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University-industry knowledge transfer and the value of industrial inventions:

Evidence from a survey of inventors of European patents

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Abstract

Although it is well known that the transfer of academic knowledge to industry often results in economically valuable outcomes, little evidence exists on what specific characteristics of the process of university-industry knowledge transfer lead to the generation of more valuable inventions. Building upon an original survey of industrial inventors of European patents, resident in the Italian region of Piedmont, we analyse the determinants of the value of inventions that have benefited from the contribution of academic knowledge, focusing on a set of project, inventor and firm characteristics. Checking a variety of model specification and controlling for selection bias and endogeneity, we find that knowledge transfer processes involving a direct collaboration between the inventor and the university (and particularly individual researchers) as well as the transfer of theoretical academic knowledge, lead to more valuable inventions. Inventors with greater cognitive proximity to the university (more educated, with experience of having worked at a university) and with greater patenting experience, are more likely to benefit from university knowledge and to produce more valuable inventions as a result.

Key words: university-industry knowledge transfer, invention value, inventor survey, patent value, collaborations

JEL codes: O31 - Innovation and Invention: Processes and Incentives; O32 - Management of Technological Innovation and R&D; O34 - Intellectual Property Rights.

1. Introduction

Much evidence has been produced, particularly since the 1990s, suggesting that the transfer of academic knowledge to industry leads to economically valuable outcomes. Academic knowledge has been linked to firms' productivity growth (Adams, 1990; Mansfield, 1991, 1998) and to the development of a large number of inventions that, in the absence of available research outcomes produced by universities, would have been developed only much later, or not at all. Numerous studies have investigated the impact of expenditure on academic research on the innovation performance of firms in the same region (in terms of their research expenditures, patents produced or new products announced), repeatedly finding evidence of a positive relationship between these variables (Jaffe, 1989; Acs et al, 1992; Autant-Bernard, 2001). However, not many studies have investigated how the production of economically valuable outcomes (in particular, inventions) is linked to the specific characteristics of the process of university-industry knowledge transfer. This lack of evidence is due, most probably, to the difficulty in finding appropriate data, both about the economic value of inventions and about the contribution of university-industry knowledge transfer to such value.

In this paper, we investigate the relationship between the characteristics of the process of university-industry knowledge transfer and the economic value of inventions that are produced as a result. We rely upon an original survey of non-academic inventors residing in the Italian region of Piedmont. The PIEMINV survey, described in greater detail in section 3, included a broad range of questions some of which asked inventors to state the monetary values, as well as several other characteristics, of their invention with the highest economic impact and of their invention which benefited the most from the contribution of university knowledge, whether these inventions had been patented or not. This information allows us to investigate, for the subset of inventions that have benefited from knowledge transfer from university, what characteristics of the knowledge transfer process are associated with higher economic value. An awareness of what features of knowledge transfer processes are linked to outcomes that are economically valuable is of great interest both to industry (as firms are increasingly aware of the potential benefits of interacting with universities to enhance their competitiveness and innovative potential), and to universities (which are increasingly expected to demonstrate success in knowledge transfer as a measurable evidence of their economic effectiveness). It is also useful to policymakers who are required to use dwindling public resources to fund research with the highest economic impact.

The paper is structured as follows. In the next section, we present a brief review of the literature on the contribution of academic research to innovation and on the determinants of the economic value of inventions. We also discuss how assessing the value of inventions is often problematic, and how we propose to deal with this issue in our empirical study. In section 3 we develop several theoretical hypotheses explaining how some features of the university-industry knowledge transfer process may contribute to the value of industrial inventions. In section 4, we describe the dataset used for the analysis, while in section 5 we explain our empirical strategy. Finally in section 6 we present our empirical results and in the final section we draw some conclusions and implications for policy.

2. The contribution of academic knowledge to industrial innovation processes and the problem of measuring the value of inventions

2.1. How does academic knowledge benefit industrial innovations?

There is by now a large amount of evidence suggesting that academic knowledge positively contributes to innovation in industry. The nature and extent of these contributions have been explored from a number of different perspectives.

Several studies have attempted to quantify the relationship between investment in research and technological progress at national level, with a macroeconomic approach. These studies have generally estimated the elasticity of technological progress, measured as variation in total factor productivity (TFP), to investment in research. Using this approach, Guellec and van Pottlesberghe (2002) studied the impact of various forms of research investment on TFP in 16 OECD countries in the period 1980-1998, finding that a 1% increase in public research expenditure increased TFP by 0.17%, a greater effect than an equal increase in private research expenditure, which increased TFP only by 0.13%. To some extent, this could be due to firms' tendency to protect the outcomes of their research activities through instruments like patents and confidentiality agreements, differently from the outcomes of publicly-funded research which are usually disseminated through openly accessible channels such as scientific publications, conferences and others. Consequently, the outcomes of public research are more likely to generate knowledge spillovers that benefit many other agents in the economy. Consistently with this argument, Haskel and Wallis (2010), using UK data, found that while government-funded research (mainly performed within universities) had a positive impact on TFP, the impact of private research investment was not significant. Also Martin (1998), using Canadian data, found a positive effect of research expenditure on TFP growth and found that a large share of this contribution was due to academic research. Studying the impact of academic research on TFP growth in the US using data from the 1950s to the 1980s, Adams (1990) found that academic knowledge provided a fundamental contribution to productivity growth, and that there was a time lag of about twenty years between the publication of academic research results and their effects on productivity thanks to their exploitation on the part of firms.

Other studies have investigated the extent to which academic research affects firms' innovation processes, in a microeconomic perspective. Mansfield (1991) showed that 11% of new products and 9% of new processes introduced in the US over a ten-year period would not have been developed without academic research, or would only have been developed with substantial delays. In a later study (1998) he found that the importance of academic research for industrial innovation processes had increased over time and that the average time lag between the publication of research results and their commercial exploitation had shortened. Jaffe (1989) found that firms' amount of patented inventions was significantly and positively correlated not only to private R&D expenditure but also to academic research expenditure within the borders of the same state, especially in pharmaceuticals, medical technology, optics, electronics and nuclear energy. Furthermore, greater academic research expenditure seemed to induce greater private R&D expenditure. Autant-Bernard (2001) obtained similar results from a sample of French firms. With a similar approach, but estimating firms' innovativeness on the basis of their product announcements (a more realistic indicator since not all innovations are patented, and not all patents are exploited commercially) Acs et al (1992) found an even stronger effect of academic research on firms' innovation performance and an even greater importance of geographic proximity to universities. Narin et al (1997), examining the citations to scientific publications in a sample of US industrial patents, found that the links between academic research and industrial innovations had intensified over time.

Despite the varied evidence of a positive contribution of academic research to industrial innovation, we do not know very much about the way in which the features of university-industry knowledge transfer processes contribute to the value of the industrial inventions that have been produced as a result. Some studies have investigated how differences in ownership of academic patents are linked to various measures of patent value. Lissoni et al. (2010), using a set of patents invented by academics ("academic patents") based in Denmark, France, Italy, the Netherlands and Sweden, showed that company-owned academic patents receive more citations than average, while academic patents owned by individual scientists or their universities receive fewer citations than non-academic ones. Crespi et al. (2006), using a sample of academic patents granted by the European Patent Office (EPO) in France, Germany, Italy, Spain, the Netherlands and the UK, showed that university-owned patents do not have a higher probability of being used than company-owned ones. Czarnitzki et al (2012) suggest that company-owned academic patents are more likely than university-owned patents to enable firms to reap short term returns and to have high blocking potential in technology markets. To the extent that patent ownership can be linked to some features of knowledge transfer (personal consultancies on the part of academics are more likely to result in company-owned patents while the results of collaborative research between university and industry are more likely to be patented by the university) then these findings would suggest that patents resulting from academic consulting activities are on average more valuable than patents resulting from collaborative research activities. While these results are suggestive, however, patent ownership does not depend only on the features of the knowledge transfer process but also, often more importantly, on other factors such as the extent to which the institutional and legal framework supports university ownership (see Geuna and Rossi, 2011 for a discussion and literature review on the institutional determinants of the ownership of academic patents).

Another line of research that provides some helpful insights concerns the general determinants of patent value. As shown in the comprehensive reviews presented by Reitzig (2003) and Sapsalis and van Pottlesberghe de la Potterie (2003) the value of patents is closely associated to forward patent citations (suggesting that more valuable patents are highly used by other inventors as a basis for their own patents), to indicators of the geographical scope of protection of a patent (suggesting that firms' decision to extend patent protection to other countries is based on the patent’s value), to indicators of family size (suggesting that valuable patents refer to inventions that are embedded in a system of other inventions or that have spun a whole family of inventions), to the amount of backward patent citations (suggesting that valuable inventions are based on a broader technological knowledge base). More ambiguous results have been found with respect to other variables such as patent scope (measured by the number of technology classes listed on the patent), patent novelty (measured in terms of citations to the scientific literature) and the patent’s indended utilization (whether as exclusion right or as bargaining chip in cross-licensing agreements). However, this literature does not provide satisfactory answers to the problem of understanding how academic knowledge contributes to the value of inventions: none of these studies specifically focus on industrial inventions that have benefited from the contribution of academic knowledge, nor do they include the features of university-industry knowledge transfer among the possible determinants of invention value. The focus is restricted to patented inventions, which are only a subset of the overall set of inventions realized by firms (Arundel and Kabla, 1998). Moreover, very few of these studies can rely upon precise measures of invention value, and instead use more or less reliable proxies. These are all aspects to which the present paper intends to contribute.

2.2. Measuring the value of inventions

The difficulty in obtaining precise information about the actual economic value of inventions has led researchers to use a variety of proxies; generally focusing on patented inventions, these proxy variables capture the extent to which patents are used and therefore economically valuable:

- forward patent citations, when not used as an explanatory variable, where the value of a patent is measured by the extent to which other patents rely upon it (Lerner, 1994; Hall, Thoma and Torrisi, 2007);
- patent opposition and renewal data, where patent value is captured by the extent to which companies find it worthwhile to spend resources in order to litigate it or renew it (Priest and Klein, 1984; Pakes and Simpson, 1989; Bebchuk, 1994; Lanjouw and Schankerman, 1997);

- company start-up activity, capturing whether a high-tech start-up has been created or not on the basis of the patent (Shane, 2001);
- the probability to get a patent granted, capturing the quality of the underlying invention (Guellec and van Pottelsberghe, 2000); and composite indicators (Lanjouw and Schankerman, 1999; van Zeebroeck, 2011).

A few studies such as Scherer and Harhoff (2000) and Patval (Gambardella, Harhoff and Verspagen, 2005) relied on targeted surveys asking respondents to provide estimates of the monetary value of their patents[1].

Despite the variety of measures used to capture the value of patents, some interesting regularities have emerged. In fact, irrespective of how patent value is measured, empirical studies agree that its distribution is highly skewed (Scherer and Harhoff, 2000) and it has been shown that there is no appreciable difference in the value distributions of corporate and academic patents (Sapsalis, van Pottlesberghe de la Potterie and Navon, 2006).

An original and valuable aspect of our study is that we could rely upon several alternative survey-based measures of invention value. Respondents to the PIEMINV survey were asked to consider two of their inventions – that which had benefited the most from the contribution of university knowledge and that which had had the highest economic impact (whether these inventions had been patented or not).[2] For each of these two inventions, respondents were asked to provide information about the monetary value of the invention (in thousand euro, at current prices)[3], as well as several other questions that have been used to construct our independent and control variables. This information allows us to investigate, for the subset of inventions that benefited from knowledge transfer from university, what characteristics of the knowledge transfer process were associated with higher economic value. In the next section, before we present our data and results, we describe the theoretical framework that guided the design of our empirical analysis.

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[1] The survey by Scherer and Harhoff (2000) posed the question: "If in 1980 you knew what you now know about the profit history of the invention abstracted here, what is the smallest amount for which you would have been willing to sell this patent to an independent third party, assuming that you had a bona fide offer to purchase and that the buyer would subsequently exercise its full patent rights?" Similarly, the PatVal project posed the question "What is your best guess of the minimum price at which the owner of the patent would sell the patent right to an independent party on the day the patent was granted?", offering a choice of ten value intervals (Gambardella, Harhoff and Verspagen, 2005).

[2] Whenever these two inventions coincided, the respondent was required to fill in the information only for the invention with the highest contribution from university knowledge.

[3] The question was modeled on the Patval questionnaire (see Gambardella, Harhoff and Verspagen, 2005). It was formulated as follows: "Suppose that, on the day in which the invention was completed (or, if the invention has been patented, on the day in which the patent was granted) a potential competitor had expressed an interested in purchasing it: what is the minimum price that the invention's owner would have asked for it?"

3. The characteristics of university-industry knowledge transfer and the value of inventions

Many empirical studies of industrial firms show that the share of firms that rely upon academic knowledge to support their innovation processes is quite high, although usually lower than the share of firms that rely upon internal sources, clients, suppliers and other partner firms (Cohen, Nelson and Walsh, 2002; Lausen and Salter, 2004; PATVAL, 2005; Abreu et al, 2008). Firms that source academic knowledge often use several knowledge transfer channels at the same time. Channels involving the commercialization of scientific research outcomes (such as the set up of spinout companies or the licensing or acquisition of university patents) are among those used least intensively (Schartinger, Schibany e Gassler, 2001; Cohen, Nelson and Walsh, 2002; Mowery and Sampat, 2005; D'Este and Patel, 2007). Instead, firms' preferred ways to source academic knowledge include the access to scientific publications and the recruitment of graduates and doctoral students (Mowery e Sampat, 2005; D'Este e Patel, 2007, Abreu et al., 2008; Bruneel et al., 2009). Direct collaborations between firms and university research teams (or individual researchers) are also relevant ways to source academic knowledge (Adams, Chiang and Jensen, 2003; D'Este and Perkmann, 2007) whose importance has increased over time (Baldwin and Link, 1998; Link and Vonortas, 2002).

Based on arguments from the literature on the economics of knowledge and on findings from the empirical literature on patent value, we can put forth several arguments about the expected relationships between the characteristics of knowledge transfer channels and invention value. In particular, in the following we argue that knowledge transfer processes that favour the transmission of tacit knowledge and the development of radically new inventions should lead to inventions with greater economic value.

Tacit knowledge. The possibility to successfully implement academic knowledge for commercial purpose should be enhanced when the knowledge transfer channel allows for the transmission of the inventors' tacit knowledge, which is necessary for the application of most codified pieces of knowledge (Dasgupta and David, 1994). This is particularly so for forms of knowledge that are complex and cutting edge, where reading blueprints and manuals can only provide a partial picture, and the involvement of the knowledge creator is fundamental in order to ensure success in implementation. Considering a sample of patents invented by academics, Sapsalis and van Pottlesberghe de la Potterie (2003), find that patents' citations to academic papers written by the same researchers who appear as inventors on the patent are positively and significantly related to patent value, while citations to academic papers written by others are negatively related to patent value. The authors suggest that a greater number of citations to one's own research indicates that the inventor is relying, when developing the patented invention, on tacit knowledge associated with substantial experience in the field. Instead, citations to academic patents written by others indicate use of publicly available knowledge with respect to which the inventor does not have a specific advantage in terms of privileged access to tacit knowledge.

The importance of tacit knowledge for the development of valuable inventions should imply that forms of university-industry knowledge transfer where the academics' tacit knowledge is transmitted more effectively should lead to more valuable inventions. Although to some extent all forms of knowledge transfer, including more "formal" ones like patent licensing, are accompanied by interpersonal interactions between academics and industrial researchers, certain channels such as direct collaborations are more conducive to interactions which are very often explicitly designed as part of the knowledge transfer process (Perkmann and Walsh, 2006). Indeed, Thursby et al. (2001), in a survey of 62 US universities, found that 71% of the inventions licensed from the university to firms required personal interactions with the inventor in order to be subsequently commercialized, suggesting the successful implementation of patented inventions for commercial purposes relies upon tacit knowledge that can only be harnessed effectively through direct collaboration with the academic inventor.

Novelty. Several studies suggest that more radical inventions are more valuable. Sapsalis and van Pottlesberghe de la Potterie (2003) argue that more radical innovations face less potential competition on the final product market. As a measure of the novelty of the invention, they use the patent's share of backward citations to patents applied for by public research institutions, arguing that inventions sourced from the scientific community are more radical. Conversely, they suggest that patents that have a high share of backward citations to patents invented by the same firm (self backward citations) are more incremental and hence less valuable. These hypotheses are supported by their data. Reitzig (2003) provides a review of several studies that have used various measures of an invention's linkage to scientific knowledge as a proxy for its novelty, and show that this is positively related to its value. We can expect several features of university-industry knowledge transfer process to support the development of more novel, and hence more valuable, inventions. First, situations in which universities contribute basic theoretical advances, rather than applied incremental knowledge, should lead to more "radically new" inventions. Second, channels of knowledge transfer that allow for broader exploration of the search space - rather than the exploitation of existing knowledge (March, 1991) based on a local search for solutions (Nelson and Winter, 1982) - should generate more novel inventions. In fact, the more the knowledge transfer process allows for an exploration of a broader search space the more likely it is to eliminate "dead ends" before resources are spent and to identify "peaks" in the technological landscape (Fleming and Sorensen, 2004) and hence more valuable solutions. Third, the more the knowledge transfer process integrates diverse knowledge across different bodies of research, the more novel the invention. Alkaersig (2010) finds a positive and highly significant effect of academic scientists' cognitive diversity both on the number of patents they applied for and on their value (in terms of forward citations received), where cognitive diversity is measured as the distance between subject categories present in a scientist's publication portfolio.

4. Data

4.1. The PIEMINV survey

The PIEMINV survey targeted the population of residents in the Piedmont region who appeared as inventors in at least one EPO patent application between 1998 and 2005 (about 4,000 patents and 3,000 inventors in Piedmont). After cleaning the address list, the PIEMINV questionnaire was sent out in autumn 2009 and spring 2010 to 2,583 inventors, who returned 938 valid responses (36% response rate).

The questionnaire was designed to investigate various aspects of university-industry interactions in the Italian region of Piedmont, and to enable quantitative measurement of the local universities' contribution to the invention process. It included four sections: (i) general information about the inventors (age, gender, education, mobility) and their inventive activity (age at first patent, office where patents were first filed, invention to innovation ratio); (ii) overall evaluation of the importance of university knowledge in the development of inventions and the relative importance of different interaction channels; (iii) evaluation of the effectiveness, frequency and nature of university-industry interaction channels used to pursue different firm objectives; (iv) assessment of the economic impact of university knowledge.

Additional information on the firms for which inventors worked was collected from the CERVED database of Italian companies' accounts (number of employees, revenue, location of head office, number of different locations, year of foundation, overall number of patent applications and granted patents, average number of citations to granted patents, sector, legal status, industry). This information was available for 769 of the 938 inventors. Information was also collected on the inventors' patents (number of patent applications and granted patents between 1998 and 2005, types of assignees, most common technology class[4], average number of backward citations, average number of forward citations, citations to academic papers, date of first patent application).[5]

The survey provides a first tentative description of the population of inventors in Piedmont. The mean age in the survey sample is 48, with most falling within the 41-50 years age group; mean age is lower among women (41), who constitute 8.2% of the sample.[6] Younger inventors are on average more educated, as 76.5% of under-40s have a tertiary degree (the sample average is 59.3%) and 6% have a PhD (sample average 3.72%). Inventors are characterized by low educational and career mobility: 79.8% attended primary and secondary school in Piedmont and 30.9% have worked for only one organization throughout their career. 50.9% of the inventors have worked for less than five different organizations and only 8.2% have had more than five different employers. Inventor mobility is correlated with educational attainment: more educated inventors are more mobile.

40% of inventors work in large firms (with more than 250 employees), and the majority are employed in five technology sectors: Manufacture of fabricated metal products (except machinery and equipment); Manufacture of computer, electronic and optical products;

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[4] Classification by macro-technology classes is according to OST-DT7 (OST, 2004)

[5] These data were available for 902 out of 938 inventors (96.2% of the sample).

[6] The share of women in the PIEMINV survey is higher than the Italian (2.7%) and the European (2.8%) shares, reported by the PatVal survey (Giuri et al., 2007)

Manufacture of electrical equipment; Manufacture of machinery and equipment n.e.c.; Manufacture of motor vehicles, trailers and semi-trailers.

Concerning patenting behaviour, almost two-thirds of inventors have patented less than five inventions during their careers; the mode is 1-2 patented inventions each. Only 7.8% have patented more than 16 inventions. In line with evidence from other regions and countries (Acs and Audretsch, 1988; Arundel and Kabla, 1998), the number of non-patented inventions is higher than the number of patented inventions (the mode is 3 to 5 non-patented inventions). The most common OST7 technology classes in the inventors' patent portfolios are Mechanical Engineering (34%) and Electrical engineering and Electronics (25.6%).

4.2. Dependent variables: the value of inventions

The PIEMINV survey collected several pieces of information that could be used to construct quantitative estimates of the economic value of certain inventions. Inventors were asked to identify and provide specific information about two specific inventions: their invention that had received the highest contribution from university knowledge[7] and their invention with the highest economic impact. The inventors were also asked to provide monetary estimates of the economic value of the two inventions.

In order to check the economic relevance of the inventions that had received the highest contribution from university knowledge, a first possibility is to count how many inventors stated that their inventions with the highest university contribution is also their invention with the highest economic impact. Of course this question was only answered by a subset of inventors who had managed to interact in some way with a university, which reduced the number of respondents for this specific section of the survey to 188. Figure (1) shows a graphical representation of our variable of interest (a dummy variable that we called *uniecon,* and is equal to 1 when the two inventions coincide): 50 out of the 188 respondents to this specific question (26%) stated that their invention that received the greatest contribution from university knowledge was also their most valuable invention,[8] suggesting that the economic value of inventions to which university contributed substantially is not negligible, and stressing the

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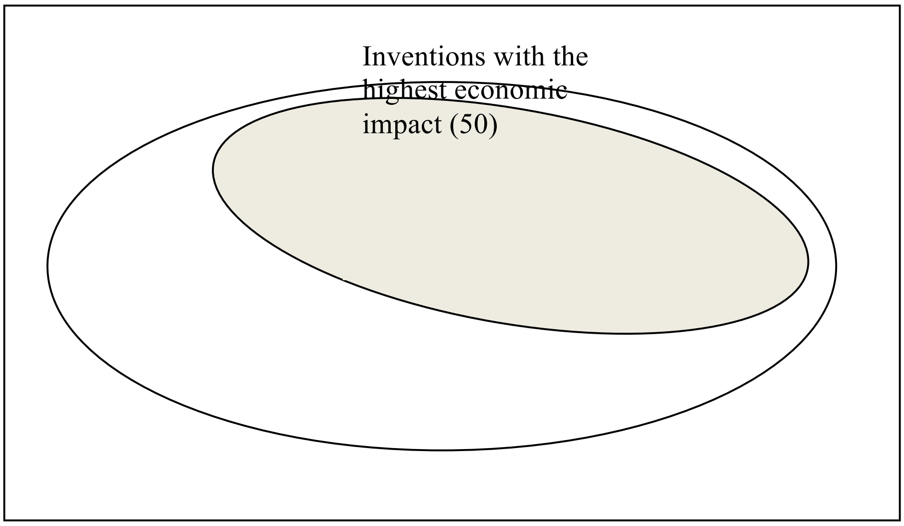
[7] The survey provided a specific explanation of what was meant by "university contribution": "*By "contribution" we mean any resource, idea, clarification, assessment provided (formally or informally) by a university, that has been instrumental in order to realize an invention*".

[8] When building the variable *uniecon* we had to eliminate inventors who had made only one invention, since in that case the two inventions would coincide by definition, without providing any real information about the invention's value.

importance to investigate what drives the economic relevance of inventions that rely heavily on university contribution.

Figure 1. Constructing the variable *uniecon*



As mentioned previously, the inventors were also asked about the specific monetary value of the invention with the highest university contribution and of the invention with the highest economic impact. Table (1) shows some basic features of the distributions of the values of the two inventions. These distributions are extremely skewed and display a large range of values, in line with the findings from the literature on patent value.[9] However focusing only on the value of the invention with the highest university contribution would result in a very noisy measure, since for an inventor it may be very difficult to estimate the exact value of one of their inventions, with some inventors possibly greatly overestimating such a value and others underestimating it. In our empirical models we therefore focus on a relative measure of invention value: the value of the invention with the highest contribution from university knowledge relative to the value of the invention with the highest economic impact (this is a ratio with values comprised between zero and one, a variable we called *ratio*). Using a relative measure of invention value allows us to overcome the problem of lack of comparability of invention values across inventors, since these estimates have a highly subjective component.[10] By taking the ratio of the two inventions' estimated values, the unit of

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[9] The Shapiro-Wilk test of normality strongly rejects the hypothesis of normality for each of the two variables (value of invention with highest contribution from university knowledge and value of invention with highest economic impact).

[10] It also allows us to ignore situations in which the respondents have provided values using the wrong unit of measurement (e.g. respondents who have reported the values in euros, or in million euros, rather than in thousand euros as requested in the survey question).

measurement problem is eliminated and we obtain a measure that, regardless all the subjective and heterogeneous units of measure used by the inventors, gives an indication of how valuable the invention was with respect to the most valuable invention in the inventors' portfolio.

The variables *uniecon* and *ratio* are our main dependent variables of interest. As table (1) shows, the variable *ratio* has fewer observations than the binary variable *uniecon*, since not all the inventors who identified the two inventions were able to provide their specific monetary values.

Table 1. Distributions of variables capturing invention value

		uniecon	Economic value of inventions with highest contribution from university knowledge	Economic value of inventions with highest economic impact	*ratio*
Value of invention (thousand euro)	Observations	188	88	70	88
	Mean	0.264	2,069,467	21,000,000	0.539
	Standard deviation	0.442	7,691,768	122,000,000	0 .431
	Maximum	1	50,000,000	1,000,000,000	1
	Skewness	1.067	5.630879	7.632365	-0.064
	Kurtosis	2.139	35.11224	61.50187	1.25

4.3 Independent variables

In Table (2) we introduce a set of inventor-level and firm-level characteristics that we expect to influence the probability to engage in collaborations with the university and the effectiveness of university-industry knowledge transfer. After a first cleaning of the original dataset, due to missing observations, incomplete answers and missing information about the firms for which the inventors work, we end up with a sample of 694 observations, which include both inventors who collaborated with the university and benefited from university knowledge and inventors who, on the contrary, did not claim to have received any substantial contribution from university knowledge. The sample of 694 inventors who fully answered the set of questions that we need for our empirical analysis is not substantially different from the overall sample of 938 respondents. The mean age (*age*) is 48 and the share of men (*male*) is 93%. 52% of inventors hold a Masters degree or a Phd (*hedu*) and about 8% have experience of working within a university (*workuni*, a dummy indicating whether the inventor has ever worked at a university). Each inventor has applied, on average, for 2.25 European patents between 1998 and 2005 (*pat9805*), a variable that proxies an inventor's patenting experience.

A number of firm characteristics affect both the probability to have some form of interaction with the university and the economic value of inventions with important contributions from the university. It has been shown that firms in certain industries are more likely to benefit from academic research in order to produce valuable inventions (Mansfield, 1991; Cohen, Nelson and Walsh, 2002; Laursen and Salter, 2004; Abreu et al., 2008). Hence, we use several dummies which capture the most common technology class in the inventor's portfolio: electrical engineering and electronics (*electr*), process engineering (*proceng*), instruments (*instr*), chemicals (*chem*), pharmaceutical (*pharma*), mechanical engineering (*mech*), consumer goods (*consumer*). From Table (2) we see that electrical engineering and mechanical engineering are the two most common technologies class among inventors. Compared with the firm's codes of economic activity, these variables capture more precisely the types of technologies in which the inventors are actually engaged, especially in the case of large multiproduct firms where the sectoral affiliation might be too generic.[11]

In the literature it is often found that larger, research-intensive firms are better able to benefit from academic research, thanks to their greater absorptive capacity (Arundel and Geuna, 2004). We have therefore considered the firm's size, using a set of dummies (*size1* indicates micro-companies, with less than 10 employees; *size2* indicates small companies with between 10 and 49 employees; *size3* indicates medium firms with between 50 and 250 employees; *size4* indicates large firms with more than 250 employees; and *foreign* is a dummy that controls whether the company's ownership is not Italian). As table (2) shows the majority (68%) of inventors work in large companies, while the remaining inventors are quite uniformly distributed among micro, small and medium firms. About 10% of the firms are foreign-owned.[12]

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[11] Two different inventors working in the same large company, such as FIAT, might indeed be specialized in very different technological fields (for example electronics rather than mechanical engineering). Using only a sectoral dummy would be misleading since it is likely that different technological disciplines have different needs with respect to the use of university knowledge

[12] This means that either these firms are Italian subsidiaries of foreign companies or they are located just outside the Italian border (as in the case of some Swiss firms). Indeed, since the PIEMINV survey was targeted at inventors who were resident in the Piedmont region, the sample does not include any inventors who worked for foreign companies located very far from the Italian border.

Table 2. Descriptive statistics. All inventors

Variable	Obs	Mean	Std. Dev.	Min	Max
male	694	0.931	0.254	0	1
age	694	48.540	10.068	30	88
age2	694	2457.4	1048.1	900	7744
hedu	694	0.523	0.500	0	1
workuni	694	0.082	0.275	0	1
pat9805	694	2.251	2.513	0	24
mech	694	0.363	0.481	0	1
electr	694	0.256	0.437	0	1
proceng	694	0.122	0.328	0	1
instr	694	0.104	0.305	0	1
chem	694	0.065	0.246	0	1
consumer	694	0.071	0.256	0	1
pharma	694	0.019	0.136	0	1
size1	694	0.082	0.275	0	1
size2	694	0.095	0.294	0	1
size3	694	0.134	0.341	0	1
size4	694	0.689	0.463	0	1
foreign	694	0.111	0.314	0	1

The PIEMINV survey also included several questions that specifically aimed to capture the characteristics of the knowledge transfer process leading to the development of the inventions with the highest contribution from university knowledge. These questions were answered only by the 188 inventors who indicated their invention with the highest contribution from university knowledge. In Table (3) we present the descriptive statistics for this subset of 188 inventors. Compared to the overall sample of 694 inventors, the share of inventors with a Masters degree or Phd (*hedu*) and the share of inventors who have experience of working within a university (*workuni*) are higher (respectively, 68% and 15%).

Several variables capture the characteristics of the knowledge process that led to the invention with the highest contribution from university knowledge. First, we include a set of variables that describe type of collaboration with the university. Direct collaborations between university and industry researchers, based on face-to-face interactions, favour the transmission of tacit knowledge to a greater extent than indirect exchanges based on, for example, the joint supervision of master and doctoral students, the sale and licensing of intellectual property, or the reading of publications. Direct collaborations can also favour the emergence of novelty by allowing a broader exploration of the search space and the integration of different competences: it is the opportunities for direct interactions provided by collaborations which open up possibilities for the emergence of unexpected outcomes and for the integration of different sources of knowledge even when the underlying knowledge is complex and not modular. The variable *collabo* indicates whether the invention with the highest contribution from university knowledge originated from a collaboration between the inventor and a university; two further variables specify whether the collaboration involved either a single university researcher (*reser*) or a university research team (*inst*). Table (3) shows that 41% of inventions with the highest contribution from university knowledge resulted from a collaboration, of which 20% from a collaboration with a single researcher and 23% from a collaboration with a university research team.

We also use three variables capturing the kind of the knowledge that the inventor considered most important for the development of his/her inventions: scientific theorems and principles (*theories*), information about other relevant sources of knowledge / about other organisations (*contact*), and solutions to technological problems / methodologies, techniques and instruments / support to prototyping (*techno*). Our expectation is that knowledge transfer processes involving the transmission of more basic knowledge like theorems and scientific principles would favour the development of more novel inventions while those involving the transmission of more applied knowledge would be related to more incremental developments. Among our 188 respondents we find that university knowledge was mostly important in order to obtain information about other relevant sources of knowledge (*contact*) and in order to obtain solutions for technological problems (*techno*).

Table 3. Descriptive statistics, restricted sample (*select*)

Variable	Obs	Mean	Std. Dev.	Min	Max
male	188	0.92021	0.27169	0	1
age	188	48.0213	10.5633	31	88
age2	188	2417.03	1115.85	961	7744
hedu	188	0.68617	0.46529	0	1
workuni	188	0.15957	0.36719	0	1
pat9805	188	2.67553	3.17005	0	24
electr	188	0.31383	0.46529	0	1
instr	188	0.15426	0.36216	0	1
chem	188	0.09574	0.29503	0	1
pharma	188	0.03191	0.17624	0	1
mech	188	0.29255	0.45615	0	1
consumer	188	0.03723	0.18984	0	1
proceng	188	0.07447	0.26323	0	1
size1	188	0.10106	0.30222	0	1
size2	188	0.07447	0.26323	0	1
size3	188	0.09574	0.29503	0	1
size4	188	0.72872	0.44581	0	1
foreign	188	0.12766	0.3346	0	1
collabo	188	0.41489	0.49402	0	1
reser	188	0.20213	0.40266	0	1
inst	188	0.23936	0.42783	0	1

contact	188	0.6117	0.48866	0	1
techno	188	0.84574	0.36216	0	1
theories	188	0.55319	0.49849	0	1

5. Empirical strategy

We are interested in explaining the economic relevance of inventions with a high contribution from university knowledge, taking advantage of a number of variables that describe the type of interactions with the university, the type of knowledge used and a set of inventor and firm characteristics. In order to do so we outline the following linear model:

$$y_i = c + \beta\, Int_i + \gamma\, Kn_i + \sum_k \delta_k INV_{ik} + \sum_m \theta_k FIRM_{im} + v_i \qquad (1)$$

Where *i* indicates the inventor; the dependent variable *y*, which measures the value of the invention with the highest university contribution, can be a dichotomous variable (*uniecon*) or a share (*ratio*). *Int* denotes the type of interactions occurred between the inventor and the university, *Kn* indicates the type of knowledge that the inventor found most useful for the development of his/her inventions, *INV* and *FIRM* indicates a set of inventors and firm level variables and v_i is an idiosyncratic error term.

In order to estimate equation (1) we must make sure to avoid any problem due to selection bias. As already mentioned in section (4) only the inventors who were able to benefit from university knowledge could answer the question related to the value of the invention with the highest contribution from university: this ability is limited to a subset of 188 inventors, hence we first need to control whether this subset of inventors is significantly different from the rest of the sample. Moreover some of the features influencing the value of contribution from university knowledge are also likely to influence the probability to have a contribution from university knowledge itself, so if we did not include a selection equation the effect of these variables would be overestimated.

Our strategy is to adopt a Tobit type II (Anemiya, 1984) estimation procedure which includes estimating both a selection equation which indicates whether inventors were able to benefit from university knowledge, and an intensity equation in which we will measure the specific effect of different variables on the economic value of inventions. The selection equation will hence be as follows:

$$SEL_i = \begin{cases} 1 & if \quad sel_i^* = z_i^{'}\gamma + e_i > c \\ 0 & if \quad sel_i^* = z_i^{'}\gamma + e_i \leq c \end{cases} \tag{2}$$

where *SEL* is a binary variable which equals 1 if an inventor declares to have benefited from university knowledge and *sel** is a latent variable which measures the general ability of an inventor to use the university as a source of knowledge. If such an ability exceeds a certain threshold level *c* then the firm will claim that his inventions do benefit from university activities. Our measure of the value of inventions with a high university contribution *y*, which depends on the set of variables *x* that we have already mentioned in equation (1), will be observed only if SEL_i is equal to 1:

$$y_i = \begin{cases} y_i^* & if \quad SEL_i = 1 \\ 0 & if \quad SEL_i = 0 \end{cases} \quad \leftrightarrow \quad y_i = \begin{cases} y_i^* = x_i^{'}\beta + \varepsilon_i & if \quad SEL_i = 1 \\ 0 & if \quad SEL_i = 0 \end{cases} \tag{3}$$

Our preferred selection variable (*select*) is a dummy that is equal to 1 if at least some of the inventor's inventions have benefited from university knowledge.[13] However in order to check for the robustness of our findings we also used three other selection variables to check whether our results are driven by our specific choice about the selection mechanism. The first alternative selection variable we have experimented with is (*ord_select*), a variable that builds on the same question of the survey used for the *select* variable: in this case we have four categories describing the share of each inventor's inventions that have benefited from university knowledge: zero (value 1), less than 50% (value 2), more than 50% but less than 100% (value 3), all (value 4). The other selection variables are a dummy equal to 1 if the inventor states that s/he has direct experience of having collaborated with a university institution or with an individual university professor (*coll*); a dummy equal to 1 if the inventor uses, and considers as important, at least one of sixteen knowledge transfer channels with the university (*channel*). In the selection equations, the independent variables capture the usual set of firm and inventor characteristics described in section (4) and that are likely to influence the probability that an inventor has benefited from university knowledge in the development of his or her inventions. In the value equation instead we will also include the variables that

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[13] This variable was based on the inventors' answers to the following question: "*How many of your inventions have received an important contribution from academic knowledge? By "contribution" we mean any resource, idea, clarification, assessment provided (formally or informally) by a university, which has been instrumental in order to realize an invention*". The possible answers were: None / less than half / more than half / All. The *select* dummy is equal to 1 if at least "less than a half" was select by the respondents.

denote the types of interactions with the university used by the inventor (*Int*) and the type of knowledge that the inventor found most useful for the development of his/her inventions (*Kn*)

6. Results

Table (4) presents the results of simple probit and ordered probit models using the different selection variables that we have identified, in order to examine the characteristics of the inventors who were able to benefit from university knowledge. Columns (1) and (2) present the results of probit regressions with the dependent variable *select* which indicates the probability that inventors have benefitted from university knowledge. Column (1) includes only inventor-level variables and shows a positive and significant effect of higher education (*hedu*), of having spent at least some months working in the university (*workuni*), and of the number of patent applications at the EPO in the period 1998-2005 (*pat9805*). The coefficient of age is negative and significant, although the positive squared term suggests that there might be a (U-shaped) nonlinear relationship. Column (2) also includes firm size and patent technology classes. The signs and significance of the coefficients of the *hedu*, *workuni* and *pat9805* variables are not affected by the inclusion of these new controls. The technology class dummies indicate that inventors specialized in chemical (*chem*), pharmaceutical (*pharma*) and electrical technologies (*electr*), as well as technologies like optics and technologies for control and medical engineering (*instr*) benefit more from university knowledge. The size dummies instead are negative (and significant for small and medium firms). Given that the reference group are micro companies with less than 10 employees the results suggest that micro companies (in most case engineering firms and start-ups) are able to rely extensively on external university knowledge, even more than large companies, who are usually supposed to be more likely to collaborate with the university. However it must be stressed that here we are not measuring the likelihood to collaborate with university, but rather the ability to benefit from university knowledge: when we use, as a dependent variable, the probability of having collaborated with the university (*coll*) (column (3)) we find that large firms have the expected positive and significant sign that is usually found in the literature. The other variables instead have the same signs found in columns (1) and (2). Also when run an ordered probit with the ordinal variable *ord_select* as dependent variable we find that the same signs of the coefficients as in columns (1) and (2). Given that the results are quite similar across specifications we chose to use *select* as our preferred selection variable, since we believe it captures more precisely the capacity of inventors to benefit from university knowledge.

Table 4. Selection equations

Variables	(1) *select*	(2) *select*	(3) *coll*	(4) *channels*	(5) *select_ord*
male	0.044	0.078	-0.022	0.025	0.160
	(0.062)	(0.056)	(0.079)	(0.087)	(0.198)
age	-0.027**	-0.026*	0.012	-0.026	-0.093***
	(0.014)	(0.014)	(0.018)	(0.017)	(0.036)
age2	0.000*	0.000**	-0.000	0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
hedu	0.163***	0.131***	0.258***	0.097**	0.437***
	(0.035)	(0.037)	(0.042)	(0.044)	(0.114)
pat9805	0.014**	0.016**	0.031***	0.015*	0.027*
	(0.007)	(0.007)	(0.009)	(0.008)	(0.016)
workuni	0.207***	0.226***	0.257***	0.199***	0.612***
	(0.072)	(0.075)	(0.077)	(0.072)	(0.168)
Size (reference 1-9 employees)					
10-49 employees		-0.147***	0.127	-0.045	-0.569**
		(0.053)	(0.101)	(0.097)	(0.249)
50-250 employees		-0.153***	0.059	0.067	-0.695***
		(0.053)	(0.095)	(0.087)	(0.228)
>250 employees		-0.108	0.181**	0.178**	-0.412**
		(0.066)	(0.078)	(0.075)	(0.193)
foreign		-0.002	-0.006	-0.035	-0.058
		(0.055)	(0.067)	(0.068)	(0.163)
Technology (reference Industrial Processes)					
Electrical engineering		0.146**	0.140*	0.261***	0.265
		(0.071)	(0.074)	(0.062)	(0.207)
Instruments		0.258***	0.250***	0.308***	0.579***
		(0.087)	(0.077)	(0.056)	(0.221)
Chemicals		0.176*	0.321***	0.351***	0.341
		(0.098)	(0.081)	(0.052)	(0.246)
Pharmaceuticals		0.302**	0.369***		0.603*
		(0.153)	(0.111)		(0.322)
Mechanical Engineering		0.062	0.041	0.095	0.126
		(0.062)	(0.069)	(0.065)	(0.196)
Consumer goods		-0.058	-0.056	0.079	-0.232
		(0.083)	(0.098)	(0.097)	(0.315)
Observations	694	694	694	657	694
pseudo-Rsquared	0.0598	0.0913	0.146	0.102	0.0679
Log-likelihood	-381.2	-368.4	-410.0	-403.5	-505.9

All models are robust to heteroskedasticity. In columns (1) , (2), (3) and (4) the numbers reported are the marginal effects (at the sample means) from a probit . In column (5) we report the coefficient of an ordered probit estimation. * Significant at 10%, ** significant at 5%, *** significant at 1%.

Table (5) present the results for the value equation (1), with the correction for the selection bias explained in equation (3). We start with the dummy variable *uniecon* as dependent variable, and hence we employ a probit measure that accounts for the selection bias.[14] The results in column (2) show a positive and significant (at the 10% level) coefficient of the *collabo* variable which indicates whether the invention involved a collaboration with a university

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[14] We use the Stata routine *heckprobit* which accounts for the selection bias problem in models with a dichotomous variable as a dependent variable

department or single university researcher. We also find that, when inventors use university knowledge in order to have access to scientific theorems and principles, the value of their inventions increases (the coefficient of *theory* is positive and significant at the 5% level). This is not the case for other types of knowledge that university can provide, such as information and contacts about other relevant sources of knowledge or about other organizations (*contact*), and solutions to technological problems, methodologies, techniques and instruments or support to prototyping (*techno*).

In column (3) we further distinguish between collaborations with a single university researcher (*reser*) or with a university research team (*inst*): the results show that the positive coefficient of the *collabo* variable in column (2) was driven mainly by collaborations with individual researchers, which indeed are positive and significant at the 5% level, while institutional collaborations are still positive but not significant. Also in column (3) the coefficient of *theories* remains positive and significant. The rho coefficient is small and not significant, meaning that when we use the dummy variable *uniecon* as dependent variable we do not face serious selection bias problems.

Table 5. Probit on uniecon with selection equation

VARIABLES	(1) *select*	(2) *uniecon*	(3) *uniecon*
collabo		0.394*	
		(0.215)	
reser			0.572**
			(0.252)
inst			0.175
			(0.247)
theories		0.575**	0.606***
		(0.227)	(0.231)
contact		0.248	0.235
		(0.224)	(0.223)
techno		0.178	0.191
		(0.284)	(0.289)
age	-0.083*	-0.115*	-0.107
	(0.043)	(0.067)	(0.065)
age2	0.001**	0.001*	0.001*
	(0.000)	(0.001)	(0.001)
pat9805	0.050**	0.016	0.017
	(0.021)	(0.038)	(0.038)
male	0.266		
	(0.228)		
hedu	0.415***		
	(0.121)		
workuni	0.625***		
	(0.205)		
size2	-0.551**		
	(0.248)		
size3	-0.563**		
	(0.243)		
size4	-0.327*		

	(0.195)		
foreign	-0.007		
	(0.174)		
tech dummies	yes	yes	yes
Constant	0.800	1.387	1.105
	(1.109)	(1.633)	(1.605)
Observations	694	694	694
Uncensored observations	-	188	188
rho	-	0.017	0.018
	-	(0.536)	(0.544)
Log-likelihood	-469.2	-469.2	-468.4

All models are robust to heteroskedasticity. In column (1) the dependent variable is *select*, in columns (2) and (3) the dependent variable is *uniecon*. * Significant at 10%, ** significant at 5%, *** significant at 1%.

Table (6) shows the results of the Tobit Type II model where the *ratio* variable is the dependent variable in the value equation. In column (2) we find that the *collabo* variable is still positive but not significant. Furthermore *theories* remains the only positive and significant variable (at the 5% level) among the possible types of university-related knowledge that inventors might find useful. In column (3) again we distinguish among the two different types of collaborations and, consistently with the previous results, we find that only collaborations with individual researchers (*reser*) have a positive and significant effect on the relative value of inventions with the highest contribution from university knowledge, while institutional collaborations are negative but not significant. Here we notice that the rho coefficient is always positive and significant, meaning that the decision to include a selection equation was appropriate.

Table 6. Tobit Type II on the ratio of the two values

VARIABLES	(1) *select*	(2) *ratio*	(3) *ratio*
collabo		0.061	
		(0.091)	
reser			0.200**
			(0.091)
inst			-0.110
			(0.107)
theories		0.187**	0.206**
		(0.094)	(0.088)
contact		0.034	0.004
		(0.099)	(0.096)
uno		0.207	0.239
		(0.157)	(0.153)
age	-0.058	-0.033	-0.030
	(0.061)	(0.036)	(0.035)
age2	0.001	0.000	0.000
	(0.001)	(0.000)	(0.000)
pat9805	0.025	-0.011	-0.024
	(0.028)	(0.017)	(0.017)
male	0.689**		
	(0.303)		
hedu	0.649***		
	(0.148)		
workuni	0.770***		
	(0.222)		

size2	-0.314		
	(0.271)		
size3	-0.374		
	(0.295)		
size4	-0.385		
	(0.249)		
foreign	0.127		
	(0.210)		
Tech dummies	included	included	included
Constant	-0.694	0.691	0.656
	(1.536)	(0.993)	(0.915)
Observations	594	594	594
uncensored	-	88	88
rho	-	0.648*	0.552*
	-	(0.386)	(0.312)
ll	-262.1	-262.1	-259.2

All models are robust to heteroskedasticity. In column (1) the dependent variable is *select*, in columns (2) and (3) the dependent variable is *ratio*. *significant at 10%, ** significant at 5%, *** significant at 1%.

6.1. Robustness checks

Another possible problem with the estimation of equation (1), beyond the already mentioned selection bias, is that the unobserved and idiosyncratic quality of an invention might be correlated with the specific channel of interaction chosen by an inventor to develop it and of course with its economic value. This would result in a typical problem of omitted variable bias, which would produce an upward bias in the estimates of our coefficients of interest (in particular we are concerned about the variables measuring the collaboration with the university).

A possible way to overcome this problem is to provide a measure of the "potential value" of the invention with the highest contribution from university knowledge: in the PIEMINV survey inventors were asked a set of question that provide a tentative and indirect measure of this potential value. Specifically we define a dummy variable equal to 1 if the invention had the highest number of potential uses (*potential*) and a dummy equal to 1 if the invention was not at an early stage of development (*latestage*). These measures allow us to control for the potential value of the invention and their inclusion should solve most of the problems related with the presence of unobserved heterogeneity concerning the quality of inventions.

These two variables (*potential* and *latestage*) are progressively introduced in the value equation, both when the dependent variable is *uniecon* and when it is the ratio of the two inventions' value (*ratio*). We estimate our models checking for the usual selection bias problems and hence we include also the selection equation. The results are shown in Table (7). In columns (2) and (5) we start by introducing the variable *potential*, which we consider as a possible determinant of the quality of an invention. The coefficient of *potential* however is positive but not significant, furthermore we find that including it does not affect the coefficients of our main variables of interest, that is *reser* and *theory*. In columns (3) and (6) we also include the dummy variable *latestage* which should provide an additional measure of the quality of an invention. In this case we find that the variable is positive and significant in the first specification, when *uniecon* is the dependent variable, while it is positive but not significant in the second specification. The coefficients of *theories* and *reser* are not affected by the inclusion of this variable. This reassures us about the fact that their positive coefficient is not due to a positive correlation between these variables and the unobserved heterogeneity in the quality of inventions.

Table 7. Robustness checks: quality of an invention

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	*select*	*uniecon*	*uniecon*	*select*	*ratio*	*ratio*
reser		0.569**	0.574**		0.200**	0.177*
		(0.252)	(0.251)		(0.091)	(0.091)
inst		0.151	0.076		-0.112	-0.145
		(0.250)	(0.247)		(0.107)	(0.103)
theories		0.603***	0.624**		0.204**	0.215**
		(0.232)	(0.244)		(0.086)	(0.085)
contact		0.245	0.273		0.005	0.014
		(0.224)	(0.227)		(0.097)	(0.099)
uno		0.174	0.233		0.234	0.215
		(0.292)	(0.298)		(0.156)	(0.165)
potential		0.119	0.028		0.020	0.022
		(0.235)	(0.236)		(0.098)	(0.094)
latestage			0.539**			0.144
			(0.241)			(0.106)
age	-0.083*	-0.107*	-0.105*	-0.056	-0.030	-0.020
	(0.043)	(0.065)	(0.063)	(0.061)	(0.035)	(0.036)
age2	0.001**	0.001*	0.001*	0.001	0.000	0.000
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
pat9805	0.050**	0.016	0.013	0.026	-0.024	-0.027
	(0.021)	(0.038)	(0.037)	(0.028)	(0.017)	(0.018)
male	0.270			0.706**		
	(0.233)			(0.304)		
hedu	0.416***			0.639***		
	(0.121)			(0.150)		
workuni	0.622***			0.782***		
	(0.204)			(0.217)		
tech	included	included	included	included	included	included
Constant	0.796	1.079	0.585	-0.761	0.670	0.336
	(1.110)	(1.602)	(1.622)	(1.540)	(0.906)	(0.951)
Observations	694	694	694	594	594	594
uncensored obs	188	188	188	88	88	88
rho	-	0.0273	0.231	-	0.497	0.547
	-			-	(0.239)	(0.216)
Wald test of indep equations	-			-	0.086	0.046
Loglikelihood	-468.3	-468.3	-465.8	-259.2	-259.2	-258.2

All models are robust to heteroskedasticity. In columns (1) and (4) the dependent variable is *select*, in columns (2) and (3) the dependent variable is *unieco*, in columns (5) and (6) the dependent variable is *ratio*. *significant at 10%, ** significant at 5%, *** significant at 1%.

7. Conclusions and policy implications

In the last 20 years a great emphasis has been put on the role of academia as a fundamental driver of technological change and of the level of competitiveness of regional and national economic systems. The underlying assumption in this perspective is that academic knowledge is a fundamental component of the inventive process within private firms and that companies that have access to it will be able to introduce more valuable innovations and increase their economic performances. The literature focused on university-industry linkages has provided a great amount of evidence about the positive effect of academic knowledge on the performances of firms able to access it (Mansfield 1991, Jaffe, 1989). While the macro-economic literature has often focused on the effect of university knowledge on the economic performances of regions or countries, mostly measured with the increase of Labor Productivity and Total Factor Productivity (Adams, 1990; and van Pottlesberghe, 2002; Haskel and Wallis, 2010), at the micro-level the analyses have measured the impact of academic research on the technological performances of firms, mostly measured through patent data and related measures (Mansfield 1998, Jaffe, 1989; Acs et al, 1992). However few studies were able to track the contribution of university knowledge to specific inventions and, most importantly, none of them was able to assess to which extent the contribution of university knowledge increases the economic value of an invention.

In this paper we are able to address both issues for a sample of non-academic inventors resident in the Piedmont region in Italy. Taking advantage of an original survey (PIEMINV) designed to study the relationships between industrial inventors and the academia, we asked to the inventors the economic value of their inventions that had a relevant contribution from academic research. Furthermore we put forward two hypotheses. The first is that the possibility to successfully implement academic knowledge for commercial purpose should be enhanced when the knowledge transfer channel allows for the transmission of the academic researchers' tacit knowledge. We hence expect that the successful implementation of inventions that rely upon tacit knowledge can be better achieved through direct collaboration with academic researchers. The second hypothesis is that, since more radical innovations face less potential competition on the final product market and are thus likely to provide higher economic returns, situations in which universities contribute basic theoretical advances, rather than applied incremental knowledge, should lead to more “radically new” inventions and hence to more profitable ones.

In order to test the hypotheses we asked the inventors which specific channel of knowledge transfer was used for the development of the invention which benefited from university knowledge and which was the type of contribution from the university that the inventors found most relevant. In order to deal with the problems related with the subjective measure of value provided by the inventors we devised a relative measure that compares the value of the invention with a high contribution from university knowledge with the invention with the highest economic impact among the inventor’s portfolio. Moreover we also took into consideration other issues related with selection bias and endogeneity due to omitted variables, in order to avoid any correlation between the error terms and our variables of interest.

Our results show that knowledge transfer processes involving a direct collaboration between the inventor and the university (and particularly individual researchers) are positively associated with the value of inventions, regardless that we measure the value with dichotomous or continuous variables. Furthermore we also find that the transfer from university researchers of theoretical academic knowledge, rather than solutions to more technical and specified problems, leads to more valuable inventions. Our results also show that inventors with greater cognitive proximity to the university, that is with a higher level of education, or with an experience of working at the university for a limited time period are more likely to benefit from university knowledge and to produce more valuable inventions as a result. Finally also the patenting experience is positively associated with the capacity to produce valuable inventions that take advantage of academic sources of knowledge.

These results highlight two policy-relevant aspects. The first is that although indirect types of access to university knowledge (such as the participation to conferences, or the reading of academic papers) might be useful for non-academic inventors, only the direct collaboration between inventors and university researcher lead to the development of inventions with a high economic value. The second key-finding is that among the many possible contributions provided by the university to the activity of researchers (such as the help for prototypes, the renting of laboratories and infrastructures and the support on the solution of specific methodologies) those that involve the transfer of basic principles and theories are the most effective in increasing the economic value of inventions. This suggests that the development of basic research by universities is not only useful for the usual social purposes of the advancement of science, but it can also be beneficial for the innovative activities of firms collaborating with academic researchers.

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