Salter and Martin, 2001). The educational role of academics through teaching became more important during the transition towards a knowledge-based economy in a society where knowledge plays a central role in our lives (Stehr, 1994). The importance of knowledge in the economy concentrated attention on classic and neo-classical models via human capital theories, such as the exogenous growth models but also the neo-Schumpeterian theories, which put innovation in the epicenter of the analysis and upgraded the role of knowledge and human capital (Schumpeter, 1934, Rosenberg, 1982, Solow, 1956). A basic component within the creative destruction created by the introduction of new goods and services is innovation, and knowledge is a protolithic as well as a rising paragon of innovation and growth. The importance of knowledge stresses the role of education; this has been always a key issue for policy makers, who consider education a vehicle which can move upwards along the production curve in the economy.

After the "first academic revolution" (Etzkowitz et al., 2000) research has been considered as a mission of the university in itself. Some universities have been oriented towards research since the 19th century and the neo-humanistic German university, while the research mission dominated universities in the USA by 1910 (Link and Scott, 2005). The academic revolution of the late 19th and 20th centuries was described as the process of introducing and developing the second mission, research, alongside the traditional scope of the university to preserve and

[3] I use Dionysos as a symbol of instinctual invention and Apollon as a symbol of organized science.

transmit knowledge (Etzkowitz, 1998). Since then, governmental funding started to dominate universities and this picture remained during the postwar era . The expansion of research was a result of an internal and external transformation. On the one hand, students are the intermediaries between university and industry, pushing the orientation of the university towards industry; and on the other hand, the industrial and governmental spheres increasingly also develop similar intermediary capabilities pulling towards research from the outside (Etzkowitz et al., 2000, Etzkowitz and Leydesdorff, 2000).

Especially when it comes to basic research, the university was considered the main actor in conducting research, and received financial support from the state for this purpose as a result of the pull by the governmental and public sphere. The result of this natural expansion of teaching to the second mission of research was reflected in the system of peer review for the evaluation of academic research, which has become an important tool of the academic career evaluation process. Therefore, the research activity of universities is mainly expressed by scientific publications, which have exponentially grown in number during recent decades (Larsen and Ins, 2010). During that era, peer evaluation was always the most important aspect in setting the processes of promotion and financial allocation (Baruch, 2003).

The previous subsection presented a model of the evolutionary expansion from the invention to the three-stage triptych invention-transfer-understanding at the micro level. The evolution was explained by the endogenous need that invention created for teaching and understanding.

Similarly, at the macro level the university is being transformed endogenously towards a university incorporating the three missions. Since the university introduced research as a mission, it started to produce scientific results. The need to communicate these scientific results outside academia created the first channels between the university and industry/society. These channels later became the infrastructure for the U-I links under the third mission. The need for organized science — because of the increased importance of knowledge — has pushed towards the introduction of the third mission.

However, this view of the university as contributing to society with the introduction of the third mission has its roots in the role of the individual scientist as a teacher, researcher and innovator. Looking through an evolutionary spectrum, the “second academic revolution” bridges the leap from the first to the second and the third mission, and this evolution reconciles the role of human knowledge with Aristotle’s epistemic purpose: that technology and episteme come from the same cause, the human need to survive (Aristotle, Politics). Under this prism, the three missions of today’s university are different sides of the same coin; that is, knowledge creation, transfer (including teaching) and application, mirroring the micro-individual level at the macro-university level, in an extension of Schumpeter’s model of the entrepreneur from the individual to the collectivity (Etzkowitz et al., 2000).

The role of the teacher, the researcher and the engineer/economic actor was embodied in the ancient scientist. Thales, for example, “the first Greek mathematician” was also famous for the big engineering projects he conducted. Pythagoras served as a mathematician, politician, musician and teacher. Archimedes later contributed to fields including engineering, architecture and hydraulics. Scientists later on during the renaissance continued in the same pattern, with Leonardo Da Vinci as a great example of a “panepistimon” (a man of all science).

The specialization and subdivision in industries and science that came with the industrial revolution developed hand in hand with the modern university structure. Nevertheless, the concept of the university as an economic actor did not fall from the sky, but has historically emerged. We might be moving towards a new type of scientist as a teacher-researcher-entrepreneur but on a different level, at the university level. Before, the attributes of the three missions were characteristics/activities of the individual. Now, they are seen as the responsibility of the university.

2.3 Structured literature review

In this subsection of the frame of reference, I present the results from a structured literature review which was carried out in order to identify and categorize the key papers within U-I interaction, commercialization and academic patenting.

The purpose of this subsection is twofold. On the one hand, after reviewing all the major works within the fields of focus, the aim is to identify and rank the most productive and influential authors, who are the leading knowledge producers within the field. The analysis also shows the role of core research scholars in developing the field over time. On the other hand, the taxonomy within the three fields with aggregate statistics provides the possibility of analyzing the comparative development and influence of these subfields across time. These descriptive statistics can be useful in order to identify the fields that attract scientific interest.

The methodology in this structured review follows the design used in similar field-bibliometric analysis for the field of innovation by Fagerberg et al. (2012) and by Landstrom et al. (2012) for the field of entrepreneurship, while the literature review by Perkmann et al. (2013) on U-I interaction was used as a baseline. As compared to the previous literature review paper, this PhD thesis extends the analysis from the field of U-I interaction as a whole to the subfields of commercialization and academic patenting.

The literature review includes papers and citations extracted from the Web of Knowledge[4] database on 20 June, 2013. The aggregate results are shown first, followed by three separate parts presenting the individualized results for each category.

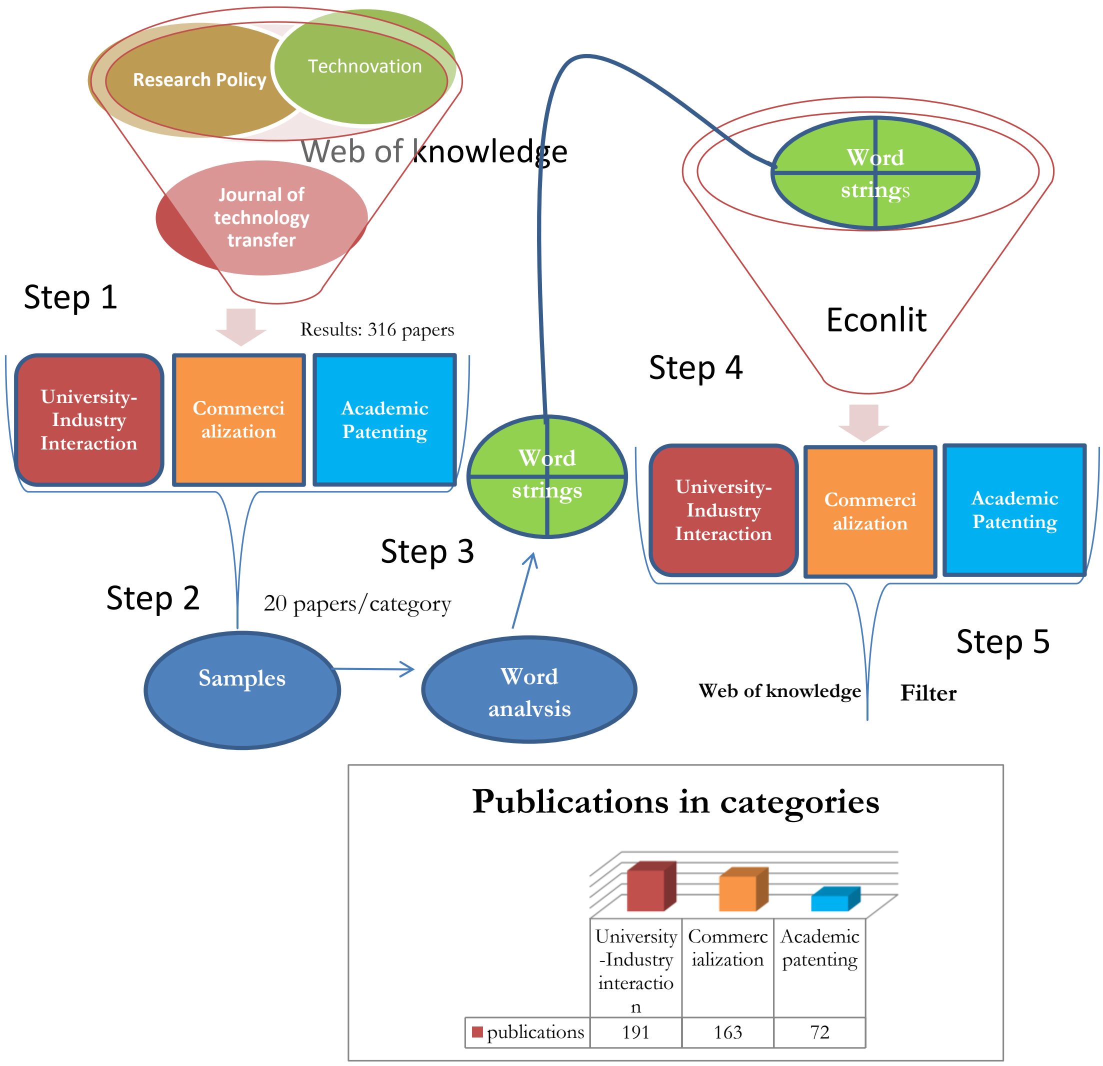
I have limited the search to journal papers in order to obtain consistent results in the comparison tables in the bibliometric analysis, which means that important work in books and other types of publications will not show up. Nevertheless, the analysis in terms of authors, journal articles, and citations within the area covers a big part of the literature relevant to this thesis. The reasons are that the fields are relatively new, there is a general shift towards journal articles and the specific nature of the area is empirically oriented, particularly in academic patenting.

2.3.1 Methodology

The methodology used is described in the following five steps. Figure 2.3 presents an overview of the methodology, to help the reader follow the detailed steps.

[4] The Web of Knowledge is the platform of scientific journals provided by Thomson and Reuters.

Figure 2.3 Methodology for the structured literature review



Step 1: Selection 1

At first I extracted from the Web of Knowledge database all articles from the journals *Research Policy, Technovation* and *Journal of Technology Transfer* in accordance with Perkmann et al. (2013) and Rothaermel et al. (2007). After reading the titles and the abstracts of these papers, those which directly referred to the topics or implied that the paper dealt with a topic within the topic of the third mission as defined in Figure 2.1 were selected and categorized under U-I interaction or commercialization. The papers within commercialization which covered the topic of academic patents were extracted separately, resulting in three different categories of extracted papers. The first selection resulted in 316 papers within the three categories from the three journals; these are shown in Table A.1 in appendix A, together with the number of records searched in the database for each of the three journals.

Step 2: Sample and word analysis

The 316 papers selected from the above three journals in the first selection were used as a source of keywords in order to continue the selections in other journals. At first, a random sample of 20 papers was extracted from each of the three categories from the pool of the previous step. The target was to generate a keyword string for searches within each field. The titles of the 20 papers of the sample in each category were analyzed to identify words that appeared in the titles. Table A.2 in appendix A presents the words within each field and the percentage of appearances in the title.

Step 3: Keyword string generation

Using the word analysis from step 2, I created the minimum number of combinations of words in each category that would have a 100% recall rate in getting the 20 papers used in the sample[5]. That means that if someone uses the combinations in search strings within the database, all the papers that were in the sample will be retrieved. Again, the main target here was to obtain the highest possible recall, not caring yet about precision, meaning that "noisy" irrelevant papers would also be retrieved with these strings. In order to increase the precision rate at this point, additional words to be found within the abstract or in all fields were added in some of the combinations where the amount of papers retrieved was otherwise large and would have required a tremendous amount of time for later manual filtering.

Step 4: Selection 2

The strings generated in the previous step were used to retrieve all the relevant articles from the database EBSCO. The EBSCO database was employed at this stage because of the higher flexibility it provides in comparison to Web of Knowledge when performing massive searches with strings. Tables A.3-A.5 in appendix A show the articles found in EBSCO for each string, applying the following settings in the search: database=Econlit, language=English, publication type=journal. The search excluded the journals *Research Policy*, *Technovation* and *Journal of Technology Transfer*, for which a manual retrieval was used in step 1 instead.

Step 5: Filtering

After the retrieval of the papers from EBSCO, a manual filtering through the papers took place in order to eliminate irrelevant papers and duplicates. Afterwards, the papers from selection 2 which appeared in Web of Knowledge were stored and added to the initial pool of selection 1. Thus, after merging selection 1 and selection 2, only the papers that belonged to Web of Knowledge were kept, in order to have consistent citation analysis later on. A last filtering took place at this stage, where I manually went through the papers in order to identify duplicates across the different categories and re-categorized the articles into the most relevant category if there was a duplicate or a paper was misplaced. In cases where the context of a paper was overlapping between two categories, then it was placed into the closest category corresponding to the main focus of the paper. The final refined results are shown in Figure 2.4.

2.3.2 Aggregate statistics

Figures 4 and 5 present the overview of the three analyzed categories in terms of authors and publications. Table A.6 in appendix A shows the top 10 journals in which the articles of these publications were published as well as the citations and the impact factor (citations/paper) within these fields.

[5] In different samples tested, the possibility of finding a new word in the title for more than 20 papers was less than 5% and therefore 20 papers was set as the sample number.

Figure 2.4 Papers retrieved in Web of Knowledge, categorized

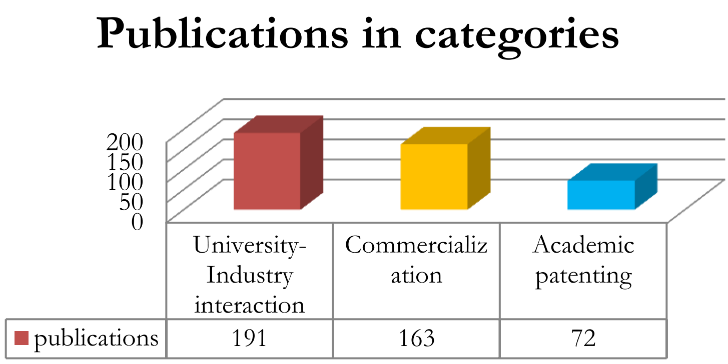


Figure 2.5 Authors per category

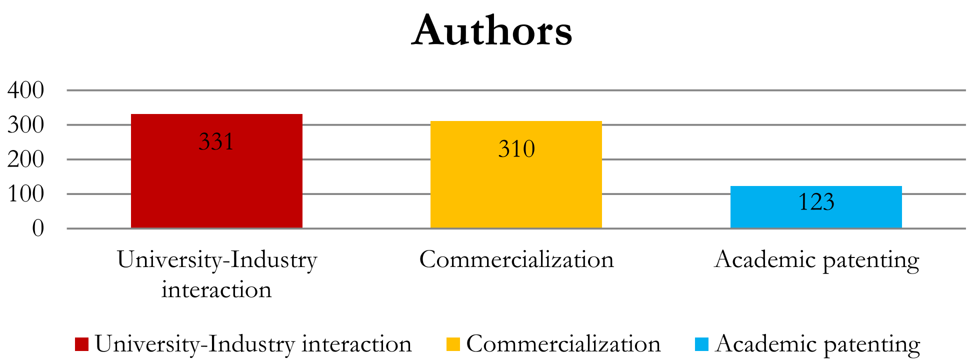


Figure 2.4 presents the number of publications across the different categories, with no duplicates and each paper being counted once in the category it fitted best. Figure 2.5 presents the number of authors among the three subfields, but here there are overlaps since authors tend to publish in adjacent areas. There were 42 authors (6.6%) with at least one article in both U-I interaction and commercialization, 30 authors (6.6%) with articles in both U-I interaction and academic patenting and 29 authors (6.7%) with articles in both commercialization and academic patenting.

In Figure 2.6 we can see the evolution of the subfields across time. Although the first papers were published in the 1980s, the boom did not occur until the last decade. This is partially explained by the increase in journal papers per se, but also indicates the increased levels of interest in the area.

Figure 2.6 Articles published in each category per year

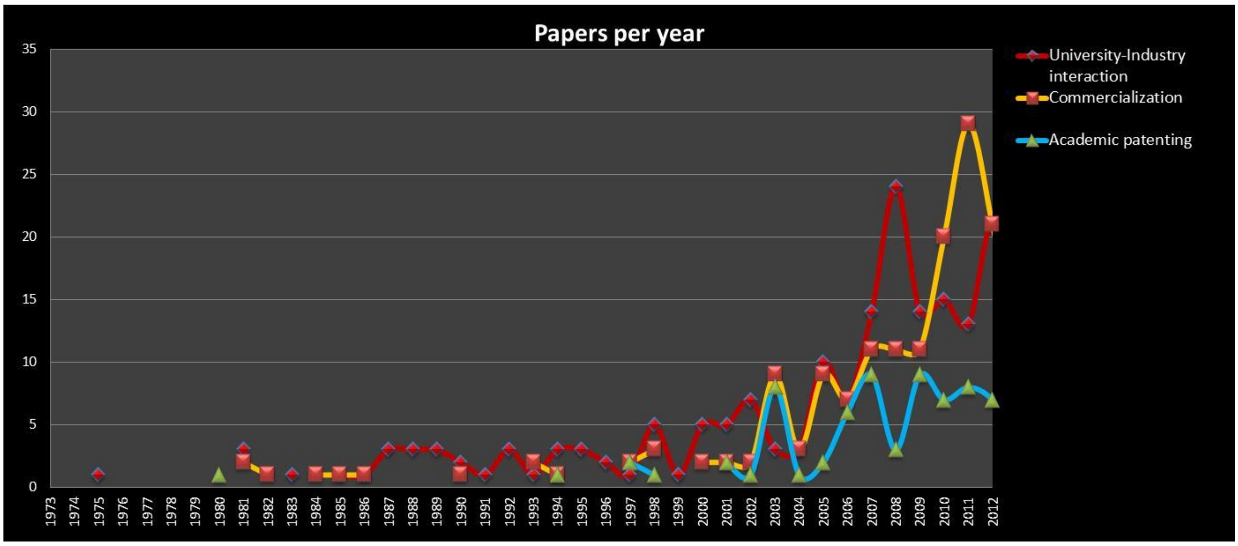
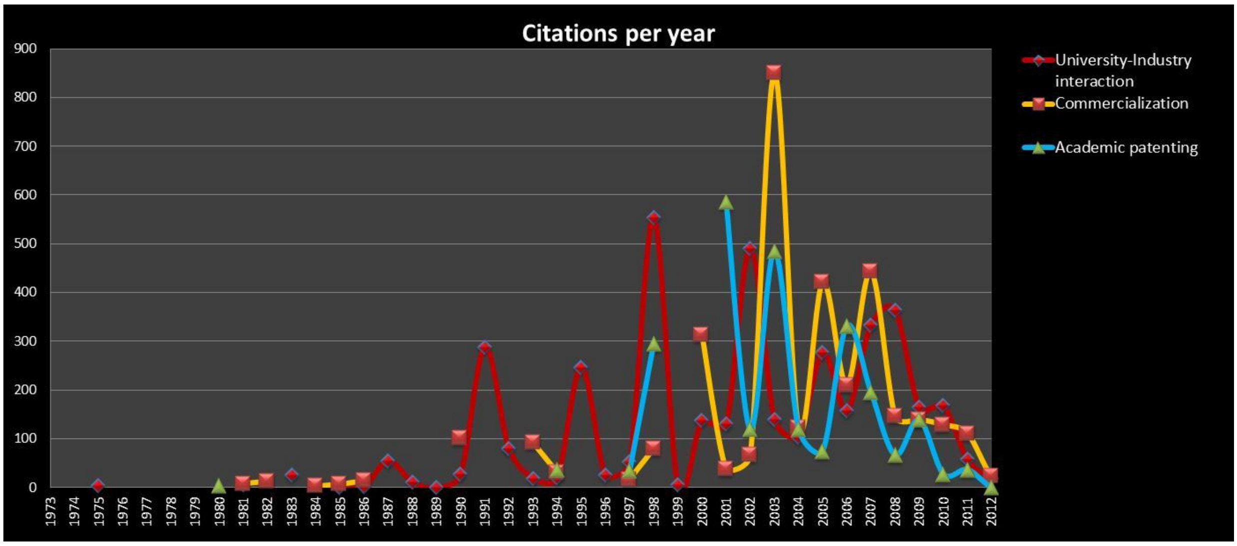


Figure 2.7 below shows the citations per year that papers within the three categories have so far received. Interestingly, the line for "academic patenting" has shifted upwards in relation to the other two lines and their shift in Figure 2.6, which means that the topic of academic patenting has attracted proportionally higher interest despite the small number of papers published.

Figure 2.7 Citations in each category per year



Field distribution within the three main journals

In Figures 2.8-2.10 on the next page we see the fraction of the articles found in *Research Policy*, *Technovation* and *Journal of Technology Transfer* and the distribution of the three preselected categories within each journal.

Figure 2.8 ***Research Policy*** **- articles found per category**

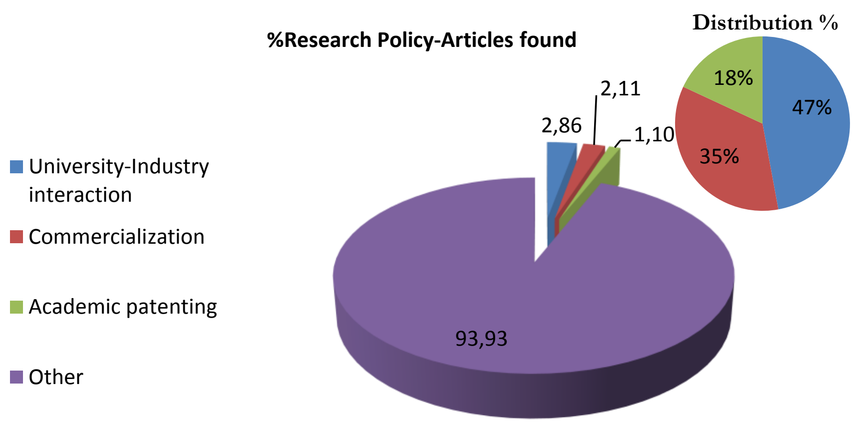


Figure 2.9 ***Technovation*** **- articles found per category**

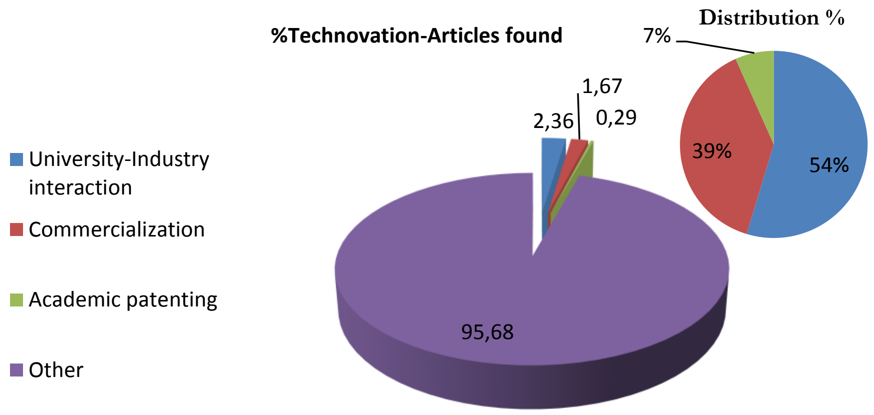
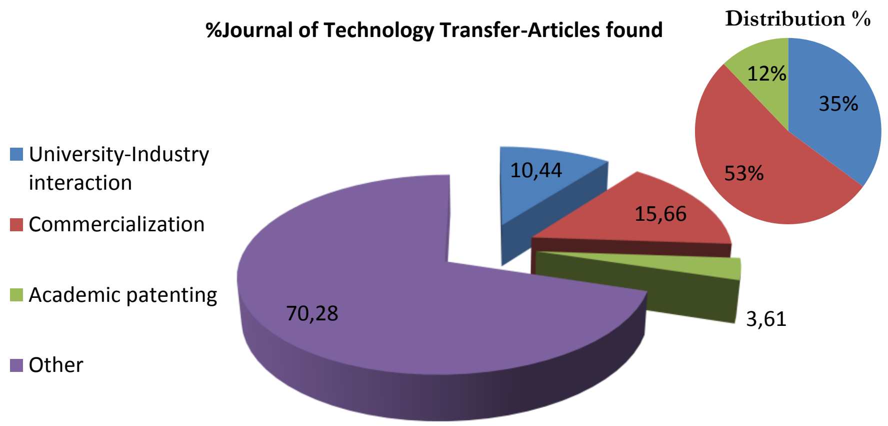


Figure 2.10 ***Journal of Technology Transfer*** **- articles found per category**



The journal which had the highest proportion of its articles within commercialization, U-I and academic patenting taken together was the *Journal of Technology Transfer*. *Research Policy* had the highest proportion of papers in academic patenting, which is congruent with the fact that papers in academic patenting are highly cited as noted previously. The next parts present the results of ranking in terms of paper and author citations as well as records by author.

2.3.3 Key research papers and scholars in U-I interaction

Table 2.1 presents the 10 most cited articles in U-I interaction. The most cited papers came from the 1990s. These are the articles that characterized the field, since they were a breakthrough in terms of either theorizing the concept of U-I interaction or modeling the design in measuring it (Etzkowitz, 1998, Mansfield, 1991). Thus, these papers became the origins within the field that everyone cites. Noticeably, these "fathers" or gurus of the field are not the ones who continued to develop the field; they do not appear in the list of most productive scholars and only D'Este, among the five most cited, appears in both lists of top producing and top cited scholars (see Table 2.2). Instead, a new generation of scholars in the 2000s has contributed the most in terms of papers.

Table 2.1 University-Industry interaction: Top 10 cited articles

Author (Year)	Title	Journal	Citations
1. E. Mansfield (1991)	Academic research and industrial-innovation	Research Policy	288
2. E. Mansfield (1995)	Academic research underlying industrial innovations - sources, characteristics and financing	Review of Economics and Statistics	240
3. H. Etzkowitz (1998)	The norms of entrepreneurial science: cognitive effects of the new university-industry linkages	Research Policy	205
4. F. Meyer-Krahmer and U. Schmoch (1998)	Science-based technologies: university-industry interactions in four fields	Research Policy	188
5. E. Mansfield (1998)	Academic research and industrial innovation: An update of empirical findings	Research Policy	142
6. F. Murray (2002)	Innovation as co-evolution of scientific and technological networks: exploring tissue engineering	Research Policy	124
7. P. D'Este and P. Patel (2007)	University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry?	Research Policy	107
8. D. Schartinger, C. Rammer, M. M. Fischer and J. Frohlich (2002)	Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants	Research Policy	95
9. K. Debackere and R. Veugelers (2005)	The role of academic technology transfer organizations in improving industry science links	Research Policy	92
10. M. D. Santoro and A. K. Chakrabarti (2002)	Firm size and technology centrality in industry-university interactions	Research Policy	85

Table 2.2 University-Industry interaction: Most productive scholars & most influential scholars

# Most productive authors	Recs	# Most influential authors	Citations (#papers)
1. D'Este P.	6	1. Mansfield E.	686 (4)
2. Boardman P. C.	5	2. Etzkowitz H.	205 (1)
3. Brostrom A.	5	3. Meyer-Krahmer F.	188 (1)
4. Woerter M.	5	4. Schmoch U.	188 (1)
5. Arvanitis S.	4	5. D'Este P.	160 (6)
6. Mansfield E.	4	6. Murray F.	124 (1)
7. McKelvey M.	4	7. Debackere K.	116 (2)
8. Perkmann M.	4	8. Siegel D. S.	114 (2)
9. Freitas I. M. B.	3	9. Patel P.	107 (1)
10. Gaughan M.	3	10. Fischer M. M.	95 (1)

2.3.4 *Key research papers and scholars in commercialization*

In contrast with the previous subsection, in commercialization the most important papers come from the 2000s, which is consistent with the graph of citations per year in Figure 2.7. Etzkowitz's papers are listed again at the top together with empirical papers, see Table 2.3. Nevertheless, apart from Etzkowitz there was no further overlap between the top authors in U-I interaction and commercialization. *Research Policy* in both categories was the journal with the most top cited publications. What we notice in Table 2.4 is that in most of the cases there is one article which receives a lot of citations, which is enough to put the author in the top 10.

Table 2.3 Commercialization: Top 10 cited articles

Author (Year)	Title	Journal	Citations
1. H. Etzkowitz, A. Webster, C. Gebhardt and B. R. C. Terra (2000)	The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm	Research Policy	255
2. D. Di Gregorio and S. Shane (2003)	Why do some universities generate more start-ups than others?	Research Policy	214
3. H. Etzkowitz (2003)	Research groups as 'quasi-firms': the invention of the entrepreneurial university	Research Policy	162
4. F. T. Rothaermel, S. D. Agung and L. Jiang (2007)	University entrepreneurship: a taxonomy of the literature	Industrial and corporate change	153
5. R. P. O'Shea, T. J. Allen, A. Chevalier and F. Roche (2005)	Entrepreneurial orientation, technology transfer and spinoff performance of US universities	Research Policy	116
6. I. Feller (1990)	Universities as engines of r and d-based economic-growth - they think they can	Research Policy	101
7. B. Goldfarb and M. Henrekson (2003)	Bottom-up versus top-down policies towards the commercialization of university intellectual property	Research Policy	99
8. B. Van Looy, M. Ranga, J. Callaert, K. Debackere and E. Zimmermann (2004)	Combining entrepreneurial and scientific performance in academia: towards a compounded and reciprocal Matthew-effect?	Research Policy	94
9. R. A. Jensen, J. G. Thursby and M. C. Thursby (2003)	Disclosure and licensing of University inventions: 'The best we can do with the s**t we get to work with'	International Journal of Industrial Organization	92
10. A. Lockett, D. Siegel, M. Wright and M. D. Ensley (2005)	The creation of spin-off firms at public research institutions: Managerial and policy implications	Research Policy	89

Table 2.4 Commercialization: Most productive scholars and most influential scholars

# Most productive authors	Recs	# Most influential authors	Citations (#papers)
1. Wright M.	9	1. Etzkowitz H.	417 (2)
2. Audretsch D. B.	7	2. Wright M.	332 (9)
3. Siegel D. S.	6	3. Shane S.	275 (3)
4. Lockett A.	5	4. Lockett A.	261 (5)
5. Amara N.	4	5. Gebhardt C.	255 (1)
6. Landry R.	4	6. Terra B. R. C.	255 (1)
7. Thursby M. C.	4	7. Webster A.	255 (1)
8. Aldridge T.	3	8. Di Gregorio D.	214 (1)
9. Clarysse B.	3	9. Rothaermel F. T.	206 (2)
10. Fini R.	3	10. Agung S. D.	153 (1)

2.3.5 Key research papers and scholars in academic patenting

In academic patenting, as mentioned previously, there were not as many papers but they were highly cited, see Table 2.5 on the next page. Comparing the list of most productive and most influential scholars with the lists in the previous subsections does not show any overlap. At the top level we see the specialized authors. The top three influential authors are Mowery, Sampat and Ziedonis who have co-authored together and who also appear in the list of most productive authors, see Table 2.6.

2.3.6 Concluding remarks

I finalize the structured literature review subsection with a couple of concluding remarks. Firstly, the results showed that the methodology of sampling papers in order to generate the keywords for articles (i.e. "fishing" in a systematic way) was effective, since the number of papers that this methodology retrieved was very high compared to similar literature review papers (e.g. (Perkmann et al., 2013). Therefore, creating a keyword algorithm which is based only on the inclusion of the conceptually relevant words might not be adequate, and a more systematic way might retrieve a higher percentage of relevant papers. Secondly, the results showed that academic patenting as a subfield attracts more attention, in terms of citations, proportionally to the number of papers and authors in the field, which might be an indicator that academic patenting attracts attention from various scientific fields and/or that it is a growing sector. In terms of authors and papers that had the biggest influence, we conclude that the few "star" scientist who defined the fields are still the most important, especially within U-I interaction, but the new generation of authors has started to rapidly produce papers within the field, especially in commercialization and academic patenting, and we would expect that some of these papers will soon become distinguished and earn high citation scores.

Table 2.5 Academic patenting: Top 10 cited articles

Author (Year)	Title	Journal	Citations
1. D. C. Mowery, R. R. Nelson, B. N. Sampat and A. A. Ziedonis (2001)	The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh-Dole act of 1980	Research Policy	316
2. R. Henderson, A. B. Jaffe and M. Trajtenberg (1998)	Universities as a source of commercial technology: A detailed analysis of university patenting, 1965-1988	Review of Economics and Statistics	295
3. R. Jensen and M. Thursby (2001)	Proofs and prototypes for sale: The licensing of university inventions	American Economic Review	271
4. D. Harhoff, F. M. Scherer and K. Vopel (2003)	Citations, family size, opposition and the value of patent rights	Research Policy	147
5. M. Balconi, S. Breschi and F. Lissoni (2004)	Networks of inventors and the role of academia: an exploration of Italian patent data	Research Policy	120
6. D. C. Mowery and A. A. Ziedonis (2002)	Academic patent quality and quantity before and after the Bayh-Dole act in the United States	Research Policy	119
7. A. Geuna and L. J. J. Nesta (2006)	University patenting and its effects on academic research: The emerging European evidence	Research Policy	110
8. J. Owen-Smith and W. W. Powell (2003)	The expanding role of university patenting in the life sciences: assessing the importance of experience and connectivity	Research Policy	104
9. R. A. Jensen, J. G. Thursby and M. C. Thursby (2003)	Disclosure and licensing of University inventions: 'The best we can do with the s**t we get to work with'	International Journal of Industrial Organization	94
10. J. S. Dietz and B. Bozeman (2005)	Academic careers, patents, and productivity: industry experience as scientific and technical human capital	Research Policy	70

Table 2.6 Academic patenting: Most productive scholars and most influential scholars

# Most productive authors	Recs	# Most influential authors	Citations (#papers)
1. Mowery D. C.	5	1. Mowery D. C.	509 (5)
2. Baldini N.	4	2. Ziedonis A. A.	509 (4)
3. Geuna A.	4	3. Sampat B. N.	438 (4)
4. Lissoni F.	4	4. Nelson R. R.	316 (1)
5. Sampat B. N.	4	5. Thursby M.	303 (2)
6. Ziedonis A. A.	4	6. Henderson R.	295 (2)
7. Acosta M.	3	7. Jaffe A. B.	295 (1)
8. Coronado D.	3	8. Trajtenberg M.	295 (2)
9. Azoulay P.	2	9. Jensen R.	271 (1)
10. Czarnitzki D.	2	10. Harhoff D.	147 (1)

2.4 University-Industry (U-I) interaction

Previously, I analyzed the transformation of the university into a three-mission actor, a transformation which was a natural progress resulting from internal and external forces. The internal forces spring from the structural constitution of the university which is dominated by the complementarity properties of the three missions. In the theoretical model described in the previous subsection, the starting element was invention which then gave birth to education and science at the micro level. The common denominator in this evolutionary trip at both the micro and the macro level is knowledge.

The development of the role of the university in increasingly knowledge-based societies as a result of internal and external influences expands the role of the university as a knowledge producing and disseminating institution (Etzkowitz et al., 2000), building up links with the industry in a reciprocal interaction. This reciprocal interaction is strengthening the U-I links in parallel with the increasing knowledge intensity which has become apparent in more and more innovations. Mansfield (1991) and (1995) has provided empirical evidence of the importance of academic research for industrial innovation, finding that 11% of products and 9% of services would not have been developed without substantial delay in the absence of academic research. The significance of academic research is further enlarged in knowledge-intensive sectors such as the drug, information processing and instrument industries (Mansfield, 1995). Further evidence for both the increasing importance of knowledge in innovation and the simultaneous empowering of U-I links is provided by the absolute and relative increase of academic patents in comparison to all patents (Mowery et al., 2001). As a result of the reciprocal interaction between the university and the industry, some firms have managed to advance knowledge and propel new technologies in many areas, such as biotechnology, pharmaceuticals and manufacturing (Santoro and Chakrabarti, 2002). Meyer-Krahmer and Schmoch (1998) found high level U-I interaction in science-based areas and even in mechanics, which is not hardcore science-based, although there is again significant variation among the fields.

The U-I interaction takes place through different formal and informal channels. In this thesis, I categorize the various forms of interaction in the following broad categories: links between university and existing firms; creation of new firms; academic patents and collaboration resulting in patented inventions. The links between university and existing firms can take place, for example, through R&D collaborations and science parks or other formal and informal types of collaboration. The main actors of these collaborations are the university researchers who interact through various channels that are not always easy to capture and quantify. D'Este and Patel (2007) highlight five broad categories of interaction: creation of new physical facilities, consultancy and contract research, joint research, training, and meetings and conferences, each reflecting largely non-overlapping modes of interaction. Since the main actors are the university scientists, the literature has paid attention to the relation between academic excellence and the U-I links; it turns out that scientific excellence is one important predictor of solid U-I links. Zucker et al. (1998) highlight the importance of "star" scientists' involvement in firms, as they are the ones most likely to grasp the opportunity of intellectual property rights (IPR) policies which promote commercialization and interaction with industry. Zucker and Darby (1996) argue that scientific eminence was a factor behind the most successful biotech companies because star scientists are able to excel in both science and technology. Debackere and Veugelers (2005) emphasize the importance of scientific excellence as the first condition for U-I links since the top performers in science are also expected to be the top performers in creating new technology, and the U-I links through science-based and technology-based ventures bridge curiosity with strategic-driven research. The overlap and complementarities between science and technology are supported by different studies which agree that science and technology reshape and reinforce each other (Murray, 2002).

The emergence of the U-I literature revitalized the discussion about the differences between basic and applied research. The traditional view separates the spheres of these two activities and considers academic research and knowledge advancement to be associated with theoretical innovation, but the new stream of literature has called into question the linear model of one way flow of knowledge from basic to applied research. The underlying contradiction between scientific and technological knowledge, between basic and applied research, is now questioned by empirical evidence in a growing number of scientific fields (Etzkowitz, 1998). Empirical evidence in favor of the complementary nature of basic and applied research comes from the study of patents and publications.

The creation of startups or spin-offs by university actors as well as the involvement of academics in patent inventions is studied separately within the literature in terms of commercialization of knowledge and academic patents, which are presented in the following subsections.

2.5 Commercialization of knowledge

In recent years, modern innovation policy has been particularly focused upon an innovation system perspective and the role of academic entrepreneurship and the commercialization of science, as an engine of transferring knowledge from universities to industry. Thus, after the introduction of the third mission, public policies focused on how to facilitate commercialization through different levels of intervention at the individual and the university level. Patents and spin-offs are often used as proxies for commercialization of university research in the literature (Henderson et al., 1998, Jaffe and Lerner, 2001, Pries and Guild, 2011, Zucker et al., 2002). Patents and university spin-offs are not the only key variables of commercialization, as additional dimensions of measuring the entrepreneurial university have been proposed (Todorovic et al., 2011). However, patents and spin-offs are considered the most tangible assets of the entrepreneurial university (Klofsten and Jones-Evans, 2000, Rasmussen et al., 2006).

At the individual level, one of the main factors of commercialization studied is the research performance of the academic. As with the U-I links, there is empirical evidence that scientific eminence is positively related to commercialization output, suggesting that entrepreneurial activities coincide with research. This indicates the Matthew effect, which leads to the most successful and well-known scientists obtaining more prestige and resources (Merton, 1959). Van Looy et al. (2004) show that engagement in entrepreneurial activities is related to increased publication output without affecting the nature of the publication. Powers and McDougall (2005) show the importance of human capital resource with knowledge experts and talents in cutting edge technologies. The empirical studies in the literature have also shown positive associations between scientific eminence and the number of spin-offs from universities (Di Gregorio and Shane, 2003).

At the university level, a key but provocative insight from Pavitt (1998) was that the university as an organization (and, by extension, commercialized university research) complements the research being done by the industrial sector. Thus, public policy became an instrument used in different countries to stimulate start-up companies, including attempts to influence national institutions, university structures and the incentives for individual researchers.

2.6 Academic patenting

By academic patents, I refer to patents that the university or the individual academics are involved with either as patent owners or as co-inventors. Academic patents have been extensively used as a quantitative measurement of innovation because of the availability of data and the lack of better proxies for innovation. The various properties of patent data allow for a huge range of operationalization possibilities. The most common variables used come for example from ownership status, where the researchers can distinguish between patents belonging to firms and those belonging to universities, inventorship status, where the number and the mix of co-inventors can be analyzed, and variables related to patent citations. Every patent application includes citations into the existent pool of knowledge in terms of references to previous patents as well as references to the scientific literature.

The shift towards a knowledge-based economy in recent decades has left its mark on academic patents. A direct result of this shift was an upsurge in academic patents. In the USA, the explosion of academic patents was seen through the high growth in university-owned patents. Trajtenberg et al. (Trajtenberg et al., 1997) found that the percentage of university-owned patents increased from 1% in 1975 to 2.5% in 1990. At the same time, the patent to R&D ratio displayed a contradictory development between university and corporate patents, with the university patents per dollar spent increasing while the overall patents per dollar decreased (Trajtenberg et al., 1997). This was the period when the Bayh-Dole Act was implemented. The Bayh-Dole Act, which was passed in the USA in 1980, allowed universities to pursue ownership of an invention, which had previously been assigned to the federal government. The Bayh-Dole Act contributed to the academic patent boost in the USA, but closer analysis has shown that the upward trend was already there, and the upsurge would have happened regardless of the Act (Mowery et al., 2001, Mowery and Sampat, 2001b, Mowery and Sampat, 2001a). Thus, the Bayh-Dole Act was an accelerating factor behind the upsurge in academic patenting but not the prime or exclusive cause.

The upsurge in academic patents was not homogenous across the technological fields, but highly skewed in favor of science-based fields such as pharmaceuticals and chemicals (Harhoff et al., 2003); this is one more 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 also led to the expansion of academic patenting in the fields of biomedicine and biotechnology as well as in computer software (Henderson et al., 1998, Mowery et al., 2001). Studies from Europe confirm the evidence of a proportionally higher increase of academic patenting in biotechnology (Meyer, 2003, Balconi et al., 2004). Academic patenting in European countries was considered to lag in comparison to the USA. However, the most recent results show that academic patents are granted at similar levels, if inventor-level data is used instead of university-owned patents (Lissoni et al., 2008).

The introduction of this new more reliable form of statistics on academic patents in Europe, mainly driven by the introduction of the KEINS database (Lissoni et al., 2008), has been followed by a boom in empirical papers studying or using academic patents. The studies on academic patents address the following broad topics: patent ownership, academic productivity, collaboration of academic inventors with the industry, inventor mobility, and commercialization of knowledge. The studies about patent ownership focus on differences in patent values when the patents are owned by different actors (Henderson et al., 1998, Sampat et al., 2003, Czarnitzki et al., 2011, Bacchiocchi and Montobbio, 2009). Research studies have scrutinized the types and intensity of collaboration between academics and the industry as well as the different career paths and the mobility of academic inventors. Commercialization of knowledge produced by academic inventors is always the main focus, as it is expected to be an innovation force which will create new jobs and growth within the country.

In Sweden, the first version of the KEINS database was constructed in 2005 by Professor Maureen McKelvey and her research group as an initial match of the EPO data with data from the Swedish universities. The data revealed that Swedish academics do not lack in terms of patent activities in comparison to US and European academics, and highlighted the value and the potential of patent studies in academia (Lissoni et al., 2008). Only a few papers explored this academic patent database, mainly due to the small number of researchers specializing in innovation in comparison to the rapid expansion of specialized research paths within the field.

Academic patents have been used in empirical studies in order to answer the question of whether basic research is substituted by applied research during the university transformation and the intensification of U-I links. Owen-Smith and Powell (2001) suggested that basic and applied research can be performed simultaneously while Ranga et al. (2003) found that industry funding did not shift the balance of patents in favor of applied research. In terms of the relationship between patenting and publishing, Geuna and Nesta (2006) found that only a few researchers had experienced delay in publication because of patenting, while most of the studies found a positive relationship between academic patenting and scientific publishing (Owen-Smith and Powell, 2003, Azagra Caro and Llerena, 2003).

3. Research design and methods

Here I present the overview of the research questions, and the basic assumptions which are common to and condition the analysis across the appended papers. Then I present the research design which includes a summary of the data, the samplings, the models and the variables used in the papers. The purpose is to categorize the papers in order to better visualize the overlaps in the research design as well as the complementarities among the four studies. The section concludes with a discussion regarding the reliability and the validity of the studies. The specific methods applied are described in detail in the appended papers. The development of the KEINS data used in this PhD thesis was part of the KEINS APE-INV project. My contribution to the project is presented separately in appendix B. The detailed steps for the database creation are presented in appendix C.

3.1 Purpose and Research questions

The broad research questions that studies within this branch of economics of innovation try to answer are: who and where are the academic inventors, which factors affect academic patenting and commercialization, how do the links between academic inventors and industry work and what is the relation between science and patenting.

Uncovering the mechanics behind the above phenomena and relations is important both from scientific and policy making perspectives. The analysis of academic patenting in Sweden can provide efficient measurements for policy evaluation purposes as well as additional macroeconomic variables. Understanding the factors affecting patenting is useful in successfully planning and boosting academic entrepreneurship and innovation in order to create universities which will be the engine of the upcoming knowledge-based economy while fulfilling their other two missions at the same time. Thus, the complementarities of science and patenting are an important aspect within the new university which will combine the three missions.

Last but not least, an important scientific question is what roles and links academics have in the collaboration within companies, what type of knowledge they create and how they transfer it into the industry. Further analysis of the above interactions will help to understand, specifically target and promote the collaboration having as a starting point both the sides of academia and industry. The importance of the above questions increases in the case of Sweden, since the universities are publicly financed and are expected to produce the necessary basic research, Sweden is a highly innovative country with an economy based on innovation. The core large firms of the Swedish economy are active in sectors (engineering, pharmaceuticals, telecommunications) of dynamic innovative environment where patenting matters.

The general research questions which drive this study are related to the theoretical background presented in Section 2 as illustrated in Figure 2.1 where the papers are positioned on the literature map. Nevertheless, this is essentially a study based on empirical papers, and therefore the specific questions answered were formulated in close connection to what the data available could provide. Table 3.1 presents the research questions across the four papers. The first row presents the initial general question driving the papers and the second row presents the specific research questions that the papers ended up focusing on.

Table 3.1 Research questions per paper

	Paper I	Paper II	Paper III	Paper IV
RQ	Who and where are the academic inventors and the academic patents?	Which factors affect commercialization through patents and spin-offs?	Which are the individual characteristics of the Swedish inventor in nanoscience?	Do academic patents differ from non-academic patents in terms of value and technological profile?
Specific	Who and where are the academic inventors in Sweden in terms of position, age, discipline, and university?	What is the trade-off between science excellence and patenting in nanoscience in Sweden? What is the role of networks as a factor and/or a result of academic excellence in terms of science and technology? What is the effect of university structures in terms of courses and facilities on commercialization of university research?	What is the trade-off between science excellence and patenting in nanoscience in Sweden?	What is the effect of academic collaboration on a firm-owned patent's value? In what type of collaboration with the industry are academic inventors more likely to engage?

There are various overlaps across all the papers and particularly in the first three papers, which are closely connected to commercialization as defined in the literature review section, while Paper IV deviates closer to the university-industry interaction (as is visually apparent in Figure 2.1). To be specific, Papers I and III investigate the distribution of patents across different variables. Papers II and III examine the relationship between mission 2 and mission 3 (within the three-mission framework presented in Section 2). Paper II also touches on the university-industry interaction, which is addressed to a greater extent in Paper IV.

3.2 Research design

This subsection presents a summary of the research design and methods used in the appended papers. It presents the basic assumptions made, the data used, the research methods and hypotheses and the econometric models. The research design follows the same pattern with self-collected data, deductive approach and testing with econometrics. However, the thesis contains methodological contributions both in terms of the methods in the data collection and processing and the econometric models used. The appendices include the contribution within the KEINS project in matching, cleaning, filtering and harmonizing the KEINS data and Paper I the descriptive statistics on academic patenting. Paper II includes operationalization of survey-based data. Paper III includes probably the most novel methodological contribution, suggesting a matching methodology which can be used in semi-parametric econometric models. Paper IV proposes a novel control variable within the stream of empirical papers studying the value of patents. The particular nuances are analyzed further in the appended papers. Table 3.2 presents the summary of the research design, the hypotheses and the models.

Table 3.2 Research Design

	Design	Hypotheses	Model
Paper I	KEINS data, descriptive statistics		
Paper II	Survey data, econometric model, deductive approach + hypothesis testing	H.1. Research performance positive effect on commercialization H.2. Network performance positive effect on commercialization H.3. Support structures positive effect on commercialization	Poisson, Logit regressions
Paper III	KEINS data, nano-science bibliometric data, econometric model, deductive approach + hypothesis testing	H.1. Academic authors who patent in nano-science perform better in terms of scientific output (publications and citations)	Semiparametric analysis: Matching
Paper IV	KEINS data, econometric model, deductive approach + hypothesis testing	H.1. Firm-owned academic patents have higher value in the long term H.2. Core patents have higher patent value H.3. The technological profile is an important control variable in order to evaluate academic patents' effect on value.	Negative binomial regressions

3.2.1 Basic assumptions

Within the literature there are research streams that criticize the use of patents as a measurement of innovation and/or the use of IPR protection (see Scotchmer (2004)). The discussion of these topics is beyond the scope of this thesis. Instead, I follow the literature stream presented in 2.6 on academic patents, meaning that I use academic patents as a proxy for empirical studies. The proxy is assumed to measure invention and the creation of new technology, and to a less confident level to act as a proxy for commercialization of new technology. The elements and the validity of patents as a commercialization proxy increase in our case because most (82%) of the patents in Sweden belong to firms (Lissoni et al., 2008). Thus, for this thesis I have accepted that patents are a valid proxy and therefore used the word "commercialization". The wording is however not the main point of this paper since it is an empirical-based thesis and therefore an ontological analysis is avoided.

In terms of using the terms "knowledge" and "technology", the underlying assumption is that technology is a subset of knowledge. This means that knowledge can exist without including technology, but not the reverse. Again, this assumption is subject to definitional discussion, so it is only used for the interpretation of this specific thesis.

3.2.2 The Data

In order to fulfill the need for academic patent data and as a step for further research, the contribution of this thesis is the creation of a new database of academic inventors in Sweden, the

KEINS 2011 database. The database is unique in the sense that it is an updated version of the KEINS 2005 database for Sweden. This thesis also contributes in terms of the methodology of constructing the database, and the harmonization of the academic data according to the norms of the Swedish National Agency for Higher Education (Högskoleverket). The KEINS data development is therefore presented separately in appendix C, in order to provide all the technicalities and the detailed steps.

The KEINS data is used in Paper I in order to create the descriptive statistics. In Paper II, the main data source is a survey conducted in engineering schools in Sweden, although the KEINS data was used as a double check for the number of patents reported in the survey. In Paper III, the KEINS data was combined with a database on nanoscience authors which was created by my co-author Berna Beyhan and includes all publications found in the Web of Knowledge. Paper IV combines data from KEINS with data collected directly from EPO and data on firms collected from the database Orbis.

3.2.3 The methods

As mentioned before, the general strategy for the empirical papers was to follow a deductive approach. One reason for this was that, as shown in Section 2, there are established theories and explanations within the phenomena covered by this thesis as well as empirical papers which give support to one theory or another. The other reason was the nature of the data, which was solidly quantitative, thus leaving less space for explorative studies by definition. Since the studies were carried out with the data in hand, the deductive process was not linear. Instead, it was a reciprocal process between the following steps: theory → general research questions → data → specific research questions → theory → hypotheses → data.

In Paper II, we used academic patents and start-up companies as dependent variables and three sets of variables in order to test the hypotheses on research performance, networks and support structures. The unit of analysis was the individual academic. We used Poisson and logit regressions for the count and the binary dependent variables respectively.

In Paper III, the biggest challenge was to define the population of nanoscientists in Sweden. In order to do that we combined two data sources on authors and inventors. To compare the two groups, which came from two different sources, we applied a semi-parametric technique of matching between pairs of authors and inventors. The unit of analysis was the individual academic. The method used was a combination of the exact and the closest neighbor matching techniques, and resulted in a treatment and a control group of matched "twins", using terminology taken from medical science as a parallelization with treatment studies. In our case, it allowed for head-to-head comparison of patenting between the "twins", avoiding the selection bias and the endogeneity problems induced by traditional econometric models.

In Paper IV, three hypotheses were tested. The paper used the technological profile classification of Granstrand et al. (1997) to categorize each patent, which is the unit of analysis. Moreover, the short-term versus long-term value variable was introduced, leading to six different econometric models. We used negative binomial regression because of the overdispersion of the dependent variable. The hypothesis testing was performed through comparison between the models. The introduction of the technological profile in combination with the split to short-term and long-term value led to interesting results. A new control variable for similar studies on patent value was proposed. Table 3.3 below summarizes the dependent and independent variables.

Table 3.3 Dependent and independent variables per paper

	Paper II	Paper III	Paper IV
Dependent Variables	Patents, spin-offs	Patents	Forward citations, short-term (<3 years) forward citations, long-term (>3 years) forward citations
Independent Variables	Publications	Publications	Academic patents
	Grants	Citations	Technological profile (core vs. non-core)
	Time allocated to firms-university actors		
	TTO		
	Incubator		
	University courses		

3.3 Reliability and validity of the studies

The studies conducted in this thesis were based on quantitative data and therefore are overall characterized by high reliability.

Nevertheless, since the data was self-collected there is some probability of deviations because of data errors. Data errors might exist because of errors in the source data (EPO) and/or mistakes in the data processing. The limited resources during the PhD did not allow for a full manual check of the population data in Paper I, but we acknowledge the limitation and in future research might improve it. As mentioned previously, there was a moderate matching in terms of choosing criteria in order to avoid type II errors. Furthermore, the previous databases were used in the filtering as a double check in terms of reliability.

In Paper II, the main data used came from a survey. In order to check for reliability, the patent data was double checked with the KEINS database. Regarding the independent variables, various reliability checks were applied, resulting in acceptable levels of Cronbach's alpha for all three sets of independent variables[6].

Paper III had a very high reliability because the sample was the result of combining two independent databases, coming from different data sources, and a manual check on each of the observations selected.

In Paper IV, the data was from PATSTAT and KEINS, two independent databases, but originating from the same source (EPO). A manual cleaning of the data was done too.

In general, the validity of this thesis is relative to the corresponding validity of the studies within the sub-fields presented in the literature review. The majority of the variables used in this study

[6] The results from the reliability tests were included in a previous version of the paper presented in the "II DIME Workshop.'Universities on a third mission: External engagement and entrepreneurship by academic researchers'. Bologna 2010", available on request.

have been extensively used in the literature and for this reason they are considered to be valid constructs. The variable for technological profile (Granstrand et al.(1997)) has not previously been used as a control for patent value. However, the intention of the paper was to suggest that this construct is a good control for patent value. In order to verify if this is true, and therefore if the suggested classification of patents is a good control, further empirical studies and tests are needed.

4. **Summary of appended papers**

This section presents an overview of the appended papers

4.1 Paper I

Title: Universities and their involvement in industrial invention as seen through academic patents.

The purpose of this paper was to provide a description of academic patents in Sweden. First, it explains the downsides of the predominant systems of calculating academic patent statistics and the distortions they create. Then it presents the KEINS system and the changes it entailed in Europe. Then it presents descriptive statistics on academic patenting in Sweden, with some comparison to other countries, as well as a discussion on ownership of academic patents in Sweden. It concludes with a discussion on scientific knowledge and appropriability related to the university and the public sector.

Measuring academic patents in Europe has followed the traditional method which was used to measure academic patents in American universities. Patent statistics in USA were ahead of European patent statistics because of the heterogeneity among European countries in terms of IPR and statistics and because of the earlier interest in studies on USPTO data. Academic patents were defined as patents where the university was listed as owner or inventor in the patent application. The universities traditionally reserved the rights to hold the patents, and therefore many of them have accumulated a considerable patent portfolio. Calculating academic patents with the same methods results in a much lower number of academic patents in Europe than in the USA. The reason is that most universities in Europe have not taken a role of patent holder as an owner or an inventor. Comparative statistics have therefore shown a significant lack of academic patenting in Europe. These statistics advocated in favor of the "European paradox", which among other things implied a small amount of entrepreneurial output in European universities, despite high public funding. Analogically, Sweden, as one of the top countries in terms of research funding to universities, was also stigmatized by the "Swedish paradox".

The KEINS database, as a project which aimed to create a harmonized method of calculating academic patents in Europe, has revealed that the gap was based on an incorrect way of calculating the data in Europe. It showed that in Europe it is more illustrative to measure academic patents as patents where academic individuals are listed as inventors, shifting the focus away from the ownership status. The new data produced numbers comparative to the US statistics. The new statistics in Sweden, as a country where the majority of patents are owned by a few big multinational firms, revealed many academic inventors and academic patents related to universities. In some technologies, such as engineering and pharmaceuticals, Swedish academics have a high performance in terms of patents, relative to the size of the country and the universities.

4.2 Paper II

Title: Investigating the complexity facing academic entrepreneurs in science and engineering: the complementarities of research performance, networks and support structures in commercialisation

Paper II studied commercialization of research in a sample of Swedish academics. Academic patents and start-up firms were used as proxy variables for commercialization. The paper was based on survey data from academic employees in universities within engineering and natural sciences. In a large list of questions, we first investigated the attitudes of academics towards commercialization and their opinions on the university's role. The econometric models used three sets of independent variables, evaluating research performance, networks and support structures. Other determinants of interest were included as control variables, such as previous experience in the industry and funding from Vinnova, the innovation agency. The study included an analysis of the Swedish institutional context and the history of the innovation centers introduced by Vinnova. The paper ended by using these results in order to discuss the implications for public policy.

The survey showed that 19.2% of the included researchers had been involved in some commercialization activity and that 76% were positive or very positive towards commercialization; these are high percentages in comparison with similar scientific areas internationally. Two variables were used to capture research performance: peer-reviewed articles published, and funding from grants. They were both used as proxies for scientific eminence, following the "star scientist" argument that the most active researchers are those who commercialize their research. The network variable incorporated social capital, which is hypothesized to have an important effect on commercialization. The survey provided variables on time spent with different business and academic actors, which were used as proxy variables for network links. Technology transfer offices, incubators and courses on entrepreneurship were the variables constituting the group of support structures.

The results show that publishing is correlated with patents and start-ups and that support structures play an important role through technology transfer offices, courses and incubators. The network variables were not positive and significant, contrary to expectations based on the literature, apart from the positive effect of links with entrepreneurs and managers on spin-off creation. From the control variables, being employed in a firm had a positive significant effect on patenting.

This paper proposes a more complex view of the relationships between the individual and the support structure in academic entrepreneurship. At the individual level, the results confirmed a positive relationship between doing science and commercializing, indicating that policy could include indirect interventions. This paper suggests that university and public policy efforts to commercialize research through patents and start-up companies are not necessarily wrong, especially in terms of support structures. Nevertheless, it would be worth further focusing on labor mobility, work experience and networks.

4.3 Paper III

Title: Academic Inventors and Knowledge Technology Transfer in Nanoscience in Sweden

Nanoscience is rapidly developing as an interdisciplinary field, affecting science, technology and business innovation. It is also a field with special interest for academic research and academic entrepreneurship because of its knowledge-intensive nature. This study used patent and publication data to delineate the field and present an overview of nanoscience in Sweden. Then, an analysis of patenting-publishing at the individual level was performed. The paper presents novel methodological approaches within the process of combining and matching different data sources.

The National Nanotechnology Initiative (NNI) in the USA defines nanotechnology as "the understanding and control of matter at dimensions between approximately 1 and 100 nanometers". Methodological and empirical papers in nanoscience have used bibliometrics in order to define the field. Keywords which direct to publications within nanoscience were used in order to retrieve data from the available scientific databases such as the Web of Science SCI. Following the above methodology, we identified the Swedish authors in nanoscience publications. Then we matched this database with the Swedish KEINS database on academic inventors from 2011. We were thus able to identify the academic inventors who had been publishing in nanoscience. We were then able to present descriptive statistics on academic patenting and academic publishing within nanoscience in Sweden.

Our data, coming from two independent data sources, provided an opportunity to focus on the dynamics of publishing and patenting at the individual level. The sample problems stemming from the unknown population of nanoscientists were dealt with using a novel semiparametric approach. We matched academics who only published in the field with the academics who both published and obtained patents. The result was a control and a treatment group where we could compare the records of each individual with their "twin's" record. The method was a combination of exact and nearest neighbor match. The criteria for the exact matching were university, discipline and position (rank).

The results showed that academic inventors are successful authors with a high number of patents and publications, providing strong support for the "star scientist" hypothesis. The differences between the treatment and the control group indicated a significant premium in terms of publication quality in favor of inventors. Citations were used as a proxy for scientific quality.

4.4 Paper IV

Title: Academic inventors, technological profiles and patent value: An analysis of academic patents owned by Swedish-based firms

This paper was an empirical study focusing on the value of academic patents. The analysis used data on Swedish patents owned by firms, and defined academic patents as patents where at least one inventor is an academic. Patent value was measured through forward citations as a proxy for economic value, and we separated this into short-term and long-term value. We introduced the technological profile classification system in order to categorize patents belonging to the core and the non-core technology of the firm.

The existing empirical papers on academic patents in the literature mainly focused on comparing university-owned patents with firm-owned patents. In this paper we shifted the focus from the ownership level to the inventorship level in consistence with the shift of academic patent statistics after the introduction of the KEINS database in Europe. Therefore, we limited the analysis to firm-owned patents but we compared academic patents with non-academic patents depending on whether or not an academic was involved in the patent.

We hypothesized that when academics get involved in industrial patents, they bring with them an inclination towards basic research. On the other hand, industrial patents have a predisposition to seek short-term returns and therefore focus on applied research. In order to check if this contradiction is imprinted in firm-owned academic patents, we tested the effect of academic involvement on short-term and long-term value separately. The assumption was that if academic patents embody elements of basic research, their value would be relatively higher in the long term when compared with non-academic patents.

In order to assess their relative value we also needed to take into account the specific types of collaborations in academic patents. We thus used the concept of technological profiles, as proposed by Granstrand. Two hypotheses were then introduced. Patents belonging to the core technology base and competences of the firm should have higher value, and when we include technological profile as a control variable the effect of academic patenting should shift. The last hypothesis assumed that, depending on the varying needs and competencies of the firm, different types of patents would have different types of contribution from academic inventors.

The results indicated that academic patents perform better in terms of citations in the long term. Patents belonging to the core technological profile of the firm had higher value both in the short term and the long term. More interestingly, when we controlled for technological profile, the advantage of non-academic patents was mitigated in the short term and totally disappeared in the long term.

5. Conclusions

5.1 Results in relation to the research questions

This section summarizes the four papers included in this PhD thesis, based on Section 4, in order to specify its contributions relative to the following research questions.

This PhD thesis addresses the following research questions:

- Who are the academic inventors?
- Which factors affect academic patenting and commercialization?
- How do the links between academic inventors and industry work?
- What is the relation between science and patenting?

In order to answer the first question, a new database was collected so that this PhD thesis could identify academic inventors and academic patents in Sweden. Paper I presented the overview of academic patenting in Sweden and Paper III analyzed academic patenting in nanoscience. Contrary to the Swedish paradox, the data revealed a high number of academic inventors and academic patents, especially in the fields of Electrical Engineering and Pharmaceuticals and the interdisciplinary field of nanoscience.

In order to answer the remaining questions, Papers II, III and IV analyzed the factors affecting patenting and commercialization, the U-I links, and the relation between science and patenting. More specifically, this analysis has operationalized the concepts into different dependent and independent variables in order to examine the causal relations and correlations among them. Table 5.1 below summarizes the findings from the econometric results.

Table 5.1 Summary of the econometric results, relative to questions 2, 3 and 4

	Paper II	Paper III	Paper IV
Dependent Variables	Patents, spin-offs	Patents	Forward citations, short-term (<3 years) forward citations, long-term (>3 years) forward citations
Independent Variables	Publications***	Publications	Academic patents
	Grants	Citations**	Technological profile *** (core vs. non-core)
	Time allocated to firms-university actors		
	TTO**		
	Incubator**		
	University courses***		

[7]

[7] ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 5.1 presents again the dependent and independent variables and includes the significance of the independent variables, as found within each paper. Paper II found that the most important factors for commercialization were university support structures such as courses as well as scientific excellence, the latter result being found throughout a number of publications. Paper IV found that academic patents owned by firms as an outcome of U-I links have significant long-term value, and they are dependent on the technological profile of the firm and the patent. Last but not least, Paper III found that there is a positive correlation between science (as measured through publications) and patenting, especially in the case of nanoscience in Sweden.

5.2 The overarching contribution of the PhD thesis

This subsection discusses the results and contributions of this PhD thesis, relative to the literature. This PhD thesis has scrutinized the role of academics and universities in the creation and transfer of knowledge, something which has become increasingly crucial in technological and economic change (Cohen et al., 2002, Mansfield, 1991, Mansfield, 1998, Salter and Martin, 2001). The need to develop the university as an active entrepreneurial actor that generates knowledge and technology, and transfers these to the industry and the society stems from the transformation towards a knowledge based economy (Florida and Cohen, 1999, Lawton Smith, 2007). This transition also induced the development of theoretical models on the three missions (Etzkowitz, 1998) as well as official public policies introducing the third mission at universities in Sweden (Benner, 2001).

This PhD thesis first set the scene by presenting the three mission model, as a broader framework in order to understand the dynamics within commercialization and U-I interaction, both of which can be seen as components of the third mission of the university in society. Furthermore, the relation between research and third mission activities has also been examined in many parts of the analysis. That there may be a relationship between them can be found, for example, in the patenting-publishing analysis within commercialization and also the academic involvement in industrial innovation. In both examples, the apparent contradiction or assumed trade-off between basic and applied research has been examined. The empirical results suggest that research and third-mission activities instead reinforce one another. In order to provide a deeper analysis of this contradiction which is latent in the hypotheses tested, a theoretical model is suggested in Section 2 of this introductory chapter. The theoretical model aims to explain the simultaneous transformation of the university and of the individual into entrepreneurial actors as an evolutionary process where the micro and the macro level are interconnected. The model should not be considered as a main contribution of this thesis, but rather as a tool in order to better understand the rationale behind the hypotheses tested.

After introducing the three missions of the university, the focus of this introductory chapter and the study shifted to U-I interaction and commercialization as a part of the third mission. The borders in the literature between the above topics and other literature related to the university's three missions are intertwined. For that reason, a structured literature review is presented, which helps to highlight the different streams of literature. This review proved influential to the research design, and to the scientific contribution of this PhD thesis. In conducting this work, academic patenting is extracted as a separate theme. Section 2 addresses the specialized papers on academic patents, which is a stream of literature that has expanded rapidly in recent years.

The structured literature review also revealed that there are many weaknesses in the traditional technique to use keyword-string data collection for a literature review, particularly in the case when the literature review is performed around a very specialized topic. The difficulties in only using keyword-string search come from the extended overlap among the fields, the various and sometimes vague definitions used, and the huge expansion of papers in scientific journals. Therefore, the method used in this introductory chapter suggests a modified sampling technique and word analysis in the titles. While useful to delineate the subject area, this literature review should not be seen as the main contribution of the thesis but rather as a guide to follow the analysis within the three themes of U-I interaction, commercialization, and academic patenting.

This PhD thesis has answered the four research questions. The main objective is to identify academic inventors and patents in Sweden, their characteristics and their role in U-I interaction and commercialization. In Sweden, there was no centralized database on academics and the only complete version of academic patents at the level of individual scientists was the database built in 2005. For that reasons, this thesis went through the process of collecting all the data, which is a time consuming and complicated process. After the data on Swedish academics was collected from the Swedish universities and harmonized, it was matched with the data from EPO to identify the academic inventors. The data collection and data processing is a main contribution of this thesis both in terms of the different methodological nuances and techniques as well as the resulted datasets.

In order to identify the academics that were listed as inventors in EPO patents, a matching and filtering method were applied and are described in appendix C. The method was based on the previous techniques used in 2005, but the methodology was adjusted and improved in order to obtain more precise results. This database has also the advantage to be able to use the previous data as a benchmark and as a second control. The data however have not been through an extensive manual check of each inventor.

Due to the huge homonymy problem in Sweden, mistakes might still be present. The strategy employed by the empirical papers based on the database, was to use the KEINS data in combination with at least one additional database and thus eliminate the probability of data errors. Following this strategy, we were able to obtain reliable results and to use different sets of variables which touch upon U-I, commercialization and academic patents in papers II, III and IV.

The empirical findings provide an overview of academic inventors and patents in Sweden, revealing that Sweden has a solid patenting culture within academia. Additionally, the level of, and specific types of, academic patents obtained show that Sweden is similar to several other European countries and to the USA. Furthermore Sweden can be said to have a competitive advantage in academic patents, relatively speaking, in some technological classes; for example in electrical engineering and nano-science.

The results indicate that the factors which favor commercialization of scientific results in Sweden are both structural and individual. Scientific excellence and collaboration with the industry are two key factors.

5.3 University-Industry (U-I) interaction

The analysis of U-I interaction was based on the assumption found in much previous literature that there is a contradiction between basic and applied research and that academics have an inclination towards basic research. This assumption led to the hypothesis that academic involvement in the industry would affect academic research. This hypothesis is in line with the arguments and the literature supporting that there might be a trade-off between traditional academic activities and third mission activities (Larsen, 2011).

U-I interaction can take place in different forms and through different channels (Bekkers and Freitas, 2008, D'Este and Perkmann, 2011). In Paper II different types of collaborations were quantified. One type of collaboration, namely having experience in a firm as an employee, was a significant determinant of commercialization of academic research, indicating that there is an overlap between academic interaction with existing firms and the creation of new patents or start-ups. Other types of informal interactions were found to take place as well but in our analysis it was difficult to find clear positive effects on academic entrepreneurship. One reason might be that these types of collaboration are still in an embryonic stage and they need more time to mature and lead to more tangible results such as starting a company. Indeed, by definition, informal collaborations usually do not have a systematic scheme. Instead they occur irregularly and without a clear agenda.

Academic collaboration as found through in industrial patents – e.g. patents owned by firms but with at least one academic as inventor – was the main official channel used in this PhD thesis to evaluate U-I interaction. Past empirical studies have compared the value of university owned academic patents to that of firm owned academic patents (Henderson et al., 1998, Sampat and Mowery, 2003, Bacchiocchi and Montobbio, 2009).

Instead of following existing literature which compares patents with different ownership status (Czarnitzki et al., 2011, Crespi et al., 2010, Sterzi, 2013, Czarnitzki et al., 2012), this thesis focused the comparison on firm owned patents. Academic patents are assumed to be the results of U-I interaction (Ljungberg and McKelvey, 2012). Academic patents include elements of research inherent to the work of the academic inventor, thus they constitute a quantitative variable which can be used to analyze the apparent contradiction between basic and applied research. Within the firms we found that academic patents increase in value (measured in citations) in the long term, verifying a predisposition towards basic research. But there is no significant difference between academic and non-academic patent values if the specific type of collaboration is taken into account.

The role of the firm, and the type of collaboration relative to the firm, is introduced and analyzed through the technological profile of the patent (Granstrand et al., 1997). Our results imply that the contribution of academics is highly dependent on the project they are involved with/in. They can either be involved in patents belonging to the core technologies of the firm or in patents belonging to the peripheral technologies of the firm. Our analysis does not have data to specify the exact and different roles academics play in these two different scenarios but the analysis does highlight the importance of the role of the academic inventor when assessing patent value. Therefore, the industry needs the university because academics can bring value that the industry lacks; and the university needs the industry since the interaction can be useful to the academics in terms of research and education (Abreu et al., 2009, D'Este and Perkmann, 2011).

To conclude, the U-I collaboration as expressed in patents has been previously underestimated. The value of these patents should be carefully assessed, taking into account the type of technology in relation to the firm. In the relation between academics and industry, different barriers have been identified, which may make the respective partners reluctant to interact (Dasgupta and David, 1994). On the one hand, firms might be suspicious about committing resources and time in order to build links with the university because of the perception that academics are good at basic research, something which cannot yield fast profits. On the other hand, academics might be suspicious about collaborating with firms because they are afraid that it will hamper the role of university to conduct basic research. This thesis has shown evidence that both these perceptions may be misguided in certain circumstances, and that instead of a contradiction, basic and applied research can be complementary activities. These findings coincide with the study by Van Looy et al.(2006) which shows that the increasing entrepreneurial activity within academia has not only caused a publishing-patenting trade-off but in fact inventors publish significantly more.

In terms of informal collaborations, this study also suggests a public policy implication that the universities should promote mobility between the industry and academia. Academics who have been employed in the industry can be valuable sources of know-how in terms of commercialization and U-I interaction. At the moment, the academic culture in Sweden can still be characterized in some fields as rigid regarding mobility, e.g. few people employed or have been employed by firms. An explanation is that academic career paths follow linear trajectories which are separate from the business world. In other words, studies from other countries suggest it is difficult for an academic to come back to the university if she has been working for some years in the industry because researchers who stay in academia are likely to be more productive over a career span (Long, 1978, Reskin, 1977).

Policies by government agencies and by universities could find some solutions, such as to systematically employ some people from the industry at the university, or to hire persons who have experience with U-I collaboration. In our study, the effects of informal networks were ambiguous.

Another avenue for improvement is the question of whether or not the university should also put more effort into improving the quality of U-I collaborations as suggested by Tartari et al. (2012). The quality of networks can be improved with mechanisms for academics to develop one-to-one relationships with industry that are meaningful and useful for their research and efficient structures dedicated to technology transfer inside the university (Tartari et al., 2012).

5.4 Commercialization of knowledge

This thesis analyzed commercialization as an outcome identified through patents and spin-off firms. The analysis of commercialization was based on the individual characteristics of academics and on organizational characteristics such as university support structures. Another important contribution of this thesis is its analysis of the relation between patenting and publishing.

Swedish public policy has been influence by the Swedish paradox and the common belief that Swedish academics underperform in regards to commercialization. Another presumption, based on the fact that the Swedish sector is mainly relied on financing to the State, is that Swedish academics would be critical or indifferent towards in commercializing the results of their results.

This PhD thesis has shown that both of these presumptions are not true. Academics in engineering in Sweden have positive attitudes towards commercialization and in fact Swedish academia performs at the same levels with academic patents as do the USA and other European countries. 1020 academic inventors were identified in Sweden with a high performance output, and especially in engineering and pharmaceuticals. The distribution of patents is skewed across disciplines and universities. Significant number of inventors and patents are found within the interdisciplinary field of nanoscience.

The Swedish system is a fertile ground for these fields because it provides an environment where both basic and applied research can develop. The high investments of R&D and public investment into science, which provide private actors incentives to invest in R&D too (Jacob and Lefgren, 2011, Van Looy et al., 2011), are combined with an academic patenting structure in this field, such that large firms with extensive technical experience and patent portfolios collaborate with academics.

Furthermore, the data show that academic patenting is dependent on age, gender and seniority. Academic patenting in Sweden is a male dominated area. Previous studies in other countries have also revealed a large gender gap in commercialization (Rosa and Dawson, 2006). These papers suggest that this gap may also in Sweden be reinforced by women's limited commercial networks and traditional barriers for women in academic careers, and cannot be explained by the underrepresentation of women in academia per se (Ding et al., 2006, Rosa and Dawson, 2006). Seniority has been also recognized in the literature as one important factor for commercialization because senior faculty members enjoy more freedom to work with the industry (Moutinho et al., 2007). In our data, this empirical fact of gender, age and seniority is verified and the majority of academic inventors are professors. Furthermore, Swedish academics tend to commercialize at a later stage of their career, and the average age of academic inventors is 55 years old.

The vast majority of academic patents taken in Sweden have the ownership assigned to firms, and this is more than 80% of the total in the 2005 database. The scientific value of these academic patents is however not diminished. This PhD thesis used patent citations as a proxy for patent value and found that academic patents do not have less value in comparison to non-academic patents also held by the firms, at least in the long term. The above is another indicator that research and third mission actions of universities are not negatively related to one another.

This PhD thesis studied both the individual characteristics and the organizational structures that affect commercialization. When it comes to individual characteristics the results suggest that the "star scientist" argument, that the most active researchers are those who commercialize their research, is verified. This study comes to contribute to previous literature, which highlighted the "Mathew effect" in science (Zucker and Darby, 1996, Van Looy et al., 2004), providing an analysis at the micro level with academic individuals and patents as units of analysis. At the macro level, the university support structures such as courses given to employees do matter. Thus, university and public policies are not necessarily wrong but may need modifications for the future.

In terms of policy implications, the main contribution of this study is that the overview of academic patenting indicates that Swedish academics perform well in commercialization. Thus, when it comes to policies the statistics taken into account in this and other work must be considered seriously for various reasons. First, academic patents do not appear as university patents. Second, academic patenting in Sweden is distributed very unevenly when categorized by different variables. Academic patenting is primarily found within a few large and old universities; they are also concentrated in few fields such as pharmaceuticals and electrical engineering: and the inventors are largely male dominated and comes at a higher level of seniority and age. Given these examples of the particularities of academic patenting, public policy needs to take into account these differences.

Another implication is that policies should focus more on the individual. Patenting is highly correlated with publishing and thus an indirect way to promote commercialization would be to increase scientific excellence. An example to this direction is to introduce peer-review more extensively in promoting the academic careers.

5.5 Future research

The methods analyzed in this study could be used in order to further explore a number of interesting topics. The conclusions of this study revealed the importance of the individual characteristics as factors affecting commercialization, as well as the concentration of academic patents in certain disciplines, in certain technological classes, and at certain organizations.

One avenue for future research is to identify psychological characteristics which are related to academic entrepreneurship and commercialization. This is already extensively used in studies in entrepreneurship, and could be extended to this topic. In the case of academic inventors, survey data and interviews could also complement the academic patent data in order to combine quantitative and qualitative research methods.

Another avenue for future research is to develop a subsection of the literature review paper to focus on academic patents. The descriptive statistics from this review show that academic patenting is not only a field where publications boomed but these publications have been also highly cited. Thus, the interest in the field might be an indicator that there are many questions related to academic patents which are mainly or partially unanswered (Lissoni, 2012). In this future literature review, the extension of the methodology for finding appropriate papers can also be specified, as a contribution relative to existing techniques.

Another avenue is to use the academic patent data at the country level, which provide the potential of doing cross-country analysis. The KEINS database has expanded in many countries in Europe, based upon similar methodology, and this gives us the possibility to compare the Swedish academic performance to the corresponding performance of other European countries, apart from Italy and France that have been included in the previous analysis. For example, cross-country analysis could be used in order to study the causes of the observed gender gap in academic inventors, as well as the effects of income motives on commercialization.

Finally, future research can scrutinize the complementarities between different activities and test the hypothesis that the knowledge-intensive technology is leading basic and applied research to emerge. Studies in biotechnology and nanoscience are good examples where advanced knowledge is needed and academics have a significant amount of patents, and where more detailed studies can be done.

The analysis of this study has shown a clear positive relation between patenting and publishing. Nevertheless, time-series studies would allow us to identify the causality order. The fact that the data refer to the total population of academics and of academic inventors and academic patents in Sweden, gives the flexibility to draw samples and then collect additional variables depending on the research questions. The width of variables collected in these data is a baseline which can be expanded into many various directions. For example, the academic inventors' patents can be linked to various variables used in the empirical papers on patents such as: patent families; networks; citations; firms.

As far as the U-I is concerned, future research should focus on the specific types of collaboration that academic inventors are involved in when they patent with firms. Academic patenting as a form of collaboration was previously underestimated as a valuable channel of commercialization through patents. Specifically, the type of collaboration should be explored in future research. Academic patents, at least in Sweden, do not appear less valuable than non-academic patents held by the firm, especially in the long term. Therefore, firms should invest in building links with academics if they aim to developing core and long-lasting advanced technologies. Firms should also seek to work with academic researchers who fit to their personalized patent portfolio and their technological competencies if they want to achieve the optimum scientific results in the collaborative patents. The relative importance of these types of factors could be assessed in future research.

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Appendices

A. Tables from the structured literature review

Table A.1 First selection draft

	Total number of papers on Web of Knowledge	**From**	**U-I interaction**	**Commercialization**	**Academic patents**	**Papers selected 1th round**
Research policy	2555	1974	71	62	27	160
Technovation	1737	1981	41	34	5	80
Journal of technology transfer	249	1994	31	36	9	76
Total numbers of papers	4541		143	132	41	316

Table A.2 Word analysis in sample titles

U-I interaction	Times found in title %	Commercialization	Times found in title %	Academic patenting	Times found in title %
universit*	75	universit*	65	patent*	90
industry	70	entrepreneur*	30	universit*	55
scienc*	15	innovation	25	academ*	40
technology	10	commercial*	20	invent*	27,5
transfer	10	academ*	15	scient*	17,5
enterprises	10	spin-off*	15	Bayh-Dole	12,5
park(science-park)	5	scholar*	5	citation*	7,5
schools	5	scient*	5	faculty	7,5
laboratories	5	incubator*	5	publish*	2,5
business	5	start-up*/startup*	5		
		technology transfer	5		
		commercialization	5		

Table A.3 U-I interaction: strings/outcome

Combinations in the title	industr*[8]	business	laborator*	enterprises*	park*	technology		Total
universit*	57	70	3	3	12	14**		
scien*	16	7	5	0	8	18		
	73	77	8	3	20	32		
university-industry							41	
Total	73	77	8	3	20	32	41	254
in all above combination, the search of "university*" was added within the field "all fields" in the search engine ** in this string, "industry" was added within the field "all fields"								

Table A.4 Commercialization: strings/outcome

Combinations in the title	universit*	academ*	scholar*	scient*	universit* (in abstract but not in title)	Total
entrepreneur*	70	30	5	9		
innovation	59	14	0	24		
commercial*	22	12	3	8		
incubator*	3	0	0	0		
spin-off*	31	17	0	0		
start-up*/startup*	6	4	0	0		
technology transfer					16	
commercialization					16	
Total	191	77	8	41	32	349

[8] The * is used in order to cover every possible character/s following the string before the star as used commonly in programming languages.

Table A.5 Academic Patenting: strings/outcome

Combinations in the title	patent*	invent* (and no patent*)		patent* + scient* (in all fields)	patent* + universit* (in all fields)	patent* + academ* (in all fields)	Total
scient*	13	4					
universit*	38	5					
citation*	57	0		5	2	1	
academ*	14	4					
invent*	58	0					
faculty	3	0					
publish*	2	1					
Bayh-Dole			4				
Total	70	14	4	5	2	1	96

Table A.6 Literature review outcome

#	Journal	Records	Citations	Citations/paper
1	RESEARCH POLICY	155	5879	37,93
2	TECHNOVATION	75	1072	14,29
3	JOURNAL OF TECHNOLOGY TRANSFER	74	445	6,01
4	INDUSTRIAL AND CORPORATE CHANGE	14	319	22,79
5	INDUSTRY AND INNOVATION	10	14	1,40
6	INTERNATIONAL JOURNAL OF INDUSTRIAL ORGANIZATION	6	332	55,33
7	REGIONAL STUDIES	6	22	3,67
8	SMALL BUSINESS ECONOMICS	5	119	23,80
9	TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT	5	28	5,60
10	ECONOMIC DEVELOPMENT QUARTERLY	4	5	1,25

B. The KEINS APE-INV project

During the second year of my PhD, I started working within the KEINS APE-INV project. Many economists and computer scientists collaborated within this project, which aimed to provide data on academic inventors in as many different European countries as possible. The first version of the KEINS data was created in 2005. My contribution was to create and provide the database on academic patents in Sweden for 2011. I hereby present the description of my contribution to the project.

My participation in the project had granted me two exchange visits to Bocconi in order to work with the the organizer of the project, Francesco Lissoni.

In the first visit, I spent there in total approximately 14 weeks during the period from 6th September 2010 until the 31 th January 2011. My work contributed to the development of KEINS, and consisted of two parts. The first part was the work on the existing data collected from Francesca Fardelli and modified with the help of Michelle Pezzoni. This data included the academic lists from 2009 for six big universities in Sweden: Chalmers, Gothenburg University, Karolinska Institute, KTH, Linköping University, and the University of Lund. Working in the initial data and using as matching criterion the Levenshtein distance[9], using Michelle Pezzoni's algorithm, I selected a cut-off point in order to get a broad matching. The next step was the cleaning of the database by deleting duplicates. The result was a preliminary academic inventors list for these six universities. The main difficulty was that Swedish data suffers from homonymy problems, as there are many thousands of Swedish inventors who have exactly the same surname and/or name registered as patent inventors. At this point I did the cleaning on the initial data which came from the EPO. The data from EPO had already been refined by the KEINS database managers in order to identify the inventors of each patent with a unique code (CODINV2[10]). However, there were still many duplicates in the CODINV2 data and so I conducted a data-cleaning in order to eliminate the duplicates for Sweden. I sent my results directly to Gianluca Tarasconi, who had access to and could modify the KEINS database. I did the cleaning only in the first round of the circle (inventors-patents-inventors) but in the future I will do the second one as well, hoping to find a useful pattern of identifying the duplicates that can later be applied to the whole database (the other countries).

The second part of my work consisted of extending and updating the database. As mentioned above, the 2009 version included six universities. In order to create a database covering the full population of Swedish academics, I collected new data for all Swedish universities in 2011. Completing the database with these lists opened up possibilities for comparisons with the 2005 database as well as cross-country comparisons, which are the targets for future work. It also allows for population studies and targeted sampling. The collection of the new data, which started in January 2011, will be described in more detail in appendix C.

In 2012, I made a second visit to the APE-INV project in order to finalize the matching for the database. The matching took place during my visit to Bocconi University in Milan, Italy, and

[9] The Levenshtein distance is a string metric for measuring the difference between two sequences, used in computer science.

[10] CODINV2 stands for "Code for inventors, number 2"; it is an update of CODINV which was the first attempt to match all the people who were named in different patents and were in fact the same person. For a more detailed description of PATSTAT, see (Lissoni, Sanditov, Tarasconi).

more specifically to the KITES research center. I spent two weeks there in total, from Monday 9th January 2012 until Friday 20th January 2012.

The main purpose of the visit was collaboration with the researchers, both computer scientists and economists, who worked with the KEINS project at the host university, in order to: 1. Get updated on and become familiar with the new distribution service of patent databases of APE-INV (http://www.ape-inv.disco.unimib.it/). 2. Learn the basic elements of the programming language (SAS) used in the specific problem of filtering and matching the inventors EPO database with the list of academics. This was the solution used by the computer scientists of the host university in similar research in the Swedish database before 2009. In the previous cases, a program written in SAS by Michele Pezzoni was used in combining SAS and Access databases. The purpose of my visit was to understand the code, adjust and run it on my databases and obtain the required skills in order to adjust, modify and improve the code in the future. 3. Discuss possible research lines and use of the data and future collaboration with other partners of the KEINS project.

During my visit, I gathered the data needed from the server which consisted of the updated files in the “disco”[11] server (Controversy, Codinv2-Codinv disambiguation, InventorsInfo, PatStat_ApplNo, PublNo) for Sweden from 1979 to 2010, as well as the corresponding “rough” files containing the information from EPO. Files which were used for the completion of Swedish Academics 2011 and the matching procedure as well as the ongoing papers are presented later. It would not have been possible to gather all this data without the valuable help of Michele Pezzoni, ex-administrator of the server, who helped to solve all the practical problems due to the recent establishment of the system. Under the guidance of Francesco Lissoni I went through SAS programming training in order to understand the basics of this programming language. Then, with the assistance of Michele Pezzoni we modified his SAS code that had been used in the Swedish KEINS database in 2009, and ran the code on my data and the data from the “disco” server. Learning to apply these techniques has helped in order to produce at the end the 2011 KEINS database for Sweden.

The database is part of the KEINS project which has created similar databases in other countries such as Italy, Belgium and Germany, with all of them having a common base at the host university of my visit. Parts of the data have been provided to the KEINS managers, and are stored in the APE-ESF server together with homogenized data from other countries for researchers who want to perform cross-country analysis. This data is available to the contributors, giving the opportunity for future research.

[11] The server is a common source with the available patent databases from EPO. For more information about the files contained there, see http://www.esf-ape-inv.eu/

C. Development of the 2011 KEINS database for Sweden

Data collection

In this section, I describe the data collection process which resulted in the database named as Swedish Academics 2011. This database includes data on the population of Swedish academics and was later used to identify the academic inventors in Sweden. In Sweden, the universities are allowed organizational autonomy and so there are big differences in the organizational structure across the universities. Moreover, each university stores the data on its employees in its own way and a central database does not exist. I therefore had to collect the data from each university separately and then unify it. For the data collection, I used the list of higher education institutes provided by the Swedish National Agency for Higher Education (Högskoleverket). The list consisted of 27 universities and higher institutes, including six universities which were not included in the previous database in 2005. I included only those institutions with permission to provide diplomas at the bachelor, master and doctoral level as well as to do research. The list with the names of the universities and their acronyms is presented in Table C.1. The update of the database offers the opportunity for comparisons with the 2005 database as well as cross-country comparisons which are the targets for future work.

Table C.1 List of Universities - Acronyms

University	Acronym	University (continued)	Acronym
1. Örebro University	ORU	15. Stockholms University	SU
2. Södertörn University	SH	16. Uppsala University	UU
3. Mid Sweden University	MIUN	17. University of Borås	HB
4. Jönköping University	HJ	18. Halmstad University	HH
5. Malmö University	MAH	19. Luleå University of Technology	LTU
6. Mälardalens University	MDH	20. The University College of Opera, Stockholm	OHS
7. Blekinge Institute of Technology	BTH	21. Karolinska Institutet	KI
8. Chalmers University of Technology	CHA	22. Umeå University	UMU
9. University of Gothenburg	GU	23. Lund University	LU
10. Linköpings University	LIU	24. Swedish University of Agricultural Sciences	SLU
11. Karlstads University	KAU	25. Linnaeus University	LNU
12. University of Gotland	HGO	26. The Swedish School of Sport and Health Sciences	GIH
13. University of Gävle	HIG	27. University of Skövde	HIS
14. KTH Royal Institute of Technology	KTH		

In order to collect the data, I contacted each of the universities and institutes by email. I also created a tracking file with all the information needed in order to replicate the process in future years for updates of the database. I received the required information from the universities in paper format by mail, and then unified it in a single database called Swedish Academics 2011. The unified database which was later used for statistics in the papers was anonymized and stored in Excel with a unique ID number for each academic (ID_ACAD).

Table C.2 below presents the data collected from the 27 universities. Two universities (SLU and UMU) stated that they were unable to provide the data during the time of collection because the effort required would be too great, and so I collected the data myself from their websites.

Table C.2 Collected and missing data from the 27 universities

List of variables	Collected	Missing
Surname	27/27	-
Name	27/27	-
Position	27/27	-
Uni. address	27/27	-
Home address	25/27	UMU SLU
Zip code	25/27	UMU SLU
Faculty	24/27	HH LU GIH
Department/Division	21/27	BTH HGO HIG LNU GIH HIS

Harmonization

A huge challenge in unifying the data was in terms of the variables for faculty, department and division. Because of the aforementioned organizational autonomy, each university used its own classification system which led to a huge heterogeneity across the universities. In order to create a reliable variable, a variable for discipline was introduced. This variable was chosen because the Swedish National Agency for Higher Education has introduced a classification system for all scientific disciplines, the Standard for Swedish Classification of Research Subjects 2011[12]. The system organizes the disciplines into five bigger categories: 1. Natural Sciences; 2. Engineering and Technology; 3. Medical and Health Sciences; 4. Agricultural Sciences; and 5. Social Sciences. Then, within each category a 3-digit number is assigned to sub-disciplines and an expanded 5-digit number to more specific subjects within each sub-discipline. For example, 2 denotes Engineering and Technology, 201 denotes Civil Engineering and 20101 denotes Architectural Engineering. In order to assign a discipline number from the above classification to every academic, the variables of faculty, department and division were used. The harmonized discipline variable of this database is an advance in comparison to the 2005 version, and allows for a more reliable analysis of inventors across disciplines.

Regarding the variable for position, the different titles were homogenized across the following categories: professor, including acting, adjunct and visiting professors; docent, a title in Sweden

[12] "Standarden för svensk indelning av forskningsämnen 2011"

which corresponds to the title of associate professor in Europe; lektor, which includes lecturers and other type of teaching employments at the same level; post-doctoral researcher; PhD student; and research assistant. Administrative and technical staff were placed into the administrative and technician categories respectively. This database is referred to as "Swedish Academics 2011" in this PhD thesis.

Matching

The two databases used for the matching were the "Swedish Academics 2011" and the list of Swedish inventors, provided by the "disco" server (containing information from EPO as described in appendix B). The list of academics consisted of 41461 observations gathered manually from the Swedish universities (see subsection on data collection). The main variables were name, surname, address, zip code, city, university, position and email address. The Swedish inventors list consisted of 44204 observations extracted from the inventors' database of EPO. Name, surname, address, zip code and city were again available. The first step of the process was to normalize the spelling in the list of academics in order to match it with the list of inventors where all the special Swedish characters of the alphabet were already normalized to English, with Ä, Ö, and Å becoming A, O, and A. Other special characters included in non-Swedish names were also normalized in the same manner. Another important problem of name normalization was to split the names and surnames in case of multiple values. Abbreviated middle names such as "Den", "Di", and "Von" had to be excluded from the split and put together with the following surname. Next, the first two initials of the name and the surname were extracted from every database and composed into a new 4-digit variable. The two databases were merged according to this value, including all values from the Swedish academics list and the matches from the inventors list. This merging resulted in a larger dataset, as there were many matches for every initial's token of the Swedish academics. The next step was to calculate a similarity score for these observations according to the similarity between the names, surnames, addresses, zip codes and cities between the data from the two databases for every observation. Finally, the five different similarity scores were added into a new variable indicating the total similarity score. Thus, we ended up having at least one similarity score for each observation of the initial Swedish academic list, which would help to identify the matches from the inventors list. The smaller the similarity score, the more probable that the match refers to the same person. At this point, we had to give a threshold which would be the initial level of acceptance according to the similarity score. We chose a high threshold because the main purpose was to avoid type II errors[13]; that is, to avoid missing potential inventors. Type I errors were left to be minimized in the process of filtering and checking later on. Therefore, a similarity score of 10 (10 characters totally different in all five fields) was chosen as the threshold, which resulted in 6830 observations. The initial number was 6 to 7 times higher than the number of matches expected as a result of trying to avoid false negatives.

[13] Type I and type II errors correspond to the standardized meaning in statistics of false positive and false negative respectively.

Filtering

For the filtering process I used some techniques used previously in the 2005 and 2009 database as well as comparisons with the previous databases and manual checking.

I summarize the filtering algorithm here. The positive criteria were used to include the match, while the negative criteria were used to exclude the match. If at least one negative criterion occurred, the match was excluded.

1. (+) Pairs with total similarity score = 0.

2. (+) Pairs with total similarity score < 10 which becomes zero when one variable is excluded. There were various reasons for exclusion from criterion 1: misspelling of the name, the address being written in a different order or with additional data, the town district name being given instead of the town name, and so on. The matches that resulted in a similarity score smaller than 5 after the first mapping were matched again in loops where one different criterion was skipped until the similarity score was 0, or the combinations were exhausted.

3. (+) The patent's applicant is a Swedish university and the professor is an employee in that university.

4. (+) Pairs from the 2005 match whose professor appears in the list of academics in 2011.

5. (+) Pairs from the 2009 match whose professor appears in the list of academics in 2011.

6. (+) The applicant is an institute related to the university with which the professor in the checked pair is affiliated.

7. (-) Pairs in which the professor's study subject is in open conflict with the patent IPC code are removed.

8. (-) Minimum age to file a patent is set at 25.

9. (-) Pairs in which the professor's subject study is not patentable are removed (humanistic or social studies).

10. (-) Pairs which appear as non-inventors in the 2005 match are removed (after double checking and exclusion of the possibility that they got the patent in the years between).

11. (-) Pairs which appear as non-inventors in the 2009 match are removed (after double checking and exclusion of the possibility that they got the patent within the years between).

The filtering resulted in 1020 accepted matched pairs from the 6830 pairs that we had kept in the previous step. The data was anonymized and stored in Excel, where each individual was assigned a unique number called ID_INV. Descriptive statistics about the academic inventors and patents are presented in the appended papers.