Three essays on inventors, inventions, and innovation

DISSERTATION

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In Dankbarkeit meiner Familie gewidmet

Abstract

Drawing on a sample of 415 inventors who have won the 'R&D 100 Award' for the most important breakthrough inventions between 2005 and 2014, this dissertation proposes empirical research on three topics within the field of inventors, invention and innovation. The work consists of three essays.

The first essay will present the summary results of a comprehensive survey of R&D awards recipients: *'The R&D 100 award inventor survey'*. In this essay, we will provide information on the characteristics of the inventors in terms of demographics and education, the context in which their innovative activity occurred, and the value of their innovations. Comparison of some of our findings with those of prior surveys will allow us to draw interesting conclusions concerning the changing characteristics of inventors and their inventive activity over time and across industrial and organizational contexts.

In the second essay we will consider a sub-sample of important awarded inventions from our survey and estimate the probability for the invention to be patented (or not) as a function of its characteristics, the characteristics of the inventor, and the characteristics of the organization. We will argue that, by taking innovations that won an important prize (i.e. R&D 100 Awards) will allow us to evaluate the determinants of innovations occurring inside and outside the patent system. To perform the analysis, we will employ logit regression models. In terms of patent propensity our findings will show that inventors' prior experience in patenting, the organization context they work in (i.e. firms) and the team size they belong to positively affect the probability to patent. We will further provide evidence on the determinants of the value and the quality of those inventions that are patented by employing traditional indicators based on forward patent citations as well as alternative indicators taken from *'The R&D 100 award inventor survey'*. Results will suggest that patented award-winning inventions are more valuable when matched to inventions in the same technological class that have been patented but not awarded.

Finally, the third essay will explore the mobility of inventors that have won the 'R&D 100 Award' for the most important breakthrough inventions multiple times. We will use detailed information concerning whether the inventor move or not after receiving the award during the 2005-2014 period, and correlate this information with indicators of job tenure and pre-award performance at the time of the award. We will employ Kaplan-Meier non-parametric analysis to highlight which systematic differences across different type of inventors affect their mobility. We will then investigate the probability of multi-award winners to move after being awarded the innovation prize by means of a complementary-log-logistic model. Results will indicate that inventors' previous and current performance with reference to patents and publications have no influence on mobility. Results will instead provide evidence that being an entrepreneur at the time of the award is positively associated with inventors' mobility.

Riassunto Breve

Utilizzando un campione di 415 inventori che hanno vinto il "R&D 100 Award" tra il 2005 e il 2014 per la più importante innovazione radicale, questa tesi analizza empiricamente tre temi riguardanti le relazioni tra premi, invenzioni, ed innovazioni. La tesi si compone di tre saggi.

Il primo saggio illustrerà i risultati di un'indagine statistica condotta sui vincitori del "R&D Awards": *"The R&D 100 award inventor survey"*. In questo saggio forniremo informazioni sulle caratteristiche degli inventori in termini demografici e di istruzione, il contesto in cui si è verificata la loro attività innovativa, e il valore delle loro innovazioni. Il confronto di alcuni dei nostri risultati con quelli di precedenti ed analoghe indagini ci permetterà di trarre interessanti conclusioni riguardanti le caratteristiche variabili degli inventori, l'evoluzione nel tempo della loro attività innovativa, le loro motivazioni, e i contesti industriali ed organizzativi in cui hanno operato.

Nel secondo saggio prenderemo in considerazione un campione di importanti invenzioni premiate e stimeremo la probabilità che l'invenzione sia brevettata (o no) in funzione delle sue caratteristiche, delle caratteristiche dell'inventore, e delle caratteristiche dell'organizzazione. Proporremo un'analisi delle innovazioni che hanno vinto un premio importante (il "R&D 100 Awards") che ci permetterà di valutare le determinanti delle innovazioni che si verificano all'interno e all'esterno del sistema brevettuale. Per eseguire l'analisi, utilizzeremo una serie di regressioni. In termini di propensione brevettuale, i nostri risultati mostreranno che la precedente esperienza brevettuale degli inventori, il contesto dell'organizzazione in cui lavorano e la dimensione del team a cui appartengono influiscono positivamente sulla probabilità di brevettare. Forniremo ulteriori risultati sulle determinanti del valore di quelle invenzioni che sono state brevettate utilizzando gli indicatori tradizionali basati sulle citazioni del brevetto e gli indicatori alternativi tratti dal *'The R&D 100 award inventor survey'*. Un confronto tra il nostro campione di invenzioni premiate e brevettate ed un campione di controllo di innovazioni simili e brevettate (ma on premiate) suggerirà che le invenzioni brevettate vincitrici del premio sono di maggiore valore.

Infine, il terzo saggio esplorerà la mobilità degli inventori pluripremiati (ovvero coloro che hanno vinto più volte il "R&D 100 Award"). Utilizzeremo informazioni dettagliate riguardo l'eventuale spostamento dell'inventore dopo aver ricevuto il premio durante il periodo 2005-2014 e correleremo, al momento del premio, questa informazione con gli indicatori di occupazione e prestazione prima del premio. Dapprima, utilizzeremo l'analisi non parametrica di Kaplan-Meier per evidenziare quali differenze sistematiche tra diversi tipi di inventori influenzano la loro mobilità. In seguito, utilizzando un modello complementary-log-logistic, studieremo le determinanti della probabilità che inventori pluripremiati siano più mobili ovvero si trasferiscano in un'altra organizzazione dopo aver vinto il premio. I risultati indicheranno che le prestazioni precedenti e attuali degli inventori con riferimento ai brevetti e alle pubblicazioni non hanno alcuna influenza sulla mobilità. I risultati forniranno invece prove che essere un imprenditore al momento del ricevimento dei premi è associato positivamente alla mobilità degli inventori.

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I am forever indebted with all the inventors who contributed in this study. Many thanks for taking time to respond to my survey and for sharing their views on technology, patenting and the joy of inventing. This piece of research was only possible thanks to their generous participation, constant feedback and interest.

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List of Abbreviations

CT: Computer Tomography

CV: *Curriculum Vitæ*

DARPA: Defense Advanced Research Projects Agency

e.g.: *exemplum gratum*

EPO: European Patent Office

et al.: *et alii*

etc.: *et cetera*

EU: European Union

HDTV: High-definition television

HTML: Hypertext Markup Language

i.e.: *id est*

inn.: innovation

Int. CI.: International Classification

IP: Intellectual Property

IPC: International Patent Classification

KEI: Knowledge Ecology International

LCD: Liquid Crystal Display

Log: logarithm

M.D.: Medical Doctor

NAE: National Academy of Engineering

NMTI: National Medal of Technology and Innovation

No.: number

Org.: Organization

PhD: *Philosophiae Doctor*

PROs: Public Research Organizations

R&D: Research and Development

ref.: reference

US: United States

USPTO: United States Patent and Trademark Office

Yrs: years

Chapter 1

Introduction

1.1. Research focus and contribution

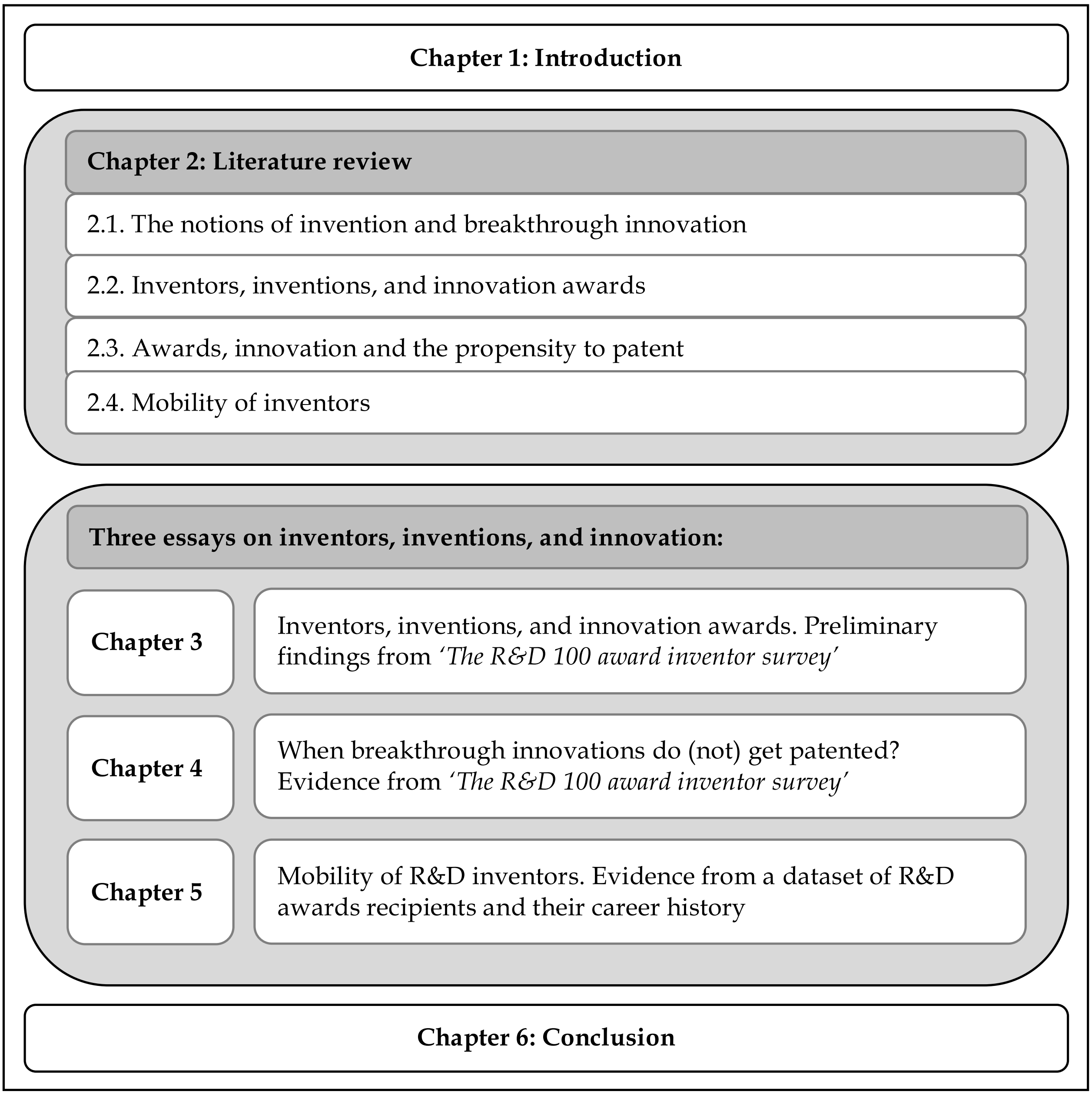
Due to its immense role in economic and social spheres, innovation has received much attention by scholars and practitioners alike. In effect, numerous studies from several streams have manifold contributed to the growth of the field. However, it is thanks to gifted innovators, scientists and inventors that this field has gained a far-reaching significance in theory and practice. For this reason, recent research in the field of economics and management of innovation has devoted increasing attention to the study of the characteristics of innovative scientists or engineers in terms of age and education (Jones, 2010; Baumol *et al.*, 2009), motivations guiding their activity (Sauermann and Cohen, 2010; Sauermann, 2017) and the organizational context in which they carry out their activity (Conti *et al.*, 2013; Singh and Fleming, 2010; Lettl *et al.*, 2009). While these researches have followed several strategies to build up their samples, in most of the cases the starting point for the identification of inventors has relied on patent data (Giuri *et al.*, 2007; Walsh and Nagaoka, 2009; Graham *et al.*, 2009).

In this dissertation we take a different standpoint and consider a sample of inventors who have won an award for the 'most important breakthrough invention' and survey them in order to analyze their characteristics, their motivations and the organizational context in which they carried out their activity. By exploiting this sample, instead of focusing only on inventors who have patented, allows us to answer to the following research questions: what are the characteristics of successful inventions and inventors? What are the determinants of the propensity to patent breakthrough inventions? What are the determinants of mobility for those inventors who have been awarded a prize? Through these three empirical essays, this dissertation contributes to the existing field of innovation economics and management by providing fresh evidence on the characteristics of successful inventions and inventors, the determinants of patenting, and the factors affecting the careers of inventors in terms of mobility. It also contributes with a novel database on the characteristics of inventors. To the best of our knowledge, no other comparable databases are currently available.

1.2. Outline of the dissertation

The dissertation consists of six chapters and is organized as shown in Figure 1.1.

Figure 1.1: Structure and outline of the dissertation



After this chapter in which the outline of the dissertation is presented, Chapter 2 summarizes the theoretical background of each one of the three essays. Initially, the concepts of invention and breakthrough innovation are introduced and a review on the current literature on inventors, inventions and innovation awards is presented.

This is then followed by a discussion on awards as instruments to stimulate innovation and the determinants of the propensity to patent. Finally, the current literature on the determinants of the mobility of inventors is examined.

Chapter 3 presents the empirical analysis of the first essay. In this first essay, we motivate and summarize the results of the *'The R&D 100 award inventor survey'* upon which this dissertation is based. Our decision to focus on a sample of inventors who received an award for the contribution to innovation is motivated by a growing literature that investigates the role of awards and prizes for spurring innovation (Brunt *et al.*, 2012; Moser and Nicholas, 2013; Chan *et al.*, 2014; Gallus and Frey, 2016). While awards and prizes seem to act as alternative incentives for promoting innovation alongside monetary rewards, some recent papers have also highlighted that only a small share of awarded innovations are actually patented (Moser 2012; Fontana *et al.*, 2013).

Thus, looking at inventors who have received an award but who have not necessarily patented their inventions, would in principle allow us to gain a better understanding of their characteristics, education and motivations above and beyond prior investigations which have mainly focused on inventors who have patented. The direct contribution of this essay is to highlight, in a precise and systematic way, what are the characteristics of inventors who are responsible for breakthrough innovations, what is the economical and technological value of these inventions, what is the context in which they occurred and whether or not they have been patented.

Chapter 4 shifts the focus to the determinants of patenting. In the second essay of this dissertation, from *'The R&D 100 award inventor survey'* we considered a sample of important inventions and estimated their propensity to be patented or not as a function of (i) the characteristics of the inventor, (ii) the characteristics of the organization (the context in which the innovation occurred), and (iii) the characteristics of the invention itself.

Patents have captivated economists, policy makers and lawyers for a very long time. A reason for this lies in the ambiguous role of patents from a social point of view. For instance, a properly designed patent system might spur innovation at a certain time and place while a weak and/or a strong patent system may generate unintended negative side effects (Boldrin and Levine, 2013). Another reason involves the strategic meaning that patents have in some sectors notably in information and communications technology (ICT) and biotechnology. Further reasons, involve boosting/hampering the development of emerging countries.

In recent years, patents have been a rich data source for the study of innovative activity. Prior works using patent data as an indicator of innovation have investigated a wide variety of aspects in the propensity to innovate across sectors (Scherer, 1965; Scherer, 1983), characteristics of inventions (Trajtenberg, Henderson and Jaffe 1997) and type of organizations carrying out the innovative process such as corporations vs. universities (Henderson, Jaffe, Trajtenberg, 1998) or public research organizations (Jaffe and Lerner, 2001).

Recent studies have instead collected information on inventors coming from patent data in order to study specific attitudes and characteristics toward the use of patents as means to appropriate economic returns from their inventions.

Studies such as Levin *et al.* (1987) and Cohen *et al.* (2000) have revealed that only in some specific sectors patents are considered to be a fundamental tool of appropriation. Other studies highlighted instead the demographic characteristics of inventors in terms of age and gender (Giuri *et al.*, 2007; Graham *et al.*, 2009; Walsh and Nagaoka, 2009); level of education (Jung and Ejermo, 2014; Nager *et al.*, 2016; Toivanen and Väänänen, 2016), motivations for engaging in inventive activity (Giuri *et al.*, 2007; Sauermann and Cohen, 2010), and patent behavior (Mariani and Romanelli, 2007).

All in all, these works have provided considerable insights on the determinants of patent propensity and tremendously enriched our understanding of the characteristics of the innovations that have been patented. Current dominant themes in the literature concern the effectiveness of patents versus secrecy for appropriating the returns from inventions (Arundel, 2000; Hussinger, 2005); the protection of intellectual property (Cohen *et al.*, 2000); and the propensity to patent (Brouwer and Kleinknecht, 1999).

There are, however, serious limitations when using patent data as indicators of innovative activity as not all-important inventions may necessarily end up being patented. Are these inventions any different from those that get patented in terms of importance, value, characteristics of the inventors? Recent works have started to shed light on these issues (Moser 2005; Moser, 2012; Thomson, 2009; Nicholas, 2011; Fontana *et al.*, 2013) but more work needs to be done. With this essay, we contribute to the current stream of literature on patents and awards by providing empirical evidence on the probability to patent inventions that have been awarded a prize. We further provide evidence on the determinants of the value and the quality of those innovations.

The third essay (Chapter 5) focuses on the mobility of inventors. Inventions are the fuel of innovation and thus the engine of economic prosperity (Schumpeter, 1934). It can be argued that, without inventors, inventions will not be happening. Research on inventors has received much attention over the past decade (Ernst, Leptien and Vitt, 2000; Greif, 2001; Staudt and Kriegesmann, 2002; Giuri *et al.*, 2007). Recently, studies on innovation have started devoting attention to the mobility of inventors. The reason is simple: inventors per se represent a specific category of highly skilled workers. Inventors are usually directly involved in the creation of new knowledge having a large effect on the diffusion of knowledge across organizations, universities and regions.

The goal of the third essay is to enlarge our understanding of the determinants of the mobility of high skilled labor, particularly with regards to the relationship between mobility and the background of inventors. Focusing on a subsample of very prolific inventors (i.e. who have been awarded multiple prizes for their breakthrough innovations) from *'The R&D 100 award inventor survey'* we study their propensity to move conditional on winning more than one award. With this study, we add up to the existing literature on mobility. We also provide new evidence that shows that inventors' past performance does not influence their decisions to move, and that moves are driven in part by inventors' entrepreneurial characteristics.

The dissertation ends with conclusions and key findings of the overall research which are summarized in Chapter 6.

Chapter 2

This chapter introduces the reader to the theoretical standpoints of the dissertation. It describes and discusses the current literature review on the topics of inventions, innovation awards, patenting, and mobility of inventors. Initially, the notions of invention and breakthrough innovation are introduced and discussed. This is then followed by a review of the state-of-the-art literature on innovation awards and innovation prizes. Subsequently, an overview of the current literature on patenting is presented. Finally, the chapter presents a summary of the most recent literature on the mobility of inventors.

2.1. The notions of invention and breakthrough innovation

What defines an invention and what defines an innovation? Simply stated, an invention is the pleasure of investing in or creating new things (Machlup, 1962). According to Utterback (1971) the starting point for an innovation is mostly an invention. An invention needs however to be successfully commercialized in order to be called an 'innovation' (Hauschildt and Salomo, 2007). Schumpeter (1939) claimed that the innovation and technological change of a nation come from the entrepreneurs, or the wild-spirits. Schumpeter divided technological change into three phases: invention as the creation of new technologies; innovation as the commercial introduction of new technologies; and diffusion as the spreading of new technologies (Arthur, 2007).

We can thus argue that invention is the creation of new technologies, innovation is the commercial exploitation of a new idea or invention and that an inventor is essentially someone who comes up with an 'out-of-the-box' idea.

While a large body of research has investigated these three phases of technological change (Robertson 1967; Thirtle & Ruttan, 1987; Basalla, 1988; Achilladelis *et al.*, 1990) relative less attention has been devoted to the phase of invention. Arthur (2007) tries to fill this gap and defines invention as a *"process – usually a lengthy and untidy one – of linking a purpose with a principle (some generic use of an effect) that will satisfy it"* (Arthur, 2007:19).

In this thesis we will focus mainly on invention as the process by which new breakthrough technologies come to exist, rather than focusing on the uncertainties that any new invention faces in the marketplace (i.e. commercialization and spreading of the innovation).

The concepts of invention and innovation have been a topic of study in the field of innovation economics and management for quite a long time, however, its meaning has been diffused and controversial. For this reason, it has been often suggested in the literature that there is no clear specification on what exactly is meant by invention as opposed to innovation, and innovation as opposed to technological change (Ruttan, 1959). In response to this noticeable gap of knowledge, economists have always faced with the problem of defining what is an 'invention'. In this thesis we will mostly rely on the theory provided by Usher (1954).

Usher defines inventions as the emergence of "new things" which require an "act of insight" going beyond the normal exercise of technical or professional skills (Ruttan, 1959). According to Usher (1954):

> *"Acts of skill include all learned activities whether the process of learning is an achievement of an isolated adult individual or a response to instructions by other individuals. Inventive acts of insight are unlearned activities that result in new organizations of prior knowledge and experience…" (Usher, 1954:526).*

Usher (1954) continues:

> *"Such acts of insight frequently emerge in the course of performing acts of skill, though characteristically the act of insight is induced by the conscious perception of an unsatisfactory gap in knowledge or mode of action" (Usher, 1954:523).*

It is worth recalling that, although inventions may be carried out by people working in any type of organization (e.g. universities); innovations occur mostly in firms; and for turning an invention into an innovation, a firm needs to combine several different types of knowledge, capabilities, skills and resources (Fagerberg, 2005).

As a result, inventions come in many dissimilar forms ranging from incremental technical change or run-of-the-mill inventions, to radical or breakthrough inventions (Schoenmakers and Duysters, 2010). Although there is a great interest around the specific characteristics of inventions, the present thesis focuses particularly on inventions which are considered as breakthroughs.

Radical or breakthrough inventions can be defined as *"those foundational inventions that serve as the basis for many subsequent technical developments"* (Ahuja and Lampert, 2001:523). Furthermore, breakthrough inventions can be seen as rare, valuable, and potentially imitable sources of competitive advantage for a firm (Barney, 1991).

In other words, breakthroughs are those inventions that the technological community has recognized as highly valuable (Ahuja and Lampert, 2001) and they do not necessarily resemble to novel inventions that differ from existing solutions (Conti *et al.*, 2013).

Lastly, the body of empirical literature focused on identifying radical and breakthrough innovations is large. These include studies that used patent citation data (e.g. Trajtenberg, 1990; Ahuja and Lampert, 2001; Singh and Fleming, 2010), studies that relied on alternative non-patent indicators such as prizes (Carpenter *et al.*, 1981; Moser 2005; Fontana *et al.*, 2012), or surveys targeting managers, inventors and/or experts (Chandy and Tellis, 2000; Criscuolo *et al.*, 2017).

2.2. Inventors, inventions, and innovation awards

This section introduces the theoretical standpoints of the first essay of this thesis. The discussion is organized as follows. Section 2.2.1. presents the historical role of innovation prizes and awards as incentives of innovation. Section 2.2.2. provides a brief overview of the rationale of innovation prizes and awards. Section 2.2.3. discusses the role of prizes and awards as an alternative to patents. Finally, Section 2.2.4. introduces literature review on prizes and awards at the organizational level. The methodology and the results of our first essay will be explained in detail in Chapter 3.

2.2.1. The historical role of innovation prizes and awards as incentive for innovation

Prizes and awards have always played an important role in society. Frey (2006) defines awards in the *"form of orders, medals, deco-rations, prizes, and titles are ubiquitous in monarchies and republics, private organizations, and not-for-profit and profit-oriented firms" (*Frey, 2006:377). The most illustrious prize awarding institution is perhaps the Nobel Foundation. Another popular example of awards in the arts media and culture are the Academy Awards (Oscars), the Emmy Awards and Grammy Awards, or the Pulitzer Prize among others.

In the academic context awards abound. Many universities confer honorary doctorates, reward outstanding student performance or best teaching awards, as well as the flow of best-paper awards that are conferred at conferences and/or by journals (Coupé, 2003). Awards in the sports field are also very common, as athletes are sometimes awarded for exceptional performance and professional careers.

In the field of innovation economics there is a surprising widespread use of awards. Prendegast (1999) argues that *"incentives are the essence of economics"* (Prendegast, 1999:7). Thus, it can be argued that awards and prizes act as incentives for innovation. Within economics, many awards are conferred in the corporate sector to highly productive employees and by governmental institutions bestowing excellence in high-tech achievements. For instance, the National Medal of Technology and Innovation (NMTI) is conferred by the President of the United States to America's leading innovators.[1]

Offering innovation prizes as stimulus to encourage research and development (R&D) and produce inventions has a long tradition. The idea of rewarding inventions coming from gifted scientists dates back at least to the seventeenth century. A famous example of inducement prizes is the Longitude Rewards offered by the British government on a method for the precise determination of a ship's longitudinal position. The Longitude Rewards were established through an Act of Parliament in 1714 to solve the greatest challenge of the century: how to trace the ship's location on the sea by knowing its latitude and retrieving its longitude.[2]

Another example of a prize conferred in the seventeenth century was offered in France for developing a workable water turbine (Reynolds, 2002). Further, throughout the eighteenth and nineteenth century, the French were attentive in offering grand and smaller prizes for national challenges (Murray *et al.*, 2012). In the eighteenth century, the British Royal Agricultural Society sponsored prizes and medals for a variety of agricultural innovations on instruments used mainly in tillage, harvesting and crop preparation (Brunt *et al.*, 2012).

The London newspaper The Daily Mail encouraged progress in the development of aviation, in November 1913 it re-opened 'The Daily Mail Atlantic Prize', a prize offered to the first aviator to cross the Atlantic in an airplane from any point in the United States, Canada, or Newfoundland to any point in Great Britain or Ireland in 72 uninterrupted hours.[3]

The enthusiasm for the use of prizes seem to have vanished in the late nineteenth century and in the twentieth century.[4] However, prizes for innovations are currently experiencing a

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[1]See also https://www.uspto.gov/learning-and-resources/ip-programs-and-awards/national-medal-technology-and-innovation-nmti for more information on the National Medal of Technology and Innovation (accessed August 1, 2017).
[2] See also https://longitudeprize.org/ for more information on the Longitude Prize (accessed August 1, 2017).
[3] See also https://www.flightglobal.com/pdfarchive/view/1918/1918%20-%201315.html for more information on the Daily Mail Atlantic Prize (accessed August 1, 2017).
[4] See generally Knowledge Ecology International, Selected Innovation Prizes and Reward Programs (2008), online at http://www.keionline.org/misc-docs/research_notes/kei_rn_2008_1.pdf (accessed August 1, 2017).

renaissance in the early twentieth first century (Khan, 2015). There have been a handful of successful global innovation prizes that have been recently launched in the United States to revitalized the interest in this topic, including government prizes such as the $3.4 million DARPA Urban Challenge and private sector prizes such as the $10 million Ansari X Prize for the first private reusable manned space craft (Kay, 2012). The X Prizes are for instance a series of philanthropically-funded contests initiated in 1995 by Peter Diamandis.[5] Thus, the idea of using prizes to spark innovation is growing. Many private firms, governments and philanthropic institutions have been offering a range of prizes to encourage innovation and achieve social benefits.

Today, the main objective of inducement prizes is to encourage efforts by contestants to accomplish a particular goal (NAE, 1999). Given its current popularity, innovation prizes are predominantly offered in the United States (Murray *et al.*, 2012; Besharov and Williams, 2012) and are also becoming an important innovation instrument in the United Kingdom (Gök, 2013).

2.2.2. The rationale underlying innovation prizes and awards

In the recent years, interest has grown in the issue of whether prizes rather than intellectual property (IP) rights protection should be granted to inventors for stimulating great discoveries. At first glance, academics, policymakers and R&D practitioners seem overly enthusiastic about prizes and awards and the way they contribute at spurring. However, in the current literature there does not seem to be a consensus concerning the rationale for giving away prizes and awards. They can alternatively be seen as traditional innovation policy instruments to overcome market failures, as means to understand the useful application of a given technology and not only the creation process, and as incentives for the creation of technologies to be subsequently put in the public domain (Gök, 2013).

Kay (2012) argues that, up to now, there exists little empirically-based evidence on how to design, manage and evaluate innovation prizes. Studies that looked at the effectiveness of innovation prizes and tackle either advantages or disadvantages associated with the specific design of prize contests are limited.

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[5] See also https://www.xprize.org/about/board-of-directors/peter-h-diamandis-md for more information on Peter Diamandis (accessed August 3, 2017).

Boudreau and Lakhani (2011) looked at a custom designed software development contest where over 500 elite software developers prepared solutions to solve the same computational algorithmic problem. All of the contestants were separated into two groups, both groups had equal skills distributions and were exposed to the same competitive institutional context. The authors found out that cash incentives boosted the effort and performance of both groups and was significantly greater for higher-skilled participants.

Kremer and Williams (2010) discussed three potential triggers for innovation reward payments. First, ex-ante technical specifications are a feature of numerous innovation prizes: generally, sponsors of these prizes specify in advance what technical specifications they are looking for and reward solely on technical specifications set ex-ante. Second, metrics for ex-post use offer incentives for firms to concentrate their R&D efforts on products that actually would be used rather than on products that only fit a set of predefined technical specifications. An example of ex-post use prizes is proposed by the Medical Innovation Prize Fund, where reward payments are given to incremental health benefits where, not only the use, but also the social value is considered. Third, ex-post discretion is basically involved in any mechanism for regarding innovation. A clear example of ex-post discretion is when a committee would prefer to reward those who are likely to make the best use of the prize reward.

The use of prizes to spark community-led innovation is also expanding. Lyndhurst (2010) shows that prizes work better when it is not enough to have a single outcome measure (i.e. reducing carbon emissions) but an accurate 'prize model design' that can improve the efficiency of innovations. An example of this rationale is NESTA's Big Green Challenge Prize.[6]

Kay (2011) reviewed existing evidence on three innovation prizes cases in the aerospace industry and their effect on innovation: the Google Lunar X Prize, Ansari X Prize, and NASA's Northrop Grumman Lunar Lander Challenge. He outlines three remarkable findings coming from these three cases: first, there exist monetary and non-monetary incentives that attract participants to partake in innovation competitions; second, core technologies should be available to all participants and should be used for problem-solving activities to address technological goals from pure research to commercialization; and third, prizes should induce innovation by tackling significant technology gaps.

[6] See also https://www.nesta.org.uk/project/big-green-challenge f or more information on NESTA's Big Green Challenge (accessed August 1, 2017).

Brunt *et al.* (2012) examined the effect of innovation prizes using data on awards for technological developments offered by the Royal Agricultural Society of England at annual competitions between 1829 and 1939. The authors draw to the conclusion that medals were more significant than monetary awards for innovation and that prizes encouraged competition.

To analyze further the role of innovation prizes as a practical incentive mechanism, Murray *et al.* (2012) developed a framework that relies on three dimension of prize analysis: objectives, design, and performance. In their study, they focus on the Progressive Automotive Insurance X Prize offered in 2006 for the development of a highly efficient vehicle. The authors highlight three points of divergence. First, the complexity of prize specifications (i.e., the target of the prize) in terms of a single universal technical goal or metric influence competition and limit the innovation effect. In other words, when the objective and criteria of a prize is poorly defined it will bias competition and introduce restraints on innovation. Second, the nature and role of incentives. While theory has always viewed prizes as a substitute for patents and as alternative incentive mechanisms, in practice policy advocates and prize organizers see patents as a complement that boosts the value of the prizes and induces further technical developments beyond the prize period. Third, the authors find that there are challenges associated with prize governance and management that create significant costs for the prize organizers.

2.2.3. Prizes and awards: an alternative to patents

Over the last years, sufficient evidence has been produced on the fact that innovation responds to incentives (Griliches 1957; Schmookler 1966; Hayami and Ruttan 1971; among others).[7] Incentives in the form of patents have been used as traditional mechanisms for rewarding innovation. Recently, many authors have paid attention to alternative types of mechanism for rewarding innovation. Patent and prizes are not identical but complementary because inventors can pursue them in parallel (Shimizu and Hoshino, 2012). However, in many cases, prizes have been proposed as an additional incentive that would supplement the rewards from exclusive rights associated with patents (KEI, 2008).[8]

[7] See also Acemoglu and Linn 2004; Finkelstein 2004; and Brunt, Lerner, and Nicholas 2008.
[8] See generally Knowledge Ecology International, Selected Innovation Prizes and Reward Programs (2008), online at http://www.keionline.org/misc-docs/research_notes/kei_rn_2008_1.pdf (accessed August 1, 2017).

In the literature, there exist studies devoted to the analysis of prizes as an alternative to IP. Much of the literature has devoted work on the debate on whether prizes could be used as a substitute for IP rights. To date, most of the studies that investigate this distinction between patents and prizes are based on a theme presented in Wright (1983). Wright (1983) is the first formal contribution that proposes to replace patents with government funded prizes and argues how asymmetric information should inform the choice among what incentive mechanisms can be used to spur innovation. The author in his classic analysis categorizes rewards to innovators on the one hand, in the form of a patent that gives the ability to charge a price over marginal cost for each use of the process or unit of a specific product; on the other hand, prizes as a lump-sum compensation that does not bring the equivalent marginal distortions.

According to Roin (2014):

> *"The debate over which system is preferable has existed for centuries and usually boils down to a single question: Can the government determine the appropriate reward for innovations without relying on intellectual property rights to reveal their value to consumers? If yes, scholars assume that prizes are superior because they avoid deadweight loss and provide equal or better incentives for innovation" (Roin, 2014:999).*

Roin (2014) nevertheless concludes that IP offers superior incentives to prizes because it provides protection against expropriation. It is a well-recognized rule that patents cannot be expropriated. However, governments, public authorities and courts can impose compulsory licensing and a restraint for the royalty (Bond and Saggi, 2014). This type of compulsory licensing can be considered as a form of "soft" expropriation for what concerns the right of exclusivity.

de Laat (1997) points out that a rationale for patents depends on their flexibility. Patents presents several characteristics that do not only depend on the duration of protection but on their protective scope against imitation, which defines the minimum improvement prerequisite that an innovation must meet to receive a new patent, while a prize represents a less rigid protection instrument.

Khan (2015), surveys and summarizes extensive empirical research using a constructed sample drawn from Britain, France, and the United States by including "great inventors", their ordinary counterparts, and prizes at industrial exhibitions. Khan (2015) claims that the systems of rewards to innovators suffers from several disadvantages in designing an incentive mechanism that promotes technological change and innovation, some of which might be inherent to their non-market orientation.

Historically, prizes have aimed at offering incentives for demonstration projects rather than at focusing on promoting access to products ready to be used at scale (Kremer and Williams, 2010). In some cases, prizes have been considered to be an additional encouragement to innovation pulling out exclusive rights associated with patents. This suggests that prizes can actually be seen as a powerful tool to boost innovative activity.

According to Davis and Davis (2004), *"more prizes have been offered for achievements in aviation in the past century than in any other technical area"* (Davis and Davis, 2004:8). By looking at early aviation contests, Davis (2004) finds out that offering a prize to cross the English Channel stimulated the innovation of bigger and better aircrafts, as fledgling firms competed to achieve higher performance leading to the first trans-Atlantic flight.

Masters and Delbecq (2008) found strengths and limitations of various prizes awarded over the past 300 years to many kinds of technologies in Europe and North America. Their paper presents a case on how prizes could be used as a tool to increase successful innovations in African agriculture. In their study, the authors suggested that a proportional-prize approach, where the prize is awarded according to the effect created in the African agriculture sector, might provide a considerably effective incentive.

Wei (2007) analyzes the legal literature evaluating the Medical Prize Innovation Act of 2005 that proposed to replace the current patent regime with a prize system. The author reviews both historical and modern precedents and argues for a more modest change which consists on a pilot program that concentrates in the development of a prize for a particular technology (i.e., when the prize constitutes the total value of the solution such as a drug to cure a specific disease) to supplement the current patent regime and bridge gaps in National Institute of Health funding.

Fisher and Syed (2008) carried out a detailed discussion on prizes applied to health problems in developing countries, examining the Health Impact Fund proposal and the Medical Innovation Prize Fund proposal. They argue that the present patent system offers incentives by stimulating firms to develop innovative pharmaceutical products to prevent others from making, using, selling, or importing those products. Given the exclusive rights conferred by the patent system, firms can sell their products for prices much higher than their real production costs. The extra profits produced by selling at a higher price induces firms to engage in inventive activity. A prize system, by contrast, will eliminate competition among manufacturers of the drugs, making the access to drugs in developing countries more affordable. Contrary to this, Encacoua, Guellec and Martinez (2006) argue that neither patents nor prizes are necessary to reward innovation except the case where reverse engineering or copying is particularly easy.

2.2.4. Prizes and awards at the organization level

Management theorist agreed that, for innovation to take place, organizations may leverage human capital to develop expertise for creating new products and services (Chen and Huang, 2009). In other words, human capital is one of the most important assets of an organization, because work is done through employees. Further, behind each innovation there is an individual or a group of individuals that can be accounted for. Accordingly, conventional wisdom defines the human component as the most important driver of innovation. Henderson (2004) states that *"the attribute that distinguishes inventors from other creative people is their orientation toward problem solving"* (Henderson 2004:107). Thus, inventors may invent for passion and enjoyment, the welfare of mankind, and, invent for the sake of getting the job done (Colangelo *et al.*, 1992; Rossman 1964; Machlup, 1962). For this reason, performance-based organizational incentives that push for the development of breakthrough technologies are central when it comes to spurring innovation.

Cohen and Sauermann (2007) show that individual incentives matter when it comes to innovation, by referring to the case of Silicon Valley or Route 128 to show innovative performance of different regions. The authors however, claim that there are still few empirical studies concerning the impact of individual-level incentives on innovation. It is important to say, that the sources of individuals' incentive depend on a sort of combination between the environmental influences, the interaction with other individuals, as well as the intrinsic and extrinsic motivations.

Deci (1975) states that *"intrinsically motivated behaviors are behaviors which a person engages in to feel competent and self-determining"* (Deci, 1975:61). In other words, individuals who want to feel competent and self-determining engage in problem-solving activities. Once they have overcome certain challenges, they will feel satisfied and will continue to engage in those activities that result in intellectual stimulation.

Individuals might also be influenced by extrinsic reasons such as career concerns, reputation (inside and outside an organization), and the hope that their effort will affect their research environment and compensations (Owan and Nagaoka, 2009). Holmstrom (1989) argues that firms do not become innovative by only hiring talented individuals that have the competences to develop key innovations, but by rewarding those individuals for their engagement in innovative activities within the firm.

However, there exists the possibility that extrinsic invention rewards could 'crowd-out' intrinsic motivations. In this context the term "crowd- out" was firstly used by Frey (1997) to highlight that there exist three psychological processes that could describe the crowding out effect. The first one is linked to the extrinsic rewards and intervention that make individuals less responsible and self-determining; the second is due to the fact that individuals may feel damaged if their involvement and competence are not appreciated; the third one works through the reduction in the opportunity to stimulate their inner motivation (Owan and Nagaoka, 2009). Formal reward structures may impede creativity because individuals are likely to perceive them as a form of controlling their inventive capabilities within the organization. Individuals will be most creative when intrinsically motivated, by the interest, enjoyment, and challenge of the work itself (Amabile, 1993).

Baker, Jensen and Murphy (1988) argue that rewards can take many different forms, comprising praise from superiors and co-workers, implied promises of future promotion opportunities, feelings of self-esteem that come from greater success and appreciation, and current and future cash rewards associated to performance.

The study of Zenger and Lazzarini (2004) on compensating for innovation explores the hypothesis that small firms have benefits over large firms in making successful incentive-intensive employment contracts that attract top engineering talent and motivate high effort.

Kohn (1993) suggests that rewards succeed at securing temporary compliance. Thus, when individuals are deprived of a proper prize for the ideas they generate, they tend to be less inclined to pursue novel, valuable projects (Barros and Lazzarini, 2012). Further, when it comes to innovation and incentives, rewarding performance of corporate R&D heads is associated with more innovative firms (Lerner and Wulf, 2007).

Organizations may grant recognition to individuals through several formal sources of status: wage distribution, distribution of scarce non-monetary resources, prominent awards or, most commonly, higher positions in the organization's hierarchy. To date, awards are widespread in almost all areas of economic and social life (Frey, 2006). Current studies have shown that awards are a valuable strategic resource as they can have a significant positive or negative impact on employee motivation and corporate performance (Gallus and Frey, 2016).

Among several streams of literature that have addressed awards as a form of incentive we can mention Markham *et al.* (2002) that analyzed a public recognition program for improving work attendance, which showed that absenteeism reduced by 52%. Magnus (1981) founds that public acknowledgement of gratitude is a more efficient tool to boost productivity than money remunerations in the form of salary.

A study conducted by Gavrila *et al.* (2005) presents an optimal solution for managing awards over time by bearing in mind that their effect depends on the number of alternative awards available. Neckermann and Kosfeld (2008) carried out a study evaluating the impact of non-monetary awards on work performance. Their results show that subjects who received the award perform significantly better than those in the control group. This study offers strong evidence on the important role of awards in firms and organizations.

Innovative human resource practices such as prizes and awards are on the one hand becoming popular in the corporate sector and have been a critical tool for firm competitiveness (Ichniowski and Shaw, 2003) and on the other, if awards are not well designed, they are a waste of resources that can have an undesirable impact on firm performance (Gubler *et al.*, 2014).

Lastly, Gallus and Frey (2016) contributed to the strategic management literature stream by explaining how an incentive system based on awards can affect employee and firm performance. The authors suggest that awards are particularly useful to retain valuable employees, however, awards do also present disadvantages that may destroy their intended value, particularly when awards between employees provoke envy among co-workers.

2.3. Awards, innovation and the propensity to patent

This section introduces the background literature of the second essay of this thesis. The section is organized as follows. Section 2.3.1. discusses patents and alternative instruments to protect inventions. Section 2.3.2. looks at the literature on the propensity to patent innovations. Methodology and results of the second essay will be explained in detail in Chapter 4.

2.3.1. Patents and alternative instruments to protect inventions

The knowledge developed in the field of patenting and invention activity has grown over the last decades. Both patenting and invention seem to go hand by hand, this however only from a theoretical point of view. In theory, *"a patent confers perfect appropriability (monopoly of the invention) for a limited time in return for a public disclosure that ensures widespread diffusion of benefits when the patent expires"* (Levin *et al.*, 1987:783).

Within the theoretical literature, the word 'patentable' refers to the legal requirement for an invention to meet novelty, non-obviousness, and industrial application criteria (Arundel and Kabla, 1998). Further, the idea that patent holders have precise rights to exclude rivals (from the economic exploitation of the invention) has allowed economists to focus on the important and complex relationships among patents, innovation, competition, and diffusion of technology (Lemley and Shapiro, 2005).

Keeping imitators away from using the harvest of their inventive and innovative activities, in other words, appropriability, is a huge concern for inventors. The problem of appropriability has been a popular topic of research over the last decades (Arrow, 1962; Levin *et al.*, 1987; Harabi, 1995). Appropriability is defined as the ability of seizing the profits generated by an innovation (Teece, 1986) or, as explained by Trajtenberg *et al.* (1997), refers *"to the ability of inventors to reap the benefits from their own innovations"* (Trajtenberg *et al.*, 1997:20). The reason is simple: knowledge is a non-rival and a (quasi) non-excludable intangible asset that can be easily acquired by an imitator (Hall *et al.*, 2014).

Blind *et al.* (2006) explain that *"the core motive to patent is the protection of own inventions from imitation, i.e. the traditional patent motive; and that the strategic motive, which is in the forefront of most investigations, is to block competitors"* (Blind *et al.*, 2006:657). Mansfield (1986) studies the relationship between patenting and innovation behavior in a random sample of 100 American manufacturing firms and finds that a significant portion of patentable inventions is not patented. In his study the author concludes that, generally speaking, firms seek patent protection when available and avoid secrecy protection.

Most of the literature on appropriability focuses on the use of patents and very little literature on secrecy as an alternative to IP protection tools. In almost all the previous literature, the conventional aim of patenting was protecting from imitation. This is further confirmed in a study by Arundel *et al.* (1995) where 80% of the firms indicated that the reason why they patent is to protect their products from imitation or to block competition. Moreover Arundel *et al.* (1995) find that patents and lead-time advantages are of great value when it comes to protect product inventions, while secrecy proves to be more valuable to protect process inventions in nearly all of industries. The authors further confirmed that for the United States as for Europe, patent protection plays a significant role for both product and process inventions in pharmaceutical and chemical industry compared to other industries.

Duguet and Kabla (1998) investigated 229 French enterprises from 12 sectors to study the determinants of both the percentage of innovations that are patented and the number of European patent applications by industrial firms. When inquiring about motives to patent, defensive blocking and improved negotiation position were named by 62% of all enterprises, suggesting that securing technological scope is a strong driving force behind patenting.

In a similar way, the investigation carried out by Cohen *et al*. (2002) concluded that for both United States and Japan, the motivation for obtaining patents on product and on process innovations is identical for both countries, namely to protect from imitation. Results of this study show that Japanese enterprises are less inclined to safeguard exclusiveness of the innovation when patenting. Instead, they use patents to keep technological room to maneuver, particularly for negotiation.

Findings by Levin *et al.* (1987) for the United States and Brouwner and Kleinknecht (1999) for the Netherlands indicate that firms in some cases do not consider patent protection as the most important mean for appropriating innovation benefits, but they prefer to rely on lead-time on competitors, secrecy or keeping qualified people in the firm, showing the importance of tacit knowledge when it comes to innovative activities.

Anton and Yao (2004) analyze the implications to keep an invention secret and to use patenting when it comes to protecting an invention. The authors point out three strategic features that are significant when it comes to the choice to patent or to keep an invention secret: (i) incomplete information about the innovation; (ii) the constraint of IP protection; and; (iii) the fact that imitation is eased by patent disclosure.

Hanel (2008) finds out that Canadian manufacturing firms that actually protected their inventions by using IP kept or enlarged their economic returns. The survey carried out by the author offers information on the influence of IP tools on profits. Results of the study also reveals that small firms use less frequently IP protection tools and that top inventors are more flexible and protect their inventions by making use of every kind of IP protection.

Hussinger (2006) studies the importance of patenting versus secrecy as effective substitutes to protect IP at the firm level. The author conducted a survey focusing on German manufacturing firms in the year of 2000. The study reveals, on the one hand, that secrecy seems to be rather important for inventions that are not yet commercialized; on the other hand, it reveals that patents appear to be an effective instrument to protect previously commercialized inventions.

Levin *et al.* (1987) studied data on American manufacturing firms, the authors conclude that, when it comes to appropriation methods and to IP protection, firms prefer secrecy over patenting. Findings on the Carnegie Mellon survey carried by Cohen *et al.* (2000) confirm results from Levin *et al.* (1987). The authors add further findings by pointing out the significance of industry differences when it comes to patenting.

Finally, alongside complexity and imitation, an innovator's decision to patent is also influenced by 'disclosure'. Indeed, when a patent is granted, the details of the invention are disclosed to the world and this disclosure might influence the decision to patent in the first instance vis-à-vis the decision to rely upon alternative appropriable mechanisms. Zaby (2010) studies the patenting decision of an innovator who is conscious that patenting an invention implicates disclosure of knowledge while secrecy does not. This disclosure of knowledge may facilitate a competitor to enter the market with a non-infringing invent-around product. Furthermore, lead-time in the market strengthens the motivation to keep the invention secret as the patent cannot protect all possible product qualities.

Another recent study by Heger and Zaby (2013) studies the role of disclosure in defining a company's choice between patenting versus secrecy. The authors show with a patent-secrecy model that the decision to patent depends on the effects a patent has on competition (i.e. entry of rivals) related with the disclosure of information required by a patent. Further, the cost of disclosure of a patent differs across firms as it depends on the competitive advantage of each specific company.

2.3.2. The propensity to patent innovations

The most widely accepted concept of patent propensity was firstly presented by Scherer (1983). Patent propensity is usually defined as the ratio between patent and R&D expenditures (Fontana *et al.*, 2013). This definition of patent propensity is still extremely difficult to construct. The reason is simple: it takes into consideration the efficiency of R&D. To address this concern Grefermann *et al.* (1974) and Kabla (1996) use a comparative restricting definition involving the percentage of innovative firms in a sector that have applied for at least one patent over a defined time.

Within the patent literature, Arundel and Kabla (1998) state that *"the patent propensity rate is a potentially valuable indicator for both innovative activities and appropriation conditions"* (Arundel and Kabla, 1998:127). Conversely, Mansfield (1986) notes that *"not all patentable inventions are patented"* (Mansfield, 1986:176). Mansfield (1986) also highlights that patenting behavior differs across industries. For instance, that roughly 80% of inventions are patented in sectors like the pharmaceutical or chemical industry; followed by automotive in which only about 60% of the inventions is patented.

Considerable insight has been gained with regard to how patents work in different industries. For instance, in the electronic industry patents are frequently shared among competitors through pooling or cross-licensing; whereas in the pharmaceutical, chemical, and biotechnology industries patents protect the extensive investment in research and compulsory clinical testing before placing the product on the market, as the manufacturing process is often easy to replicate and can be copied with a fraction of the investment (Lehman, 2003).

Cohen *et al.* (2000) carried out a survey questionnaire administered to 1,478 R&D labs in the US manufacturing sector in 1994, and found out that some industries such as the electronics, in which the number of exploitable innovations is high, make significantly more strategic use of patents than the rest of the manufacturing sector. In the manufacturing sector, so-called 'discrete product industries', patents are used to block out competition by establishing patent barriers, i.e. to stop improvements on substitutes by a number of patents around the own actual inventions; whereas in electro-technical industry, i.e. 'complex product industries' the main objective is to have more bargaining power in negotiations for cross-licensing.

Authors such as Roberts (1999) and Kash and Kingston (2001) debate along similar lines affirming that patents can be seen as a "currency"[9] in the market for technology and knowledge and that the role of patent portfolios is to discourage new market competitors who are dependent on the incomplete systems of other suppliers, but have not been competent to build up "currency" reserves themselves (see Blind *et al.*, 2006).

Consistent to the above-mentioned findings, Reitzig (2004), based on a dataset of 612 European patents and related inventions from five different industries, argues that patent fences in selected discrete technologies are merely used to exclude competitors whereas in complex technologies patent thickets represent exchange forums for complementary technology.

Brouwer and Kleinknecht (1999) also analyzed firms' propensity to patent using a new indicator of innovative output and data covering firms' actual patent applications from the Netherlands. Results from their study highlight that the propensity to patent is considerably greater among R&D collaborators and differs within sectors and by firm size. In particular, smaller innovators have a lower probability of applying for a patent, however, when they do apply for a patent, they tend to have a higher number of patent applications compared to larger firms in relative terms, i.e. the number of patent applications increases less than proportionately with the number of employees.

Licht and Zoz (2000) explore the link between R&D expenditures and patents at the firm level and concluded that the share of patent applications increases with firm size. In other words, large firms are more likely to apply for patents in more than one country, whereas the home patent office appears particularly more relevant for small firms.

Kortum and Lerner (1997) investigated the causes of a dramatic surge of US patenting in the late 1980s and early 1990s. The data used for this study consisted on international and domestic data on patent applications and grants. Results of the study suggest that an increase in patent propensity could theoretically explain the rise in patent application and grants. They further claim that factors related to technology improvements (i.e. shift to more applied activities) driven by changes in the management of innovation are more likely to justify the upsurge in patenting activity.

[9] In Hall and Ziedonis (2001) the authors used the term "bargaining chips" to denote the accumulation by firms of patent portfolios.

Some scholars advocate that patents are relatively important in industries such as pharmaceuticals, chemicals, and machinery, where the cost of replicating an innovation is substantially less than the initial cost of invention, while patents seem to be irrelevant compared to different appropriation methods, such as lead-time advantages or technical complexity, in industries that create complex products that are costly to copy, or where high investment costs and knowledge generate fences that constraint competition from new entrants. These opinions about the different uses of patents indicate that there are industry differences in the propensity to patent inventions (Levin *et al.*, 1987; Arundel *et al.*, 1995; Harabi, 1995).

Recently, several studies have also offered insights on the institutional factors that relate to patenting, looking in particular at the effect of the Bayh-Dole Act, given the dramatic increase in university patenting (Mowery *et al.*, 2001; Mowery and Sampat, 2004; Shane, 2004; among others). The Bayh-Dole Act of 1980 gave universities, non-profit research institutions, and small business the right to own, patent and, commercialize inventions resulting from research funded by federal grants.

Mowery *et al.* (2001) studied the growth of patenting and licensing by American universities during the 1980s and 1990s, after the enactment of the Bayh-Dole Act which occurred in 1980. In their study, the authors analyzed the outcomes of the Bayh-Dole Act in three leading universities; two of these universities were active in patenting and licensing before the Bayh-Dole act and the third one turns out to be active after. Findings indicate that the Bayh-Dole act was only one of various reasons behind the rise of university patenting and licensing. Other reasons that contributed to the growth in university patents and licenses independently of Bayh-Dole are the shift of universities' research portfolio, the role of science and new technologies, and the rise in federal financial support for basic biomedical research in universities in the late 1960s, along with the growth of research in biotechnology that started in the late 1960s. It further seems that the Bayh-Dole act had little influence on the content of academic research at these three universities.

Similarly, Geuna and Nesta (2006) look at university patenting and its effect on academic research in Europe. After surveying the existing fragmentary data on the growth of university owned patents and university invented patents (i.e. data on university-invented patents) in Europe, they find evidence that university patenting is rising. This occurrence remains yet dissimilar across countries and disciplines. In a dynamic setting however, they fear that the increase in university patenting exacerbates differences across universities in terms of financial resources and research outcomes.

It is well known that no European university holds a patent portfolio as large as MIT's or Stanford's (Göktepe, 2008). Most of studies on university patenting and licensing have been made on American universities compared to European universities. Further, many European universities do not hold any patents at all (OECD 2003; Lissoni *et al.*, 2007). Scholars such as Lissoni *et al.* (2007) have constructed systematic data on patents for European universities to tackle the 'European Paradox' in university patenting. The authors found that French, Italian and Swedish university-owned patents represent less than 1% of the total number of domestic patents.

Lastly, a more recent study carried out by Lissoni (2012) finds out that academics contribute significantly to patenting in Europe, in particular in science-based technologies such as pharmaceuticals and biotechnology, followed by chemicals and materials, measurement and scientific instruments, and lastly electrical engineering and electronics. In this study, the author defines 'academic patenting' as any patent signed at least by one academic scientist, while working at his or her university. The author uses as the unit of analysis information on inventors from Denmark, France, Italy, the Netherlands, Sweden, and the United Kingdom contained in patent applications filed at the European Patent Office (EPO) since 1978 and by matching it to information on academic scientist as provided by government.

2.4. Mobility of inventors

This section introduces the background literature of the third essay of this thesis. The section is organized as follows. Section 2.4.1. presents the literature review about mobility of inventors. Methodology and results of our third essay will be explained in detail in Chapter 5.

2.4.1. Background literature on the mobility of inventors

The vast literature of management and economics of innovation has given less attention to the topic on mobility of high skilled personnel such as inventors, researchers and scientists. Nevertheless, it has endlessly been recognized by the literature as being one of the most significant mechanisms for the transfer of knowledge. The type of knowledge that the innovation community is interested in is the so called tacit knowledge embedded in high skill staff, which is difficult to codify and transfer (Breschi and Lissoni, 2001).

Broadly speaking, mobility is when researchers decide to leave a firm and accept a job at another firm (Jaffe *et al.*, 1996).[10] It is interesting to note that what matters for knowledge production and transfer are the tacit skills embodied in people. Thus, when moving, inventors bring their tacit knowledge with them (Dosi, 1988). Given the fact that much of the knowledge in organizations is tacit in nature, it becomes clear that mobility affects its creation and retention, suggesting that mobility of personnel becomes, in an equal manner, a threat and an opportunity for firms. On the one hand, incoming inventors become an asset for firms who hire them. On the other hand, they are a liability for firms when they decide to move out (Kaiser, Kongsted and Rønde, 2008).

Zucker, Darby and Torero (2002) modeled labor mobility as a function of scientists' quality (measured by scientific citations) and their reservation wage. This reservation depends on labor quality and the cost of moving and is reliant on the trial frequency (number of potential firm employers), potential interfering offers from universities, and experienced increase in productivity of top scientists already in firms. The authors applied the model to bioscience and biotechnology industries and discovered that the time a star scientist remains in a university before moving to a firm is significantly: (i) decreased as the quality of the bio-scientist and his or her focus on human genetics increases; (ii) decreased as the expected occurrence of offers increases with the number of local firms commercializing the technology and the percentage of ties to scientists outside the bio-scientists' organization; and finally, (iii) decreases by experienced increase in productivity by other nearby star scientists who have already moved to firms.

Almeida and Kogut (1999) look at the relationship between patents and inventors' mobility using data on US patents in the semiconductor industry. The authors define mobility of inventors as "*the number of times that a major patent holder changes firms, as revealed in an analysis of all semiconductor patent*" (Almeida and Kogut, 1999:913). Further, they show that an essential mechanism by which knowledge is transferred is the interfirm mobility of human capital.

Research on inventors' mobility among firms has emerged in the last decade. For example, Stolpe (2002) investigated the nature of R&D knowledge spillovers in the field of Liquid

[10] Mobility in general terms is the propensity of an individual to move amongst different levels in a society or employment while migration is an example of international mobility in which individuals choose to settle in a new country. More information on the distinction between "mobility" and "migration" and a survey on migration can be found in Lissoni (2017).

Crystal Display (LCD) technology by assessing the effect of inventors' changing organizational and collaborative affiliation on the probability of citations in US patents filed between 1976 and 1995, while controlling for geographic localization effects. The author does not find empirical support for the common assumption that localized citation patterns and collaborative links between individuals are straightforward evidence of geographically localized knowledge spillovers and knowledge diffusion in the specific setting of LCD technology.

Likewise, Hoisl (2007) analyses the connection between inventor productivity and inventor mobility. Her main findings show that, on the one hand, the level of education has no effect on inventor productivity. On the other, that making use of external sources of knowledge and firm size have a significant influence on productivity and affects negatively inventor mobility. Further, inventors who move are more productive than non-movers, and while mobility rises productivity, a rise in productivity reduces the probability to move.

A recent contribution on mobility of Japanese inventors by Nakajima, Tamura, and Hanaki (2010) investigated the effects of inventors' collaboration network on their productivity and mobility using US patent data, contributing with empirical evidence to shed light on the importance of networks. To achieve this, they classified networked vs. non-networked inventors by means of information revealed in patent documents such as technology class, assignee, and co-inventors. The authors found that networked inventors are more productive and have longer tenure than non-networked inventors. Further findings show that the greater productivity and longer tenure of networked inventors are not exclusively explained by unobserved ability of inventors or unobserved characteristics of firms.

A further contribution in the literature on Japanese workers' mobility is done by Fujiwara and Watanabe (2013). Instead of using investments in R&D and human resources as indicators of innovations, both authors follow a less conventional way by investigating the relationship between innovation and the mobility of knowledge workers. Their main objective is to examine the role that the movement of knowledge workers plays in innovation and growth of new corporations that recruited them from mature companies. In their analysis, the contribution to the literature was twofold. Firstly, they find that, when innovation is measured by the number of patents, the contribution on innovation of highly experienced and highly specialized researchers from developed countries was especially high. Second, when innovation is measured by the quality of the patent, the number of researchers, and their years of experience, both exhibited positive effects on firm innovativeness and growth.

Another recent study on Japanese inventors' mobility by Umeno and Isamu (2015) empirically examines the relationship between inventors' mobility and organizations' productivity by building a dataset of mobile inventors using patent data. Two key findings are derived from the study: first, mobile inventors are more productive than stable inventors who have never relocated. Second, inventors with greater ex-ante productivity display higher mobility, while the effect of mobility on the ex-post productivity for more productive inventors is positive when compared to the one of less productive inventors. Further, productivity of stable inventors is greater in organizations where inventors have gain more experience in different organizations, more specifically when mobile inventors come from outside of the firm. This last finding suggests the existence of knowledge spillovers from mobile inventors to stable inventors which contribute to organizations' high productivity.

Crespi, Geuna and Nesta (2006) analyze the mobility of inventors from academia to private firms for six European countries. They pay particular attention to the factors that affect the mobility of academics and their choices to stay, to move to the private sector, to move to a different public research organization (e.g. another university). Interestingly, findings from this study show that leaving academia is a significant phenomenon, at least for the sub-sample of university researchers that hold patents from the EPO. Further, the higher is the value of the patent, the higher is the probability of a move to a company. When it comes to younger researchers, who are defined as those with less experience and less seniority, they are more prone to move and do it shortly after the application and/or the granting of a patent. Finally, the more incremental is the knowledge, the greater is the occurrence of moving to a company.

Breschi and Lenzi (2010) study the pattern of mobility of inventors using a rich data set on US inventors and their patents filed to the EPO between 1978 and 2004. The authors detect two unique spatial patterns: inventors move in similar proportions both at short and large spatial distances (i.e., around three hours and more than eight hours driving distance). Remarkably, in the biggest innovative urban areas, inventors' inflows and outflows mostly involve distant areas rather than near areas.

Similarly, Miguélez and Moreno (2014) document the determinants of geographical mobility of inventors across European regions. According to the authors, the mobility of these high skilled individuals contributes to the geographical diffusion of knowledge and reshapes the geography of talent. Employing EPO data from 1975 to 2005, they highlight that physical distance is an important forecaster of inventors' mobility patterns. Finally, job opportunities, as well as social and institutional relations and technological and cultural proximity, play a key role in facilitating inventor's mobility.

Additional evidence on inventors' mobility is provided by a recent publication by Gorin (2016). The author investigates the factors that drive skilled individuals to move to clusters within a limited number of urban areas. By making use of a large-dataset the author provides evidence on the patterns and determinants of inventors' mobility across urban areas. Gorin (2016) reports that inventors' mobility happens mainly among comparatively large and collocated urban areas due to the high level of circular and intra-firm mobility. Besides, employment opportunities, social networks, as well as numerous practices of proximity are significant determinants of inventors' mobility.

Chapter 3

Inventors, inventions, and innovation awards. Preliminary findings from *'The R&D 100 award inventor survey'*

3.1. Introduction

Innovation economists are interested in many issues related to inventors' characteristics such as, education, demographics, innovative activity and value of innovations. In this essay, we present preliminary results of a comprehensive survey on innovators who have won the 'R&D 100 Award' between 2005 and 2014. From 1963 the 'R&D 100 Award' has been awarded every year by the US based magazine *"Research & Development"* to the 100 most technologically significant new products available for sale or licensing in the year preceding the evaluation. For a sample of winners we have collected information about their employment at the time of the invention, educational background, industry or academic tenure, and motivations driving their inventive activity. Our sample includes 415 inventors. In addition to this, we have also information about the invention that was awarded, the use and value of the invention and how the R&D activity was carried out within the organization of the respondent at the time of the invention.

Using these data, we carry out a preliminary analysis of the following aspects. First, we look at the inventors and their innovating organizations. In particular we try to understand how award recipients are distributed across firms, universities and Public Research Organizations (PROs). Second, we look at some demographic characteristics of the inventors, their gender, how and where they were educated. Third, we look at those inventions that were either patented or not patented and try to relate them to the demographics of inventors and/or to the characteristics of the organizations.

Our preliminary findings highlight the main characteristics of the awarded inventions and inventors. The inventions are mostly product innovations, build upon previous inventions done mostly elsewhere and in collaboration. The representative inventor is 48 years old, male, works in firms or PROs, has a PhD degree in engineering and is not motivated by monetary rewards. We also find that around 75% of our sample of awarded inventions were patented and that the distribution of the patent value is less skewed than it might be expected from prior studies (Giuri *et al.*, 2007; Fontana *et al.*, 2012; Fontana *et al.*, 2013).

Though our findings are mainly descriptive and exploratory in nature, they provide the following contributions. First, they provide novel evidence on the characteristics of inventors and inventions that have received an award for the pre-eminence and importance of their innovative effort. To our knowledge, no prior research has provided such a comprehensive study on this type of important innovations. Second, we rely upon information on recipients of R&D awards instead of using patents as primary source of information on the inventors. Thus, we are in principle able to differentiate in our analysis between inventions that have been patented and those that have not.

The rest of the essay is structured as follows. In Section 3.2. we introduce the R&D 100 Awards and summarize the characteristics of the *'The R&D 100 award inventors survey'* by detailing the process of data collection and the response rate. Section 3.3. reports the results concerning the demography and the education of inventors as well as their organizations. Section 3.4. focuses on the invention. Section 3.5. focuses on the use and value of the awarded invention. Section 3.6. concludes.

3.2. The R&D 100 Awards

Over the last 55 years, the magazine *Research & Development* (previously called *Industrial Research*) has annually awarded prizes to the most significant '100 breakthrough inventions' that were incorporated into actual products available for sale or licensing in the year preceding the prize. Moreover, this magazine awards not only the 100 most significant new technical products but also the innovators responsible for their development. The Chicago Tribune has called the R&D 100 Awards the "Oscars of Invention" (Chicago Tribune, 1992). Today, these awards *"carry considerable prestige within the community of research and development professionals"* (Block and Keller, 2009:464). In other words, it can be stated that, from its foundation in 1959 to date, the magazine represents probably *"one of the most authoritative regular publications for R&D practitioners"* (Fontana *et al.*, 2012:791).[11]

[11] For more details on the aims and the requirements for being awarded the R&D 100 prize see also Fontana *et al.* (2013).

To the best of our knowledge, the R&D 100 Award data has been so far used in seven scientific publications by academic scholars. Three of these earlier studies have drawn on a sample of patents covering the awarded R&D inventions and other "control" patents on non-awarded inventions randomly drawn from other sources, such as the United States Patent and Trademark Office (USPTO) database, to provide an important validation of the use of forward citations as an indicator of patent quality (Carpenter *et al.*, 1981), to assess the impact of different Schumpeterian regimes on the generation of breakthrough inventions (Fontana *et al.*, 2012) and to systematically compare patented and unpatented innovations across industrial sectors (Fontana *et al.*, 2013). Scherer (1989) employs the mean and maximum R&D costs of the R&D 100 Awards to study the distribution of R&D investments, while other authors have use the data to understand the significance of public institution in the US innovation system (Block and Keller, 2009).

A further study that uses data from the R&D 100 Awards is Verhoeven, Bakker, and Veugelers (2016). The authors offer three ex-ante indicators which could predict the technological importance of a patent: novelty in recombination, novelty in technological and scientific knowledge origins. Their approach consisted in analyzing a focal patent and whether it cites other technological inventions or scientific literature from areas that were never cited before in the same patent class. Findings in this study show that the combination of the combinatorial novelty and the novelty in knowledge origins can be regarded as a strong identifier of breakthrough inventions.

Another more recent work has instead used the information on the R&D 100 recipients to conduct a survey of the characteristics of those individuals who created successful innovations in terms of knowledge creation and economic impact in US (Nager *et al.*, 2016). This work was aiming at providing the demographics of US inventors. However, its aim and scope are rather narrow as they are limited to a comparison of the results with other three samples of innovation output namely: the Triadic Patents Life Science, the Triadic Patents Information Technology for the period 2011-2014, and, the Triadic Patents Large Tech Companies (2014-2015).

3.2.1. The R&D 100 award inventor survey

Between 2005 and 2014, the magazine awarded 6,830 innovators and 1,779 organization with 995 prizes.[12] The number of awards given in each year ranges between 95 and 102 awards. Fontana, *et al.* (2013) noted that *"the requirement of awarding 100 inventions was apparently interpreted with some degree of flexibility"* (Fontana *et al.*, 2013:1784) by the magazine. The number of recipients of an R&D 100 Award increases gradually until 2012 (see Table 3.1 below).

'The R&D 100 award inventor survey' was administered between June 2016 and January 2017. The survey targeted a sample of 4,630 inventors and was conducted by mail and professional-social networks, through a questionnaire. The questionnaire was piloted before implementation and special care was devoted to make sure that the respondents were those who were responsible of the invention and/or those who were the best-informed individuals with respect to all the questions.[13]

We argue that the results of *'The R&D 100 award inventor survey'* present a unique collection of information about the profile of prize winners (the inventors), the context in which the invention occurs, and the characteristics of the breakthrough inventions.

3.2.2. Data collection

The type of approach we used for constructing our sample started with an automated script written in *Ruby*. This script parses firstly, the HTML code of each page of the magazine *Research and Development* collecting: the year of the award, an identification number for each invention, the name of the organization(s) involved in the invention, and the first and last names of the award winners. Secondly, the *Ruby* code reconstructs for each name retrieved an email address using both the organization's name and other information available on the web. As this automatic search tool might not yield to complete results, additional information was retrieved through "manual" web searches. For some inventors, we were not able to find any email address, but a successful contact was found on professional-social networks. Through this exercise, we were able to identify contacts for 90% of the population of awarded inventions and 68% of the population of inventors.

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[12] There are two reasons for choosing this time frame. First, this work is the continuation of a prior study by Fontana *et al*. (2013) that considered a sample of R&D 100 prizes ranging from 1977 and 2004. Second, the start date 2005 does not go too far back in time, allowing respondents to reliably recollect events that led to the awarded inventions.

[13] For further information on details about the questionnaire, pilot testing, basics of the survey, and problems encountered during the survey please refer to Appendix A.

3.2.3. Survey response rate

Table 3.1 reports the population, sample size and response rate by inventions and inventors.

Table 3.1: ***'The R&D 100 award inventor survey'*****. Population, sample size and response rate**

	Awards				Inventors			
Year of the award	**Population of R&D 100 Awards**	**Targeted Sample of R&D 100 Awards (% of population)**	**Awards with responses**	**Response rate by invention**	**Population of inventors**	**Targeted sample (% of population)**	**Responding inventors**	**Response rate by inventor**
2005	102	63(62%)	19	30.16%	202	154(76%)	25	16.23%
2006	95	89(94%)	31	34.83%	467	312(67%)	36	11.54%
2007	99	93(94%)	26	27.96%	462	315(68%)	32	10.16%
2008	100	94(94%)	21	22.34%	479	351(73%)	28	7.98%
2009	99	92(92%)	33	35.87%	647	448(69%)	45	10.04%
2010	100	73(73%)	34	46.58%	787	545(69%)	49	8.99%
2011	100	98(98%)	39	39.80%	1072	681(64%)	55	8.08%
2012	100	100(100%)	37	37.00%	1092	694(64%)	50	7.20%
2013	100	98(98%)	40	40.82%	886	633(72%)	51	8.06%
2014	100	97(97%)	32	32.99%	726	497(69%)	44	8.85%
Total	**995**	**897(90%)**	**312**	**34.78%**	**6820**	**4630(67.89%)**	**415**	**8.96%**

The response rate varies across inventions and inventors. In terms of inventions, the overall response rate is equal to 35%, covering 312 inventions. In terms of inventors, the overall response rate is equal 8.96%, corresponding to 415 inventors. It also varies throughout the ten-year period. The year with the highest response rate by invention is 2010, with 47% of targeted inventions. In contrast, only 22% of inventions awarded in 2008 are captured in the survey. The year with the highest response rate by inventor is 2005, with slightly more than 16% of targeted inventors. The year with the lowest response rate by inventor is 2012, with only 7.20% of targeted inventors responding.

During the implementation of the survey, some inventors expressed different concerns about the questionnaire. Specifically, 30% of them were interested in partaking and expressed their interest to follow-up with the outcome of this study. One-fourth of participants that got in touch with us, expressed their concern about not having enough knowledge to answer to some specific questions. For instance, some of them were only involved in the commercialization and the marketing of the breakthrough invention, and for this reason they were not in the position to clarify enough details. Some other, were PhD students and/or junior researchers not directly involved in the invention. Few of the inventors (11%) who contacted us, enquired about the legitimacy and the confidentiality of the survey, underlying the high trustworthiness of the data. Participation in the study was voluntary and we received occasional messages refusing to participate in the study (7%). It can be thus argued, that all those participants who answered the survey (N=415) were knowledgeable about their own inventions and subject field.[14]

3.3. The R&D 100 inventors

In this section, we will report our findings on some demographic characteristics of the respondents such as age and education; experience in the technical field of the invention as well as details concerning the organizations behind the inventions.

3.3.1. Inventors and their innovating organizations

Table 3.2 below reports the composition of our sample by gender and organization.

[14] Please refer to Appendix A for details on communication with inventors.

Table 3.2: Inventors and organizations. Population, sample size and response rate

	Population of inventors (% of the population)	Targeted sample (% of the sample)	Responding inventors (% of respondents)	Survey response rate
Inventors				
TOTAL	**6820**	**4630**	**415**	**8.96%**
Breakdown by gender:				
Male	6034(88%)	4143(89%)	383(92%)	9.24%
Female	786(12%)	487(11%)	32(8%)	6.57%
Organizations				
TOTAL	**1779**	**1618**	**415**	**25.65%**
Breakdown by organization type:				
PROs	579(33%)	537(33%)	193(46%)	35.94%
Universities	200(11%)	192(12%)	44(11%)	22.92%
Firms	1000(56%)	889(55%)	178(43%)	20.02%
Breakdown by firm size: [a)]				
1-10 employees	84(8%)[b)]	77(9%)[c)]	13(7%)[d)]	16.88%
11-50 employees	198(20%)	182(20%)	42(24%)	23.08%
51-200 employees	133(13%)	121(14%)	28(16%)	23.14%
201-500 employees	59(6%)	51(6%)	11(6%)	21.57%
501-1000 employees	49(5%)	45(5%)	7(7%)	15.56%
1001-5000 employees	74(7%)	72(8%)	16(9%)	22.22%
5001-10000 employees	46(5%)	39(4%)	13(7%)	33.33%
10001+ employees	204(20%)	173(19%)	48(27%)	27.75%

a) Information on size is missing for 153 firms (15%).
b) Percentages in this column are calculated by using the total population of firms N=847.
c) Percentages in this column are calculated by using N=889 targeted firms.
d) Percentages in this column are calculated by using N=178 responding firms.

In the population of 6,820 inventors that received a prize during the period of 2005-2014, we identified a total of 6,034 (88%) male inventors and a total of 786 (12%) female inventors. This proportion was kept in our targeted sample while in our sample of respondents, female inventors amounts to 8% compared to 92% of male inventors. This overrepresentation of male inventors compared with female inventors is not new, though the proportion of female inventors in our study is higher than that of prior surveys of inventors. Giuri *et al.* (2007) reports just 2.80% of female inventors in their sample of European inventors. Walsh and Nagaoka (2009) instead report a share of female inventors of 5.20% for the US sample and 1.70 % for the Japanese sample (Walsh and Nagaoka, 2009).

As reported in Table 3.2, our targeted sample consisted of 1,618 organizations that received the prize for their inventions during the 2005-2014 period. Among these, 55% were firms, 33% were PROs and 12% were universities. While this breakdown is similar to the breakdown in the overall population, the breakdown of respondents by organization type slightly underestimate firms (43%) and overestimates PROs (46%). We believe that inventors working in firms were more reluctant to respond to the survey due to confidentiality reasons.[15]

Respondents firms were further broken down by size category in order to catch the intrinsic variability of this sample. Among respondent firms, very big organizations (with more than 10,000 employees) are the most represented (27%), followed by small firms with 11-50 employees and 51-200 employees (20% and 16% respectively). Again these shares seem representative of the reference firm population from which the targeted sample was taken. Our targeted sample is however drawn only from the winning organizations, since the R&D magazine does not release any data on the selection process and the initial number and names of candidates.[16]

3.3.2. Who are the R&D 100 inventors and how were they educated?

Table 3.3 summarizes the most relevant information concerning the demographics and education of the inventors in our sample of respondents.

[15] As previously mentioned 11% of targeted inventors raised issues of legitimacy and confidentiality of the study. More information on communication with inventors can be found in Appendix A.

[16] Data on the initial number of candidates (finalists) prior to 2014 is not available. The R&D 100 Magazine reports the list of finalist starting from 2014. See also https://www.rd100conference.com/awards/winners-finalists/year/2018/ for more information on the R&D 100 Award Winners and Finalists.

Table 3.3: Demographics and education for the R&D 100 inventors

Demographics	Responding inventors (% of respondents)	Educational background	Responding inventors (% of respondents)
Age range (at time of invention:		**Highest degree at time of invention:**	
20 - 40 years	102(25%)	High school or lower	3(1%)
41 - 60 years	239(58%)	Technical college or junior college	6(1%)
61 -80 years	52(13%)	University or college Bachelor	56(14%)
		University Master's	75(18%)
		Ph.D., M.D. or equivalent	269(65%)
		Other [c)]	5(1%)
Age (mean)	47.76	**Discipline of the highest degree:**	
Age (standard deviation)	10.35	Biomedical	34(8%)
		Engineering	197(48%)
		Hard Sciences	154(37%)
		Social Sciences	10(2%)
Place of birth:		**Place where the degree was earned:**	
Americas[a)]	241(58%)	Americas	315(76%)
Asia	79(19%)	Europe	64(15%)
Europe	67(16%)	Asia	24(6%)
Other [b)]	9(3%)	Other [d)]	8(2%)

a) Includes USA (N=225), Canada and Latin America (N=16).
b) Includes Australia, Brunei and Cameroon.
c) MBA and PhD student.
d) Includes Australia and South Africa.

Note: 4% of respondents did not disclose their age. 5% of respondents did not disclose their place of birth and the discipline of their highest degree. 1% of respondents did not disclose where their highest degree was earned.

When they received the award, most of our surveyed inventors (58%) were between 41 and 60 years old; one quarter of them were between 20 to 40 years old (25%). 13% of our respondents were between 61 to 80 years old.[17] The age of the surveyed inventors at the time they were awarded ranged from 20 to 80 years, with an overall mean of 48 years and a standard deviation of 10.35. Prior studies found that the average age of the US inventor was 47 (Walsh and Nagaoka, 2009) and in the case of European inventors was 45 years (Giuri, *et al.*, 2007; Nager *et al.*, 2016). Thus, the average age of our respondents is consistent with previous studies suggesting also that the average inventor age when he/she developed a breakthrough invention does not seem to have changed over the last years.[18]

[17] 22 respondents (4% of the sample) did not disclose their age.
[18] Keep in mind that the Walsh and Nagaoka (2009) study refers to patents taken between 1995 and 2001, while the PatVal study (Giuri *et al.*, 2007) refers to patent taken between 1993 and 1997.

Results of the survey show that 58% of our inventors were born in the Americas (mostly in US). Asian inventors make up a 19% of our respondents; followed by a 16% of European inventors. A minority (3%) were born elsewhere.

Concerning the educational background, prior surveys reported that 77% of European inventors have a university degree and only 26% hold a doctorate degree (Giuri *et al.*, 2007), compared with 46% of US inventors holding a doctorate degree (Walsh and Nagaoka, 2009). Differently from these results, one of the most striking characteristics of the respondents to our survey is that more than half of them (65%) hold a PhD or equivalent degree suggesting that inventors in our sample are highly educated. Overall, 97% of the respondents have completed a university education: a bachelor, master or doctorate degree.

When we break down the sample by discipline of the highest degree, it is evident that most of inventors have a degree in engineering (48%) compared to 37% of degrees in hard sciences (physics, chemistry, mathematics and applied related fields); biomedical (8%) and social sciences (2%). Our results are consistent with prior studies (Toivanen and Väänänen, 2016; Jung and Ejermo, 2014) that report that inventors are more likely to have an engineering education and that this type of degree is correlated with the propensity to invent and patent.

From our survey data, we could identify that 76% of R&D 100 winners earned their highest degree in the Americas. Non-US born inventors seem to be attracted at earning a degree in the Americas (more specifically in US). This can be clearly depicted from the number of Asian born inventors that seem to have acquired only 6% of higher education in their country of origin. This information can be found in Table 3.3.

When looking at where non-US born inventors earned their highest degree we discovered that roughly 55% of inventors earned their highest degree in their country of origin followed by 39% of degrees earned in US and 6% earned worldwide. Table 3.4 reports non-US born inventors and where their highest degree was earned (N=171 foreign inventors).[19]

[19] 95% of the sample of inventors reported their country of origin (N=396).

Table 3.4: Non-US born inventors and their highest degree

	Non-US born inventors	Highest degree earned in country of origin	Highest degree earned in US	Highest degree earned worldwide (excluding US) e)
Americas (excluding US) a)	16(9%)	11(12%)	5(8%)	
Europe b)	67(39%)	53(56%)	7(10%)	7(64%)
Asia c)	79(46%)	23(24%)	52(79%)	4(36%)
Other d)	9(6%)	7(8%)	2(3%)	
	171(100%)	94(55%)	66(39%)	11(6%)

a) Includes Argentina, Canada, Mexico, and Venezuela.
b) Includes Belarus, Denmark, Finland, France, Germany, Greece, Italy, Macedonia, Poland, Romania, Spain, Sweden, Switzerland, The Netherlands, United Kingdom, and Ukraine.
c) Includes Bangladesh, India, Iran, Iraq, Japan, Lebanon, Pakistan, People's Republic of China, Russia, South Korea, Turkey, and, Vietnam.
d) Includes Australia, Brunei and Cameroon.
e) Includes Germany, Greece, Hungary, Israel, Japan, Russia, South Africa, Spain, Switzerland, and United Kingdom.

In Table 3.5 we also consider whether our respondents won more than one R&D 100 Award during the 2005-2014 time period. This is true for 383 people (8% of the targeted sample) and 134 respondents (3% of the total).

Table 3.5: Recipients of more than 1 award

	Targeted sample (% of the sample)	Recipient of more than 1 Award (% of the sample)	Responding inventors (% of the sample)	Survey response rate
Recipient of more than 1 Award				
TOTAL	**4630**	**383(8%)**	**134(3%)**	**2.89%**
Breakdown by gender:				
Male	4143(89%)	345(90%)	129(96%)	3.11%
Female	487(11%)	38(10%)	5(4%)	1.03%

After looking at their education and demographic characteristics, we then wanted to understand something about the working environment of the respondents and gain some information about their working experience. This information is reported in Table 3.6.

Table 3.6: Type of working units and years of experience

	Responding inventors (% of respondents)
<u>**Type of unit at the time of the invention:**</u>	
Research and development	330(80%)
An independent research and development unit or its sub-unit	21(5%)
A sub-unit attached to a unit with its primary focus on non-R&D such as manufacturing	5(1%)
Manufacturing	16(4%)
Software development	10(2%)
Other	32(8%)
<u>**Years of experience**</u> (mean)	14.62
<u>**Years of experience**</u> (standard deviation)	9.92
<u>**Years of experience**</u> (range):	0-50 years

Number of observations = 414

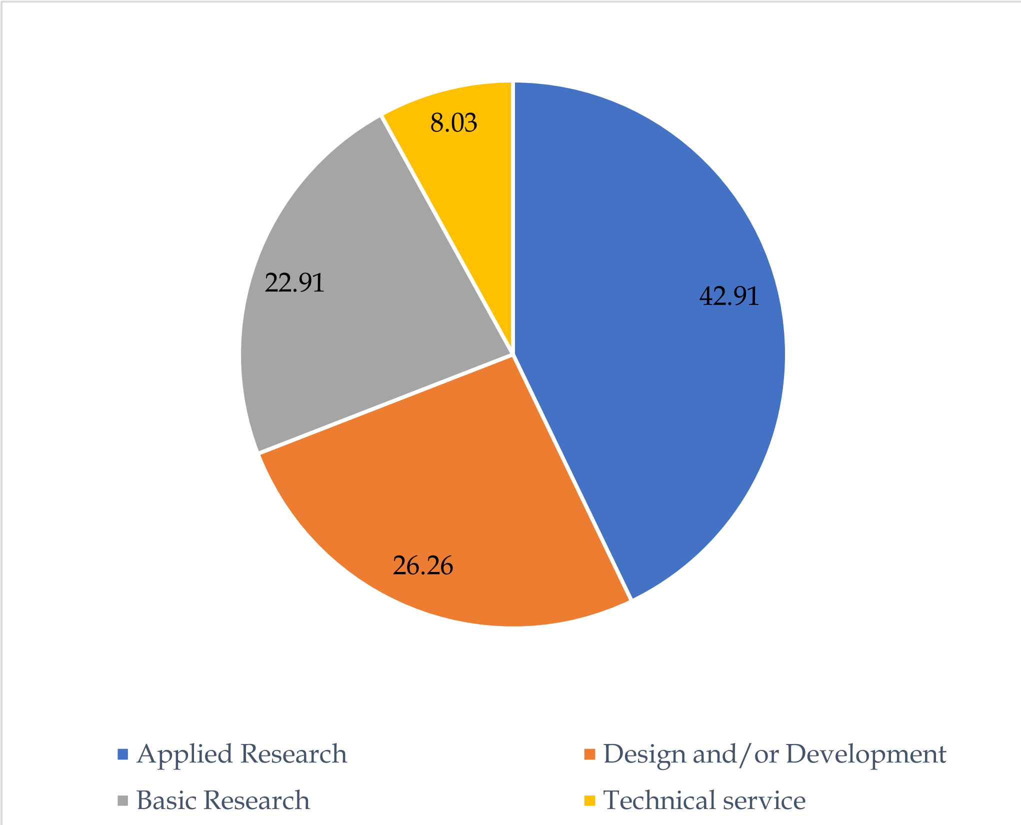
The average inventor in our sample has almost 15 years of experience working in the field, and worked mostly in research and development units (80%) within their organizations. All in all, this suggest that inventive activity leading to breakthrough inventions occurs when inventors are not new in their fields, during their late careers and possessing deep expertise and knowledge.

3.3.3. Efforts and rewards from inventing

Inventors spent more than 40% of their time/effort directly on applied research, whereas they dedicated around 23% of their time in basic research or in design and development activities. Only 8% of the activity was spent in non-creative activities such as technical service (see Figure 3.1).[20]

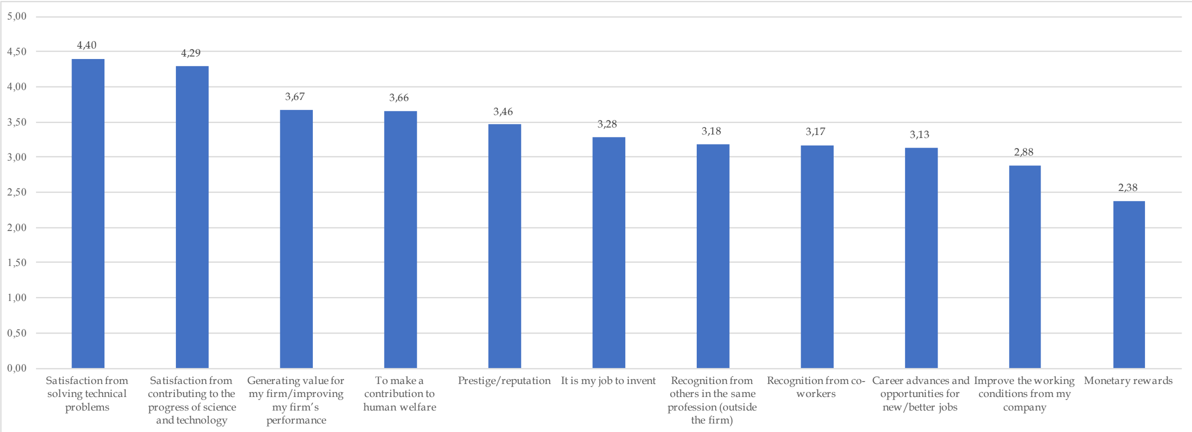
[20] The exact wording of the question on R&D effort was: "At the time of the research leading to the awarded invention, approximately what percentage of your R&D effort was:". The possible answers were: (a) Basic Research (scientific research with no specific commercial objectives); (b) Applied research (scientific or engineering research with specific commercial objectives; (c) Design and/or Development (technical activity translating research findings into product or processes); (d) Technical service (providing manufacturing support, troubleshooting, etc.)

Figure 3.1: Inventor share of R&D effort



Similarly to the findings from other surveys (Giuri, *et al*, 2007; Sauermann and Cohen, 2010) our surveyed inventors seem to be driven by genuine scientific and technological motivations for engaging in their inventive activity (see Figure 3.2 below). When they were asked to assess on a numerical Likert scale (1 = not important; 5 = very important) the importance of 11 reasons to work on inventing, the "social" motivations such as solving problems, contributing to progress of science and technology, or to the human welfare scored quite high in terms of importance (4.40, 4.29 and 3.66 respectively). Recognition from peers such as co-workers and colleagues outside the organization scored similarly but much lower (3.18 and 3.17 respectively). Career advances and monetary rewards scored even lower in terms of importance (3.13 and 2.38 respectively).

Figure 3.2: Average importance of 11 reasons to work on inventing (scale 1-5)



Number of observations = 415

3.4. The R&D 100 breakthrough inventions

There is a great interest around the specific characteristics of inventions, as they might come in many dissimilar forms, ranging from incremental technical change or run-of-the-mill inventions, to radical or breakthrough inventions (Schoenmakers *et al.*, 2010). Radical or breakthrough inventions are defined as *"those foundational inventions that serve as the basis for many subsequent technical developments"* (Ahuja and Lampert, 2001:523). In other words, breakthroughs are those inventions that the technological community has recognized as highly valuable (Ahuja and Lampert, 2001) and they do not necessarily resemble highly novel inventions that differ from existing solutions (Conti *et al.*, 2013).

The R&D 100 Award is conferred to inventions which are considered to be breakthroughs.[21] Across the years innovative products such as the flashcube (1965), the fax machine (1975), the halogen lamp (1974), and the HDTV (1998) have received the award. The R&D magazine identifies inventions in a wide range of different industries, yet there exist some limitations. First, the awards are mostly inclined towards product innovations rather than process innovations. Second, military innovations are not considered. Third, the awards rarely recognize new pharmaceutical products and hardware or software developed by the largest computer firms; nevertheless, there are many awards for medical devices and equipment

[21] Fontana *et al.* (2013) specify the main criteria used by the jury to assess the radicalness of the awarded inventions: "(i) technological significance (i.e., whether the product can be considered a major breakthrough from a technical point of view); (ii) competitive significance (i.e., how the performance of the product compares to rival solutions available on the market)."

(Block and Keller, 2009). Aware of these limitations, a section of the survey asked respondents several questions about the characteristics of the awarded inventions.

3.4.1. The characteristics of the invention and of the innovative process

Table 3.7 reports some statistics on the characteristics of the awarded inventions as well as on the characteristic of the invention process.

Table 3.7: Invention characteristics and process

Invention characteristics	**Responding inventors (% of respondents)**	**Invention process**	**Responding inventors (% of respondents)**
Type of invention:		**Collaborating inventors (range):**	
Product	217(52%)	0 - 10 inventors	363(89%)
Process	47(11%)	11 - 20 inventors	31(7%)
Both	151(37%)	21 - 30 inventors	8(2%)
		Higher 30 inventors	7(2%)
Build on a previous invention:		Range	0-60 inventors
Yes	176(42%)	Mean	6.95
No	212(51%)	Standard deviation	7.15
Don't know	27(7%)	Median	5.00
Previous invention in the same organization: [a]		**Research length (in person months):**	
Yes	77(19%)	0 - 33 months	234(58%)
No	126(30%)	34 - 67 months	135(33%)
Don't know	6(1%)	68 - 101 months	21(5%)
		Higher 102 months	15(4%)
		Range	0-168 months
		Mean	33.59
		Standard deviation	27.44
		% of total working time spent on inventing:	
		Range	1-100 %
		Mean	44.92
		Standard deviation	30.87

[a] This question was answered only by 209 inventors. Percentages in this question are calculated by drawing on the total sample of answers N=415.

More than half of breakthrough inventions were products, whereas 37% were both, a product and a process invention. About 42% of inventions were substantially built on an existing invention that, in 30% of the cases, was developed in another organization. The largest share of inventions was completed in less than three years (33 months). The average size of the team of inventors is around 7 and it ranges between 0 and 60 inventors (median: 5 inventors). The average inventor devoted less than 50% of his/her working time on inventing or on R&D activities when the invention was developed.

Concerning the composition of the team of inventors, we asked respondents to identify the organizations to which the collaborating inventors belonged. These results are summarized in Table 3.8.

Table 3.8: Collaborating organizations by organization type

Collaborating organizations	All sample	Firms	PROs	University
Inventor's own organization (% of respondents)	304(73%)	178(58%)	108(36%)	18(6%)
Government research organizations (% of respondents)	131(32%)	35(27%)	76(58%)	20(15%)
Universities (% of respondents)	77(19%)	31(40%)	15(20%)	31(40%)
Customers (% of respondents)	36(9%)	23(64%)	10(28%)	3(8%)
Other firms (% of respondents)	36(9%)	15(42%)	18(50%)	3(8%)
Suppliers (% of respondents)	33(8%)	21(64%)	11(33%)	1(3%)
Non-competitors (%of respondents)	16(4%)	5(31%)	9(56%)	2(13%)
Hospitals (% of respondents	11(3%)	5(46%)	3(27%)	3(27%)
Competitors (% of respondents)	3(1%)	1(33%)	2(67%)	0(0%)
Other (% of respondents)	18(4%)	9(50%)	8(44%)	1(6%)

Note: the number of respondents is considerable different for Firms, PROs and University. Data for this table comes from a 'multiple answer question'. Inventors were allowed to select more than one answer.[22]

When looking at the frequencies for the whole sample of respondents, we find that most of the collaborations (73%) have occurred within the inventor's own organization, followed by government research organizations (32%) and universities (19%). Only a minority of the respondents collaborated with customers (9%), suppliers (8%), other firms (9%), non-competitors (4%), and competitors (1%). However, when these results are broken down by type of organization (in which the respondents work) we observe much more heterogeneity.

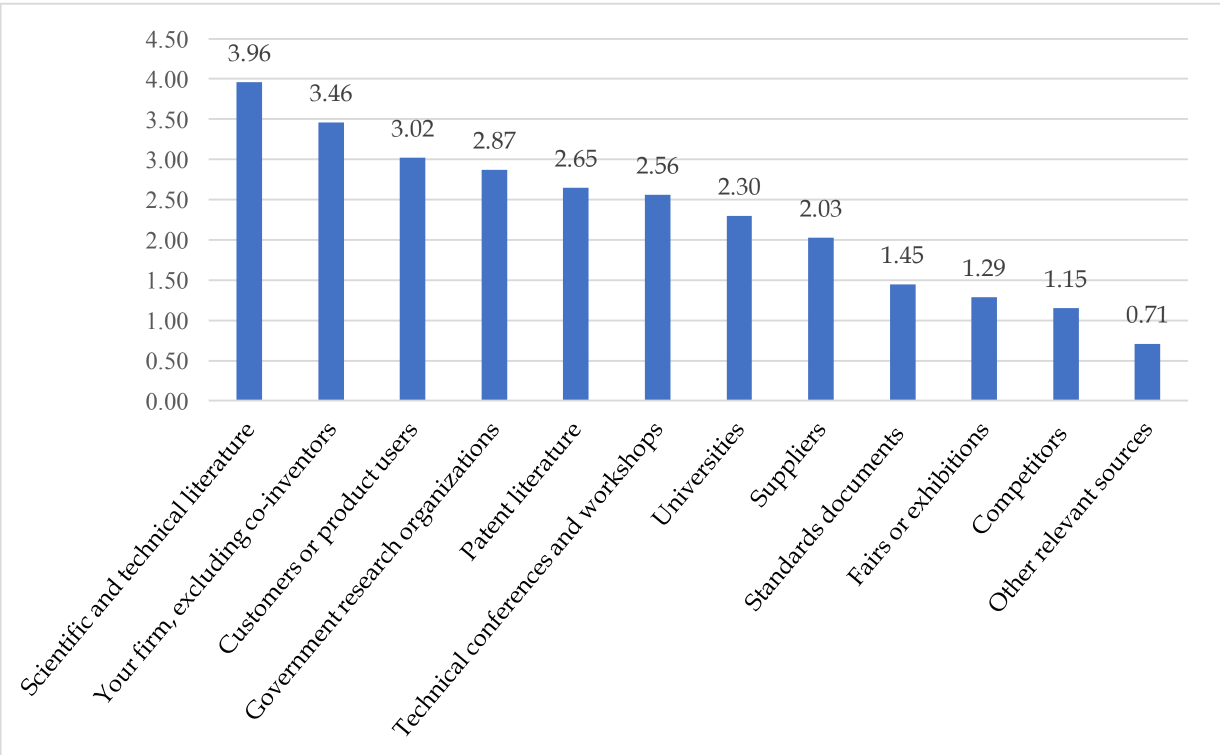
[22] For more information on this question and the exact wording of the same please refer to Appendix C, question A5.2.

For instance, suppliers and customers were the most frequently chosen partners for firms but not for PROs and universities. Collaborations between firms, universities and government research organizations are also frequent, but less frequent than between firms and universities (27% against 40% respectively). Finally, it is possible to note that universities tend to collaborate mostly with other academic institution (40%) rather than with any other type of organization. A similar trend is observed in the collaboration between government research organizations and other PROs (58%).

3.4.2. The context of the innovative activity

As the majority of inventors reported that the awarded invention was not built upon a previous invention it is relevant to understand what were their sources of inspiration and rate their importance. We thus asked inventors to rate, using a numerical Likert scale (0 = I did not use this source; 1 = not important; 5 = very important), 12 different sources of knowledge inspiring their inventions. Figure 3.3 summarizes the average score of the responses for each item.

Figure 3.3: Average importance of 12 sources of knowledge for inspiring the research (scale 0-5)

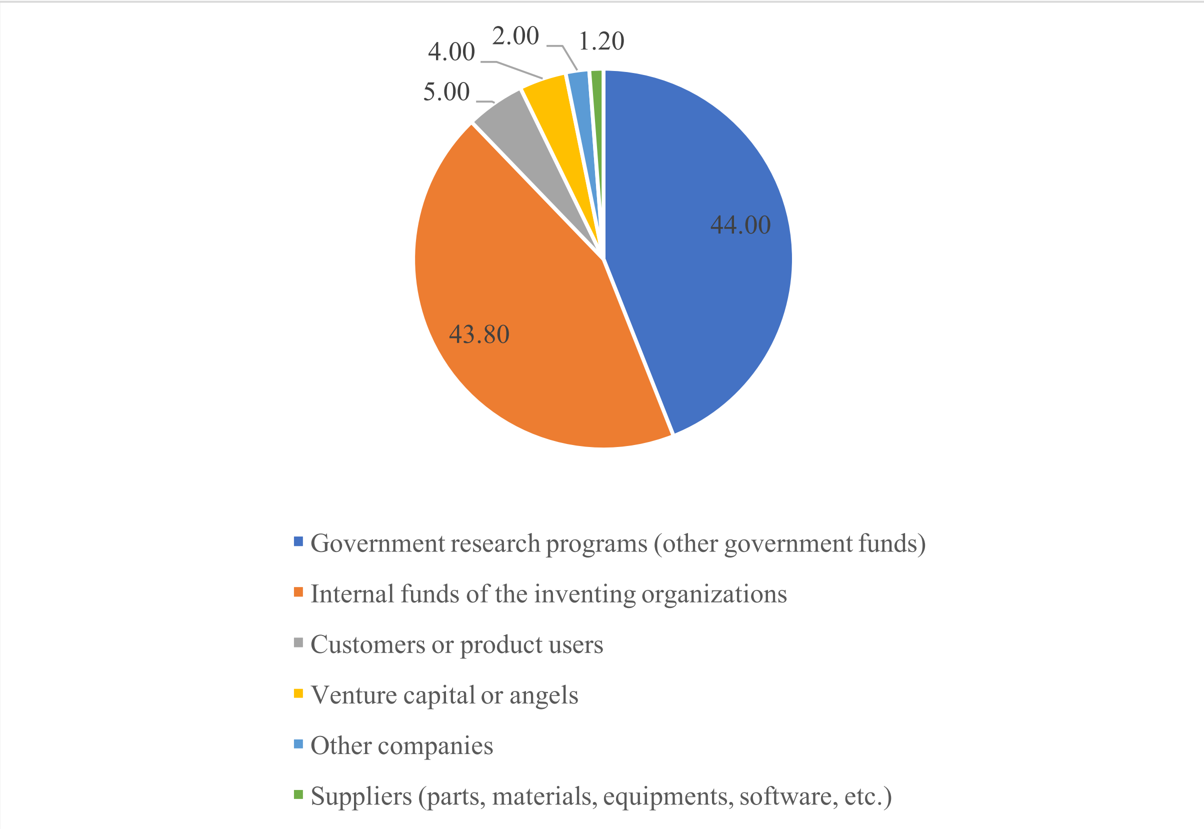


Number of observations = 415

Results suggest that, alongside internal sources, the most relevant sources of knowledge are represented by scientific and technical literature followed by customers, and government research organizations. The highest score of the scientific and technical literature, much higher than patent literature and much higher than the score reported in the PatVal survey (Giuri *et al.*, 2007),[23] suggests a substantial familiarity or 'absorptive capacity' with this type of knowledge by our respondents, which may just reflect the presence of universities and PROs in our sample or the existence of important linkages between firms and these institutions. On average, other industry sources like suppliers and competitors are considered less important as *stimuli* for breakthrough inventions. The importance of academic institutions in inspiring invention is limited, as well as attendance to conferences and workshops.

Besides being sources of inspiration, external organizations and partners can also affect the rate and direction of the inventive process by directly funding the research. Figure 3.4 below reports the breakdown of the funding for the R&D 100 inventions by source of funding.

Figure 3.4: Sources and shares of funding



'Government research programs or other government funds' and 'internal funds of the inventing organization' together contribute to almost 90% of the total funding for the inventions in our sample with an equal share. 'Venture capital or angels' contributed for 4%

[23] This difference may arise because PatVal focuses only on patented inventions and not necessarily breakthroughs.

of the total funding of the breakthrough inventions. A limited but non-negligible share of source of funding (5%) came from customers and product users interested in further technological developments.

Finally, to complete the analysis of the context of the inventive activity, we framed different types of scenarios and asked inventors about their invention creative process. The vast majority of inventions (69%) turned out to be the result of a targeted research project, while some others were unexpected by-products of the R&D project (10%). Only in 5% of the cases, the invention came from personal inspiration and creativity. This information is summarized in Table 3.9.

Table 3.9: The invention creative process

Scenarios:	**Responding inventors (% of respondents)**
The invention was the targeted achievement of a research or development project.	287(69%)
The invention was an unexpected by-product of a research or development project, not directly related to the main target of the project.	42(10%)
The idea for the invention was directly related to your normal job (which is not inventing), and was then further developed in a (research or development) project.	36(9%)
The invention was an expected by-product of a research or development project, not directly related to the main target of the project.	29(7%)
The idea for the invention came from pure inspiration/creativity not directly related with your professional field of expertise.	21(5%)

3.5. The use and value of the R&D 100 inventions

3.5.1. Technical and economic value of the inventions

Among its goals, the R&D 100 prize aims at awarding the most relevant invention in terms of both technological significance (i.e., whether the product can be considered a major breakthrough from a technical point of view) and competitive significance (i.e., how the performance of the product compares to rival solutions available on the market). However, both technical and economic significance can be assessed along several dimensions. In addition to this, as the selection of the winners occurs each year among a pool of heterogeneous applicants, awarded inventions might differ in terms of technical and competitive significance over time.

To gauge the extent of both the technical and the economic value of the inventions in our sample, we asked respondents to rate their inventions according to both their technical significance and economic value compared to other technical developments in their respective fields at the time of the invention. In both cases the evaluation was carried out relatively to other inventions in the US and worldwide. Results of these estimations are shown below.

Figure 3.5: Technological significance of the invention (US vs. Worldwide)

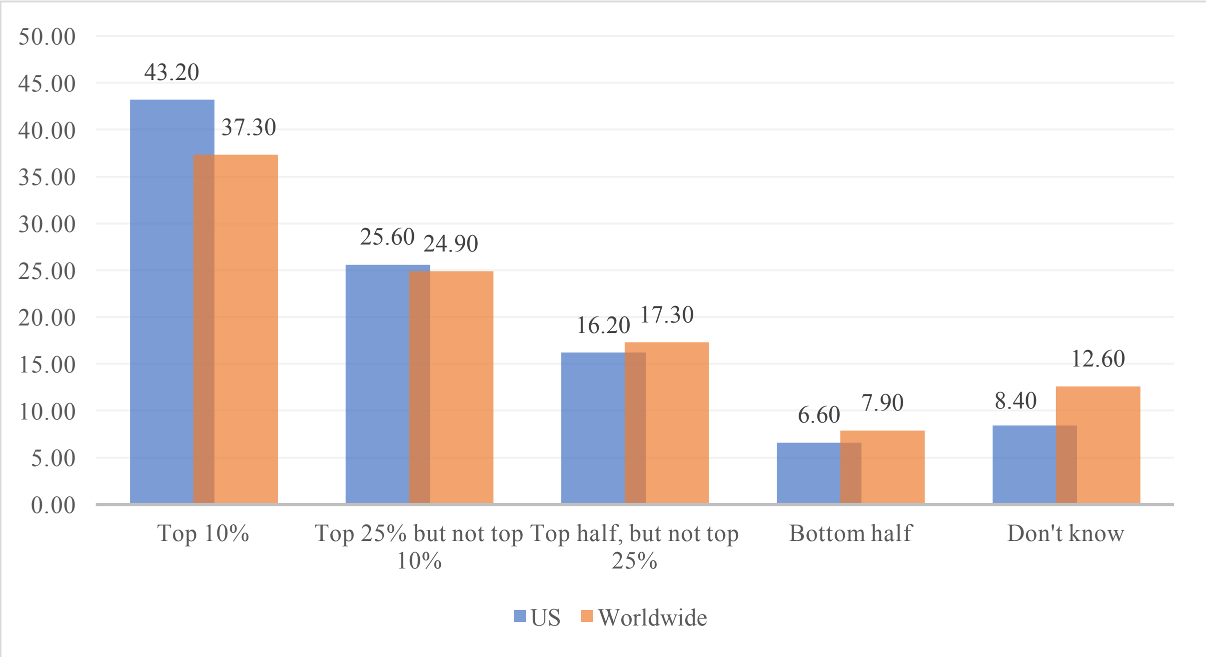


Figure 3.6: Economic significance of the invention (US vs. Worldwide)

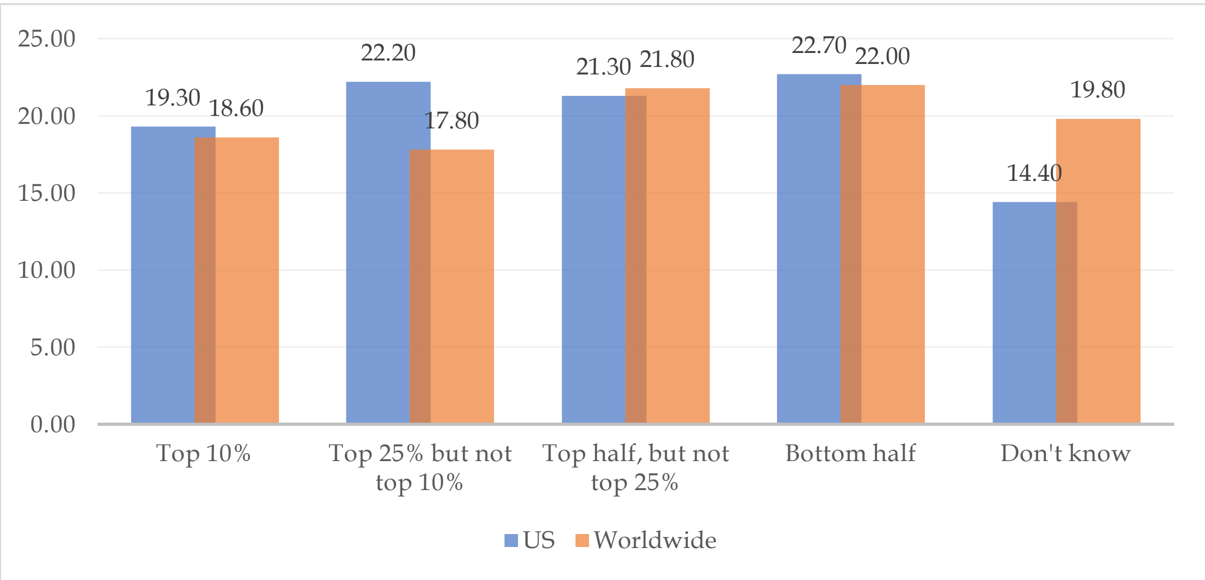


Figure 3.5 reports the results for the technical significance of the invention. In 43.20% of the cases, respondents rate their inventions in the top decile. The distribution is skewed with almost 70% of respondents rating their inventions in the top 25% when compared to other US inventions. Less skewed when compared to other inventions worldwide. Figure 3.6 reports instead the results for the economic significance of the invention. In this case, the distribution is much more uniform with 41% of respondents rating their inventions in the top 25% when compared to other US inventions but also one fifth of the sample rating their economic value in the bottom half. This difference in the distribution of the responses between the technical and the economic value is striking and confirms that the old divide between invention and innovation is still out there. It may also suggest that respondents were more conservative in their evaluation of the economic benefits because of lack of sufficient information. The latter interpretation is plausible in the light of the relatively higher number of respondents who said they could not rate the economic value (14.40% in Figure 3.6 against 8.40% in Figure 3.5).

3.5.2. Inventions and patents

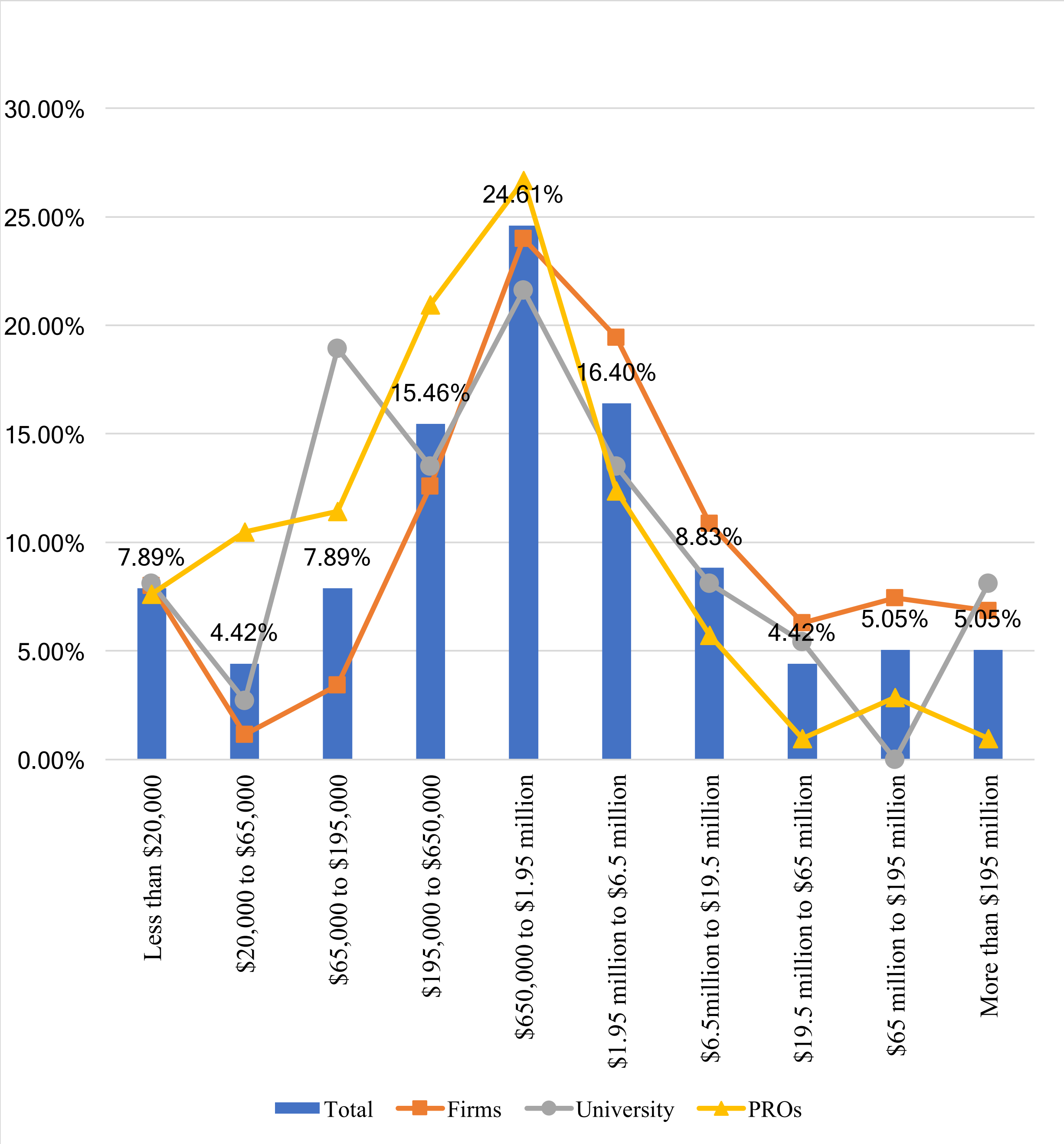
As highlighted in the introduction, an important advantage of our survey with respect to prior investigations is that our sample of inventors has been constructed starting from a population of awarded inventions and not from a population of patents. This allows us to make a distinction between awarded inventions that were patented and not. The distinction is relevant because prior research using the R&D 100 data has highlighted that only a small share (less than 10%) of the awarded inventions had actually been patented (Fontana *et al.*, 2013).[24]

Results of the survey show that nearly three-fourths of awarded inventions were patented. Those who patented the invention were subsequently asked to re-evaluate the current patent value if a potential competitor would have been interested in buying the patent.[25] Figure 3.7 shows the distribution of responses for the overall sample and by organization types.

[24] It is important to note that in the Fontana *et al*. (2013) the patent propensity was estimated for awards given within the 1977-2004 time period and with a different methodology. In this case, we directly asked inventors to declare whether or not the invention was patented. Most importantly: the higher patenting rate reported by the respondents of this survey could be explained by a non-response-bias driven by the cost of information disclosure. Inventors could be more reluctant to respond to the questions of the survey when the innovation is not protected by a patent, whereas for patented invention the disclosure cost has already been paid with the publication of the patent.

[25] The exact wording of the question, similar to the one contained in the PatVal survey (Giuri *et al*., 2007), was: "This is a hypothetical question: Suppose that on the day in which this invention was patented, the applicant had all the information about the value of the patent that is available today. If a potential competitor of the applicant was interested in buying the patent, what would be the minimum price the applicant would demand?"

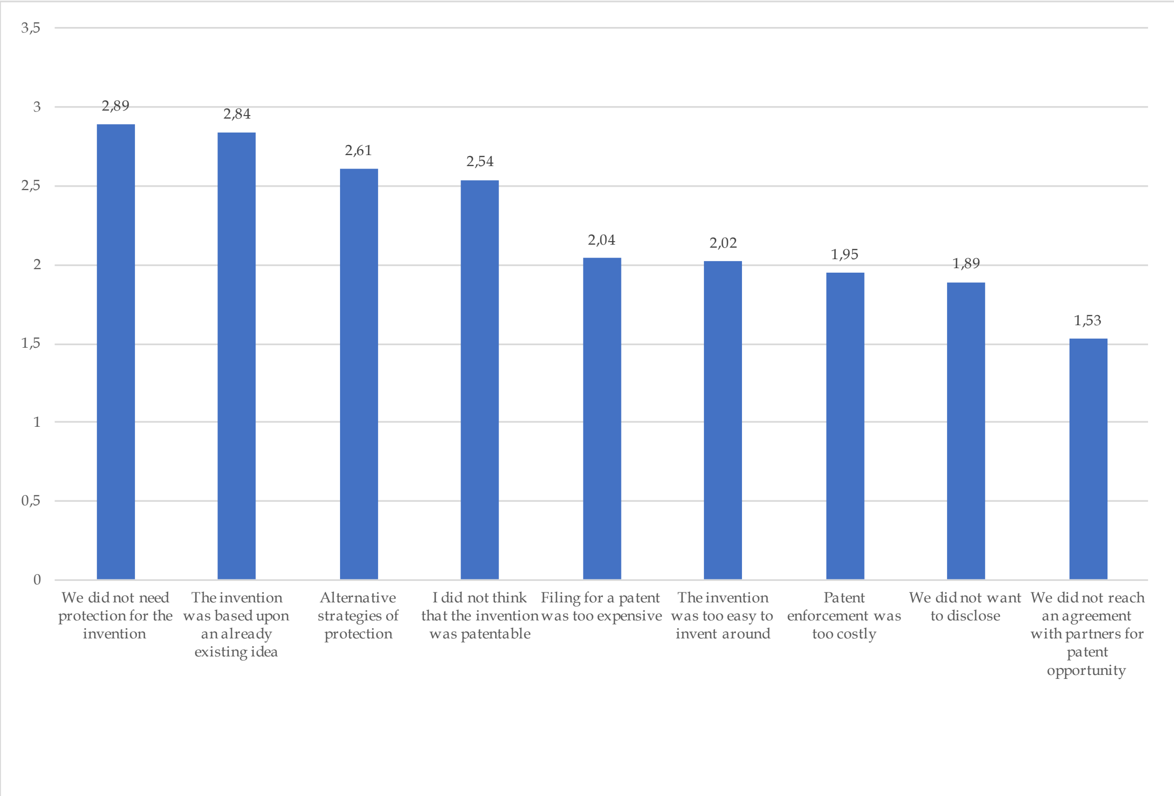
Figure 3.7: Estimated patent value



Contrary to what we would expect from prior studies (Harhoff *et al.*, 2003; Giuri *et al.*, 2007) the distribution of patent values is not much skewed. If it is true that less than 15% of the patents have a value higher than $19.5 million, it is also true that slightly more than 20% value less than $195.000 with the bulk of the patents valued between $195,000 and $19.5 million. Important differences in the evaluation exist across organizations, with a much more skewed distribution for inventors working in universities and PROs than for inventors working in firms.

Finally, we identified 9 possible reasons for not patenting and asked respondents who did not apply for a patent to evaluate them on a numerical Likert scale (1 = not important; 5 = very important). Figure 3.8 shows the average evaluations.

Figure 3.8: Average importance of 9 reasons for not patenting the invention (scale 1-5)



The distribution of the evaluation is rather uniform as no reason clearly stands out among the others. No need for patent protection or lack of novelty of pre-requisites for patenting seems to be among the most important reasons. Costs associated to patenting, both in terms of filing a patent and in terms of patent enforcement were also deemed important for not patenting. In some cases, alternative strategies of appropriation were also pursued.

3.6. Conclusion

As awards and prizes are increasingly being used alongside monetary rewards to acknowledge significant contributions and motivate employees and inventors, the empirical literature in innovation studies and management lacks of a comprehensive empirical evidence on what are the inventions that are most likely to receive an award and who are the inventors who benefit from them. *'The R&D 100 award inventor survey'* was designed to provide a first comprehensive assessment of what are the characteristics of the inventive process leading to awarded innovations, what is their value, and what are the characteristics of the inventors who receive such awards.

This paper has presented the preliminary findings of the survey. Concerning the characteristics of the awarded inventors, our findings suggests that the average awardee inventor is male, 48 years old, highly educated, with a background in engineering who works mainly in the R&D department of small and medium sized firms. Intrinsic motivations, such as the satisfaction of inventing or the improvement of human welfare, rather than monetary rewards and or career concerns, are the main drivers of the research commitment. In terms of characteristics, our results highlighted that the average awarded invention is the outcome of team work, it lasted less than three years and it was generally the outcome of team work involving mainly internal collaborators, but tapping external sources of knowledge, mainly from scientific and technical literature for idea generation. Most of the inventions were product innovations and the distribution of their perceived economic value tends to be rather uniform. On the contrary, the distribution of their technical value is rather skewed towards the top decile. Finally, only three quarters of the awarded inventions were patented and the distribution of the value of those that were patented is rather bell-shaped.

Interesting as they might be, these findings are mainly exploratory and limited. However, they provide indications for future avenues of research. Among the range of possible topics that can be addressed with these data, there is the issue of the determinants of patenting breakthrough inventions. Contrary to existing surveys on inventors which based the construction of their samples from patent data, our sample allows us to study the determinants of the propensity to patent, which we expect to differ across organizations, value of the inventions and individual motivations, as well as demographic characteristics of the inventor. Another aspect relates to the relationship between the motivations for engaging in innovation and the characteristics of the context in which the invention occurred, controlling again for the individual characteristics of the inventor as well as of the invention. A further issue concerns the relationship between the receipt of the award and the productivity or the career of the inventor. Some of these topics will be explored in the remaining essays of this dissertation. Others will be explored in future research.

Chapter 4

When breakthrough innovations do (not) get patented? Evidence from *'The R&D 100 award inventor survey'*

4.1. Introduction

The ultimate goal of the patent system is to protect the rights of inventors and assignee(s) to reap the benefits from the invention and prevent others from imitating. For this reason, it must be designed in such a way to balance the public interest and the interest of innovators. Patents play an important role in inventive activity. There exist however considerable limitations when using patent data as an indicator of innovative activities. The reason is simple: not all innovations are (or can be) patented.[26] In this essay, we take a unique novel dataset on breakthrough innovations which won a prize between 2005 and 2014 and study the factors affecting their propensity to be patented or not. Our findings show that inventors' prior experience in patenting, the organization context they work in (i.e. firms) and the team size they belong to, positively affect the probability to patent.

This chapter is organized as follows. In Section 4.2. we introduce the data based on the *'The R&D 100 award inventor survey'* and assess the representativeness of our sample using a control sample. Section 4.3. reports the results of the econometric exercise, focusing on the probability to patent an awarded invention as well as the value and quality of patented inventions. Section 4.4. concludes.

4.2. The 'R&D 100 Awards' inventor database

Our sample relies upon a unique data set of breakthrough innovations which were awarded a prize between 2005 and 2014. The data were collected from the annual 'R&D 100 Awards' competition run by the US magazine R&D 100 which has awarded, over the last 55 years, not only the 100 most significant new technical products but also the innovators responsible for them. The data collection for our sample consisted of two phases. We first retrieved additional information, on those inventors who have been awarded the R&D 100 Award prize, such as their CVs and their current email addresses. We then targeted them with a survey (*'The R&D 100 award inventor survey'*) that started in June 2016 and ended in January 2017. The aim of the

[26] See also Moser (2005); Thomson (2009); Nicholas (2011); Moser, (2012); Fontana *et al.* (2013).

survey was to gather information on several characteristics of both the innovation process and the awarded inventors. The questionnaire consisted of four sections, (i) the invention process (i.e. sources of knowledge leading to the invention, type of invention, etc.), (ii) the use and value of the invention (i.e. technical and economic value of the invention, reasons for patenting (or not), how to protect firm's competitive advantage, etc.), (iii) R&D activity leading to the invention, and, (iv) career and background of the inventors who received the award.

The R&D 100 magazine, over a ten-year period, awarded 995 inventions. From this targeted sample of 995 awarded inventions we have information on 31% of those inventions (N=312). Then, our final sample consists of 415 inventors (383 male and 32 female) responsible for the 312 awarded inventions. Results of the survey show that most of the awarded inventions over the period of 2005-2014 were done in collaboration. Out of 409 respondents, 89% worked in a team of less than 11 inventors, 7% in a team of 11 to 20 inventors, and 4% in a team with more than 21 inventors.

Following prior studies that have confirmed that only a share of awarded innovations is patented (Moser 2012; Fontana *et al.,* 2013), we followed this principal idea and asked, in our survey, the following question: "Was the awarded invention patented?". From our final sample of respondents, 301 (73%) answered that they patented their invention. The most striking result to emerge from this question is that roughly one fourth (N=114) of awarded inventions were not patented. We argue that, occasionally, innovators rely on alternative methods to patent in cases where their invention presents a technological advancement.[27] Further, the propensity to patent varies considerably across industries, technological sectors and organizations (Mansfield, 1986; Graham *et al.*, 2009; Moser 2012; Fontana *et al.*, 2013).

In recent years, there has been a considerable interest in the limitation of using patent data as indicators of innovative activity, as not all-important inventions may necessarily end up being patented (Moser 2005; Moser, 2012; Thomson, 2009; Nicholas, 2011; Fontana *et al.*, 2013). However, more research needs to be done. For this reason, we believe that our dataset offers a unique opportunity to study innovations occurring inside and outside the patent system.

As previously mentioned, the set of awarded inventions (covered by the survey) is smaller than the set of responding inventors. Consequently, in our final sample the total number of

[27] Most inventors reported that the awarded invention was not built upon a previous invention. More details can be found in our previous essay in Chapter 3, Section 3.4.1.

inventions that were patented is 229. The subjects responsible for the development of these inventions, were subsequently asked to indicate the patent number of their inventions. The overall number of responses to this question was 131, which corresponds to 57% of the awarded inventions. Table 4.1 reports this information more in detail.

Table 4.1: Sample size and awarded inventions

Survey respondents		Awarded inventions	
	Total responses (% of responses)		**Total responses (% of inventions)**
Total number of respondents	415	**Total number of inventions**	312
Female inventors	32(8%)	of which patented	229(73%)
Male inventors	383(92%)	of which not patented	83(27%)
Respondents that patented	301(73%)	Patented inventions matched to a patent number (USPTO patents)	131(57%)
Respondents that did not patented	114(27%)		

Using the patent number provided by the respondents, we retrieved the following information (i) publication year of the patent; (ii) number of forward patent citation(s); (iii) International Patent Classification (Int. Cl.).[28] This last information was collected by using Google Patents[29] and PatentsView.org.[30] We identified 59 different IPC classes out of the 131 patents with a publication year between 1983 and 2016.

All in all, we have four sets of observations: (i) the set of respondents (N=415), (ii) the set of awarded inventions (N=312), (iii) the set of declared patented inventions (N=229), and, (iv) the set of patented inventions associated to a USPTO patent number (N= 131).

[28] The International Patent Classification (IPC) is a hierarchical patent classification scheme used worldwide to categorize the content of patents according to the technological areas they belong to. The IPC was established under the Strasbourg Agreement (1971). In accordance with this agreement, it has been determined that the abbreviation "Int. Cl." may precede the classification symbols on published patent documents. See http://www.wipo.int/classifications/en for more information.
[29] Accessed April 2, 2017.
[30] Accessed April 6, 2017.

4.2.1. Measures

In this study, we will use the dataset to estimate, the probability to patent an R&D 100 invention, and the value and quality of the invention conditional on patenting. The questionnaire we used for the survey contained several questions aimed at assessing the significance of the invention along several dimensions.[31] Our main dependent variables are built on the following information:

In the survey, we asked inventors whether they had or not patented their awarded invention.

1. **Whether the R&D 100 invention was patented or not.** This variable is equal to 1 if the invention was patented (N=301) and 0 if not (N=114).

The main economic returns of patented innovations come mostly through either commercialization and licensing, which can bring benefits in terms of royalties. For this reason, we used survey answers on licensing and commercialization of the awarded inventions as a proxy to capture their value.

2. **Patented invention was commercialized.** This variable is defined for the inventions that were patented (No. of observations: 301) and captures those that commercialized as a product, process or service.[32]
3. **Patented invention was licensed.** This variable is defined for the inventions that were patented (No. of observations: 301) and captures those that were licensed out to an independent party.[33]

The R&D 100 magazine awards each year the 100 most significant new technical products in terms of both technological and competitive significance. In the survey, we asked respondents to rate their inventions in relation to their technical and economic value comparing them to other technical developments in their same filed during the year when the invention was developed. The assessment was carried out comparatively to other rival inventions available both in the US and worldwide.

[31] Our questionnaire contained questions similar to those used in previous surveys such as the European Inventors Survey 2003 (i.e. PatVal) and the '2007 Georgia Tech Inventor Survey'.

[32] This variable was defined only for patented inventions. The exact wording of this question was: "Has the patent applicant/owner ever used the patented invention in a product/process/service that has been commercialized?". The possible answers were: (a) Yes; (b) No; (c) Not yet, but still investigating the possibilities.

[33] This question seizures whether inventors transferred interest in a patent to a licensee who can benefit from the patent and enforce intellectual property rights. When inventors answered 'Yes' subsequent questions on the type of licensing and number of licensees were asked. For more information on this question and the exact wording of the same please refer to Appendix C, question B11.

4. **Technical significance of the invention in US.** This variable was constructed by asking R&D 100 inventors whether their inventions can be considered a breakthrough from a technical point of view in US (No. of observations: 407). This variable is a categorical one and has been reverse coded where 0 corresponds to the higher significance and 4 to the lowest. [34]
5. **Technical significance of the invention worldwide.** Like the previous variable, this variable was constructed from the same question where we asked whether the awarded invention can be considered a breakthrough from a technical point worldwide (No. of observations: 405).
6. **Economic value of the invention in US.** This variable (No. of observations 409) was constructed by asking the inventors to rate how the performance of the awarded invention compares to rival solutions available on the US market. This variable is categorical and has been reverse coded where 0 corresponds to the higher significance and 4 to the lowest[35].
7. **Economic value of the invention worldwide.** This variable (No. of observations 404) captures how performance of the awarded invention compares to rival solutions available worldwide. We construct this variable in a similar way like the previous one.

Those subjects who declared that they had patented their invention, were also requested to reassess the present value of their patent in case a potential competitor would have been interested in buying the patent.

8. **Estimated patent value.** This variable (No. of observations: 301) is a re-evaluation of the current patent value.[36]

Additionally, we also include the 'number of citations received' as a dependent variable.

9. **Number of citations received.** This variable contains information on the number of forward patent citations for those inventions that had the USPTO patent number reported in the survey. We subsequently looked for those USPTO patents and retrieved

[34] Exact wording of the question on the technical significance in the US and worldwide: "Compared to other technical developments in your field during the year the invention was invented, how would you rate the technical significance of your invention, in the US and worldwide". The possible answers were: (a) Top 10%; (b) Top 25% but not top 10%; (c) Top half, but not top 25%; (d) Bottom half; (e) Don't know.

[35] Exact wording of the question on the economic value of the invention in the US and worldwide: "Compared to other technical developments in your field during the year the invention was invented, how would you rate the economic value of your invention, in the US and worldwide) The possible answers were: (a) Top 10%; (b) Top 25% but not top 10%; (c) Top half, but not top 25%; (d) Bottom half; (e) Don't know.

[36] Exact wording of the question: "This is a hypothetical question: Suppose that on the day in which this invention was patented, the applicant had all the information about the value of the patent that is available today. If a potential competitor of the applicant was interested in buying the patent, what would be the minimum price the applicant would demand?".

information on the number of forward patent citations using Google Patents and PatentsView.org.

Table 4.2 lists the dependent and explanatory variables that will be used in the analysis.

Table 4.2: List of variables

Variable name	Type	Values
Dependent variables		
Invention was patented	Dummy	1 Yes, 0 No
Patented invention was commercialized	Dummy	1 Yes, 0 No
Patented invention was licensed	Dummy	1 Yes, 0 No
Technical significance of the invention in US Technical significance of the invention Worldwide Economic value of the invention in US Economic value of the invention Worldwide	Categorical	1: Top 10%, 2: Top 25% but not top 10%, 3: Top half, but not top 25%, 4: Bottom half
Estimated value of the patent	Categorical	1: Less than $20,000 2: $20,000 to $65,000 3: $65,000 to $195,000 4: $195,000 to $650,000 5: $650,000 to $1.95M 6: $1.95M to $6.5M 7: $6.5M to $19.5M 8: $19.5M to $65M 9: $65M to $195M 10: More than $195M
Number of citations received	Continuous	
Explanatory variables		
Inventor characteristics		
Multi-award winner	Dummy	1 Yes, 0 No
Amount of working hours	Continuous	Weekly
No of publications	Continuous	
No of applied patents	Continuous	
PhD highest degree	Dummy	1 Yes, 0 No
Experience in the field	Continuous	No of yrs
Age (Log)	Continuous	No of yrs
Organization Tenure (Log)	Continuous	No of yrs
Organization characteristics		
Organization Type	Categorical	1: Pub. Res. Org. 2: University 3: Firm
Organization size (Log)	Continuous	No of employees
Invention characteristics		
Duration of research leading to invention	Continuous	No of months
Type of innovation	Categorical	1: Product innovation 2: Process innovation 3: Both product & process
Number of collaborating inventors	Continuous	
Research effort	Continuous	Full time man/months

We divided our explanatory variables in three groups capturing respectively: the characteristics of the inventor, the characteristics of the organization, and the characteristics of the invention. General demographics, experience and productivity of the inventor may reinforce the probability of a breakthrough to occur and to be patented. For this reason, we control for these characteristics of the inventor by using the following variables. [37]

First, we control for the number of total R&D 100 Awards received by a single inventor. Being a multi-award winner, can affect the probability of patenting or not a breakthrough innovation.

1. **Multi-award winner.** This dummy variable defines whether the inventor is a winner of more than one R&D 100 Award throughout the course of his/her workable life. (No. of observations: 413).

Second, we account for efforts on inventing.

2. **Amount of working hours.** This variable quantifies the number of hours, in a typical week, the respondent works on inventing (No. of observations: 412).

Third, some inventors might be keen on publishing and patenting. We control for these by looking at the number of publications and applied patents three years prior to the awarded invention.

3. **No. of publications.** This variable includes the number of articles that the respondent published in scientific journals in the three years prior to the awarded invention (No. of observations: 407).
4. **No. of applied patents.** This variable includes the number of patents that the respondent applied for in the three years prior to the awarded invention (No. of observations: 406).

Fourth, we control for several demographic factors such as education, experience and length of the career of the inventor. Indeed, demographic factors such as level of education and age of the inventor have been studied by previous works (Giuri *et al.*, 2007; Walsh and Nagaoka, 2009[38]; Nager *et al.*, 2016[39]). It is interesting to note that respondents in our sample are highly educated, 65% of them hold a PhD or equivalent degree. Further, the average age of our

[37] More information on R&D 100 inventors can be found in our first essay in Chapter 3, Section 3.3.
[38] Walsh and Nagaoka (2009) study refers to patents taken between 1995 and 2001, while the PatVal study (Giuri *et al.*, 2007) refers to patents taken between 1993 and 1997.
[39] Nager *et al.* (2016) studies the demographics of US inventors, comparing R&D 100 patent awards for the period 2011 to 2014 with other three samples of innovation: the Triadic Patents Life Science, the Triadic Patents Information Technology for the period 2011-2014, and, the Triadic Patents Large Tech Companies (2014-2015).

respondent is 48 years. The "representative" inventor in our sample has almost 15 years of experience working in his/her field.[40] The age of the inventor is the difference between the year of birth of the inventor and the year of the awarded invention.[41] To control for the length of experience in the field, we count the number of years the inventor worked in the technical field.[42] Finally, we control for the length of the career of the inventor at the time of the award.

5. **PhD highest degree.** Dummy variable indicating whether the inventor holds a PhD at the time of the invention (No. of observations: 414).
6. **Experience in the field.** Number of years the inventor worked in the technical field of the invention (No. of observations: 405).
7. **Age (Log).** Age of the inventor (logarithm of the years) at the time of the award (No. of observations: 393).
8. **Organization tenure (Log).** Job tenure of the inventor (logarithm of the years) at the time of the award (No. of observations 403).[43]

Innovations can occur in all kinds of organizations (Galbraith, 1982), for this reason we asked the respondents to identify the organizations to which they belonged at the time of the award. We identified three types of organizations: Public Research Organizations (PROs), universities and firms. The size of the organizations is given by the number of employees at the time of the award. Variables capturing innovative and patent activity at the organization level are the following:

9. **Organization type.** Type of organization that received the award – 3 types: PROs, university, and firm.
10. **Organization size (Log).** Logarithm of number of employees (No. of observations: 410).

We also control for specific characteristics of the awarded inventions, such as the length of the research, type of innovation, collaboration and research effort. Awards given by the R&D 100 magazine go mostly to product innovations rather than process innovations (Block and Keller,

[40] Please see Chapter 3, Section 3.3.2.
[41] We asked in the survey to disclose their year of birth, 22 respondents (5% of the sample) did not disclose this information.
[42] This information was retrieved by asking inventors the question: "At the time of the invention, how many years had you worked in the technical field of the invention." See the questionnaire in Appendix C.
[43] This information was computed as the difference between the year of the award and the year the inventor joined his/her organization at the time of the award. This latter information was retrieved from question D8 of the survey. The exact wording of the question was: "In which year did you join this organization (or start your business if self-employed)?"

2009). Results from our survey support this finding.[44] We have previously outlined that most of the inventions were done in collaboration. We argue that there is a good probability that the higher the effort, the higher would be the value of the patent, for this reason we lastly control for research efforts.

11. **Duration of the research leading to the invention.** Length in months of the research leading to the awarded invention (No. of observations: 405).
12. **Type of innovation.** Type of the awarded invention – product, process, or both (No. of observations: 415).
13. **No. of collaborating inventors.** Number of inventors working on the awarded invention (No. of observations: 409).
14. **Research effort.** Number of full-time man-months required to complete the awarded invention (No. of observations: 400).

Table 4.3 summarizes the main descriptive statistics of the variables that will be used for the analysis. The surveyed inventors, on average, collaborate in teams composed of 7 inventors (mean: 6.951), have 15 years of experience (mean: 14.617), have published 10 articles on scientific journals (mean: 10.499), and filed 4 patents (mean: 3.781) during the three years prior to the awarded invention. The average number of forward patent citations is 25 (mean 25.412). The single inventor spent roughly 50 hours per week on inventing (mean: 49.604). The length of the research leading to the awarded invention is approximately of 34 months (mean: 33.585).

[44] Findings in our previous essay, in Chapter 3, Section 3.4.1. demonstrated that 52% of awards were given to breakthrough inventions involving products, 37% were both a product and a process invention. Just 11% of awards were given to process innovations.

Table 4.3: Summary descriptive statistics

Variable name	No of observations	Mean	SD	Min	Max
Invention was patented	415	0.725	0.447	0	1
Patented invention was commercialized	301	0.691	0.463	0	1
Patented invention was licensed	301	0.385	0.487	0	1
Technical significance of the invention in US	407	2.029	1.094	1	4
Technical significance of the invention Worldwide	405	2.210	1.151	1	4
Economic value of the invention in US	409	2.763	1.146	1	4
Economic value of the invention Worldwide	404	2.869	1.151	1	4
Estimated value of the patent	301	5.389	2.097	1	10
Number of citations received	131	25.412	38.193	0	304
Multi-award winner	413	0.324	0.469	0	1
Amount of working hours	412	49.604	14.220	2	160
No of publications	407	10.499	17.273	0	200
No of applied patents	406	3.781	11.197	0	200
PhD highest degree	414	0.650	0.478	0	1
Experience in the field	405	14.617	9.922	0	50
Age (Log)	393	3.863	0.221	3.135	4.394
Organization Tenure (Log)	403	2.378	0.788	0	3.807
Organization Type	415	1.964	0.946	1	3
1: Public Research Organization	415	0.465	0.499	0	1
2: University	415	0.106	0.308	0	1
3: Firm	415	0.429	0.496	0	1
Organization size (Log)	410	7.386	2.112	1.792	9.210
Duration of research leading to invention	405	33.585	27.444	0	168
Type of innovation	415	1.841	0.929	1	3
1: Product innovation	415	0.523	0.500	0	1
2: Process innovation	415	0.113	0.317	0	1
3: Both product & process	415	0.364	0.482	0	1
No of collaborating inventors	409	6.951	7.151	0	60
Research effort	400	94.786	132.167	0	500

4.2.2. Assessing the quality of the 'R&D 100' award inventions

To assess whether the value of our sub-set of patented awarded inventions (N=131) is higher when compared to other patented inventions, we measured the patent citations of an analogous random sample of patents. Earlier studies have performed this similar exercise on patent data to provide an important rationale for the use of forward citations as an indicator of the quality of patents (Carpenter *et al.*, 1981), to systematically compare patented and unpatented innovations across industrial sectors (Fontana *et al.*, 2013) and to investigate inventor-level characteristics promoting novel inventive effort (Verhoeven *et al.*, 2016).

In our set of R&D 100 patented inventions (N=131) we identify 59 different IPC classes. The criteria for determining an 'eligible match' were the 4-digit IPC class and the publication year of the focal patent referring to the awarded invention. We then built, for each focal patent, a matched random sample of twenty USPTO patents with the same granted year and IPC class.

This exercise leaves us with a control group of N=2,617 matched patents. For each patent of the control group (N=2,617) we then retrieved the number of forward patent citation(s).[45]

By employing the non-parametric Mann-Whitney test we confirm that there is a "quality premium", in terms of number of forward citations, for the R&D 100 invention that got patented. In other words, inventions that have been patented and received an R&D 100 Award are more valuable compared to those that have been patented in the same technological class but not awarded. Results of this analysis are reported in Table 4.4.

Table 4.4: Patent citations received by R&D 100 inventions and a random sample of patents (matched by granted year and technology class)

	Number	Mean	Median	Standard deviation	Min	Max
R&D 100 Patents	131	25.412	13	38.193	0	304
Random Sample	2617	7.003	1	24.490	0	592

Note: The Mann-Whitney test rejects the Null Hypothesis of equal populations.

4.2.3. Assessing the value of 'R&D 100' inventions

In this section, we present some descriptive statistics on several alternative characteristics, such as (i) licensing, (ii) commercialization, (iii) technical and economic significance of the invention in the US and worldwide, (iv) estimated patent value, and (v) patent citations, to assess the value and quality of the inventions conditional on patenting.

Around three fourths of breakthrough inventions were patented (N=229) between 2005 and 2014. The propensity to patent awarded inventions remains constant throughout the ten-year period with a slight decline from 2005 to 2009. This information is shown in Figure 4.1.

45 The number of forward patent citation(s) for the control group was collected by using Google Patents and PatetentsView.org, accessed April 6, 2017.

Figure 4.1: Count of patented and awarded inventions by year

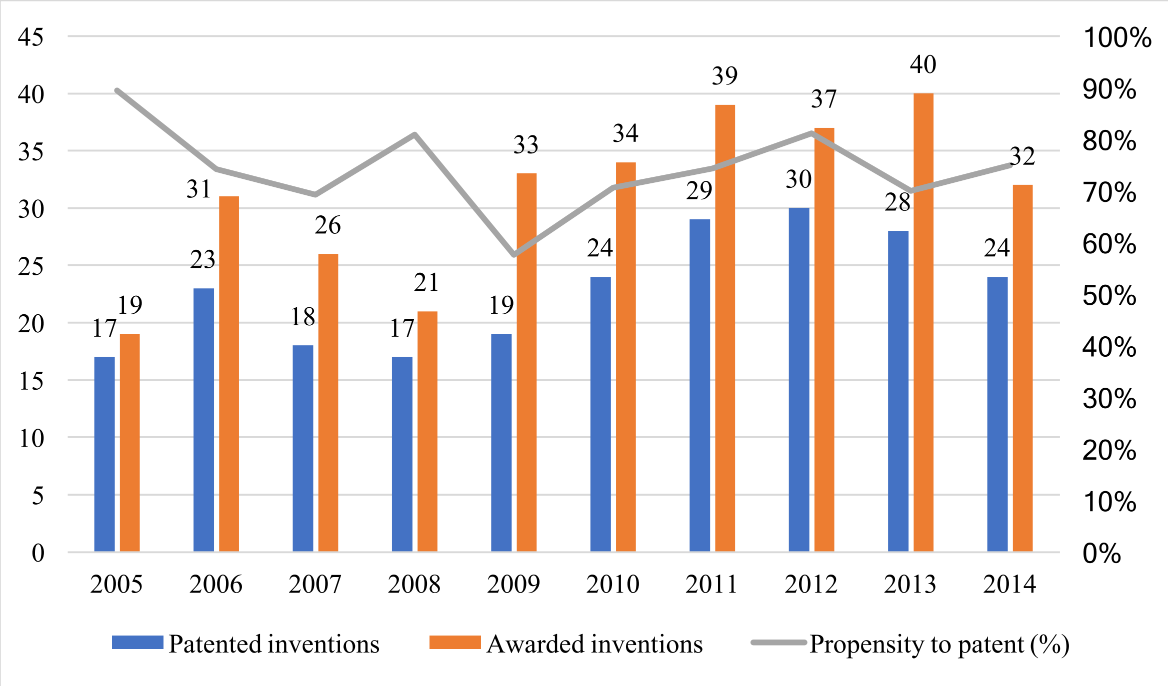
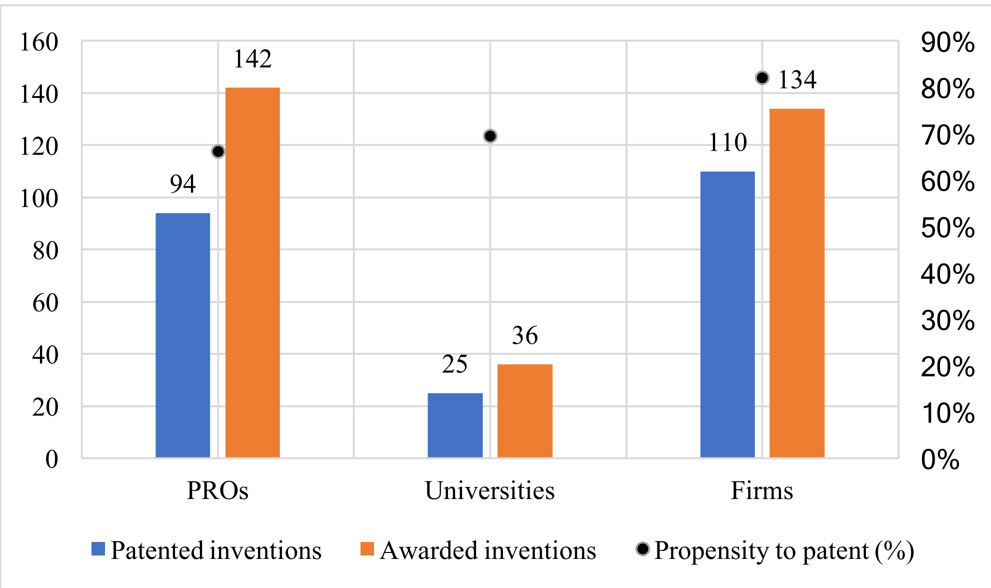


Figure 4.2 displays the count of patented inventions and awarded inventions classified by organization type. The figure clearly indicates that firms patent more their awarded inventions (82%) followed by universities (69%). PROs seem to patent less (66%) compared to firms and similarly to universities.

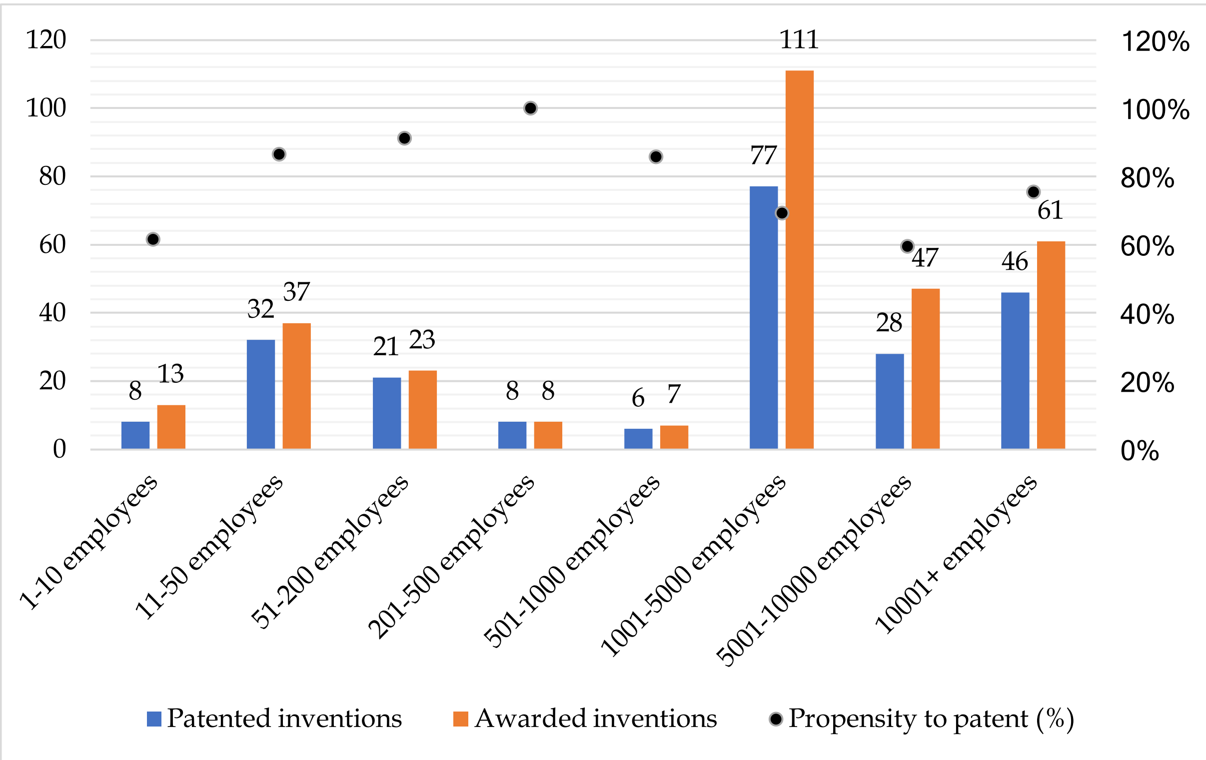
Figure 4.2: Count of patented and awarded inventions by type of organization



As expected, Figure 4.2 shows that the propensity to patent is higher for firms than for universities and PROs. When we look at the propensity to patent distributed by organization size, we notice that this distribution is unevenly. We expected that very big organizations (with more than 10,000 employees) have the highest propensity to patent. However, this is not always true, as we can observe in Figure 4.3, since also small organizations (with more than 11 employees but no more than 500 employees) and medium size organizations (with 501 to 1,000 employees) patent almost all of their breakthrough inventions.

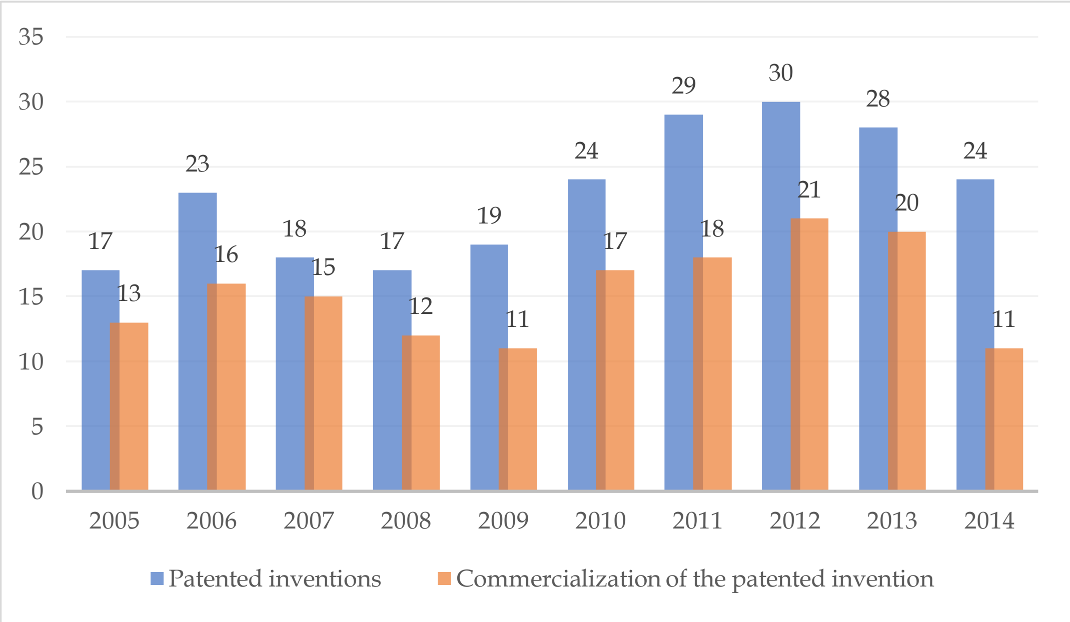
An explanation for this is that large organizations have more resources for patenting and for enforcing patent litigations. Further, compared to small firms, large companies can likewise exploit more effectively alternative strategic appropriation tools such as reputation, lead-times and complementary assets (Teece, 1986; Teece, 2006). Furthermore, if small organizations do not have the resources and capabilities for commercializing their inventions (e.g. because it is outside of their core business), the only way to exploit it occurs by patenting and licensing them out. Finally, small firms may be forced to patent by their investors or to attract additional funding (Hall and Lerner, 2010).

Figure 4.3: Count of patented and awarded inventions by organization size



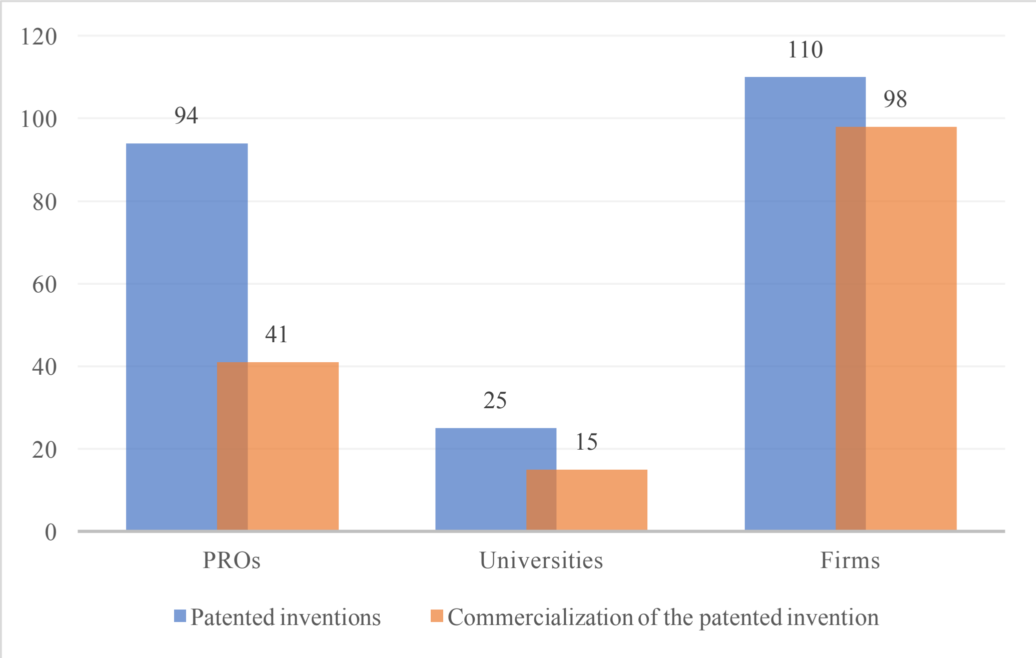
As most awarded inventions in our sample were patented it is relevant to understand how many of those patents were commercialized and licensed. From the subset of patented inventions, we identify 154 of them that were commercialized. In Figure 4.4 we report the count of patents and commercialized inventions by year. We observe that the commercialization of patented inventions happens more frequently in 2007 (83%) followed by 2005 (76%), and during the years 2008, 2010 and 2013 (71% respectively).

Figure 4.4: Count of patents and commercialized inventions by year



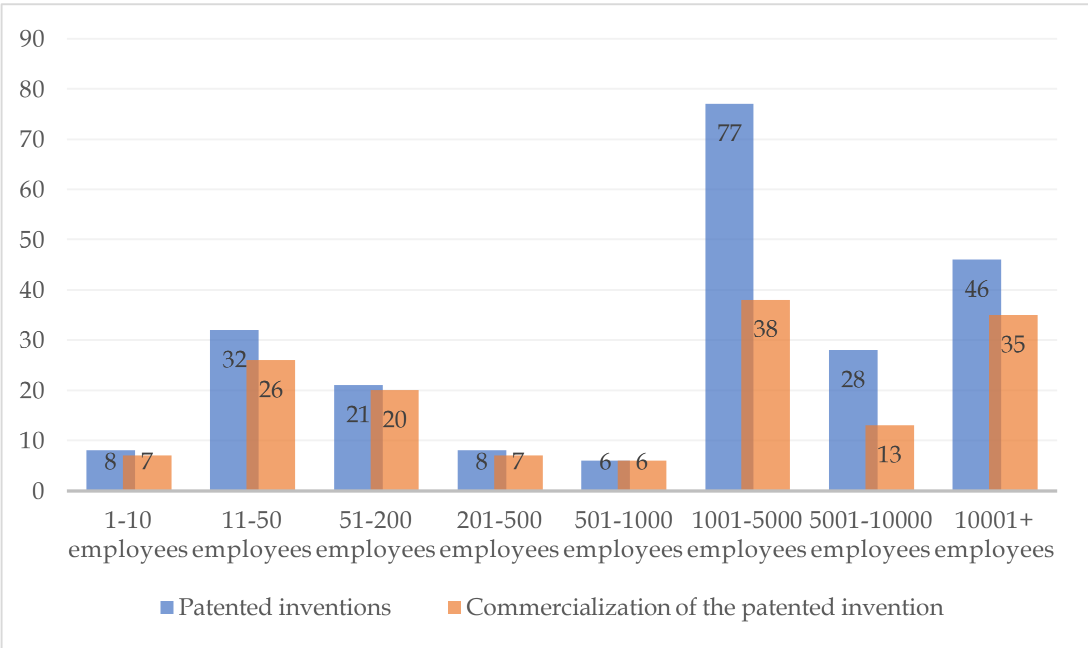
Looking at Figure 4.5, which shows the count of patents and commercialized inventions by type of organization, it can be clearly seen that firms are the ones that commercialize the greatest number of patents (89%). Further, the number of commercialized patents is higher for universities (60%) than for PROs (44%).

Figure 4.5: Count of patents and commercialized inventions by type of organization



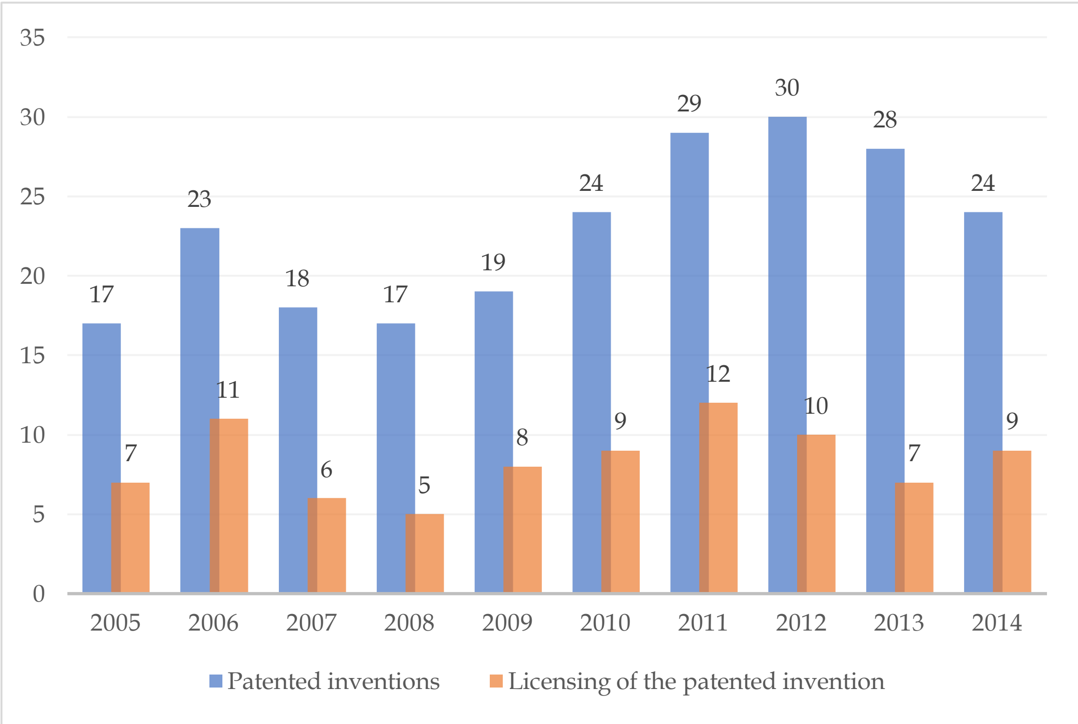
As shown in Figure 4.3, small organizations (with more than 11 employees but no more than 500 employees) and medium size organizations (with 501 to 1,000 employees) show a relatively high propensity to patent. In the same way, small (95%) and medium (100%) organizations commercialized their patented inventions. This information is presented in Figure 4.6.

Figure 4.6: Count of patents and commercialized inventions by organization size



In Figures 4.7 to 4.9 we consider how many of the patented inventions were licensed. Results from our dataset suggest that around 37% (N=84) of inventions were licensed. Figure 4.7 shows that the licensing of patented inventions happened the most in 2006 (48%) and 2009 (42%), followed by the years 2005 and 2011 (41% respectively).

Figure 4.7: Count of patents and licensed inventions by year



We further observe that, in terms of shares, PROs were more prone to license patent inventions (53%) compared to firms (44%) and universities (21%). This information can be found in Figure 4.8.

Figure 4.8: Count of patents and licensed inventions by type of organization

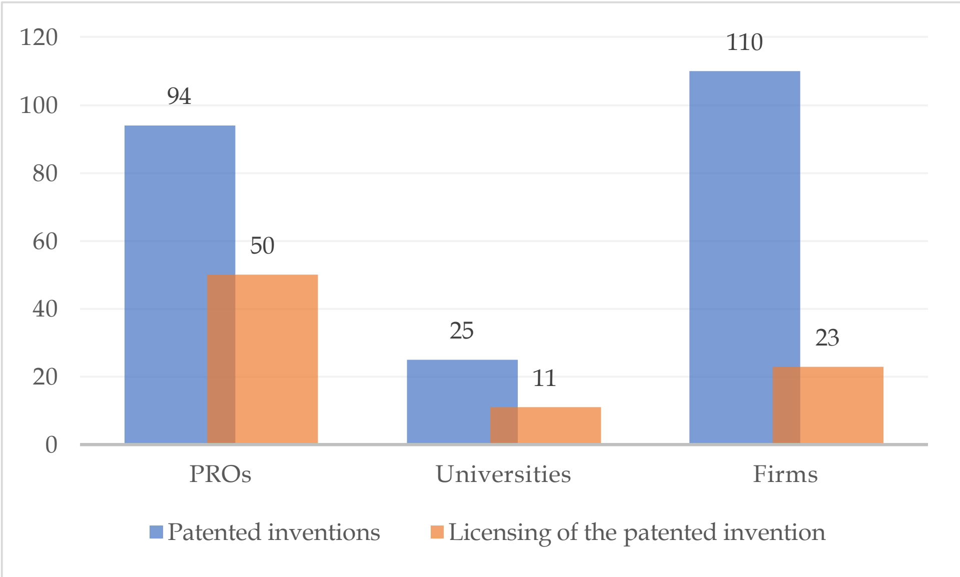
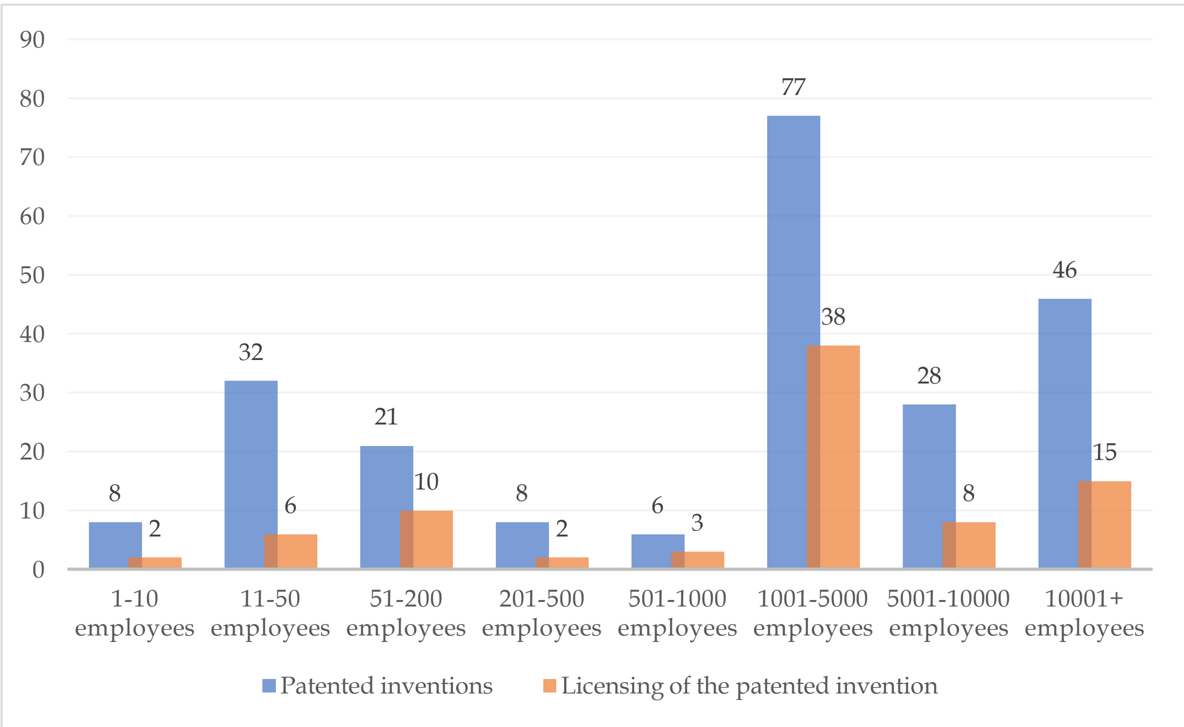


Figure 4.9 displays the count of patents and licensed patent inventions by organization size. In terms of counts, the figure shows that medium-size organizations with 1,001 to 5,000 employees licensed the largest number of patented inventions. This trend is followed by very big organizations and small firms with more than 10,000 employees and, 51-200 employees respectively. In terms of shares, small firms licensed their patent inventions the most.

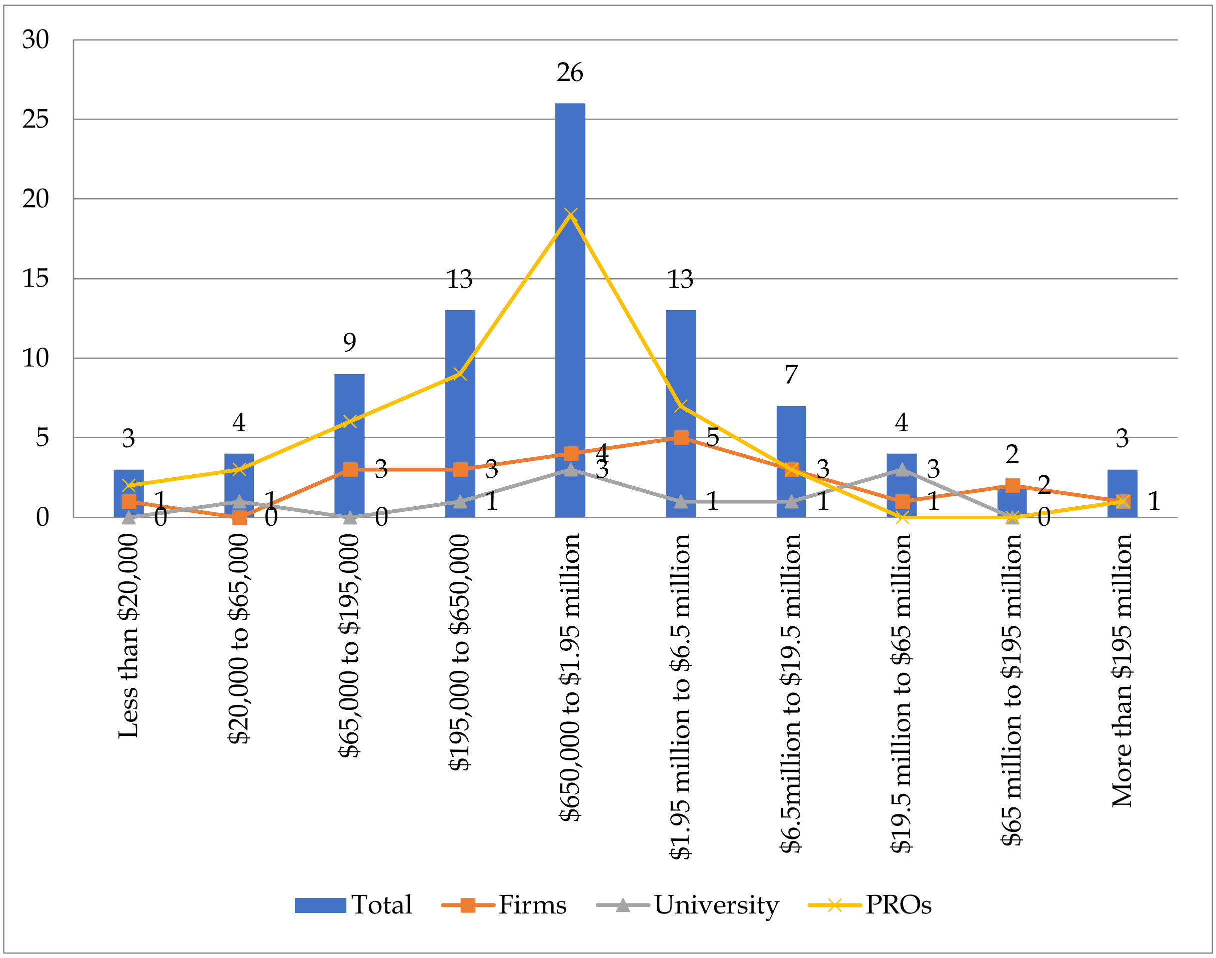
Figure 4.9: Count of patents and licensed inventions by organization size



As previously mentioned in Section 4.2.1., those inventors who declared that they had patented their awarded invention were subsequently requested to evaluate the current patent value of their inventions. This indicator gives us much information on the distribution of patent value of those inventions that were first patented and then commercialized and/or licensed.

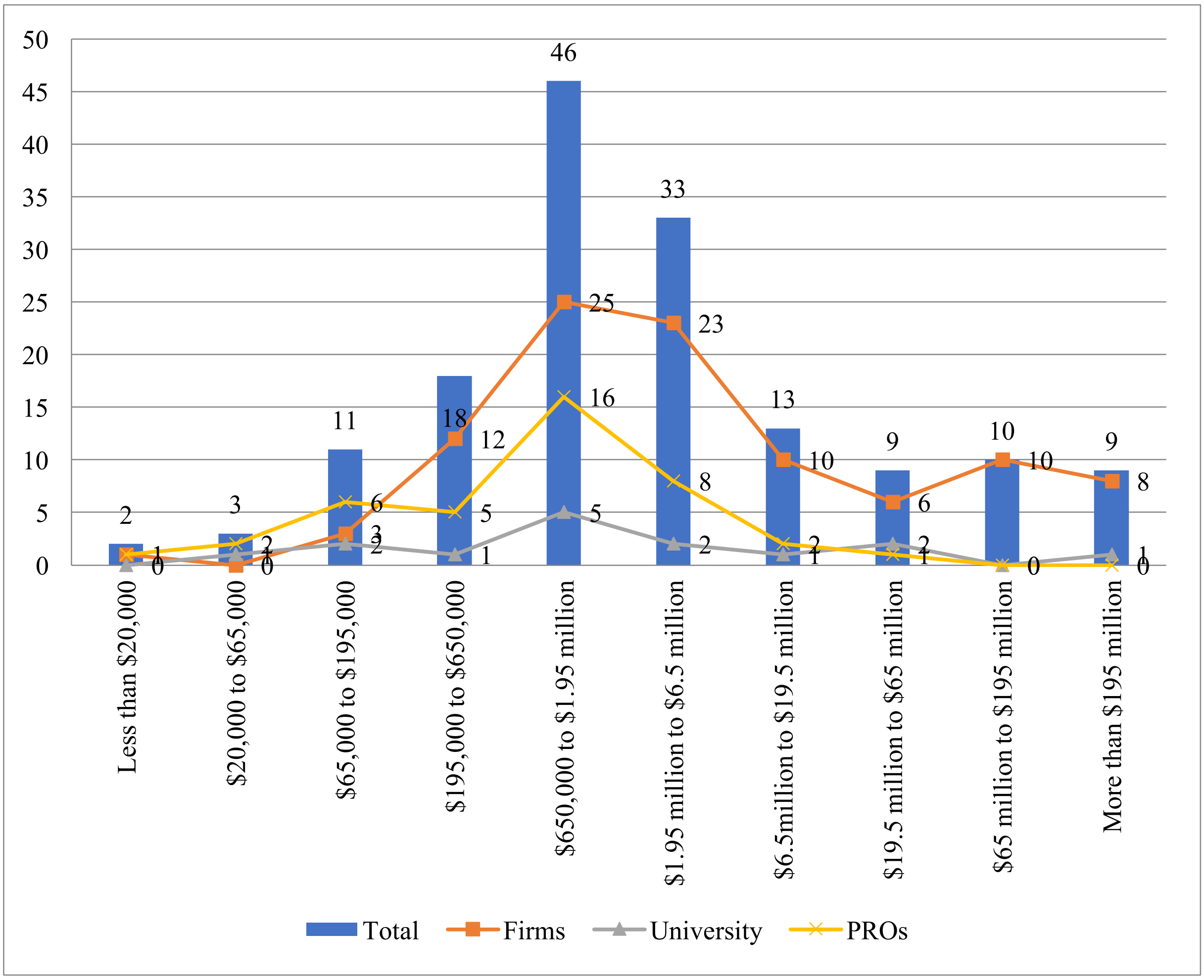
The distribution of patent value of those inventions that licensed their patent is not much skewed. PROs valued most of their licensed patents between 65,000 and 1.95 million dollars. Firms on the other hand licensed their patents in a much more scattered way than PROs and rated them with a value between $1.95 million to $6.5 million. Universities that licensed their patents rated their value between $650,000 and $1.95 million and between $19.5 million to $65 million. Figure 4.10 presents the estimated patent value for licensed patents.

Figure 4.10: Estimated patent value and licensed inventions



PROs, firms and universities that commercialized their patents, estimated the bulk of their patents with a higher price, between $650,000 to $1.95 million and $1.95 million to $6.5 million. Figure 4.11 displays the estimated patent value of patents that were commercialized.

Figure 4.11: Estimated patent value and commercialized inventions



4.3. The econometric exercise

In this section, we carry out three analyses. First, we estimate the probability for the awarded invention to be patented as a function of its characteristics, the characteristics of the organization, and the characteristics of the inventor. Second, for the subsample of those awarded inventions that were patented, we will look at the determinants of the value of the invention. This will be done using several alternative indicators of the value of the invention such as licensing, commercialization, technological and economic significance and the inventor's self-assessment of the estimated patent value. Third, we will use patent citations to estimate the determinants of the quality of patented innovations that won a prize.

4.3.1. Estimating the probability to patent an awarded invention

In order to predict the probability to patent an awarded invention we perform a logit regression where we regress the dependent variable whether the invention was patented against a set of characteristics (i.e. inventor, organization, and invention) as independent variables.[46] All the variables used in this analysis were summarized in Section 4.2.1., Table 4.2.

Model 1 reports the estimated coefficients for all the inventor characteristics, without including organization and invention characteristics. Model 2 includes both inventor characteristics and organization characteristics. Model 3 reports the estimated coefficients for the full model including all the set of characteristics (inventor, organization and invention). Lastly, Model 4 presents the average marginal effects for the full model. Results of the logit regression can be seen in Table 4.5. For each independent variable, a coefficient is presented together with its standard error (in brackets).

[46] We used the dummy variable "invention was patented" with values 1=Yes, 0=No.

Table 4.5: Estimating the probability to patent an awarded invention. Logit regression

Variable name	Model 1	Model 2	Model 3	Model 4
Inventor characteristics				
Multi-award winner	0.019	-0.006	0.081	0.011
	(0.289)	(0.292)	(0.298)	(0.050)
Amount of working hours	-0.013	-0.016*	-0.014	-0.002
	(0.009)	(0.009)	(0.009)	(0.002)
No of publications	-0.002	0.005	0.009	0.002
	(0.010)	(0.011)	(0.011)	(0.002)
No of applied patents	0.382***	0.338***	0.314***	0.050***
	(0.109)	(0.102)	(0.103)	(0.011)
PhD highest degree	0.208	0.401	0.378	0.064
	(0.268)	(0.279)	(0.296)	(0.049)
Experience in the field	-0.007	-0.004	-0.008	-0.002
	(0.015)	(0.015)	(0.015)	(0.003)
Age (Log)	1.240*	1.081	0.919	0.146
	(0.745)	(0.768)	(0.802)	(0.134)
Organization Tenure (Log)	-0.361*	-0.224	-0.180	-0.028
	(0.202)	(0.210)	(0.217)	(0.037)
Organization characteristics				
PRO (ref.)		-	-	-
University		0.022	-0.073	-0.001
		(0.414)	(0.434)	(0.084)
Firm		0.588*	1.088***	0.155***
		(0.323)	(0.378)	(0.060)
Org. Size (Log)		-0.022	0.037	0.004
		(0.073)	(0.081)	(0.013)
Invention characteristics				
Duration of research			0.008	0.001
			(0.006)	(0.001)
Product inn.(ref.)			-	-
Process inn.			0.850*	0.112
			(0.478)	(0.063)
Both product & process			0.113	0.012
			(0.281)	(0.049)
No of collaborating inventors			-0.064**	-0.010***
			(0.025)	(0.004)
Research effort			-0.001	0.000
			(0.001)	(0.000)
Constant	-3.073	-2.878	-2.947	-
	(2.601)	(2.804)	(2.955)	-
No of observations	380	375	359	359
Wald Chisq.	19.64***	25.48***	34.51***	-
Log Pseudo Likelihood	-195.649	-190.445	-175.783	-
Pseudo Rsq	0.127	0.136	0.169	-

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Each model contains a vector of award year time dummy. In Appendix B, Table B.1, we also computed the Variance Inflation Factor which is 1.83.

In Model 1, we firstly regressed the dependent variable against the inventor characteristics. We observe a statistically positive and significant association between the number of applied patents (0.382***) by those inventors who received the R&D 100 Award and the probability to patent. Having won numerous awards, published in scientific journals, holding a PhD, possessing experience in the field and working hours spent on inventing do not seem to exert a significant effect on the probability to patent an awarded invention. We observe a positive correlation at 10% of significance between the age of the inventor (1.240*) and the probability to patent. This suggest that the older the inventor, the more likely an awarded invention will be patented. Further, we observe a negative and significant correlation on the probability to patent and the job tenure of the inventor at the time of the award (-0.361*). This indicates that, in general, junior tenured inventors are likely to patent their awarded inventions. Similar studies on young international inventors have found a significant correlation between those inventors who applied for a patent(s) and the probability to start a new business (Link and Welsh, 2013).[47]

We then added to the specification the characteristics of the organization (Model 2). It is apparent from Table 4.5 that, once again, the number of applied patents by the inventor has a strong positive correlation (0.338***) with the probability to patent. In terms of organization characteristics, results from the regression suggest a positive association (significant at 10%) between the probability to patent an awarded invention and working in a firm. Thus, firms have a higher probability to patent an awarded invention than PROs (0.588*).

It is interesting to note that, when including the characteristics of the organization, both the job tenure variable and the age of the inventor, that were weakly significant in the prior model become not significant. Finally, there is a negative statistical association between the probability to patent and the number of hours the inventor spent on inventing (-0.016*), suggesting that, the more hours inventors spent on an awarded invention, the less likely this invention will be patented. This counterintuitive result is not robust to the inclusion of further characteristics (see Model 3).

In our final model (Model 3), we include all the three set of characteristics: inventor, organization, and invention. We can observe that the strongest positive associations with the propensity to patent concern the number of past applications by the inventor (0.314***) and

[47] This study (Link and Welsh, 2013) uses a unique database of young inventive scientist drawn from the 'TR100 inventor award' and studies their propensity toward a new business formation based on their creative achievements.

the type of organization (firms) (1.088***). It is interesting to note that there is a negative association with the number of collaborating inventors and the propensity to patent (-0.064**). It appears that, the more inventors collaborate during the invention process, the less probable the invention will be patented. The reason for this could be that, having too many inventors in a team implies a higher difficulty to set and attribute the property rights of the invention amongst the team members.

We also find that process innovations have a relatively higher probability to be patented (0.850*). Taken together, findings in this model, would seem to suggest that prior experience in patenting by the inventor increases the probability to patent. Further, firms patent more than other type of organizations. Lastly, collaborative inventions are less likely to be patented. In our view, results of this model provide a powerful tool to assess the size and direction of the selection bias for forthcoming research.

Lastly, in Model 4 we present the average marginal effects for the full model.

4.3.2. The value of patented inventions

In this section, we will estimate the value of patented inventions. For our estimates, we rely on a set of Heckman selection models which include a selection equation and an outcome equation. This statistical procedure is used to correct for selection bias (Heckman, 1979). For this reason, it is common to look for exclusion restrictions in the form of a variable(s) that generate nontrivial variation in the selection equation but does not affect the outcome equation directly. Valid exclusion restrictions require the use of suitable instruments.

We employ a Heckman-Probit regression to analyze the determinants of licensing and commercialization of patented inventions.[48] In our case, the selection equation is similar to a standard binary logistic model – whether the awarded invention was patented or not (see section 4.3.1., Model 3). The instrumental variable that we will use in the selection equation and exclude in the response equation is *the number of patents that the respondent applied for in the three years prior to the awarded invention.* We assume that, *ceteris paribus*, the instrumental variable (No. of patents) does not have a direct effect on the value of inventions (the dependent variable of the outcome equation) *ceteris paribus*. The outcome equation provides information on the effects of the independent variables on other alternative indicators such as licensing

[48] Van de Ven and Van Praag (1981).

and commercialization of patented inventions. Results of this analysis are shown in Table 4.6 and Table 4.7 respectively.

Table 4.6 presents the results of the Heckman-Probit regression analyzing the determinants of commercialization of patented inventions. Model 1 reports the Probit regression without exclusion restriction (selection equation). Model 2 reports the Probit regression on the dependent variable commercialization with exclusion restriction (outcome equation). In Model 2, we highlight a strong positive correlation between being a firm and the commercialization of a patented product (1.445***). Previously presented descriptive statistics support this association, as noted in Figure 4.5, firms were the ones that commercialized the most their patented inventions compared to PROs and universities. On the other hand, there is a slightly negative association between the number of collaborating inventors and the commercialization of patented inventions (-0.026**) and a much less significant correlation between research duration and commercialization.

We then observe the value of Ath rho. Ath rho is a measure of the correlation between the error term, i.e. the unobservable of the two equations. Ath rho is strongly positively correlated with commercialization and indicates that the number of applied patents (along with other unobservable characteristics) has a positive indirect influence on this variable. Results from this regression are shown in Table 4.6.[49]

[49] Table B.2 in the Appendix reports the standard Probit estimates without the selection equation. This gives an idea about the direction and magnitude of the selection bias on each independent variable.

Table 4.6: Analyzing the determinants of commercialization of patented inventions. Heckman-Probit regression

Variable name	Dependent variable	
	(1) Patent	(2) Commercialization
Inventor characteristics		
Multi-award winner	0.065	0.089
	(0.176)	(0.167)
Amount of working hours	-0.006	0.009
	(0.006)	(0.006)
No of publications	-0.001	0.006
	(0.004)	(0.004)
No of applied patents	0.117***	-
	(0.030)	-
PhD highest degree	0.256	0.017
	(0.175)	(0.165)
Experience in the field	-0.011	0.000
	(0.009)	(0.009)
Age (Log)	0.586	0.107
	(0.478)	(0.454)
Organization Tenure (Log)	-0.056	-0.027
	(0.128)	(0.124)
Organization characteristics		
PRO (ref.)	-	-
University	0.154	-0.079
	(0.257)	(0.260)
Firm	0.591***	1.445***
	(0.214)	(0.205)
Org. Size (Log)	0.025	0.047
	(0.044)	(0.043)
Invention characteristics		
Duration of research	0.003	0.006*
	(0.004)	(0.004)
Product inn.(ref.)	-	-
Process inn.	0.422	0.323
	(0.264)	(0.255)
Both product & process	0.111	0.235
	(0.162)	(0.170)
No of collaborating inventors	-0.032***	-0.026**
	(0.012)	(0.012)
Research effort	-0.001	0.000
	(0.001)	(0.001)
Constant	-1.847	-2.088
	(1.739)	(1.685)
ath rho		15.624***
		(3.078)
Total No of observations	359	
Censored observations	99	
Uncensored observations	260	
Wald Chisq.	76.05***	
Log Pseudo Likelihood	-303.224	

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Each model contains a vector of award year time dummies.

The Heckman-Probit regression analyzing the determinants of licensing patented inventions is presented in Table 4.7.[50] Model 1 reports the Probit regression without exclusion restriction (selection equation). Model 2 reports the Probit regression on the dependent variable licensing with exclusion restriction (outcome equation). In Model 2 we observe a negative correlation between being a company and licensing (-1.198***). This association can be further confirmed by previously commented descriptive statistics (see Figure 4.8) were it was shown that PROs licensed more patented inventions compare to firms and universities. Moreover, the size of the organization negatively impacts the licensing of patented inventions (-0.124***). Further, there is a positive relationship between the job tenure of the inventor at the time of the award and the likelihood to license patented inventions (0.351***). Finally, we observe an extremely slight association with licensing and research effort required to complete the awarded invention. Ath rho[51] is negatively correlated with licensing and indicates that the number of applied patents may have and indirect negative impact in the licensing process (-12.328***).

[50] Table B.2 in the Appendix reports the standard Probit estimates without the selection equation. This gives an idea about the direction and magnitude of the selection bias on each independent variable.
[51] As previously mentioned, Ath rho is a measure of the correlation between the error term, i.e. the unobservable of the two equations.

Table 4.7: Analyzing the determinants of licensing of patented inventions. Heckman-Probit regression

Variable name	Dependent variable	
	(1) Patent	(2) Licensing
Inventor characteristics		
Multi-award winner	0.107	-0.112
	(0.167)	(0.163)
Amount of working hours	-0.010	0.000
	(0.006)	(0.006)
No of publications	0.013*	-0.005
	(0.007)	(0.004)
No of applied patents	0.118***	-
	(0.040)	-
PhD highest degree	0.228	-0.034
	(0.174)	(0.166)
Experience in the field	-0.008	-0.011
	(0.009)	(0.009)
Age (Log)	0.650	-0.347
	(0.496)	(0.484)
Organization Tenure (Log)	-0.114	0.351***
	(0.125)	(0.132)
Organization characteristics		
PRO (ref.)	-	-
University	-0.038	-0.037
	(0.255)	(0.269)
Firm	0.708***	-1.198***
	(0.220)	(0.212)
Org. Size (Log)	0.004	-0.124***
	(0.051)	(0.045)
Invention characteristics		
Duration of research	0.007*	-0.001
	(0.004)	(0.003)
Product inn.(ref.)	-	-
Process inn.	0.514*	0.118
	(0.283)	(0.269)
Both product & process	0.067	0.150
	(0.166)	(0.158)
No of collaborating inventors	-0.038*	-0.011
	(0.013)	(0.014)
Research effort	-0.001	0.001*
	(0.001)	(0.001)
Constant	-1.922	2.196
	(1.778)	(1.763)
ath rho		-12.328***
		(0.515)
Total No of observations	359	
Censored observations	99	
Uncensored observations	260	
Wald Chisq.	49.24***	
Log Pseudo Likelihood	-314.516	

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Each model contains a vector of award year time dummies.

In order to analyze the determinants of the value of patented inventions we rely upon a Heckman's two-step estimator. This method comprises the estimation of a Probit model for the selection function, which is then followed by the insertion of a correction factor (called the inverse Mills ratio) in the outcome equation.

The first stage in our two-step estimator is a choice model – whether the awarded invention was patented or not – and models the probability of an invention to be patented. For this step, it was used a model similar to a standard binary logistic model, namely a Probit model. This Probit model includes the same instrumental variable used previously (No. of applied patents) that is omitted in the second stage. The correction factor, called inverse Mills ratio, is subsequently calculated using the Probit model estimates.

The second stage examines the effects of the independent variables on the value of the patent by performing an ordered Probit regression,[52] adding the correction factor inverse Mills ratio as additional predictor, and excluding the instrumental variable 'No. of patents'. Results of the application of this two-step selection method for a variety of indicators of patent value are shown in Table 4.8.

Model 1 reports the Probit regression without the exclusion restriction (first step). Models 2 to 6 report the Ordered Probit regressions with the inverse Mills ratio and the exclusion restriction (second step). It should be noted that, in Models (2) through (5), the dependent variable is reverse coded, i.e. 1 corresponds to the higher significance and 4 to the lowest, hence, the estimated coefficients will be commented with the opposite sign.

In Model 2, there is a significant positive correlation between the amount of working hours (0.014***) and the technical significance of the invention in the US. This suggest that from a technical point of view the higher the amount of hours spent working on the invention the higher is the value of the breakthrough in the US. Process innovation is slightly and positively correlated (0.345*) with the technical significance of the breakthrough in the US. This suggests that process innovations in the US are considered of a greater technical value. When looking at the economic significance of breakthroughs in the US (Model 3), we found that there is a positive correlation between the amount of working hours (0.011**) and when the innovation is both product and process (0.220*). This result suggests that product and process innovations in the US have a superior economic value compared to just process or just product innovations.

[52] See Chiburis and Lokshin (2007) for a two-step estimation of an ordered-probit selection model.

Model 4 reports that there is again a positive correlation between the amount of working hours (0.012**) and both product and process innovation (0.242*) and the technical significance of the invention in the world. These results are similar with what we observe in Model 2 (technical significance in US). In contrast to the technical significance in US, the age of the inventor shows a negative correlation (-0.725**) in terms of technical significance worldwide. This implies that the older the inventor involved in the invention, the lower the technical significance of the breakthrough worldwide.

The economic significance of the invention worldwide (Model 5) has strong a positive correlation with the amount of working hours (0.014***) and a negative correlation with the age of the inventor (-0.775**). These findings suggest that the higher the number of hours the inventor spent working on the invention, the greater will be the economic value of the patented invention worldwide. Consistent with the technical significance of the patented invention worldwide, results of these correlations indicate that, the older the inventor working in the invention, the lower is the perceived economic value of the invention.

In Model 6, we notice that the number of publications has a small negative impact on the estimated value of the patent (-0.011***). Conversely, being a firm (0.818***) has a direct strong correlation with the estimated patent value, along with the size of the organization (0.094**) and the number of working hours by the inventor (0.012***). Further, the length of the tenure in the organization has a negative correlation (0.182*) with the estimated patent value.

Table 4.8: Analyzing the determinants of value of patented inventions. Two-step selection method

Variable name	Dependent variable					
	(1) Patent	(2) Tech. Significance in US	(3) Ec. Significance in US	(4) Tech. Significance in The World	(5) Ec. Significance in The World	(6) Estimated patent value
Inventor characteristics						
Multi-award winner	0.037	-0.162	-0.154	-0.186	-0.148	0.105
	(0.174)	(0.135)	(0.135)	(0.127)	(0.130)	(0.147)
Amount of working hours	-0.007	-0.014***	-0.011**	-0.012**	-0.014***	0.012***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)
No of publications	0.005	0.000	0.001	0.002	0.001	-0.011***
	(0.006)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
No of applied patents	0.148***	-	-	-	-	-
	(0.046)	-	-	-	-	-
PhD highest degree	0.254	-0.035	-0.129	-0.074	-0.177	0.051
	(0.173)	(0.154)	(0.149)	(0.142)	(0.151)	(0.160)
Experience in the field	-0.006	-0.002	0.005	-0.002	-0.006	0.000
	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)
Age (Log)	0.625	-0.032	-0.056	0.725**	0.775**	-0.006
	(0.465)	(0.362)	(0.356)	(0.365)	(0.381)	(0.370)
Organization Tenure (Log)	-0.101	0.146	0.078	-0.098	-0.104	-0.182*
	(0.125)	(0.099)	(0.100)	(0.098)	(0.104)	(0.102)
Organization characteristics						
PRO (ref.)	-	-	-	-	-	-
University	-0.039	-0.210	-0.080	-0.070	0.061	-0.042
	(0.260)	(0.224)	(0.235)	(0.235)	(0.224)	(0.237)
Firm	0.626***	0.010	-0.073	-0.069	-0.132	0.818***
	(0.210)	(0.228)	(0.223)	(0.219)	(0.226)	(0.232)
Org. Size (Log)	0.014	-0.028	-0.045	-0.048	-0.051	0.094**
	(0.045)	(0.035)	(0.035)	(0.036)	(0.037)	(0.038)
Invention characteristics						
Duration of research	0.005	0.000	0.001	0.003	0.003	0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Product inn.(ref.)	-	-	-	-	-	-
Process inn.	0.457	-0.345*	-0.153	-0.181	-0.072	0.155
	(0.285)	(0.225)	(0.214)	(0.236)	(0.242)	(0.239)
Both product & process	0.071	-0.171	-0.220*	-0.242*	-0.178	0.072
	(0.166)	(0.139)	(0.136)	(0.132)	(0.135)	(0.148)
No of collaborating inventors	-0.037***	0.004	-0.001	-0.007	-0.008	0.012
	(0.014)	(0.011)	(0.010)	(0.012)	(0.014)	(0.011)
Research effort	-0.001	0.000	0.000	0.000	0.000	0.001*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	-1.996	-	-	-	-	-
	(1.717)	-	-	-	-	-
Inverse Mills Ratio		0.355	0.686*	0.562**	0.705***	-0.564*
		(0.334)	(0.328)	(0.314)	(0.330)	(0.361)
No of observations	359	355	352	356	351	260
Wald Chisq.	41.50***	26.18***	30.59***	26.72***	31.18***	85.44***
Log Pseudo Likelihood	-177.429	-443.795	-455.891	-466.990	-444.959	-498.802
Pseudo Rsq	0.169	0.025	0.030	0.026	0.033	0.073

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Model (1), the selection equation, is a Probit estimation. Models (2) through (6) are Ordered Probit. In Models (2) through (5) the dependent variable is reverse coded (i.e. 0 corresponds to the higher significance and 4 to the lowest). The selection equation contains a vector of award year time dummies.

4.3.3. The quality of patented inventions

So far, we have analyzed the probability to patent and the value of patented R&D 100 inventions using indicators based on the subjective evaluation of the respondents to the survey. In this section, we will study the value of the patented inventions using another indicator based on forward citations. To date, many authors have claimed that there are several benefits to the use of patent data. Patent data contains highly detailed information on the innovation in terms of technologies, assignees, and geography (Hall *et al.*, 2005). Studies such as the one by Trajtenberg (1990) demonstrate that there is a connection between patent counts weighted by forward citations and the social value of innovations.[53]

Jaffe *et al.* (2000) carried a study on inventors that was divided into two groups: 'citing inventors' and matched 'cited inventors'. One group (the 'citing inventors' group) responded questions about two patents that they had cited plus a third placebo patent (technologically similar) that was not cited, while the other group (the matched 'cited inventors' group) answered analogous questions about the citing patents. Results of this study confirm that there is an important correlation between the number of citations a patent received and its importance as perceived by the inventors. Lanjouw and Schankerman (2004) use citations, together with other measures (e.g. number of claims and number of countries in which an invention is patented), as a proxy for patent quality.

Mariani and Romanelli (2007) use patent data to estimate the value of patents by carrying out a study on the determinants of the productivity of industrial inventors in terms of quantity and quality of the innovations that they produce. Evidence from these previous studies suggest that patent data, and in particular forward citations, proved to be useful for determining the quality of patents. For this reason, we will use the number of forward citations that the R&D 100 patent received as a proxy for its quality.

To measure the quality of R&D 100 patents, we perform once again a two-step selection method using the inverse Mills ratio. The first step of this method is performed exactly as in section 4.3.2., where we modeled our dependent variable (Whether the R&D 100 invention was patented or not) without exclusion restrictions and then compute the inverse Mills ratio. Since the dependent variable "Number of citations received" is a count variable, in the second step we carry out a Poisson regression (Model 1) and a Negative Binomial regression (Model

[53] The study of Trajtenberg (1990) reveals that patent counts weighted by a citations-based index are highly correlated with the social gains from innovation in Computer Tomography (CT) and that simple patent counts, give only indication about innovation inputs (R&D expenditures).

2), adding the inverse Mills ratio as an additional predictor and the exclusion restriction (number of applied patents).[54]

Results of the two-step selection method are reported in Table 4.9.[55] Column 1 reports the Probit regression without exclusion restriction (first step). Columns 2 and 3 report the Poisson and Negative Binomial regressions with the inverse Mills ratio and the exclusion restriction respectively (second step). Looking at the determinants of the quality of patented inventions we can observed that having a PhD is inversely correlated with the number of citations both using a negative binomial (-1.016***) or a Poisson regression (-0.965***). Moreover, process innovation is negatively correlated with the quality of the patent as expressed by number of forward citations in both type of regressions. The duration of research has also negative impact on the number of patent citations in both type of regressions (with a coefficient of -0.011** for the Poisson regression and -0.010** for the Negative Binomial regression).

[54] Cameron and Trivedi (2009).

[55] Table B.2 in the Appendix reports the standard Probit estimates without the selection equation. This gives an idea about the direction and magnitude of the selection bias on each independent variable.

Table 4.9: Analyzing the determinants of the quality of patented inventions. Two-step selection method

Variable name	Dependent variable		
	(1) Patent	**(2) No of citations**	**(3) No of citations**
Inventor characteristics			
Multi-award winner	0.037	0.112	-0.097
	(0.174)	(0.207)	(0.211)
Amount of working hours	-0.007	(-0.010)	-0.009
	(0.005)	0.011	(0.006)
No of publications	0.005	(-0.002)	0.003
	(0.006)	0.008	(0.011)
No of applied patents	0.148***	-	-
	(0.046)	-	-
PhD highest degree	0.254	-0.965***	-1.016***
	(0.173)	(0.243)	(0.252)
Experience in the field	-0.006	-0.021*	-0.021*
	(0.009)	(0.013)	(0.012)
Age (Log)	0.625	0.161	0.940
	(0.465)	(0.942)	(0.870)
Organization Tenure (Log)	-0.101	0.066	-0.089
	(0.125)	(0.244)	(0.168)
Organization characteristics			
PRO (ref.)	-	-	-
University	-0.039	0.529	0.471
	(0.260)	(0.365)	(0.376)
Firm	0.626***	-0.629	-0.516
	(0.210)	(0.430)	(0.387)
Org. Size (Log)	0.014	-0.075	-0.039
	(0.045)	(0.075)	(0.062)
Invention characteristics			
Duration of research	0.005	-0.011**	-0.010**
	(0.003)	(0.004)	(0.004)
Product inn.(ref.)	-	-	-
Process inn.	0.457	-0.924**	-0.943**
	(0.285)	(0.396)	(0.365)
Both product & process	0.071	-0.321*	-0.230
	(0.166)	(0.204)	(0.215)
No of collaborating inventors	-0.037***	0.029	0.039*
	(0.014)	(0.031)	(0.023)
Research effort	-0.001	0.002	0.001
	(0.001)	(0.001)	(0.001)
Constant	-1.996	-	-
	(1.717)	-	-
Inverse Mills Ratio		-2.165***	-1.698***
		(0.925)	(0.763)
No of observations	359	123	123
Wald Chisq.	41.50***	79.78***	47.10***
Log Pseudo Likelihood	-177.429	-1825.612	-502.754
Pseudo Rsq	0.169	0.239	-

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Model (1), the selection equation, is a Probit estimation. Model (2) is a Poisson. Model (3) is a Negative Binomial. The selection equation contains a vector of award year time dummy. Models (2) and (3) contain a vectors of patent publication year dummies.

4.4. Conclusions

The patent system is one of the most important institutions created for stimulating and rewarding innovative activity. In some cases, however inventors may choose not to patent their inventions.

In this essay, we shed light on the question of how the propensity to patent an award-wining innovation is affected by the characteristics of the innovation, the organization, and the inventor. By examining a sample of innovations which received an award and relying upon information on inventors collected through *'The R&D 100 award inventor survey'* we first checked the higher quality of the 'R&D 100' awarded inventions by constructing a control sample. Then we provided evidence on the value of 'R&D 100' inventions with respect to (i) licensing, (ii) commercialization, (iii) technical and economic significance of the invention (in the US and worldwide), (iv) estimated patented valued, and (v) patent citations. Descriptive results show that: (1) around three fourths of breakthrough inventions were patented between 2005 and 2014 with a constant propensity to patent throughout the ten-year period; (2) firms patented most, followed by universities and PROs that patented with lower propensity. We expected that bigger organizations (with more than 10,000 employees) to have the highest propensity to patent breakthrough inventions. However, this turned out not to be true in our sample as small organization (with more than 11 employees but no more than 500 employees) and medium size organization (with 501 to 1,000 employees) patented most;[56] (3) when it comes to commercializing patented innovations, our results shows that firms commercialized the greatest number of patents, followed by universities and PROs. Consistently to the previous result, small and medium size organizations tend to commercialize the most their patented innovations; (4) PROs are more prone to license their patented inventions, followed by firms and universities. Further, medium size organizations with 1,0001 to 5,000 employees tend to license the largest number of innovations. Lastly, the distribution of patent value tends to be rather uniform, for instance PROs, firms and universities that commercialized their patents tend to assign to highest value to the bulk of their patents.

In terms of patent propensity, results from our econometric exercise show that prior experience in patenting by inventors increases the probability to file for a patent. Further, collaborative inventions are less likely to be patented. This finding is reasonable, as having too

[56] As previously mentioned in Section 4.2.3. and depicted in Figure 4.2, small and medium size organizations may end up patenting because they do not always have the resources and capabilities for commercializing their inventions, and, because they may be forced to patent by their investors and/or for attracting additional funding.

many inventors may entail more difficulties in setting and accrediting the property rights among them. Firms seem to patent more than other type of organizations.

Concerning the determinants of commercialization and licensing of patented inventions, our findings suggest that firms commercialize more their patented inventions compared to other type of organizations. On the contrary, PROs seem to license more patented inventions compare to firms and universities. It is interesting to note, that the decision to license a patented innovation is directly influenced by the job tenure of the inventor at the time of the award.

When it comes to analyzing the determinants of value of patented inventions, results from our study suggest that, from a technical point of view, the higher the number of hours spent working on the invention, the higher is the perceived value of the breakthrough innovation in the US and worldwide. Further, process innovations in the US are considered of a greater technical value. Contrary to this, product and process innovations have a higher technical significance and economic value worldwide. Concerning the characteristics of the inventor, our findings suggest that, the older the inventor involved in the innovation, the lower the technical significance and the lower the economic value of the breakthrough worldwide.

Chapter 5

Mobility of R&D inventors. Evidence from a dataset of R&D awards recipients and their career history

5.1. Introduction

Prizes and awards are means of recompensing inventors' individual or collective excellence. In this essay, we empirically explore whether being a multiple recipient of a prize plays a role in affecting the career moves of awarded inventors. Career moves are defined in terms of mobility between organizations.

With the increasing use of patent data, previous studies have concentrated in analyzing the connection between inventor productivity and mobility (e.g. Hoisl, 2007), collaboration networks (e.g. Nakajima *et al.*, 2010), R&D performance (Fujiwara and Watanabe, 2013), geographical mobility (e.g. Miguélez and Moreno, 2014; Gorin, 2016), professional and personal factors (e.g. Azoulay *et al.*, 2016), among other topics. However, we know little about what drives R&D award recipients involved in breakthrough innovations to move. This study aims at adding up to the existence evidence and literature. To the best of our knowledge, this is the first work that looks deeply at the characteristics of such type of inventors. Our findings suggest that inventors' past performance, as measured by previous patents and publications, have no influence on mobility. Entrepreneurial characteristics instead seem to play an important role.

The organization of this essay is as follows. Section 5.2. introduces the dataset of inventors defining the means of data collection, measures and variables, and descriptive statistics of the variables employed in the analysis. In Section 5.3. we report the outcomes of the econometric exercise that models the probability for multi-award recipients to move from one employer to another after receiving a 'R&D 100' prize. Section 5.4. presents the robustness controls of our results. Section 5.5. concludes.

5.2. The inventors dataset

In this paper, our sample relies upon a unique data set of prize-winning innovators that have been awarded more than one R&D 100 Award throughout the period 2005 and 2014. We focus on the academic and the industry background of a subsample of inventors who won more than one R&D 100 Award. We try to establish whether winning multiple times such an award influenced inventor's innovative activity in terms of patents, publications and entrepreneurial activity. Initially, the data were drawn from the annual 'R&D 100 Awards' by collecting information on those inventors that won the R&D 100 Award such as their *Curriculum Vitæ* (CVs) and their current email addresses. We then prepared *'The R&D 100 awards inventor survey'* that was addressed to survey award winners. The survey lasted about 7 months from June 2016 until the end of January 2017. With the survey, we aimed at gathering information on several characteristics of both the inventors and the innovation process leading to the awarded invention.

The questionnaire is comprised of four sections: (i) the invention process (i.e. sources of knowledge leading to the invention, type of invention, etc.); (ii) the use and value of the invention (i.e. technical and economic value of the invention, reasons for patenting (or not), how to protect firm's competitive advantage, etc.); (iii) R&D activity leading to the invention; (iv) career and background of the inventors who received the award.[57]

The final sample of respondents includes 415 inventors (383 male and 32 female) responsible for 312 awarded inventions. One question in the survey asked these inventors whether they were recipients of more than one R&D 100 Award. Results from the survey show that 134 inventors (or 35% of respondents) won more than one R&D 100 Award throughout the course of their workable lives.[58]

Among these 134 respondents, 129 are male inventors and 5 are female inventors. From our survey data, we could identify 312 inventions from the 995 inventions that the R&D 100 magazine awarded over the ten-year period. Out of these 312 inventions, 117 inventions were developed by inventors that were awarded more than one R&D 100 Award. Table 5.1 summarizes this information.

[57] For more details on the survey structure, please refer to Chapter 3, Section 3.2.1., *'The R&D 100 award inventor survey'*.
[58] Inventors who won more than one R&D 100 Award during the period of 2005-2014 are defined in this study as 'multi-award winners'.

Table 5.1: Sample size and awarded inventions

Survey respondents		Awarded inventions	
	Total responses (% of responses)		**Total responses (% of inventions)**
Total number of respondents	415	**Total number of inventions**	312
Female inventors	32(8%)		
Male inventors	383(92%)		
Total number of respondents that won more than one award	134(32%)	of which awarded to inventors that won more than one award	117(38%)
Female inventors	5(4%)		
Male inventors	129(96%)		

During the preliminary phase of our study, we have also collected a great number of CVs from R&D 100 awardees. Information on the CVs was collected via Google searches and on professional networks.[59] Among these CVs we selected those respondents who were recipients of more than one award and constructed a database containing a series of information about the career of the respondents, their educational background, their prior positions (also in other organizations) and whether or not they moved after the award. More specifically, we used the CVs to: (i) collect information concerning whether the inventor move or not after receiving the R&D 100 during the 2005-2014 time period; (ii) construct indicators of experience other than the job at the time of the award; (iii) construct indicators of job tenure at the time of the award. We finally merged this CV based dataset with the answers from our survey. Our final sample is made of 134 respondents that received more than one R&D 100 Award containing information collected via the survey and data coming from the collected CVs.

[59] Specifically, LinkedIn, ResearchGate and Xing.

5.2.1. Measures and variables

The present study will use the matched inventor/inventions dataset to study the determinants of the probability of inventors to move after getting an 'R&D 100 Award' during the time period 2005-2014. We define inventors as 'mobile' if they have moved from one employer to another after receiving an 'R&D 100 Award'.

Our dependent variable is the following.

1. **Moved after the award**. This dummy variable is equal to 1 in case the inventor moved after receiving the prize and 0, otherwise. We identify a 'move' when one inventor shifts from one organization to another. This variable was manually created by using information coming from the CVs. Those who moved are N=26 (23 male and 3 female) from a total of 134 responding multi-award winners.[60]

Our explanatory variables were divided into five groups, aiming at capturing respectively: individual characteristics, academic background, indicators of job tenure, indicators of experience, and indicators of pre-award performance. We first account for several individual characteristics that include demographic factors such as gender and age at the time of the award.

2. **Gender**. The explanatory variable gender was obtained from the survey and was created by taking the value 0 in case of male inventors and 1, otherwise. In our multi-award winner sample we have N=129 male inventors and N=5 female inventors from a total of N=134.

3. **Age (Log)**. This explanatory variable represents the age of the inventor (logarithm of the years) at the time of the award. We constructed this variable by subtracting the year when the award was received and the year of birth of the multi-award winner. The year of birth was requested in the section of basic demographic information from the survey (No. of observations: 123).[61]

We also account for the previous employment before the award was received.

4. **Inventor moved within 5 years prior to the award**. This dummy variable was obtained from our survey. The survey asked whether the respondents had changed job within 5

[60] The mobility of multi-award winners is of interest for a number of motives. Firstly, these are inventors who have been recognized throughout their working careers for their contribution to innovation and breakthroughs. Secondly, multi-award winners in our sample hold also honorific prizes and recognitions other than the R&D 100 Awards. Lastly, these multi-award winners have a notorious career in their fields, are highly educated and can be considered as best-in class scientists.

[61] 11 respondents (8% of the dataset) did not disclose their age.

years prior to receiving the award. Inventors could answer 'yes' or 'no' to this question. In case the inventor answered with 'yes' the variable took the value of 1 and 0, otherwise.[62] No. of observations: 134.

Second, we take into consideration the academic background of the inventor.

5. **PhD highest degree in US**. This dummy variable was obtained from our survey. In the questionnaire, we asked respondents for their highest degree when the research leading to the invention was conducted. Inventors could select their level of education by choosing among five options.[63] It is interesting to note that in our sample of multi-award winners 78% of respondents hold a PhD or equivalent degree (N=104) and 60% of them (N=81) earned their highest degree in the Americas (more specifically in US).[64] Based on the multi-award winners subsample, we created this dummy variable taking the value 1 in case the multi-award winner had a PhD degree in the US and 0, otherwise (No. of observations: 134).

Third, we then control the job tenure at the time of the award.

6. **Job tenure at the time of the award (Log)**. This explanatory variable represents the job tenure of the inventor (logarithm of the years) at the time of the award. This variable includes data from survey responses. In the questionnaire, a question concerning the year the inventor joined the organization that received the R&D 100 Award was asked. We constructed this variable by subtracting the year when the award was received and the year the multi-award winner joined the organization (No. of observations: 127).[65]

Fourth, we control for indicators of experience other than job tenure.

7. **Founder at the time of the award.** This explanatory variable is equal to 1 in case the inventor was founder of a firm at the time of the award and 0, otherwise.[66] This variable was manually created by using information from the CVs. The number of those who were effectively founders at the time of the award is 14, from a total of responding multi-award winners of 134.

[62] The exact wording of the question was: "Within the 5 years prior to the invention, did you work full-time for one year or more for another employer, including the case of a temporary posting to a university or government lab?".
[63] The options were: (a) High school or lower; (b) Technical college or junior college; (c) University or college Bachelor; d. University Master's; (e) Ph.D., M.D. or equivalent; (f) Other (please specify).
[64] For more information on the full sample of respondents from '*The R&D 100 award inventor survey*', please refer to Chapter 3, Section 3.3.2. "Who are the R&D 100 inventors and how were they educated?".
[65] 7 multi-award winners (5% of the dataset) did not disclose the year they joined the organization where they received the R&D 100 Award.
[66] The inventor was founder of a commercial organization that operates on a for-profit basis.

Lastly, we control for the inventor academic performance by using number of published scientific research and number of applied patents.

8. **No. of publications.** The number of publications by multi-award winners was also obtained from the questionnaire. This explanatory variable includes the number of articles that the respondent published in scientific journals in the three years prior to the awarded invention (No. of observations: 133).
9. **No. of applied patents**. We obtained the number of applied patents by multi-award winners from our questionnaire. This variable includes the number of patents that the respondents applied for in the three years prior to the awarded invention (No. of observations: 133). Table 5.2 summarizes the variables just described.

Table 5.2: List of variables

Variable name	Type	Values
Dependent variables		
Moved after award	Dummy	1 Yes, 0 No
Explanatory variables		
Individual characteristics		
Gender	Dummy	0 Male, 1 Female
Age during award (Log)	Continuous	No of years
Inventor moved five years before the award	Dummy	1 Yes, 0 No
Academic background		
PhD highest degree in US	Dummy	1 Yes, 0 No
Indicators of job tenure		
Job tenure at the time of the award (Log)	Continuous	No of years
Indicators of experience (other than job)		
Founder at the time of the award	Dummy	1 Yes, 0 No
Pre-award performance		
No of publications three years before the award	Continuous	
No of applied patents three years before the award	Continuous	

Table 5.3 reports the main descriptive statistics of the variables that will be employed for the analysis. In our subsample of multi-award winners, 19% of them experienced a move right after receiving the award. Mobility also happened five years prior to winning an R&D 100 Award in 30% of cases. Regarding educational background, 60% of inventors in our sample hold a PhD degree earned in US. It is also interesting to note that 10% of multi-award winners were founders at the time of the award. Lastly, R&D 100 multi-award winners on average, have published 15 articles on scientific journals (mean: 14.985), and filed around 4 patents (mean 4.180) three years prior the awarded invention.[67]

[67] Findings in the essay "When breakthrough innovations do (not) get patented? Evidence from the *'The R&D 100 award inventor survey'*", Chapter 4, Section 4.2.1. showed that R&D 100 inventors have published on average 10 articles on scientific journals (mean: 10.499), and filed 4 patents (mean: 3.781) three years prior the awarded invention. This evidence seems to suggest that multi-award winners are on average more 'productive' than non-multi-award winners.

Table 5.3: Summary descriptive statistics

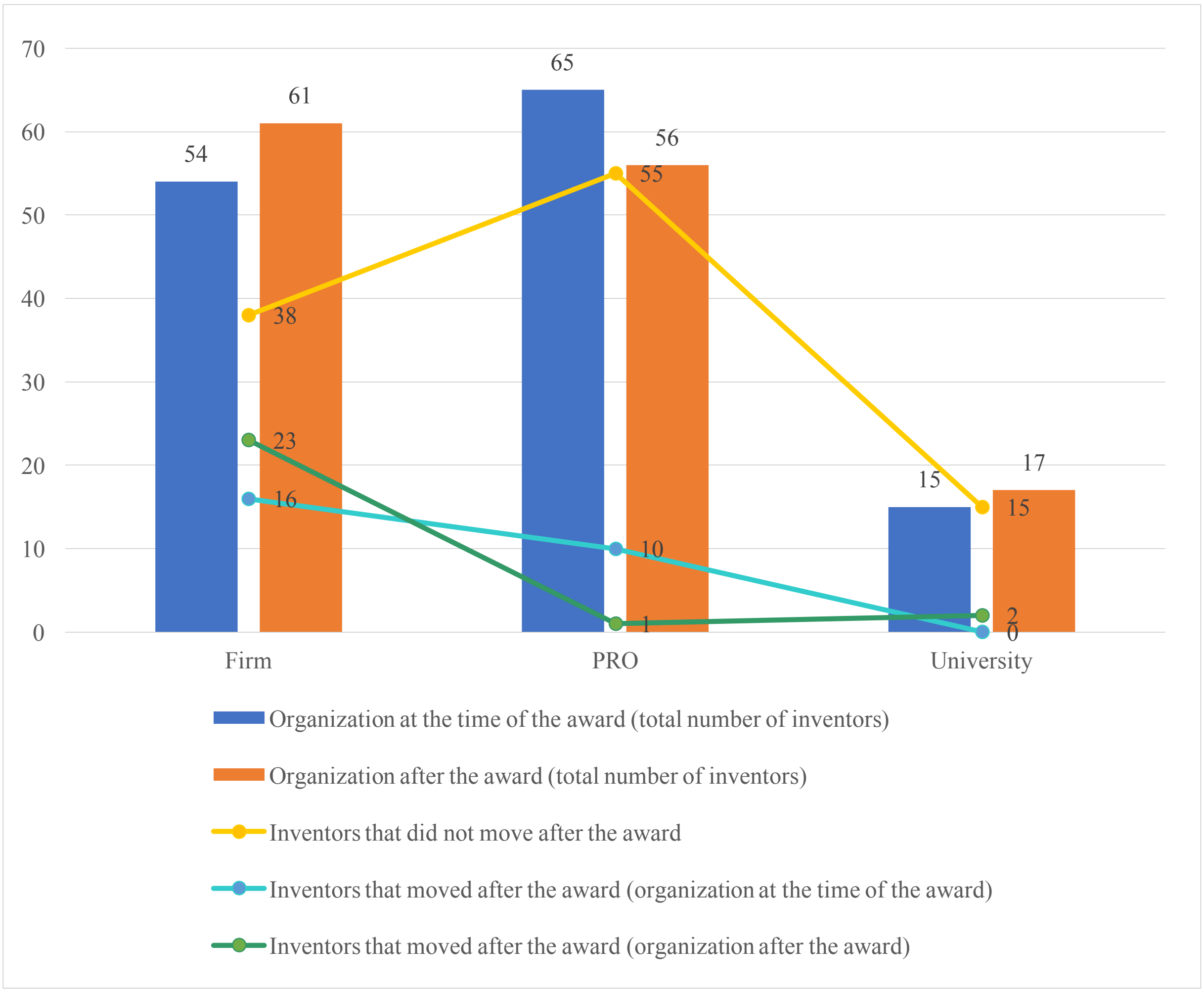
Variable name	No of observations	Mean	SD	Min	Max
Moved after award	134	0.194	0.397	0	1
Gender	134	0.037	0.190	0	1
Age during award (Log)	123	3.938	0.203	3.401	4.344
Inventor moved five years before the award	134	0.299	0.459	0	1
PhD highest degree in US	134	0.604	0.491	0	1
Job tenure at the time of the award (Log)	127	2.589	0.793	0	3.714
Founder at the time of the award	134	0.104	0.307	0	1
No of publications	133	14.985	24.688	0	200
No of applied patents	133	4.180	4.883	0	35

5.2.2. Descriptive statistics

In this section we report some preliminary descriptive statistics for some of the explanatory variables that will be used in the econometric exercise such as: (i) gender, (ii) whether the inventor moved five years before the award, (iii) organization type during award, and (iv) whether the invention was patented.

Figure 5.1 shows the organizations at the time of the award and after the award as well as the mobility of inventors. In terms of total number of inventors at the time of the award, the figure shows that most of the inventors were working at PROs (N=65) followed by firms (N=54) and university (N=15). Further, we can observe that the total number of inventors in PROs after receiving the award decreases by N=9 inventors. At the same time, we observe that the total number of inventors in firms increases by N=7 and N=2 for university. This figure suggests that multi-award winners who received a R&D 100 prize while been employed in PROs would move to another type of organization after receiving the award.

Figure 5.1: Inventors and their organizations



In Figures 5.2 to 5.5 we present Kaplan-Meier curves to study whether systematic differences exist across different types of inventors who moved after being awarded a 'R&D 100' prize. We grouped multi-award winners according to: (i) gender; (ii) whether the inventor moved five years before the award; (iii) the organization type during the award; (iv) and whether their invention was patented or not. The Kaplan-Meier estimator is a non-parametric estimate of survivor function S(t):

$$\hat{S}(t) = \prod_{(j|t_j \leq t)} \frac{(n_j - d_j)}{n_j} \quad (1),$$

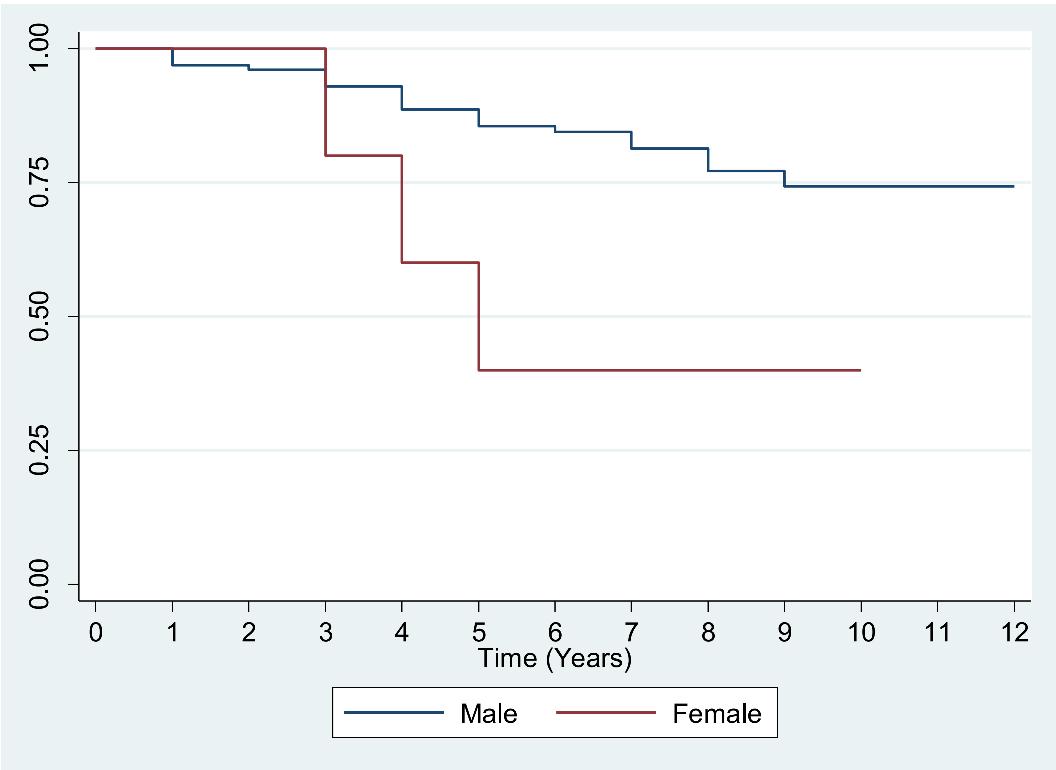
where t_j $(k = 1, \ldots, K)$ are the observed time of failures with n_j the number of subjects at risk at time j and d_j the number of failures at time j.[68] The product is over all observed failures times less than or equal to t.

[68] We consider a "failure" when the inventor moves to another organization after receiving the award.

Our curves are presented in the form of step functions, given their non-continuous nature. Lastly, we compare survival across groups by employing a log-rank test.

We first examine, in Figure 5.2, whether differences in mobility exist across gender. The horizontal axis represents time (a 10-year period) and the vertical axes the shares of inventors staying at the organization where the R&D 100 prize was obtained.[69] Initially at the beginning and end of the first and third period we see some moves coming from male inventors and no moves from female inventors. However, as time passes, we can see that female inventors leave their organization at a much faster pace. By the end of the tenth period following the award, we can observe that 75% of male inventors (or 97 out of 129 male inventors) have remained at the organization where they got the prize. When comparing both curves, the log-rank test rejects the null hypothesis of equality across the two groups (chisq = 0.018).

Figure 5.2: Kaplan Meier estimate of S(t) for Gender

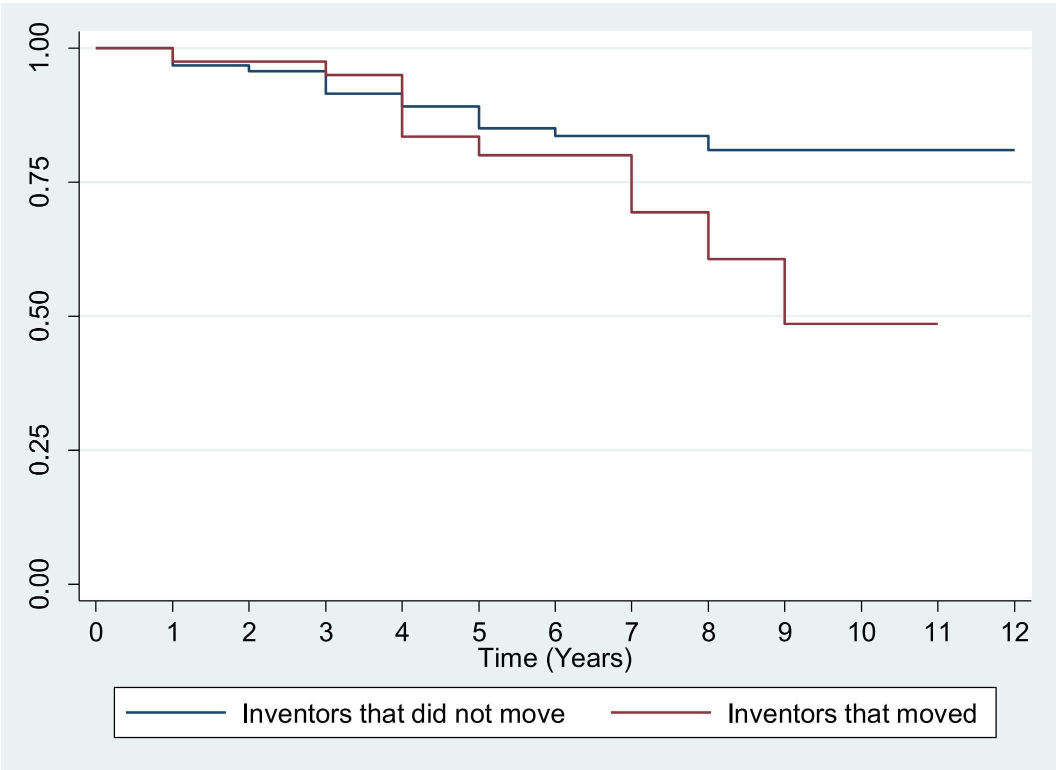


[69] Awards given within the 2005-2014 time period.

Figure 5.3 displays the Kaplan-Meier estimates for the likelihood of an inventor leaving the organization where they won the 'R&D 100' prize conditional on having not moved five years prior to the award. Mobility is much higher for those who moved five years prior to the invention (only 50% from this group remained at the organization that won the award) compared to those that did not move.

This suggests that those inventors who were more mobile in the past move after the award. When comparing both groups, the log-rank test weakly rejects the null hypothesis of equality across the two groups (chisq = 0.092).

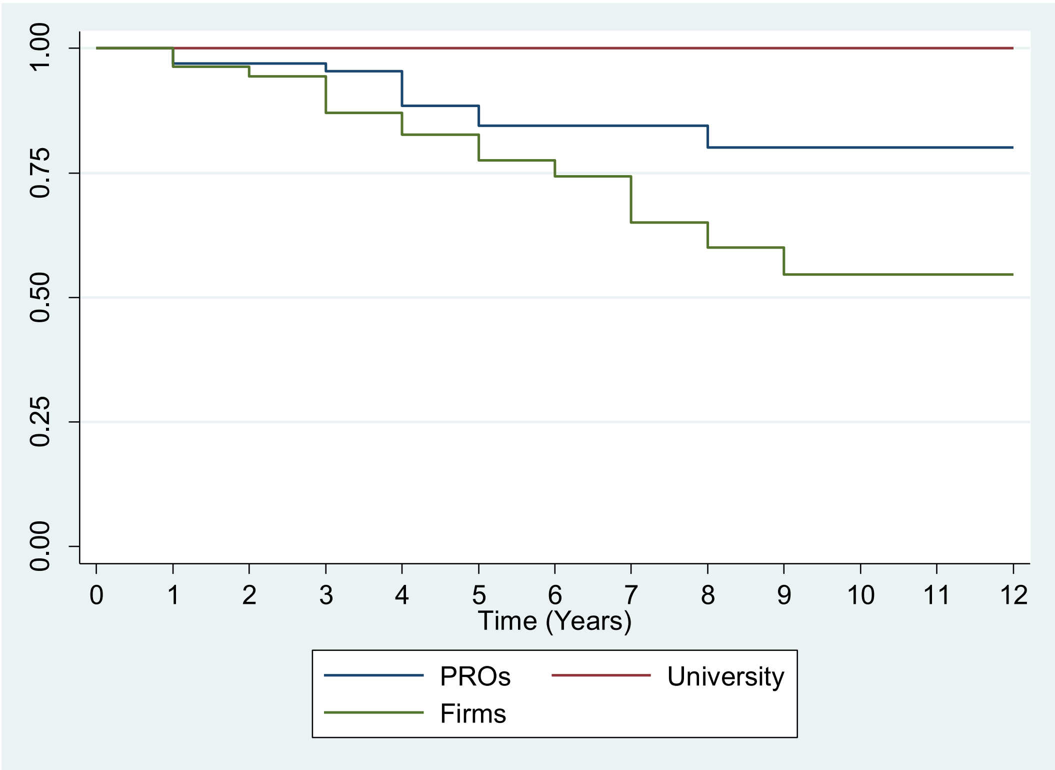
Figure 5.3: Kaplan Meier estimate of S(t) for inventor mobility five years before the award



In Figure 5.4, we present non-parametric Kaplan-Meier estimates for the likelihood of multi-award winners moving from the organization in which they won the 'R&D 100' prize by type of organization they were working at the time of the award. We have divided inventors' organizations in three different groups: PROs, university and firms. One interesting result emerging in Figure 5.4 is that inventors in our sample working at universities do not move after the award.

Another result is that inventors who were employed by firms move relatively more frequently (after receiving the award) than those that were working on PROs. By the end of the study period we observe that roughly more than 75% of those inventors working for PROs did not leave their current jobs by the tenth year. When comparing the three groups, the log-rank test weakly rejects the null hypothesis of equality (chisq = 0.011).

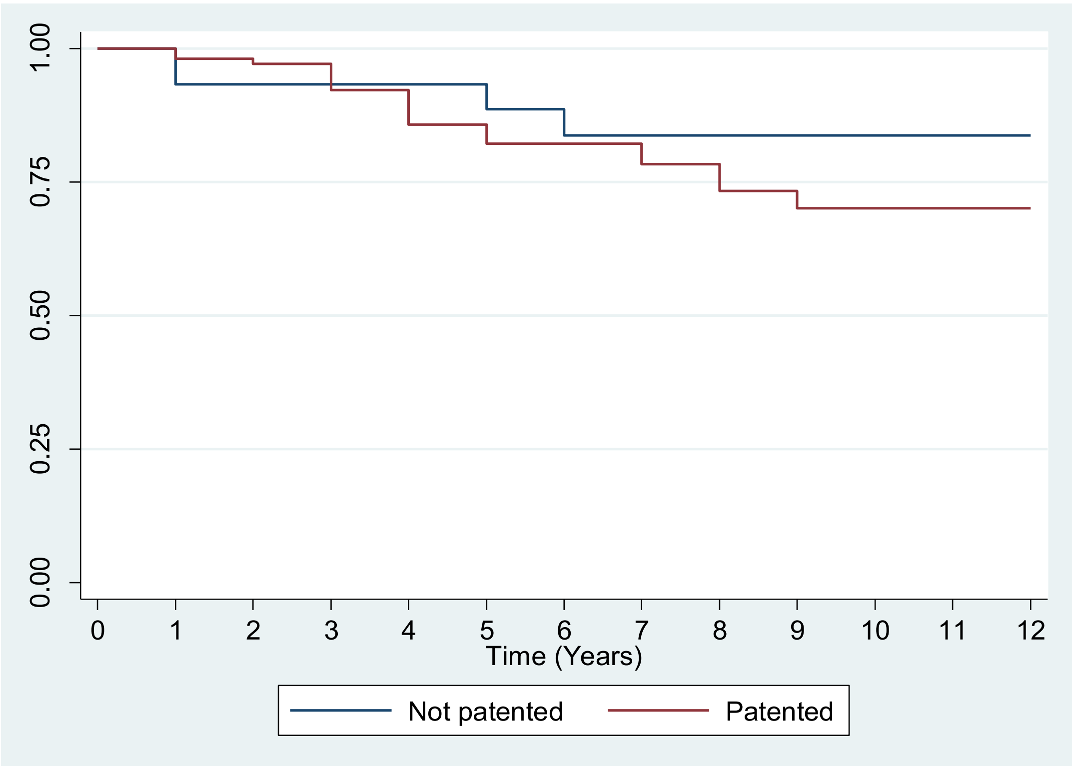
Figure 5.4: Kaplan Meier estimate of S(t) for organization type during award



Finally, Figure 5.5 plots the non-parametric Kaplan-Meier estimates of the mobility of inventors after receiving an 'R&D 100' award conditional on whether the awarded invention was patented or not. We initially observe a higher mobility for those multi-award inventors whose invention was not patented compared to those who patented. However, as we move out over time, we can see that those who patented the invention moved more quickly than those who did not.

By the end of the study period slightly less than 75% of inventors that patented the awarded invention continued to work at the same organization, compared to more than three quarters of those who did not patent. When comparing the two groups, we could not reject the null hypothesis of equality (chisq = 0.395). For this reason, we will include this variable in our econometric exercise.

Figure 5.5: Kaplan Meier estimate of S(t) for awarded patented and not patented invention



5.3. The econometric exercise

In this section, we estimate the probability for an R&D 100 multi-award winner to move after winning the award. More specifically we estimate a discrete time version of a proportional hazard model called the complementary-log-logistic model. The complementary-log-logistic model can be written as follow:

$$\pi(x) = 1 - exp\left[-exp\left(X_{pxn}^{T}\beta_{px1}\right)\right] \quad (2).$$[70]

This type of model represents a good alternative to logistic regression analysis for binary response variables given the fact that, in each discrete time interval, two kinds of outcomes are possible (0 and 1). The complementary log-log transformation takes a response restricted to the interval 0 and 1 and converts it in (-∞, +∞) interval. Thus, by employing the complementary log-logistic regression, we can analyze inventor's mobility across different specifications. We regress the dependent variable, i.e. whether the inventor moved after receiving the award, against different independent and control variables (i.e. individual characteristics, academic background, indicators of job tenure, indicators of experience and pre-award performance). The variables used in this analysis were summarized in Section 5.2.1., Table 5.2.

Model 1 reports the estimated coefficients for individual characteristics, including however only gender and inventor's age during the award. This model does not include among individual characteristics whether the inventor had moved five years before the award. Other specifications such as academic background, indicators of job tenure and experience as well as pre-award performance are not included in this model.

Model 2 contains individual characteristics (gender and age of the inventor at the time of the award) as well as academic background. In Model 3 individual characteristics (gender and inventor's age at the time of the award), academic background and indicators of job tenure are taken into consideration. Model 4 reports the estimated coefficients for individual characteristics (gender and age of the inventor during the award), academic background, indicators of job tenure and experience.

[70] Unwin (2012).

Model 5 summaries the estimated coefficients for individual characteristics (gender, age of the inventor at the time of the award and whether the inventor moved five years before the award), academic background, indicators of job tenure and experience. In Model 6 are presented the estimated coefficients for the full model including individual characteristics, academic background, indicators of job tenure, indicators of experience and pre-award performance. Finally, Model 7 presents the average marginal effects for the full model. Table 5.4 reports the results of the complementary-log-regression. The table reports for each independent variable the estimated coefficient together with its standard error (in brackets).

Table 5.4: Complementary-log-log Model of the probability to move after winning the award

Variable name	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Individual characteristics							
Gender	1.808**	1.879**	1.789**	2.071***	2.020**	1.858**	0.060**
	(0.771)	(0.758)	(0.717)	(0.757)	(0.815)	(0.922)	(0.031)
Age during award (Log)	-1.875*	-1.831*	-0.766	-1.437	-1.649	-1.643	-0.053
	(1.051)	(1.061)	(1.121)	(1.301)	(1.485)	(1.479)	(0.048)
Inventor moved 5 years before the award	-	-	-	-	-0.636	-0.691	-0.022
					(0.721)	(0.756)	(0.024)
Academic background							
PhD highest degree in US	-	0.260	0.747	0.774	0.762	0.716	0.023
		(0.450)	(0.594)	(0.610)	(0.631)	(0.633)	(0.021)
Indicators of job tenure							
Job tenure at the time of the award (Log)	-	-	-0.714***	-0.586**	-0.716**	-0.737**	-0.024**
			(0.267)	(0.296)	(0.319)	(0.317)	(0.011)
Indicators of experience (other than job)							
Founder at the time of the award	-	-	-	2.252***	2.571***	2.567***	0.083***
				(0.708)	(0.827)	(0.851)	(0.029)
Pre-award performance							
No of publications	-	-	-	-	-	-0.007	0.000
						(0.022)	(0.001)
No of applied patents	-	-	-	-	-	0.039	0.001
						(0.057)	(0.002)
Award year fixed effect							
2006	0.810	0.819	0.614	1.600	1.770	1.842	0.064
	(0.817)	(0.811)	(0.812)	(0.978)	(0.976)	(1.000)	(0.031)
2007	-0.395	-0.328	-0.095	0.697	0.529	0.686	0.014
	(1.151)	(1.130)	(1.075)	(1.288)	(1.291)	(1.278)	(0.028)
2008	0.810	0.767	0.492	1.531	1.429	1.396	0.039
	(0.891)	(0.911)	(0.927)	(1.055)	(1.061)	(1.106)	(0.035)
2009	-0.256	-0.236	-0.266	0.146	0.120	0.219	0.003
	(1.028)	(1.019)	(0.987)	(1.043)	(1.023)	(0.975)	(0.015)
2010	-0.841	-0.872	-0.876	-0.751	-0.736	-0.613	-0.007
	(1.236)	(1.239)	(1.234)	(1.251)	(1.240)	(1.287)	(0.014)
2011	-0.154	-0.168	-0.216	0.573	0.612	0.636	0.012
	(1.044)	(1.049)	(1.059)	(1.185)	(1.165)	(1.245)	(0.025)
2012	0.577	0.634	0.712	1.179	1.353	1.504	0.044
	(0.921)	(0.916)	(0.891)	(0.971)	(1.034)	(1.161)	(0.039)
2013	1.397	1.417	1.558	2.381	2.614	2.744	0.144
	(0.947)	(0.935)	(0.935)	(0.999)	(1.100)	(1.158)	(0.081)
2014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	-	-	-	-	-	-	-
lnt	0.277	0.282	0.357	0.510	0.553	0.564	0.018
	(0.315)	(0.314)	(0.322)	(0.325)	(0.316)	(0.310)	(0.010)
Constant	3.239	2.896	0.070	1.133	2.355	2.295	2.295
	(4.345)	(4.383)	(4.386)	(4.922)	(5.708)	(5.629)	(5.629)
No of observations	718	718	718	718	718	718	718
Zero outcomes	693	693	693	693	693	693	693
Nonzero outcomes	25	25	25	25	25	25	25
Wald Chisq.	15.770	17.620	27.70***	42.500***	48.750***	51.080***	-
Log Pseudo Likelihood	-99.957	-99.776	-96.396	-90.526	-89.873	-89.605	-

Robust standard errors between brackets. * Significant at 10%; ** significant at 5%; *** significant at 1%.

In Model 1, we find that there is a positive correlation between the gender (1.808**) of multi-award winners and the probability to move after receiving the R&D 100 Award. This suggests that female inventors are more likely to move than male inventors. In addition to this, we observe a negative correlation at 10% of significance between the age of the inventor (-1.875*) and the probability to move. This suggest that younger inventors are expected to be more mobile after winning a R&D 100 prize.

We then include academic background together with individual characteristics such as gender and age of the inventor at the time of the award (Model 2). As we can observe, the coefficient of our variable academic background (i.e. PhD highest degree in US) is not significant. Thus, inventors who have acquired a doctoral degree in the US do not show a higher propensity to move after receiving the award. There is still a positive correlation between gender (1.879**) and the mobility of the inventor after winning a R&D 100 prize, as well as a negative correlation between the age of inventor and the probability to move (-1.831*).

In Model 3 we include our indicator of job tenure. We find that there is a strong negative association with job tenure at the time of the award (-0.714***) and the probability of an inventor to move right immediately after winning the prize. Thus, the longer the inventors have been employed by their current organization, the less likely they will move right after winning the award. Once we control for job tenure, the coefficient age of the inventor is no longer significant. However, there is again a positive correlation between gender (1.789**) and the probability of multi-award winners to move.

Model 4 adds indicators of experience other than job, more specifically whether the multi-award winners were entrepreneurs or company founders at the time of the award. Results indicate that being a founder at the time of the award is positively associated with inventors' mobility. The coefficient (2.252***) is significant at the 1% level, suggesting that having founded an organization before receiving the award has a significant effect on the probability of a move. Also, gender is still positive and significant (2.071***) at 1% level and job tenure at the time of the award appears to be slightly less significant (-0.586**) compared to Model 3.

Model 5 adds as an additional variable whether the inventor moved five years before the award, which turns out to be non-significant. In this model, we noticed that the coefficients of the variables job tenure at the time of the award (-0.716**) and being a founder at the time of the award (2.571***) are significant at 5% and 1% level. When looking at individual characteristics we observed that gender is the only indicator with a positive correlation (2.020**).

In our final specification model (Model 6), we include the indicators of pre-award performance such as number of publications and number of applied patents by multi-award winners. For comparison, recent contributions noted that there is a positive correlation between inventor's productivity and mobility. Trajtenberg (2005) found that patents coming from mobile inventors receive more citations, confirming that mobility has a positive impact on inventive output in the form of patents.[71] A study on a German sub-sample of PatVal-EU inventors measures the productivity of EU inventors by linking the number of patent applications per inventor to the age of the inventor showing that mobile inventors are more productive than those who do not move (Hoisl, 2007). Thus, it is common in the literature to use patents as indicators of inventive output and inventors' performance. However, in our study both indicators, number of publications and number of applied patents do not show any significance when it comes to inventors' mobility. Further, in this model, we observe once again a positive correlation at 5% between gender (1.858**) and the probability of a move. Job tenure at the time of the award shows a negative association (-0.737**). Lastly, the indicator being a founder is strongly correlated with the likelihood of observing a move (2.567***).

Finally, Model 7 reports the average marginal effects for the full model.

5.4. Robustness checks

We control for the robustness of our results by performing two types of checks (see Table 5.5). We first re-run our complementary log-logistic regression by changing the baseline time function employing, respectively, a linear one (Model 8), a quadratic one (Model 9) and piece-wise (Model 10). We then change the estimation mode from a discrete time estimation to a continuous time by using a Cox proportional model (Model 11). Table 5.5 reports for all four regressions, the dependent variables given a set of indicators such as (i) gender, (ii) whether the inventor moved five years before the award, (iii) organization type during the award, (iv) and whether their invention was patented or not.

[71] In Trajtenberg (2005), the author uses US patent documents and finds that 33% of inventors have changed employer at least once.

Table 5.5: Complementary-log-log model (robustness check)

Variable name	Model 8 (t)	Model 9 (t_sq)	Model 10 (dur)	Model 11 (stcox)
Individual characteristics				
Gender	1.800**	1.839**	1.932**	1.750***
	(0.915)	(0.892)	(0.859)	(0.596)
Age during award (Log)	-1.604	-1.608	-1.621	-1.477
	(1.473)	(1.445)	(1.405)	(1.119)
Inventor moved five years before the award	-0.639	-0.703	-0.617	-0.445
	(0.749)	(0.742)	(0.733)	(0.556)
Academic background				
PhD highest degree in US	0.681	0.739	0.767	0.642
	(0.617)	(0.642)	(0.645)	(0.548)
Indicators of job tenure				
Job tenure at the time of the award (Log)	-0.711**	-0.742**	-0.720**	-0.614**
	(0.312)	(0.316)	(0.312)	(0.292)
Indicators of experience (other than job)				
Founder at the time of the award	2.498***	2.539***	2.429***	2.127***
	(0.828)	(0.866)	(0.841)	(0.668)
Pre-award performance				
No of publications	-0.007	-0.008	-0.008	-0.008
	(0.022)	(0.022)	(0.022)	(0.020)
No of applied patents	0.037	0.042	0.046	0.043
	(0.057)	(0.057)	(0.055)	(0.050)
t	0.115	0.672	-	-
	(0.066)	(0.344)		
t_sq	-	-0.055	-	-
		(0.032)		
durat1	-	-	-0.979	-
			(1.163)	
durat2	-	-	-2.135	-
			(1.466)	
durat3	-	-	-0.570	-
			(1.101)	
durat4	-	-	0.070	-
			(1.153)	
durat5	-	-	0.048	-
			(1.182)	
durat6	-	-	-0.960	-
			(1.483)	
durat7	-	-	0.056	-
			(1.237)	
durat8	-	-	0.337	-
			(1.215)	
Constant	2.373	1.317	3.432	-
	(5.557)	(5.677)	(5.530)	
No of observations	718	718	682	760
Zero outcomes	693	693	657	-
Nonzero outcomes	25	25	25	25
No of subjects	-	-	-	123
No of failures	-	-	-	25
Wald Chisq.	56.620***	51.930***	65.170***	7269.440***
Log Pseudo Likelihood	-90.171	-88.579	-85.455	-93.076

Robust standard errors between brackets. * Significant at 10%; ** significant at 5%; *** significant at 1%.
Each model contains a vector of award year time dummy.

Comparing the results of Model 6 in Table 5.4 and the results of Model 8 in Table 5.5, we find that the main relationships gender, job tenure and founder at the time of the award remain significant showing a positive and negative association at 5% between gender (1.800**) and job tenure at the time of the award (-0.711**) with the likelihood of observing a move. Being a founder at the time of the award in Model 8 remains strongly significant (2.498***).

The coefficients for the dependent variables gender, job tenure and founder at the time of the award in Model 9 (see Table 5.5) retain their original signs when compared to Model 6 (see Table 5.4). The only difference that can be found is that the coefficients of gender and being a founder at the time of the award become slightly smaller and job tenure during the award vaguely larger. Likewise, when comparing Model 10 to Model 6, we observed that the variables gender, job tenure and founder at the time of the award maintain their original signs. Further, we observed that the coefficients gender and founder at the time of the award become smaller in magnitude and gender slightly greater.

In Model 11, we noticed that the coefficients of the variables gender (1.750***), job tenure at the time of the award (-0.614**), and being a founder at the time of the award (2.127***) are significant at 1%, 5% and 1% level respectively. The overall robustness presented in Table 5.5 is reflected in similar results when relating to results in Model 6 (Table 5.4). The only distinction arises in Model 11 where the level of significance for the independent variable gender is superior than in Model 6.

5.5. Conclusion

In this essay, we looked at the determinants of the probability of inventors to move on from their current job after getting an innovation award. We put particular emphasis on a subsample of R&D 100 winners, i.e. those who were awarded more than one R&D 100 Award throughout the period 2005 and 2014. We employed a new sample of inventors drawn from '*The R&D 100 awards inventor survey*' and supplemented this information with another novel dataset constructed by using CV data of multi-award winners from which we collected information concerning whether they moved after receiving the innovation award.

We first presented Kaplan-Meier curves to highlight systematic differences across types of inventors. We then proceeded by estimating the probability of a multi-award winner to move after receiving the innovation award by means of a complementary-log-logistic regression model.

Kaplan-Meier analysis showed the following results: first, female inventors leave the organization where they received the award at a much faster pace compared to male inventors. Second, inventors who moved five years prior to the awarded invention are more prone to move after receiving the prize. Third, inventors employed at universities do not move after the award, this trend is also followed by those working for PROs that did not leave their current jobs by the tenth year. In contrast to this, inventors who were employed by firms move repeatedly after receiving the prize. Lastly, in terms of patented awarded inventions, those who patented move faster compared to those who did not patent.

Findings of the complementary-log-logistic model suggested that academic background is not critical in explaining inventors' mobility. Inventors who have been longer employed by the organization where they developed the awarded invention are less prone to move after being awarded. The econometric exercise exhibits two striking results: firstly, having been a company founder at the time of the award has a positive influence on the probability of a move. Secondly, pre-award experience in terms of patented inventions and scientific publications do not show any effect on inventors' mobility. Robustness checks of our analysis support these findings.

Chapter 6

Conclusion

This thesis tackled the following research questions. First, which are the inventions that actually received an innovation award and who are the inventors most likely to benefit from them? Second, how is the propensity to patent an award-winning innovation affected by the characteristics of the innovation, the organization, and the inventor. Third, being a multiple recipient of a prize plays a role in affecting the career moves of inventors responsible for breakthroughs?

Each question was tackled in a separate essay relying upon a novel dataset of award recipient inventors constructed through a survey purposely carried out for the aim of this thesis: *'The R&D 100 award inventor survey'*. The purpose of the first essay was to present the summary findings of the *'The R&D 100 award inventor survey'*. This essay puts the emphasis on the identification of the characteristics of the inventive process leading to the awarded innovations, their value and finally, the characteristics of the inventors receiving such awards. The main findings of this essay were the following: (i) the "representative" awardee inventor is male, 48 years old, highly educated, with a background in engineering working mainly in the R&D department of small and medium size companies; (ii) the "average" awarded invention is the outcome of a collaborative team work which lasted less than three years and generally used external source of knowledge such as scientific and technical literature; (iii) most of the inventions are product innovations and the distribution of their economic value tends to be rather uniform, contrary to the distribution of their technical value which is rather skewed towards the top decile; (iv) only three quarters of awarded inventions are patented. These descriptive results complement some of the existing literature on survey of inventors that however, based the construction of their samples on patented innovations. By employing a different methodology to construct the sample, our analysis allowed to capture the characteristics of inventions that also occurred outside the patent system.

As not all innovations end up being patented (but patent data is a priceless asset for research on innovation since it includes information on inventions, inventors and citations), the study performed in the second essay examines the propensity to patent of R&D 100 Awards recipients. Again using the results of *'The R&D 100 award inventor survey'* this research explores how the propensity to patent an award-winning innovation is affected by the characteristics of the innovation, the organizational context, and the characteristics of the inventor. In the study, we found that around three fourths of breakthrough inventions that received an award were patented between 2005 and 2014, with a constant share of patented inventions throughout the ten-year period. Further, firms are more likely to patent their awarded inventions and commercialize them than other type of organizations. Conversely, PROs seem to license more patented inventions compared to firms and universities. Outcomes of this study also showed that, from a technical point of view, the value of patented inventions is considered superior in the US when the number of working hours spent on inventing is higher. Further, process innovations in the US are considered of a greater technical value. On the contrary, product and process innovations have higher technical significance and economic value worldwide. Findings also show that the older the inventor involved in the innovation, the lower the technical significance and economic value of the breakthrough innovations worldwide. The above-mentioned findings in this essay provide some novel insights to the growing literature on the propensity to patent when looking at innovations occurring inside and outside the patent system.

The last essay presented in this dissertation considers the determinants of inventors' mobility after getting an innovation award. This research examined the propensity to move by taking into consideration detailed information concerning previous and current career history of a sub-sample of inventors who received more than one R&D 100 Award. The findings of this essay suggest that female inventors move from the organization where they received the award much faster than male inventors. Inventors who moved five years prior to the awarded invention are more prone to move again. Further, inventors who were employed by firms were more mobile than inventors employed at universities and PROs. Likewise, those multi-award winners who patented their inventions move faster compared to those that did not patent. In terms of patented awarded inventions, those who patented were more mobile compared to those who did not patent. Overall findings in this research showed that being a founder at the time of the award makes an inventor to be more mobile. Lastly, pre-award experience in terms of scientific publications and patents do not show any effect on inventors' mobility.

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Appendix A

A.1. Basics of the survey

'The R&D 100 award inventor survey' is the outcome of a joint project between two Italian universities and a US university. The pilot and a major part of the survey were carried out between May and October 2016. The final phase of the survey was conducted between November 2016 and January 2017. The survey was implemented in Qualtrics and used both email and alternative methods of communication such as professional-social networks (LinkedIn and Researchgate).

Our targeted sample of 4,630 of R&D 100 winners were approached by email (2,399) and via professional-social networks (2,231). For being able to reach out most of our sample we adopted the strategy of dividing these two categories in Project 1 (2,399 email contacts) and Project 2 (2,231 professional network contacts). It was much easier to contact inventors via email rather than via professional-social networks. Responding inventors for Project 1 totaled N=279 (256 male and 23 female) from total responding inventors N=415.

Contacting inventors via professional-social networks was a time-consuming task. We reached out to 2,152 inventors via LinkedIn asking whether they were interested in participating in the study, out of them 523 accepted the request (475 male and 48 female), at the end of this exercise we got 122 (113 male and 9 female) inventors that participated and completed the survey. The missing 79 were contacted in professional networks, specifically Researchgate and Xing; and brought in 4 completed surveys (4 males). Responding inventors for Project 2 totaled N=126 (117 male and 9 female) from total responding inventor N=415.

The piloting of our questionnaire was conducted between May and June 2016. The audience size was of 100 inventors and we had a success rate of 10%. The total number of responding inventors for the pilot amounted N=10 (10 male, 0 female). Our total of responding inventors N=415 (383 male and 32 female) is thus made up of the totals of responding inventors of Pilot, Project 1 and Project 2.

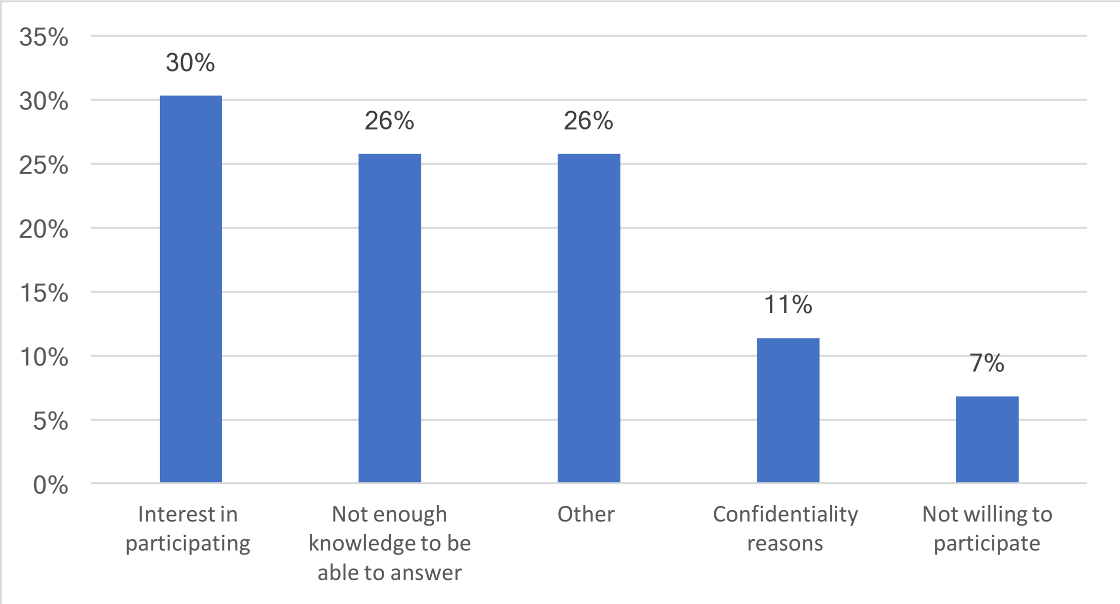
A.2. The questionnaire

The questionnaire consisted of four sections: (A) The invention process (12 questions); (B) Use and value of the invention (17 questions); (C) R&D activity (8 questions); and (D) Inventor career and background (13 questions). To allow, an albeit indirect, comparison with existing surveys the questionnaire contained questions similar to those used in previous surveys such as the European Inventors Survey 2003 (i.e. PatVal) and the '2007 Georgia Tech Inventor Survey'.

A.3. Communication with the inventors

Communication with the inventors happened throughout the pilot and surveying phase. The total number of messages exchanged via email and professional networks amounts 1,650. The number of inventors that reached out to express their concerns or appreciation for the survey amounts 132. As shown in Figure A1, the reasons for not participating to the study were mainly for a) not enough knowledge to be able to answer, b) other (being grateful to be considered in the study, contacted the wrong person within the company), c) confidentiality reasons, d) no willingness to participate.

Figure A1: Reasons for not participating



Appendix B

Table B.1: Estimating the probability to patent an awarded invention. Linear probability model

Variable name	LPM
Inventor characteristics	0.041
Multi-award winner	(0.051)
Amount of working hours	-0.001
	(0.002)
No of publications	0.002
	(0.001)
No of applied patents	0.004**
	(0.002)
PhD highest degree	0.107**
	(0.053)
Experience in the field	-0.002
	(0.003)
Age (Log)	0.153
	(0.142)
Organization Tenure (Log)	-0.006
	(0.038)
Organization characteristics	
PRO (ref.)	
University	-0.018
	(0.085)
Firm	0.231***
	(0.063)
Org. Size (Log)	0.011
	(0.013)
Invention characteristics	
Duration of research	0.001
	(0.001)
Product inn.(ref.)	-
Process inn.	0.127*
	(0.082)
Both product & process	0.021
	(0.053)
No of collaborating inventors	-0.010***
	(0.004)
Research effort	0.000
	(0.000)
Constant	0.049
	(0.527)
No of observations	359
Rsq	0.138
Adj Rsq	0.074

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Each model contains a vector of award year time dummies. We computed for this model the VIP after OLS and the Variance Inflation Factor is 1.83.

Table B.2: Standard Probit estimates without the selection equation

Variable name	Dependent variable		
	(1) Commercialization	(2) Licensing	(3) No of citations
Inventor characteristics			
Multi-award winner	0.063	-0.085	0.046
	(0.201)	(0.193)	(0.234)
Amount of working hours	0.014**	-0.003	-0.005
	(0.007)	(0.006)	(0.006)
No of publications	0.004	-0.004	0.003
	(0.005)	(0.005)	(0.010)
No of applied patents	-0.005	0.013**	0.008**
	(0.007)	0.007	0.003
PhD highest degree	-0.340	0.270	-0.817***
	(0.216)	(0.208)	(0.257)
Experience in the field	0.004	-0.019	-0.034***
	(0.011)	(0.011)	(0.012)
Age (Log)	-0.215	-0.242	1.295
	(0.559)	(0.574)	(0.999)
Organization Tenure (Log)	-0.008	0.531***	-0.217
	(0.152)	(0.165)	(0.170)
Organization characteristics			
PRO (ref.)	-	-	-
University	0.045	-0.099	0.620
	(0.310)	(0.313)	(0.385)
Firm	1.540***	-1.182***	-0.059
	(0.268)	(0.255)	(0.310)
Org. Size (Log)	0.056	-0.153**	0.050
	(0.057)	(0.055)	(0.068)
Invention characteristics			
Duration of research	0.004	0.001	-0.004
	(0.004)	(0.004)	(0.004)
Product inn.(ref.)	-	-	-
Process inn.	0.151	0.437	-0.750**
	(0.301)	(0.294)	(0.313)
Both product & process	0.261	0.295	-0.011
	(0.211)	(0.199)	(0.170)
No of collaborating inventors	-0.004	-0.036*	0.011
	(0.018)	(0.022)	(0.019)
Research effort	-0.000	-0.001*	0.001
	(0.001)	(0.001)	(0.001)
Constant	-0.591	1.045	0.284
	(2.083)	(2.085)	(3.650)
Total No of observations	260	260	123
Wald Chisq.	-	-	79.31
Log Likelihood	-127.112	-137585	-499.685

Robust standard errors between brackets. *Significant at 10%; ** significant at 5%; *** significant at 1%. Each model contains a vector of award year time dummies.

Appendix C

The R&D 100 Award inventor study – Questionnaire

'The R&D 100 award inventor survey'

INSTRUCTIONS: The survey is designed to be responded by R&D 100 Award winners. Please answer each item based on your best estimate. It is not necessary for you to search your files or consult with your colleagues to provide more detailed answers. Instead, please answer to the best of your ability based on your understanding of your invention and its development and use. On the basis of pre-tests, it should typically require 15/20 minutes to complete this questionnaire.
Please note: We use the term "firm" throughout the survey to refer to your workplace. If you work in a university, government lab, etc., or are self-employed, please think of your workplace when answering questions about your "firm". When finished, please return the questionnaire by clicking on the SEND button at the end of the on-line questionnaire.

YOUR RESPONSE IS VERY IMPORTANT TO US. If we can assist you in any way, or if you have any questions or comments, please contact me by phone and/or email.

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Statement of Confidentiality
The information you provide will be held in the strictest confidence. We will neither publish, release, nor disclose any information on, or identifiable with, individuals or their organizations or companies, business units, or R&D units.

Section A: The Invention Process
We want to begin by asking you several questions about the research that led to the awarded invention described in the email. Please think of the research project that resulted in this awarded invention when answering the following questions.

A1. **At the time the research project began**, which of the following would best describe the purpose of your research leading to this invention, in relation to the business objective of your firm? Please select the most relevant answer.

- ○ a. Creating a new process
- ○ b. Improving an existing process
- ○ c. Creating a new product
- ○ d. Improving an existing product
- ○ e. Enhancing the technology base of your firm (without reference to a specific product or process)
- ○ f. Other (please specify): ______________________________

A2. Approximately how long did the research leading to the awarded invention last? Please specify in months (e.g. 7 months, input 7). ______________________________

A3. Which of the following scenarios best describes the **creative process** that led to your invention? Please select the most relevant answer.

○ a. The invention was the targeted achievement of a research or development project

○ b. The invention was an unexpected by-product of a research or development project, not directly related to the main target of the project

○ c. The invention was an expected by-product of a research or development project, not directly related to the main target of the project

○ d. The idea for the invention was directly related to your normal job (which is not inventing), and was then further developed in a (research or development) project

○ e. The idea for the invention came from pure inspiration/creativity not directly related with your professional field of expertise

A4. Which of the following would best describe the type of the invention awarded?

○ a. Product

○ b. Process

○ c. Both

A5. The following questions ask about the collaborations (if any) that created this invention.

A5.1 First, please indicate the **number of (collaborating) inventors** working on the awarded invention (including yourself). ______________________________

A5.2 Second, identify the **organizations** to which the collaborating inventors belonged.

- ☐ a. Your firm
- ☐ b. Suppliers for parts, materials, equipment, software, etc. (including contract manufacturers)
- ☐ c. Customers and product users
- ☐ d. Competitors
- ☐ e. Non-competitors within the same industry
- ☐ f. Other firms
- ☐ g. Universities
- ☐ h. Government research organizations
- ☐ i. Hospitals (including university hospitals), foundations, or private research organizations
- ☐ j. Other (please specify): ____

A6. How important were the following **sources of knowledge for inspiring the research** that led to the awarded invention? **(0 = I did not use this source; 1 = not important; 5 = very important)**

	0	1	2	3	4	5
a. Scientific and technical literature	○	○	○	○	○	○
b. Patent literature	○	○	○	○	○	○
c. Fairs or exhibitions	○	○	○	○	○	○
d. Technical conferences and workshops	○	○	○	○	○	○
e. Standards documents (for example ISO standards or contributions)	○	○	○	○	○	○
f. Your firm, excluding co-inventors (6)	○	○	○	○	○	○
g. Universities	○	○	○	○	○	○
h. Government research organizations	○	○	○	○	○	○
i. Customers or product users	○	○	○	○	○	○
j. Suppliers	○	○	○	○	○	○
k. Competitors (for example, by reverse engineering)	○	○	○	○	○	○
l. Other relevant sources (please specify): ____	○	○	○	○	○	○

A7. Approximately how many **full-time person-months** did the research leading to the awarded invention require (including those of co-inventors and other members of the research team)? [An example: If you worked full-time on the research for 8 months with two collaborators, one working full-time for 4 months and the other one part-time for 3 months: the answer would be 8 + 4 + 3/2 = 13.5 full-time person-months.] ____________________

A8. What were the **sources and approximate shares (%) of funding** for the research leading to this invention, including funding for personnel?
a. Internal funds of the inventing organizations (including subsidiaries): _______
b. Government research programs or other government funds: _______
c. Customers or product users: _______
d. Suppliers for parts, materials, equipment, software, etc.: _______
e. Venture capital or angels: _______
f. Other companies: _______
Total: ________

A9. Did the invention **build** in a substantial way on a previous invention that you knew?

- a. Yes
- b. No
- c. Don't know

Skip To: A11. If A9. Did the invention build in a substantial way on a previous invention that you knew? = b. No
Skip To: A11. If A9. Did the invention build in a substantial way on a previous invention that you knew? = c. Don't know

A10. Was this **previous invention** one that had been made in the same organization?

- a. Yes
- b. No
- c. Don't know

A11. Are you a recipient of **more than one R&D 100 Award**?

- Yes
- No

Section B: Use and Value of the Invention
We want to ask you about how the awarded invention has been used. While you may not know the exact answers to some of these questions, your "informed guesses" are sufficient. Once again, this information will never be disclosed in ways that would enable anyone to identify you, or your firm.

B1. Compared to other technical developments in your field during the year the invention was invented, how would you rate the **technical significance of your invention**, in the **US (Row A)** and **worldwide (Row B)**?

	Top 10%	Top 25% but not top 10%	Top half, but not top 25%	Bottom half	Don't Know
A: US	○	○	○	○	○
B: Worldwide	○	○	○	○	○

B2. Compared to other technical developments in your field during the year the invention was invented, how would you rate the <u>**economic value**</u> **of your invention**, in the **US (Row A)** and **worldwide (Row B)**?

	Top 10%	Top 25% but not top 10%	Top half, but not top 25%	Bottom half	Don't know
A: US	○	○	○	○	○
B: Worldwide	○	○	○	○	○

B3. **In your opinion**, as a general attitude how important are the following for <u>protecting your firm's competitive advantage</u> for the commercial product/process/service based on this invention? **(1 = not important; 5 = very important)**

	1	2	3	4	5
a. First mover's advantage in follow-up R&D (developing complementary technologies and the patent portfolio)	○	○	○	○	○
b. First mover's advantage in commercialization (short lead-time between patenting and commercialization)	○	○	○	○	○
c. Complementary manufacturing capability	○	○	○	○	○
d. Complementary sales/service capability	○	○	○	○	○
e. Patents	○	○	○	○	○
f. Secrecy	○	○	○	○	○
g. Product/process complexity	○	○	○	○	○
h. Collaboration with other firms having complementary technologies	○	○	○	○	○
i. Other (please specify):	○	○	○	○	○

B4. Was the awarded invention **patented**?

○ a. Yes

○ b. No

Skip To: B15. If B4. Was the awarded invention patented? = b. No

B5. In what patent office(s) was it patented? **(Tick all that apply)**. In case the invention is covered by more than one patent, please indicate here only what you consider the **most significant patent**.

	Patent number	Year first filing	Year extension
a. US Patent office (USPTO)			
b. European Patent Office (EPO)			
c. Japanese Patent Office			
d. WIPO			
e. Other national patent offices (indicate country)			

B6. How important were the following **reasons for patenting** this invention at the time of the invention? **(1= not important; 5 = very important)**

	1	2	3	4	5
a. Commercial exploitation (to obtain exclusive rights to exploit the invention economically)	○	○	○	○	○
b. Licensing (to obtain exclusive rights to license the invention in order to generate licensing revenues)	○	○	○	○	○
c. Cross-licensing (to improve your bargaining position when trading your own patent rights for other firms' patent rights)	○	○	○	○	○
d. Pure defense (to ensure that the use of your own technology not be blocked by others)	○	○	○	○	○
e. Blocking patents (preventing others from patenting similar inventions, complements or substitutes)	○	○	○	○	○
f. Preventing inventing-around other key patents of your Firm	○	○	○	○	○
g. Inventor's reputation (patents as an element of evaluation of the inventor/research unit)	○	○	○	○	○
h. Firm's reputation (patenting enhances the technological reputation of the firm)	○	○	○	○	○

B7. This is a hypothetical question: "Suppose that on the day in which this invention was patented, the applicant had all the information about the value of the patent that is available today. If a potential competitor of the applicant was interested in buying the patent, what would be the minimum price the applicant would demand?"

- ○ Less than $20,000
- ○ $20,000 to $65,000
- ○ $65,000 to $195,000
- ○ $195,000 to $650,000
- ○ $650,000 to $1.95 million
- ○ $1.95 million to $6.5 million
- ○ $6.5million to $19.5 million
- ○ $19.5 million to $65 million
- ○ $65 million to $195 million
- ○ More than $195 million

B8. Has the patent applicant/owner ever **used the patented invention** in a product/process/service that has been commercialized?

- ○ a. Yes
- ○ b. No
- ○ c. Not yet, but still investigating the possibilities

Skip To: B10. If B8. Has the patent applicant/owner ever used the patented invention in a product/process/service... = a. Yes

B9. If the patent was not used either as a commercial product/process/service by the applicant firm, for licensing, or for starting a new company, **what are the reasons for it not yet being commercialized**? Please check all that apply.

- ☐ a. We are still actively exploring the commercial possibilities of this invention
- ☐ b. The technology is used internally as a research tool to develop other commercial technologies
- ☐ c. The patent is used or was used for blocking other firms from patenting similar inventions
- ☐ d. The patent is used or was used for preventing inventing-around our products/processes by other firms
- ☐ e. The technology or market environment has changed so that it reduced the value of this invention
- ☐ f. The low technical level of the patented invention
- ☐ g. Lack of interest from potential licensees
- ☐ h. Lack of capital for starting a new firm based on the technology
- ☐ i. The firm has not been able to develop any application technologies for this basic invention
- ☐ j. The line of business for this invention has been downsized
- ☐ k. The new line of business based on the invention has not been successful
- ☐ l. The development of complementary technology in other technology fields is delayed

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B10. While many innovations involve a **combination** of products, processes, and services, would you characterize the commercial application of the patent as primarily involving a new product, process, or service?

- ○ a. Product
- ○ b. Process
- ○ c. Service
- ○ d. Don't know

B11. Have the patent(s) **been licensed** by (one of) the patent-holder(s) to an independent party?

- ○ a. Yes
- ○ b. No
- ○ c. No, but willing to license
- ○ d. Don't know

Skip To: B14. If B11. Have the patent(s) been licensed by (one of) the patent-holder(s) to an… = b. No
Skip To: B14. If B11. Have the patent(s) been licensed by (one of) the patent-holder(s) to an… = d. Don't know
Skip To: B14. If B11. Have the patent(s) been licensed by (one of) the patent-holder(s) to an… = c. No, but willing to license

B12. If the patent(s) are licensed, is it part of a **cross-license?**

- a. Yes
- b. No
- c. Don’t know

B13. How many **licensees** have taken a license to the patent(s)?

- a. Please indicate an approximate number ____________________
- b. Do not know/cannot remember

B14. Has this patent been **exploited commercially** by yourself or any of your co-inventors for starting a new company?

- a. Yes
- b. No
- c. Don’t know

Skip To: End of Block If B14. Has this patent been exploited commercially by yourself or any of your co-inven... = a. Yes
Skip To: End of Block If B14. Has this patent been exploited commercially by yourself or any of your co-inven... = b. No
Skip To: End of Block If B14. Has this patent been exploited commercially by yourself or any of your co-inven... = c. Don’t know

B15. If the invention **was not patented** how important were the following <u>reasons for not patenting this invention</u> at the time of the invention? **(1= not important; 5 = very important)**

	1	2	3	4	5
a. The invention was based upon an already existing idea	○	○	○	○	○
b. I did not think that the invention was patentable	○	○	○	○	○
c. Filing for a patent was too expensive	○	○	○	○	○
d. Alternative strategies of protection (trade secrets, lead-times) were considered better options than patenting	○	○	○	○	○
e. We did not want to disclose	○	○	○	○	○
f. We did not reach an agreement with partners for patent opportunity	○	○	○	○	○
g. The invention was too easy to invent around	○	○	○	○	○
h. Patent enforcement was too costly	○	○	○	○	○
i. We did not need protection for the invention	○	○	○	○	○

B16. With the **benefit of hindsight**, do you consider that <u>not patenting the invention</u> was a mistake for your firm?

○ a. Yes

○ b. No

Skip To: End of Block If B16. With the benefit of hindsight, do you consider that not patenting the invention was a... = b. No

B17. If you have **answered Yes to the previous question** can you specify how important were the following reasons for your answer? **(1= not important; 5 = very important)**

	1	2	3	4	5
a. Due to the lack of patent protection, competitors were able to imitate easily the invention	○	○	○	○	○
b. Due to the lack of patent protection, myself and the other members of the inventing team did not receive enough credit for this achievement	○	○	○	○	○
c. Due to the lack of patent protection, my firm did not receive enough credit for this achievement	○	○	○	○	○

Section C: R&D Activity

Now we would like to ask you about your own work activity. Please think about a typical week at the time when you were working on the invention that was awarded.

C1. At the time of the research leading to the **awarded invention**, approximately what **percentage of your R&D effort** was:

a. Basic Research (scientific research with no specific commercial objectives): ______________________________
b. Applied Research (scientific or engineering research with specific commercial objectives): __________________
c. Design and/or Development (technical activity translating research findings into products or processes): _____
d. Technical service (providing manufacturing support, troubleshooting, etc.): _____________________________
Total: ____

C2. At the time of the invention, about **how many hours** did you work in a typical week? ___________

C3. Please tell us the **share of overall working time** that you spent on **"inventing"** or on R&D activities at the time of the invention (e.g. 10% please input 10): ___________________________________

C4. In the three years prior to the awarded invention, how many **articles** did you publish (including co-authored articles) in scientific journals (including refereed conference proceedings)? ____

C5. In the three years prior to the awarded invention, how many **patents** did you apply for? ____

C6. During the research leading to the awarded invention, how important to you were the following **reasons to work on inventing**? **(1=not important; 5=very important)**

	1	**2**	**3**	**4**	**5**
a. Satisfaction from solving technical problems	○	○	○	○	○
b. Satisfaction from contributing to the progress of science and technology	○	○	○	○	○
c. It is my job to invent	○	○	○	○	○
d. Generating value for my firm/improving my firm's performance	○	○	○	○	○
e. Career advances and opportunities for new/better jobs	○	○	○	○	○
f. Prestige/reputation	○	○	○	○	○
g. Recognition from co-workers	○	○	○	○	○
h. Recognition from others in the same profession (outside the firm)	○	○	○	○	○
i. Improve the working conditions from my company (e.g., increased research budget)	○	○	○	○	○
j. Monetary rewards	○	○	○	○	○
k. To make a contribution to human welfare	○	○	○	○	○

C7. Who took the **decision** to submit the invention for an R&D 100 Award?

- a. Myself
- b. It was a collective decision of the inventing team
- c. My boss
- d. Other (please specify): ____________________

C8. What were the **reasons for submitting** the invention to the R&D 100 Awards? **(1=not important; 5=very important)**

	1	2	3	4	5
a. Improving my own reputation/prestige	○	○	○	○	○
b. Improving reputation/prestige of our laboratory	○	○	○	○	○
c. Improving reputation/prestige of our firm	○	○	○	○	○
d. Advertise the invention for commercialization	○	○	○	○	○
e. Advertise the invention in order to attract partners	○	○	○	○	○
f. Advertise the technological strength of our firm	○	○	○	○	○
g. Establishing priority and preventing competing firms from entering in this field of research	○	○	○	○	○

Section D: Career and background

The following questions ask about your career and background.

D1. When the research leading to the invention was conducted, your **highest degree** was:

- ○ a. High school or lower
- ○ b. Technical college or junior college
- ○ c. University or college Bachelor
- ○ d. University Master's
- ○ e. Ph.D., M.D. or equivalent
- ○ f. Other (please specify): ____________________

D1.1 **Please also indicate:**

D1.2 g. The **year** in which this degree was earned: ____________________

D1.3 h. The **country** in which it was earned: ____________________

D1.4 **For University Bachelor's or higher:**

i. The **discipline** in which the highest degree was earned (e.g. mechanical engineering, biochemistry): ____________________

D2. At the time of the invention, how many **years** had you worked in the **technical field of the invention**? ____________________

D3. What is the approximate **number of invention disclosures** that you made to your firm in the last three years? ____________________

Skip To: D5. If D3. What is the approximate number of invention disclosures that you made to your firm in the las... = none
Skip To: D5. If D3. What is the approximate number of invention disclosures that you made to your firm in the las... = 0

D4. For what **percent** of those inventions did you or your firm **apply for a patent**? (e.g. 25% please input 25): ____________________

Employment before the invention

D5. Within the 5 years prior to the invention, did you **work full-time** for one year or more for **another employer**, including the case of a temporary posting to a university or government lab?

- ○ a. Yes
- ○ b. No

Skip To: End of Block If D5. Within the 5 years prior to the invention, did you work full-time for one year or more for... = b. No

D6. Which of the following **best describes** your previous organization?

- ○ a. University or school
- ○ b. Federal government research organization
- ○ c. State or local government research organization
- ○ d. Supplier to my current firm, for parts, materials, equipments, software, etc. (including contract manufacturers)
- ○ e. Customers or users of my current firm's products/services
- ○ f. Competitor of my current firm's products/services
- ○ g. Non-competitor of my current firm within the same industry
- ○ h. Hospital (including university hospital), foundation, or private research organization

Employment at the time of the invention

D7. Which of the following **best describes the type of the organization** where you worked when you invented this patent? If you worked in a subsidiary of a larger organization, please include the parent company and its subsidiaries in the number of employees.

- ○ A firm with less than 100 employees
- ○ A firm with 100-250 employees
- ○ A firm with 250-500 employees
- ○ A firm with 501 or more employees
- ○ University or college
- ○ Hospital (including university hospital), foundation, or private research organization
- ○ Federal government research organization
- ○ State or local government research organization

D8. In which **year** did you join this organization (or start your business if self-employed)? ___________

D9. Which **best describes the type of unit** to which you belonged at the time of the invention?

- ○ a. Research and development
- ○ b. An independent research and development unit or its sub-unit
- ○ c. A sub-unit attached to a unit with its primary focus on non-R&D such as manufacturing
- ○ d. Manufacturing
- ○ e. Software development
- ○ f. Other (please specify): ____

Section D
Finally, we would also like to ask you for some basic demographic information.

D10. Year of birth: ____

Skip To: D11. If D10. Year of birth: =

D11. Country of birth: ____

D12. Gender:

- ○ a. Male
- ○ b. Female

D13. Did you have **children** at the time of the invention?

- ○ a. Yes
- ○ b. No

Interest for the study
If you would like, we will send you directly the results of the statistical analysis from this survey in your technology field. Please indicate your e-mail address if you are interested in receiving the final report of this research: ____

THANK YOU FOR YOUR COOPERATION!
PLEASE SEND YOUR COMPLETED QUESTIONNAIRE
BY CLIKING ON THE BUTTON BELOW

Bibliography

Acemoglu, D., & Linn, J. (2004). Market size in innovation: theory and evidence from the pharmaceutical industry. *The Quarterly Journal of Economics*, 119(3), 1049-1090.

Achilladelis, B., Schwarzkopf, A., & Cines, M. (1990). The dynamics of technological innovation: the case of the chemical industry. *Research Policy*, *19*(1), 1-34.

Ahuja, G., & Morris Lampert, C. (2001). Entrepreneurship in the large corporation: A longitudinal study of how established firms create breakthrough inventions. *Strategic management journal*, *22*(6- 7), 521-543.

Almeida, P., & Kogut, B. (1999). Localization of knowledge and the mobility of engineers in regional networks. *Management science*, *45*(7), 905-917.

Amabile, T. M. (1993). Motivational synergy: Toward new conceptualizations of intrinsic and extrinsic motivation in the workplace. *Human resource management review*, 3(3), 185-201.

Amesse, F., Desranleau, C., Etemad, H., Fortier, Y., & Seguin-Dulude, L. (1991). The individual inventor and the role of entrepreneurship: A survey of the Canadian evidence. *Research Policy*, *20*(1), 13-27.

Anton, J.J., & Yao, D.A. (2004). Little patents and big secrets: managing intellectual property. *RAND Journal of Economics*, 1-22.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity: Economic and social factors* (pp. 609-626). Princeton University Press.

Arthur, W.B. (2007). The structure of invention. *Research policy*, *36*(2), 274-287.

Arundel, A. (2001). The relative effectiveness of patents and secrecy for appropriation. *Research policy*, *30*(4), 611-624.

Arundel, A., & Kabla, I. (1998). What percentage of innovations are patented? Empirical estimates for European firms. *Research policy*, *27*(2), 127-141.

Arundel, A., Van de Paal, G., & Soete, L. (1995). PACE Report: Innovation strategies of Europe's largest firms: Results of the PACE survey for information sources, public research, protection of innovations and government programmes. *Final Report, MERIT, University of Limburg, Maastricht*.

Azoulay, P., Ganguli, I., & Zivin, J. G. (2017). The mobility of elite life scientists: Professional and personal determinants. *Research policy*, 46(3), 573-590.

Baker, G.P., Jensen, M.C., & Murphy, K.J. (1988). Compensation and incentives: Practice vs. theory. *The journal of Finance*, *43*(3), 593-616.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, *17*(1), 99-120.

Barros, H.M., & Lazzarini, S.G. (2012). Do organizational incentives spur innovation?. *BAR-Brazilian Administration Review*, *9*(3), 308-328.

Basalla, G. (1988). The evolution of technology. *Cambridge University Press*. Cambridge MA.

Baumol, W.J., Schilling, M.A., & Wolff, E. N. (2009). The superstar inventors and entrepreneurs: How were they educated?. *Journal of Economics & Management Strategy*, *18*(3), 711-728.

Besharov, D.J., Williams, H. (2012). Innovation Inducement Prizes: Connecting Research to Policy. *Journal of Policy Analysis and Management*, 31 (3) 2012, pp. 752-776.

Blind, K., Edler, J., Frietsch, R., & Schmoch, U. (2006). Motives to patent: Empirical evidence from Germany. *Research Policy*, *35*(5), 655-672.

Block, F., & Keller, M.R. (2009). Where do innovations come from? Transformations in the US economy, 1970–2006. *Socio-Economic Review*, *7*(3), 459-483.

Boldrin, M., & Levine, D. K. (2013). The case against patents. *The journal of economic perspectives*, *27*(1), 3-22.

Bond, E. W., & Saggi, K. (2014). Compulsory licensing, price controls, and access to patented foreign products. *Journal of Development Economics*, 109, 217-228.

Boudreau, K., & Lakhani, K. (2011). Field Experimental Evidence on Sorting, Incentives and Creative Worker Performance. *Harvard Business School*, 11-107.

Breschi, S., & Lenzi, C. (2010). Spatial patterns of inventors' mobility: Evidence on US urban areas. *Papers in Regional Science*, *89*(2), 235-250.

Breschi, S., & Lissoni, F. (2001). Knowledge spillovers and local innovation systems: a critical survey. *Industrial and corporate change*, *10*(4), 975-1005.

Breschi, S., Lissoni, F., & Montobbio, F. (2007). The scientific productivity of academic inventors: new evidence from Italian data. *Econ. Innov. New Techn.*, 16(2), 101-118.

Brouwer, E., & Kleinknecht, A. (1999). Innovative output, and a firm's propensity to patent.: An exploration of CIS micro data. *Research policy*, *28*(6), 615-624.

Brunt, L., Lerner, J., & Nicholas, T. (2012). Inducement prizes and innovation. *The Journal of Industrial Economics*, *60*(4), 657-696.

Cameron, A.C., & Trivedi, P.K. (2009). Microeconometrics with STATA. *College Station, TX: StataCorp LP*.

Carpenter, M.P., Narin, F., & Woolf, P. (1981). Citation rates to technologically important patents. *World Patent Information*, *3*(4), 160-163.

Chan, H.F., Frey, B. S., Gallus, J., & Torgler, B. (2014). Academic honors and performance. *Labour Economics*, *31*, 188-204.

Chandy, R. K., & Tellis, G. J. (2000). The incumbent's curse? Incumbency, size, and radical product innovation. *Journal of marketing*, *64*(3), 1-17.

Chen, C.J., & Huang, J. W. (2009). Strategic human resource practices and innovation performance—The mediating role of knowledge management capacity. *Journal of business research*, *62*(1), 104-114.

Chiburis, R., & Lokshin, M. (2007). Maximum likelihood and two-step estimation of an ordered-probit selection model. *Stata Journal*, *7*(2), 167-182.

Cohen, W. M., Goto, A., Nagata, A., Nelson, R. R., & Walsh, J. P. (2002). R&D spillovers, patents and the incentives to innovate in Japan and the United States. *Research policy*, 31(8-9), 1349-1367.

Cohen, W.M., & Sauermann, H. (2007). Schumpeter's prophecy and individual incentives as a driver of innovation. *Perspectives on innovation*, 73-104.

Cohen, W.M., Nelson, R. R., & Walsh, J.P. (2000). Protecting their intellectual assets: Appropriability conditions and why US manufacturing firms patent (or not) (No. w7552). *National Bureau of Economic Research.*

Colangelo, N., Kerr, B., Hallowell, K., Huesman, R., & Gaeth, J. (1992). The Iowa Inventiveness Inventory: Toward a measure of mechanical inventiveness. *Creativity Research Journal*, *5*(2), 157-163.

Conti, R., Gambardella, A., & Mariani, M. (2013). Learning to be Edison: inventors, organizations, and breakthrough inventions. *Organization Science*, *25*(3), 833-849.

Coupé, T. (2003). Revealed performances: Worldwide rankings of economists and economics departments, 1990–2000. *Journal of the European Economic Association*, *1*(6), 1309-1345.

Crespi, G., Geuna, A., & Nesta, L.J. (2006). Labour mobility of academic inventors: career decision and knowledge transfer.

Criscuolo et al. (2017) "Lifting the veil on patents and inventions", *Working Paper*, https://sites.insead.edu/facultyresearch/research/file.cfm?fid=60330.

Davis, L., & Davis, J. (2004, May). How effective are prizes as incentives to innovation? Evidence from three 20th century contests. In *DRUID summer conference* (Vol. 2004).

De Laat, E.A. (1997). Patents or prizes: Monopolistic R&D and asymmetric information. *International Journal of Industrial Organization*, *15*(3), 369-390.

Deci, E. (1975). Intrinsic motivation. New York: Plenum.

Dosi, G. (1988). The nature of innovative process. Technological Change and Economic Theory. *Printer Publishers*, New York.

Duguet, E., & Kabla, I. (1998). Appropriation strategy and the motivations to use the patent system in France: an econometric analysis at the firm level. *Annales d'Économie et de Statistique*, 49-50.

Encaoua, D., Guellec, D., & Martinez, C. (2006). Patent systems for encouraging innovation: Lessons from economic analysis. *Research policy*, *35*(9), 1423-1440.

Encaoua, D., Hall, B.H., Laisney, F., & Mairesse, J. (2000). The economics and econometrics of innovation. *Kluwer Academic Publishers*. Boston, MA.

Ernst, H., Leptien, C., & Vitt, J. (2000). Inventors are not alike: the distribution of patenting output among industrial R&D personnel. *IEEE Transactions on engineering management*, *47*(2), 184-199.

Fagerberg, J. (2005). Innovation: A guide to the literature. In J. Fagerberg, D. C. Mowery, & R. Nelson (Eds.). The Oxford handbook of innovation. *Oxford University Press.* Oxford.

Fisher, W.W., & Syed, T. (2010). A prize system as a partial solution to the health crisis in the developing world. *Incentives for Global Public Health.*

Fontana, R., Nuvolari, A., Shimizu, H., & Vezzulli, A. (2012). Schumpeterian patterns of innovation and the sources of breakthrough inventions: evidence from a data-set of R&D awards. *Journal of Evolutionary Economics*, *22*(4), 785-810.

Fontana, R., Nuvolari, A., Shimizu, H., & Vezzulli, A. (2013). Reassessing patent propensity: Evidence from a dataset of R&D awards, 1977–2004. *Research Policy*, *42*(10), 1780-1792.

Frey, B.S. (1997). Not just for the money: An economic theory of personal motivation. Cheltenham, UK. Brookfield, USA: Edward Elgar.

Frey, B.S. (2006). Giving and receiving awards. *Perspectives on Psychological Science*, *1*(4), 377-388.

Frey, B.S., & Gallus, J. (2017). Towards an economics of awards. *Journal of Economic Surveys*, *31*(1), 190-200.

Frey, B.S., & Neckermann, S. (2008). Awards: A view from psychological economics. *Zeitschrift für Psychologie/Journal of Psychology*, *216*(4), 198-208.

Fujiwara, A., & Watanabe, T. (2013, December). The effect of researcher mobility on organizational R&D performance: researcher mobility and innovation. In *ISPIM Innovation Symposium* (p. 1). The International Society for Professional Innovation Management (ISPIM).

Galbraith, J.R. (1982). Designing the innovating organization. *Organizational dynamics*, *10*(3), 5-25.

Gallus, J., & Frey, B.S. (2016). Awards: A strategic management perspective. *Strategic Management Journal*, 37, 1699–1714.

Gavrila, C., Caulkins, J. P., Feichtinger, G., Tragler, G., & Hartl, R. F. (2005). Managing the reputation of an award to motivate performance. *Mathematical Methods of Operations Research*, *61*(1), 1-22.

Geuna, A., & Nesta, L. J. (2006). University patenting and its effects on academic research: The emerging European evidence. *Research policy*, *35*(6), 790-807.

Giuri, P., Mariani, M., Brusoni, S., Crespi, G., Francoz, D., Gambardella, A., Garcia-Fontes, W., Geuna, A., Gonzales, R., Harhoff, D., Hoisl, K., Le Bas, C., Luzzi, A., Magazzini, L., Nesta, L. Nomaler, O., Palomeras, N., Patel, P., Romanelli M., Verspagen, B., (2007). Inventors and invention processes in Europe: results from the PatVal-EU survey, *Research Policy,* 36, 1107–1127.

Gök, A. (2013). The impact of innovation inducement prizes. *Compendium of Evidence on the Effectiveness of Innovation Policy Intervention*. London: NESTA.

Göktepe, D. (2008). Inside the ivory tower: Inventors and patents at Lund university (Doctoral dissertation).

Gorin, C. (2016). Patterns and determinants of inventors' mobility across European urban areas. HAL Id: halshs-01313086, https://halshs.archives-ouvertes.fr/halshs-01313086.

Graham, S.J., Merges, R.P., Samuelson, P., & Sichelman, T. (2009). High technology entrepreneurs and the patent system: Results of the 2008 Berkeley patent survey. *Berkeley Technology Law Journal*, 1255-1327.

Grefermann, K., & Röthlingshöfer, K. C. (1974). Patentwesen und technischer Fortschritt: kritische Würdigung der Zusammenhänge in ausgewählten Branchen der Bundesrepublik Deutschland anhand empirischer Untersuchungen. *Patent-und Lizenzpolitik der Unternehmen* (Vol. 1). Otto Schwartz.

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica, Journal of the Econometric Society*, 501-522.

Gubler, T., Larkin, I., & Pierce, L. (2016). Motivational spillovers from awards: Crowding out in a multitasking environment. *Organization Science*, *27*(2), 286-303.

Hall, B. H., & Lerner, J. (2010). The financing of R&D and innovation. In *Handbook of the Economics of Innovation* (Vol. 1, pp. 609-639). North-Holland.

Hall, B. H., & Ziedonis, R. H. (2001). The patent paradox revisited: an empirical study of patenting in the US semiconductor industry, 1979-1995. *RAND Journal of Economics*, 101-128.

Hall, B., Helmers, C., Rogers, M., & Sena, V. (2014). The choice between formal and informal intellectual property: a review. *Journal of Economic Literature*, *52*(2), 375-423.

Hall, B.H., Jaffe, A., & Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of economics*, 16-38.

Hanel, P. (2008). The use of intellectual property rights and innovation by manufacturing firms in Canada. *Econ. Innov. New Techn.*, *17*(4), 285-309.

Harabi, N. (1995). Appropriability of technical innovations an empirical analysis. *Research policy*, *24*(6), 981-992.

Harhoff, D., Scherer, F.M., Vopel, K., 2003. Exploring the tail of patented invention value distribution. In: Granstrand, O. (Ed.), *Economics, Law and Intellectual Property: Seeking Strategies for Research and Teaching in a Developing Field*. Kluwer Academic Publishers, Boston, MA, 279–309.

Hauschildt, J., & Salomo, S. (2007). Innovationsmanagement, 4., überarbeitete, ergänzte und aktualisierte Auflage. *München: Vahlen*.

Hayami, Y., & Ruttan, V. W. (1971). *Agricultural development: an international perspective*. Baltimore, Md/London: The Johns Hopkins Press.

Heckman, J. J. (1979). Sample Selection Bias as a Specification Error. *Econometrica*, 47, 153-161.

Heger, D., & Zaby, A. K. (2013). The heterogeneous costs of disclosure and the propensity to patent. *Oxford Economic Papers*, *65*(3), 630-652.

Henderson, R., Jaffe, A.B., & Trajtenberg, M. (1998). Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. *The review of economics and statistics*, *80*(1), 119-127.

Henderson, S.J. (2004). Inventors: The ordinary genius next door. *Creativity: From potential to realization*, 103-125.

Hoisl, K. (2007). Tracing mobile inventors—the causality between inventor mobility and inventor productivity. *Research Policy*, *36*(5), 619-636.

Holmstrom, B. (1989). Agency costs and innovation. *Journal of Economic Behavior & Organization*, *12*(3), 305-327.

Hussinger, K. (2006). Is silence golden? Patents versus secrecy at the firm level. *Economics of Innovation and New Technology*, *15*(8), 735-752.

Ichniowski, C., & Shaw, K. (2003). Beyond incentive pay: Insiders' estimates of the value of complementary human resource management practices. *The Journal of Economic Perspectives*, *17*(1), 155-180.

Jaffe, A.B., & Lerner, J. (2001). Reinventing public R&D: Patent policy and the commercialization of national laboratory technologies. *Rand Journal of Economics*, 32,167-198.

Jaffe, A.B., & Trajtenberg, M. (1996). Flows of Knowledge from Universities and Federal Labs: Modelling the Flows of Patent Citations Over Time and Across Institutional and Geographic Boundaries. *NBER Working Paper*, No. 5712.

Jaffe, A.B., Trajtenberg, M., & Fogarty, M. S. (2000). The meaning of patent citations: Report on the NBER/Case-Western Reserve survey of patentees (No. w7631). *National bureau of economic research*.

Jones, B. F. (2010). Age and great invention. *The Review of Economics and Statistics*, *92*(1), 1-14.

Jung, T., & Ejermo, O. (2014). Demographic patterns and trends in patenting: Gender, age, and education of inventors. *Technological Forecasting and Social Change*, *86*, 110-124.

Kabla, I. (1996). The patent as indicator of innovation. *INSEE studies*, *1*, 57-72.

Kaiser, U., Kongsted, H.C., & Rønde, T. (2008). Labor mobility and patenting activity. *University of Copenhagen, Department of Economics, Centre for Applied Microeconometrics (CAM) Working Paper*, *7*.

Kash, D.E., & Kingston, W. (2001). Patents in a world of complex technologies. *Science and Public Policy*, *28*(1), 11-22.

Kay, L. (2011). The effect of inducement prizes on innovation: evidence from the Ansari XPrize and the Northrop Grumman Lunar Lander Challenge. *R&D Management*, *41*(4), 360-377.

Kay, L. (2012). Opportunities and challenges in the use of innovation prizes as a government policy instrument. *Minerva*, *50*(2), 191-196.

Khan, B.Z. (2015). Inventing Prizes: A Historical Perspective on Innovation Awards and Technology Policy. *Business History Review*, *89*(4), 631-660.

Kohn, A. (1993). Punished by rewards: The trouble with gold stars, incentive plans, A's, praise, and other bribes. Boston: Houghton Mifflin Harcourt.

Kortum, S., & Lerner, J. (1997). Stronger protection or technological revolution: What is Behind the Recent Surge in Patenting?. *Carnegie-Rochester Conference Series on Public Policy*, Vol. 48 (1998).

Krabel, S., & Flöther, C. (2014). Here today, gone tomorrow? Regional labour mobility of German university graduates. *Regional studies*, *48*(10), 1609-1627.

Kremer, M., & Williams, H. (2010). Incentivizing innovation: Adding to the tool kit. *Innovation policy and the economy*, *10*(1), 1-17.

Lanjouw, J.O., & Schankerman, M. (2004). Patent quality and research productivity: Measuring innovation with multiple indicators. *The Economic Journal*, *114*(495), 441-465.

Lehman, B. (2003). The pharmaceutical industry and the patent system. *International Intellectual Property Institute*, 1-14.

Lemley, M.A., & Shapiro, C. (2005). Probabilistic patents. *The Journal of Economic Perspectives*, *19*(2), 75-98.

Lerner, J., & Wulf, J. (2007). Innovation and incentives: Evidence from corporate R&D. *The Review of Economics and Statistics*, *89*(4), 634-644.

Lettl, C., Rost, K., & Von Wartburg, I. (2009). Why are some independent inventors 'heroes' and others 'hobbyists'? The moderating role of technological diversity and specialization. *Research Policy*, *38*(2), 243-254.

Levin, R.C., Klevorick, A.K., Nelson, R. R., Winter, S.G., Gilbert, R., & Griliches, Z. (1987). Appropriating the returns from industrial research and development. *Brookings papers on economic activity*, *1987*(3), 783-831.

Licht, G., & Zoz, K. (2000). Patents and R&D: An Econometric Investigation Using Applications for German, European and US Patents by German Companies. In *The economics and econometrics of innovation* (pp. 307-338). Springer US.

Link, A.N., & Welsh, D.H. (2013). From laboratory to market: On the propensity of young inventors to form a new business. *Small Business Economics*, *40*(1), 1-7.

Lissoni, F. (2013). Academic patenting in Europe: a reassessment of evidence and research practices. *Industry and Innovation*, 20(5), 379-384.

Lissoni, F. (2017). International migration and innovation diffusion: an eclectic survey. *Regional Studies*, 1-13. DOI: 10.1080/00343404.2017.1346370

Lissoni, F., Llerena, P., McKelvey, M., Sanditov, B. (2008). Academic patenting in Europe: new evidence from the KEINS database. *Research Evaluation*, 17 (2), 87-102.

Love, J. (2013). Selected innovation prizes and reward programs. KEI Research Note 2008: 1, http://www.keionline.org/misc-docs/research_notes/kei_rn_2008_1.pdf. Accessed 01 August 2017.

Lyndhurst, B. (2010). The Big Green Challenge: Final evaluation report. *NESTA: London*.

Macdonald, S. (1986). The distinctive research of the individual inventor. *Research Policy*, *15*(4), 199-210.

Machlup, F. (1962). The Supply of Inventors and Inventions. In The rate and direction of inventive activity: Economic and Social Factors, *Princeton University Press*, 143 – 170.

Magnus, M. (1981). Employee recognition: A key to motivation. *Personnel Journal*, 60, 103–107.

Mansfield, E. (1986). Patents and innovation: an empirical study. *Management science*, *32*(2), 173-181.

Mariani, M., & Romanelli, M. (2007). "Stacking" and "picking" inventions: The patenting behavior of European inventors. *Research Policy*, *36*(8), 1128-1142.

Markham, S.E., Scott, K., & McKEE, G.A.I.L. (2002). Recognizing good attendance: A longitudinal, quasi- experimental field study. *Personnel Psychology*, *55*(3), 639-660.

Masters, W. A., & Delbecq, B. (2008). Accelerating innovation with prize rewards. History and Typology of Technology Prizes and a New Contest Design for Innovation in African Agriculture.

Miguélez, E., & Moreno, R. (2014). What attracts knowledge workers? The role of space and social networks. *Journal of Regional Science*, *54*(1), 33-60.

Moser, P. (2005). How do patent laws influence innovation? Evidence from nineteenth-century world's fairs. *The American Economic Review*, *95*(4), 1214-1236.

Moser, P. (2012). Innovation without patents: Evidence from World's Fairs. *The Journal of Law and Economics*, *55*(1), 43-74.

Moser, P., & Nicholas, T. (2013). Prizes, Publicity and Patents: Non-Monetary Awards as a Mechanism to Encourage Innovation. *The Journal of Industrial Economics*, *61*(3), 763-788.

Mowery, D.C., & Sampat, B.N. (2004). The Bayh-Dole Act of 1980 and university–industry technology transfer: a model for other OECD governments?. *The Journal of Technology Transfer*, *30*(1-2), 115-127.

Mowery, D.C., Nelson, R. R., Sampat, B.N., & Ziedonis, A.A. (2001). The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh–Dole act of 1980. *Research policy*, *30*(1), 99-119.

Murray, F., Stern, S., Campbell, G., & MacCormack, A. (2012). Grand Innovation Prizes: A theoretical, normative, and empirical evaluation. *Research Policy*, *41*(10), 1779-1792.

Nager, A., Hart, D.M., Ezell, S., & Atkinson, R.D. (2016). The demographics of innovation in the United States. *ITIF. Web-version: http://www2.itif.org/2016-demographics-of-innovation. pdf.*

Nakajima, R., Tamura, R., & Hanaki, N. (2010). The effect of collaboration network on inventors' job match, productivity and tenure. *Labour economics*, *17*(4), 723-734.

National Academy of Engineering (NAE). 1999. Concerning federally sponsored inducement prizes in engineering and science. Washington, DC. *Web-version: http://newton.nap.edu/catalog/9724.html.*

Neckermann, S., & Kosfeld, M. (2008). Working for nothing. The Effect of Awards on Employee Performance Mimeo, *University of Zurich, Switzerland*.

Nicholas, T. (2011). Did R&D firms used to patent? Evidence from the first innovation surveys. *The Journal of Economic History*, *71*(4), 1032-1059.

OECD (2003). Turning Science into Business, OECD Publications, Paris.

Owan, H., & Nagaoka, S. (2009). Intrinsic and Extrinsic Motivation for Inventors, forthcoming as a RIETI Working Paper.

Prendergast, C. (1999). The provision of incentives in firms. *Journal of economic literature*, *37*(1), 7-63.

Reitzig, M. (2004). The private values of ‘thickets' and ‘fences': towards an updated picture of the use of patents across industries. *Economics of Innovation and New Technology*, *13*(5), 457-476.

Reynolds, T.S. (2002). Stronger than a hundred men: a history of the vertical water wheel (Vol. 7). *Johns Hopkins University Press*. Baltimore.

Roberts, B. (1999). A tale of two patent strategies. *Electronic Business*, *10*(25), 79-84.

Robertson, T.S. (1967). The process of innovation and the diffusion of innovation. *The Journal of Marketing*, 14-19.

Roin, B.N. (2014). Intellectual Property Versus Prizes: Reframing the Debate. *The University of Chicago Law Review*, 999-1078.

Rossman, J. (1964). Industrial creativity: The psychology of the inventor. New Hyde Park, NY: University Books.

Ruttan, V.W. (1959). Usher and Schumpeter on invention, innovation, and technological change. *The quarterly journal of economics*, 596-606.

Sauermann, H. (2017). Fire in the belly? Employee motives and innovative performance in startups versus established firms. *NBER Working Paper 23099.*

Sauermann, H., & Cohen, W. M. (2010). What makes them tick? Employee motives and firm innovation. *Management Science*, *56*(12), 2134-2153.

Scherer, F.M. (1965). Firm size, market structure, opportunity, and the output of patented inventions. *The American Economic Review*, *55*(5), 1097-1125.

Scherer, F.M. (1983). The propensity to patent. *International Journal of Industrial Organization*, *1*(1), 107-128.

Scherer, F.M., (1989). Comments on Z. Griliches patents: recent trends and puzzles. *Brookings Papers on Economic Activity* 9, 291–330.

Schmookler, J. (1966). Invention and Economic Growth. *Harvard University Press*. Cambridge, MA.

Schoenmakers, W., & Duysters, G. (2010). The technological origins of radical inventions. *Research Policy*, *39*(8), 1051-1059.

Schumpeter, J.A. (1934). The Theory of Economic Development. *Harvard University Press*. Cambridge, MA.

Schumpeter, J.A. (1939). *Business cycles* (Vol. 1, pp. 161-74). New York: McGraw-Hill.

Shane, S. (2004). Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States. *Journal of Business Venturing*, *19*(1), 127-151.

Shimizu, H., & Hoshino, Y. (2012). The Nature of Inventive Activities: Evidence from a Data-Set of the Okouchi Prizes and a Comparison with the R&D 100 Awards. IIR Working Paper WP#12-02, http://hdl.handle.net/10086/22188.

Singh, J., & Fleming, L. (2010). Lone inventors as sources of breakthroughs: Myth or reality?. *Management science*, *56*(1), 41-56.

Staudt, E., & Kriegesmann, B. (2002). Zusammenhang von Kompetenz, Kompetenz Entwicklung und Innovation. Arbeitsgemeinschaft Betriebliche Weiterbildungsforschung e. V./Projekt Qualifikations-Entwicklungs-Management (Hrsg.): Kompetenzentwicklung und Innovation. *Die Rolle der Kompetenz bei Organisations-, Unternehmens-und Regionalentwicklung. Edition QUEM*, *14*, 15-70.

Stolpe, M. (2002). Determinants of knowledge diffusion as evidenced in patent data: the case of liquid crystal display technology. *Research Policy*, *31*(7), 1181-1198.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research policy*, *15*(6), 285-305.

Teece, D. J. (2006). Reflections on "profiting from innovation". *Research Policy*, *35*(8), 1131-1146.

Teece, D.J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research policy*, *15*(6), 285-305.

Thirtle, C.J., & Ruttan, V.W. (1987). The role of demand and supply in the generation and diffusion of technical change. New York: Harwood.

Thomson, R. (2009). *Structures of change in the mechanical age: Technological innovation in the United States, 1790–1865*. John Hopkins University Press, Baltimore.

Toivanen, O., & Väänänen, L. (2016). Education and invention. *Review of Economics and Statistics*, *98*(2), 382-396.

Trajtenberg, M. (1990). A penny for your quotes: patent citations and the value of innovations. *The Rand Journal of Economics*, 172-187.

Trajtenberg, M. (2005, May). Recombinant ideas: the mobility of inventors and the productivity of research. In *CEPR-Conference, Munich*.

Trajtenberg, M., Henderson, R., & Jaffe, A. (1997). University versus corporate patents: A window on the basicness of invention. *Economics of Innovation and new technology*, *5*(1), 19-50.

Umeno, S. Y., & Yamacuhi I. (2015). Inventors' Mobility and Organizations' Productivity: Evidence from Japanese rare name inventors.

Unwin, A. (2012). Regression for Categorical Data by Gerhard Tutz. *International Statistical Review*, 80(2), 342-343.

Usher, A. P. (1954). A History of Mechanical Inventions. *Harvard University Press*, Cambridge MA.

Utterback, J. M. (1971). The process of technological innovation within the firm. *Academy of management Journal*, *14*(1), 75-88.

Van de Ven, W. P., & Van Praag, B. M. (1981). The demand for deductibles in private health insurance: A probit model with sample selection. *Journal of econometrics*, 17(2), 229-252.

Verhoeven, D., Bakker, J., & Veugelers, R. (2016). Measuring technological novelty with patent-based indicators. *Research Policy*, *45*(3), 707-723.

Walsh, J. P., & Nagaoka, S. (2009). Who invents? Evidence from the Japan & US inventor survey. *RIETI Discussion papers*.

Wei, M. (2007). Should prizes replace patents: A critique of the medical innovation prize act of 2005. *BUJ Sci. & Tech. L.*, *13*, 25.

William, A., & Delbecq, B. M. (2008). History and typology of technology prizes and a new contest design for innovation in African agriculture.

Wright, B. D. (1983). The economics of invention incentives: Patents, prizes, and research contracts. *The American Economic Review*, *73*(4), 691-707.

Yamauchi, I., Onishi, K., & Suzuki, T. (2014). How to trace mobile inventors in the Japanese patent data? A unique name approach. *IIPR Discussion Paper Series 2014-01*.

Zaby, A. K. (2010). Losing the lead: the patenting decision in the light of the disclosure requirement. *Economics of Innovation and New Technology*, *19*(2), 147-164.

Zenger, T. R., & Lazzarini, S. G. (2004). Compensating for innovation: Do small firms offer high-powered incentives that lure talent and motivate effort?. *Managerial and Decision Economics*, *25*(6- 7), 329-345.

Zucker, L. G., Darby, M. R., & Torero, M. (2002). Labor mobility from academe to commerce. *Journal of Labor Economics*, *20*(3), 629-660.