How good are VCs at valuing technology? An analysis of patenting and VC investments in nanotechnology

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Abstract

This paper analyzes how VC firms evaluate the patent portfolios of startup companies in their financing decisions. On one hand, we determine whether the amount of VCs' financing is associated with the size, technological composition and scope of patent portfolios of startup companies. On the other hand, we examine whether the valuation of patents varies across different types of VC firms, depending on their degree of industry specialization and affiliation. We provide empirical evidence from a sample of 332 VC-backed companies in the nanotechnology sector.

Key-words: venture capital, patents, specialization, nanotechnology

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1. Introduction

The economic literature points to a superior ability of Venture Capital firms (VCs) in accurately assessing the value of early-stage companies' technological capabilities and patent portfolios. For instance, previous studies has shown a positive association between patenting rates and total amount of VC financing (Baum and Silverman, 2004; Mann et al., 2007) and between the breadth of patent protection and VCs' valuation of new companies (Lerner, 1994). Moreover, previous work has examined the effects of venture capital on patented innovations at the industry level (Kortum and Lerner, 2000; Lerner, 2002) or at the company level (Bertoni et al., 2006), showing a positive association between venture capital and patent productivity.

In general, however, there is only a limited understanding of the determinants of patent value that are more directly taken into consideration by VC firms in their investment decisions. On the contrary, it is likely that such decisions are influenced by other factors in addition to simple patent counts and patent scope. In particular, no attempt has been made in the literature to assess whether VCs value the *technological composition* of patent portfolios in their investment decisions.

In addition to that, it should be noted that there exists a high heterogeneity in the characteristics of VC firms as well, in terms of age, affiliation, managerial style, reputation, previous experience, stage and industry focus. It is thus likely that VCs differ in their ability to effectively value the size, composition and scope of patent portfolios. In particular, several scholars have acknowledged the importance of maintaining a high degree of specialization for controlling risk and gaining access to networks and information, or possessing a deeper knowledge of the ventures' environment (Gupta and Sapienza, 1992; Norton and Tanenbaum, 1992). Specialization might confer competitive advantages in terms of reduced information asymmetries and uncertainty in the valuation and selection process (Cressy et al., 2007). Moreover, the affiliation of the VC firms, separating Independent Venture Capitalists from Corporate Venture Capitalists, is likely to assess their selection

criteria and valuation skills as well, due to differences in objectives and capabilities (Bertoni et al., 2006; Gompers, 2002). All these studies suggest that the ability to evaluate technology and intellectual property might not be the same for all VCs, but it might be a function of their degree of specialization in the industry and type of affiliation.

However, to our knowledge no attempt has been made in the literature to assess whether and how VCs consider the technological composition of patent portfolios in their financing decisions, or whether they differ in their valuation ability. In this paper, we address such issues by investigating how different characteristics of startups' patents influence the VC financing process. More specifically, the purpose of the paper is twofold: on one hand, we determine whether the amount of VCs' financing obtained by the company is associated not only with the size and scope of start-ups' patent portfolios, but also with its technological composition, in particular for what concerns the share of patents belonging to core technological areas for the company. On the other hand, we examine whether the valuation of patent portfolios varies across VCs, depending on their affiliation and degree of industry specialization. We argue that the VC's ability to assess the patent portfolios of the investee company should be better-off if the VC is specialized in the same industry of the investee company and if the VC is affiliated to a corporation.

We analyze such topics in the emerging field of nanotechnology, defined as the study and use of the unique characteristics of materials at the nanometer scale. Although nanotechnology is still at an early stage of development and its full market potential will disclose in the next years, there has been a real "boom" in the number of nanotechnology patents registered all over the world, as well as in the number of nanotech ventures financed by VCs. This field thus represents an ideal setting to test our predictions.

Our sample includes all VC-backed companies in the nanotechnology sector identified by the commercial database Venture Expert over the period 1985-2006, corresponding to 332 companies. For each VC-backed company, we collected information about the total amount of VC financing obtained in the initial investment round and on the size and composition of the patent portfolios at that date. In particular, we were able to identify those patent applications more directly related to nanotechnology, by using the code Y01N, recently introduced by the European Patent Office in order to facilitate interdisciplinary searches and monitor trends in

nanotechnology. We complemented such information by gathering data on the affiliation (Independent vs. Corporate) and the number of investments (both in the nanotechnology sector and in all sectors) of all the VC firms investing in nanotechnology. For each VC firm, these data were used to construct measures of type of affiliation and degree of investment specialization in nanotechnology (Cressy et al., 2007).

Results from our regression analyses show that the simple number of patents applied by the company before the first investment round does not have a significant impact on the amount of financing received, controlling for the age, the stage of development, the degree of market diversification, the location of the company. On the contrary, the stock of patents belonging to the nanotechnology class has a positive and significant effect on VC financing. Moreover, VCs specialized in nanotechnology tend to place more value on nanotech patents in their financing decisions than unspecialized VCs.

The rest of the paper is organized as follows. We first briefly summarize previous literature which have addressed the relationship between patenting and VC investments. Moreover, we discuss the association between the degree of specialization of the VC firm and its type of affiliation and its ability to evaluate patent portfolios of the investee company. We then describe the nanotech sector, the sample and the variables used in the empirical analysis. We turn to present the results of different regression analyses. In the final section we outline the main conclusions to be drawn from the theoretical and empirical analysis, and discuss the implications for future research.

2. Background

Venture Capitalists (VCs), i.e. financial intermediaries investing equity in young companies, are a distinct type of investors for entrepreneurial companies operating in dynamic and uncertain industries. The activities of VCs can be generally represented as a process involving five major steps: deal origination, deal screening, deal evaluation, deal structuring and post investment activities (Tyebjee and Bruno, 1984). We focus on the second and third step, in which the venture capitalist applies a set of criteria to conduct preliminary and detailed analyses of the ventures and decide which

ventures will be funded. VCs attempt to assess the probability of success or failure by evaluating information surrounding the particular venture. To receive funding, new ventures must pass an initial screening (typically a review of the business plan) followed by a complex process of due diligence.

The importance of understanding in more depth the selection criteria adopted by VCs is linked to the fact that early-stage companies have a very little performance history to adopt conventional financial methods. Thus, one of the major peculiarities of VC investments is the difficult and uncertain valuation on which the selection process is based. The venture capitalist has to rely on a subjective assessment procedure driven not only by the start-ups' business plans, but also by a multidimensional list of characteristics.

A deeper understanding of the criteria employed by successful VCs in evaluating new ventures, in particular for what concerns the role played by patent portfolios, is important for two main reasons: from the VCs' point of view, it would provide a useful framework for evaluating entrepreneurial ventures and reduce the failure rates of the new ventures they finance. From the entrepreneurs' point of view, it could clarify the factors leading to a higher likelihood in obtaining VC financing.

2.1 Criteria adopted by VC firms in the evaluation of startups

Several studies have tried to highlight the most important features considered by VCs in the selection of new ventures to fund. Zopounidis (1994) provides a useful summary of these works, dividing them according to the different methodologies applied: descriptive methods, evaluation using linear statistical methods and multi-criteria evaluation. Looking through such categorization, these works yield almost the same set of investment evaluation criteria. In particular, three major studies provide some generally useful ranking of the relative importance of various decision factors.

Tyebjee and Bruno (1984) conduct a factor analysis, finding that VCs evaluate potential deals in terms of five basic characteristics: market attractiveness, product differentiation, managerial capabilities, environmental threat resistance and cash-out potential. Also, Muzyka, Birley and Leleux (1996) provide a comprehensive list of the evaluation criteria considered important by venture capitalists, obtaining similar key characteristics: financial, product-market, strategic-competitive, fund, management team, management competence, and deal criteria. Finally, the study by

MacMillan, Siegel and Narasimha (1985) identified 27 criteria categorized into six groups: entrepreneurial personality, entrepreneurial experience, characteristics of product or service, characteristics of market, financial characteristics and venture team. They also refer these clusters to six different types of risk, depending on the source stemming them, internal (management and leadership) or external (industry, markets and competitors) to the firm: risk of losing the entire investment, risk of being unable to bail out if necessary, risk of failure to implement the venture idea, competitive risk, risk of management failure and risk of leadership failure.

A further attempt to refine the criteria into a broader classification tries to split the studies into two macro-categories, depending on the criteria on which the studies focus their analyses. The first group includes studies interested in the characteristics of the entrepreneurial team as a potential driver of the investment decision by VCs. The second group, instead, explores the importance of the technological capabilities developed by the new venture and investigates their relationship with the likelihood of VC financing. We will briefly summarize the findings of the former group of studies, and then focus in more depth on the latter group in the following section, given its relevance for the purpose of our paper.

Concerning with the importance of the entrepreneurial team, there is a strand of literature relating educational and management experience to the amount of financial resources obtained by the venture. MacMillan, Siegel and Narasimha (1985), administering a questionnaire to a group of 14 VCs in U.S., highlight that the most important criteria determining whether or not a VC will finance a start-up is the quality of the entrepreneur in terms of his/her experience and personality. Drawing on human capital-based studies, Bates (1990) finds that educational skills are positively correlated with the received financial resources in entrepreneurial ventures. A study by Kaplan and Stromberg (2004) suggests that the experience of start-up management teams is important in guiding the investment decisions by VCs. Fried and Hisrich (1994) advise that social ties are an important reason for investing, because they help in the screening of activities with a high potential growth. Also in a recent study by Hsu (2007), the importance of social capital in the VC's valuation process is investigated. The results suggest that prior founding experience, founders' social network (considered as a tool to recruit executives) and founding teams with a doctoral degree holder are positively related to the likelihood to be funded with higher valuations.

2.2 The relationship between patenting and VC investments

In addition to the abovementioned factors, the economic literature points to a superior ability of VCs in accurately assessing the value of new ventures' technologies and patent portfolios. The majority of the studies confirms that patents are an important signal of a startup's innovative capabilities and ability to obtain complementary resources, increasing the likelihood that it will obtain VC financing.

Kortum and Lerner (2000) examine the patterns that can be discerned at the aggregate industry level rather than at the company level. The authors examine the relationship between the total number of patents issued at the USPTO and the amount of VC financing across 20 manufacturing industries between 1965 and 1992 in the United States. They observe that increases in VC activities in an industry are associated with higher patenting rates. Furthermore, this causality disappears when the impact of VC is measured in terms of patent-R&D ratio, rather than number of patents.

In a study of 204 biotech startups that were founded in Canada between 1991 and 2000, Baum and Silverman found that startups with more patent applications and grants obtained significantly more VC financing. A recent study by Mann and Sager (2007) in the software and biotechnology industries investigates the relationship between number of patents, receipt of venture financing and progression trough the VC cycle. Its findings suggest that patenting increases the likelihood of start-up firms to receive VC financing, even though the relationship seems to be present in later financing rounds, but weak, if not absent, in initial ones. It shows also that the relationship between patenting rates and VC financing depends less on the size of the patent portfolio than on the firm's receipt of at least one patent. However, the study does not address the causation issue, related to the possibility that funding might facilitate patenting.

Besides presenting some controversial results, the literature on this topic provides a limited understanding of the determinants of patent value that are more directly taken into consideration by VC firms in their investment decisions. On the contrary, it is likely that such decisions are influenced by other factors in addition to simple patent counts. An exception is represented by work by Lerner (1994), predicting that the breadth of patent protection is significantly associated with higher valuations by VCs. His regression analyses based on a sample of 535 financing rounds at 173 VC-backed

biotechnology companies show that patent scope (as proxied by the count of different IPC classes to which the patent is assigned) positively affects the valuation of new biotech companies by VCs.

However, all the abovementioned studies have made no attempt to assess whether and how VCs consider the technological content of the patent portfolios in their financing decisions, or whether they differ in their valuation ability. In this paper, we first address the former issue, by investigating how the technological composition of the startup's patent portfolio influence the VC financing process. Not only in fact patents differ in their potential economic value, but they also differ in terms of fit with the core technological capabilities of the company. When deciding to invest, for instance, in a biotech or a nanotech startup, it is likely that VCs put more emphasis and importance in the assessment of those patents that are more directly related to the core business of the company. As a first contribution of the paper, we therefore intend to assess whether VCs value the technological contents of the investee company's patent portfolio, in addition to its size and scope, during the selection and financing process.

We then turn to examine whether the selection skills (i.e. the ability to appropriately value a technology) vary across different types of VCs, depending on their degree of industry specialization and on their affiliation, as discussed in the next section.

2.3 The heterogeneity of VC firms and its impact on the valuation of patent portfolios

The role of specialization: specialist vs. generalist VC firms

Most of the financial and strategic literature on venture capital tends to consider VC firms as an homogeneous group, ignoring their significant differences in objectives, investment decisions and managerial styles. On the contrary, more recent work has showed that VC characteristics – and in particular their degree of specialization in a particular industry - can make a difference with respect to the outcome of their investments (Cressy et al., 2007; Gompers et al., 2005).

VCs adopt different strategies as to the composition of their portfolios of investments (Gupta and Sapienza, 1992; Norton and Tenenbaum, 1993). Some VC firms tend to specialize in specific industries and development stages, so to acquire expertise and gain greater value, whereas others follow a more generalist approach, diversifying their investments across a wide variety of industries and technologies. For instance, the empirical study by Gupta and Sapienza (1992) shows that VCs focusing in early

stage ventures prefer less industry diversity and narrower geographic scope when compared to other VCs. Furthermore, larger VCs prefer greater industry diversity and broader geographic scope than smaller VCs.

Following the predictions of the resource-based theories of the firm (Barney, 1991), previous experience cumulated in a given industry thanks to specialization might allow VC managers to gain a better understanding and deeper knowledge of the technological, market and competitive specificities of the investee companies' context. This, in turn, might facilitate not only the correct assessment of new investment opportunities, but also allow them to effectively add value to the investee companies, through more competent monitoring and advice. Busenitz et al. (2004) point out that VCs' learning should result in long-term positive performance implications, given that a VC investor with a significant experience of both successes and failures in a industry could have gained a deeper insight into how to select potential "winners" and improve their performance over time.

Norton and Tanenbaum (2002) acknowledge the importance of maintaining a high degree of specialization for controlling risk and gaining access to networks and information. Similar results are found also by Cressy et al. (2007) who argue that possessing a deeper knowledge of the ventures' environment confers competitive advantages in terms of reduced information asymmetries and uncertainty in the valuation and selection process.

The critical role played by the specialization has been also highlighted by Gompers et al. (2005) who point out that, when there are complementarities and a direct relationship among the investments embedded within the portfolio, the VC firm more quickly liquidates its investments through IPOs and with higher valuations. Building on such results, the Authors thus recognize "[…] the importance of industry-specific human capital and the network of industry contacts to identify good investment opportunities, as well as the know-how to manage these investments" (Gompers et al., 2005, p.5).

These studies suggest that the ability to evaluate technology and intellectual property might not be the same for all the VCs, but it might be a function of their degree of specialization in the industry. Thus, we expect that the VC's performance in the assessment of patent portfolios should be better-off if the VC is specialized in the same industry of the investee company.

The role of affiliation: Independent vs. Corporate Venture Capitalists

Concerning the heterogeneity of VC firms, a further distinction can be drawn between Independent Venture Capitalists (VCs), where the capital is provided by professional financial intermediaries, and Corporate Venture Capitalists (CVCs), where the investor is a non-financial entity. The two types widely differ in terms of incentives, monitoring behavior, time horizon, scale of capital invested and the set of objectives pursued (Chesbrough, 2000). As far as the last dimension is concerned, VCs have the dominant financial aim to liquidate their investments through IPO or selling out the company to a larger firm in the shortest possible time. Differently, CVC is generally considered as a way to capture the value from strategic assets, open up a window on new promising technologies or businesses, respond more competitively in dynamic industries and support demand for core products (Brody and Ehrlich, 1998). CVC can be useful to accelerate market entry, monitor technological changes that could affect further strategic investments, provide access to highly qualified human capital, create new opportunities, develop an entrepreneurial culture and increase internal efficiency of R&D (Dushnitsky and Lenox, 2006). The existence of these critical differences explains the need to analyze VC and CVC as autonomous forms of new ventures financing.

In the previous literature, such evidence led to the analysis of the distinct contributions of VC and CVC to innovation, and broadly to ventures' growth. More precisely, the economic literature frequently points out the active role of VC in the businesses they finance, not only through monitoring, but also by providing valuable support and governance. For instance, previous studies have shown the significant role played in terms of professionalization of start-up firms (Hellmann and Puri, 2002), the improvement of ventures' performance at the IPO (Brav and Gompers, 1997) and the positive association between VC and patenting rate (Kortum and Lerner, 2000). About CVC, several studies point out its role as an important source of technological innovation for corporations, by providing a window on emerging technologies, market opportunities and new business models (Markham et ali, 2005). Jain and Kini (1995) compare the growth of VC and CVC-backed firms with non-VC counterparts, finding that the former outperforms the latter. In a recent study by Bertoni, Colombo and Grilli (2007), the results suggest that, even though both VC and CVC positively affect ventures growth, the benefits of the former considerably exceed those of the latter.

Nevertheless, in these studies no attempt has been made to compare the decision-making process and the criteria used by VC and CVC in their ventures selection. This distinction could be important to assess whether and how VCs and CVCs differently consider some dimensions in their financing decisions, i.e. the quality of patent portfolios, or whether they differ in their valuation ability. If the abovementioned differences do not matter, a basic measure of technology based on the total number of patents owned by the ventures could be adequate to screen entrepreneurial activities. On the other hand, CVCs are affiliated to corporations with well-defined core-businesses and competences, possessing internal expertise and knowledge that can be leveraged in the course of the due diligence process. As a consequence, it is likely that CVCs develop more expertise (when compared to VCs) in the evaluation of specific technological capabilities. We could therefore expect that their investment decisions are influenced by other factors in addition to simple patent numbers, for instance by measures which capture the technological content and the quality of patents.

3. Methods

3.1 The context

Nanotechnology can be defined as the study and use of the unique characteristics of materials at the nanometer scale, between the classical large-molecule level to which traditional physics and chemistry apply and the atomic level in which the rules of quantum mechanics take effect (Lemeley, 2005). Although the scientific interest in the “nano” world can be traced backed at least to the 1950s, a key-date for the industrial development of nanotechnology is 1981, with the design of the Scanning Tunnelling Microscope by IBM scientists. The STM allowed researchers to “see” atoms and molecules at the nanometre scale, a precondition to find novel proprieties at the nanoscale and make use of this knowledge to develop new materials and products. Indeed, the wide interest in nanotechnology stems from the fact that the ability to operate with atomic precision allow scientists to produce materials with improved or new optical, magnetic, thermal or electric proprieties, opening up a broad range of commercial applications.

An important characteristic of patents in nanotechnology is their inter-disciplinarity: nanotechnology is sometimes referred to as a general-purpose technology, because in its advanced form it will have significant impact on almost all industries and all areas of society. It attracts scientists from many areas of science (i.e., physics, chemistry, biology, computer science, etc.), and in the wide spectrum of potential market applications, which can involve very different businesses (such as computers, flat-panel displays, diagnostic products sensors, lighting devices and many others).

The field of nanotechnology is an optimal setting to study how VC firms evaluate patent portfolios in their investment decisions for various reasons. First, several new ventures have been created in nanotechnology in the United States and other countries in the world, mainly spun out of universities and government laboratories. The creation and growth of new companies has been favoured by the wide availability of funding by governments, established companies and venture capitalists. In particular, VC investments in the nanotech field has steadily increased over the last decade, reminiscing the earlier development of the biotech industry. Second, patents represent an important and effective mechanism to protect the returns stemming from nanotech investments, as witnessed by a real "boom" in the number of nanotechnology patents registered all over the world during the last 10 years. According to the Wall Street Journal, "[P]atents awarded annually for nanotechnology inventions have tripled since 1996, with 10-fold or greater increases in some areas during the past years". For many nanotech startups, the intellectual-property portfolio represent the main asset, to be exploited through business models based on the commercialization of new products (vertical integration) or on licensing revenues.

In addition to that, the definition of what is a nanotechnology patent is not an easy task, given the newness of the field and the many different scientific and technical areas involved. Such characteristics make it extremely difficult to adopt conventional IPC classes to tag nanotech patents, inducing high levels of uncertainty for patent examiners, inventors and prospective investors, including VCs.

In order to facilitate interdisciplinary searches and monitor trends in nanotechnology, the EPO has recently developed a new code (the Y01N) in order to tag all nanotech patents[2]. All European patent applications have been classified ex-post by a group of

[2] In the Y01N subclass the term 'nanotechnology' "[…] covers all things with a controlled geometrical size of at least one functional component below 100 nanometers (nm) in one or more dimensions

patent experts in order to tag them, if the case, with the new code. The new classification has been publicly disclosed by the EPO since January 2006. From that date, with a simple query on the search engines of the EPO website, it is possible to collect information on all the patents granted in the nanotech field.

3.2 The sample

We created a sample of companies operating in nanotechnology and financed by VC funds over the period 1985-2006. Our data on VC investments in nanotechnology are taken from Thomson Venture Economics (*Venture Expert*), which can be considered as the most comprehensive commercial data source on the global VC industry. All VC-backed companies taking place worldwide in the field of nanotechnology over the period 1985-2006 were identified[6], amounting to 361 companies. For each company, we collected from Venture Expert the following information: country, main industries (according to the 4-digit Venture Expert Industry Classification), VC firms investing in the company (including the lead investor in syndicated deals), founding year, year of the first and subsequent stages of investment, amount raised (in US $) in each financing round. Information on the initial amount of funding received by VC was available for only 332 companies, which therefore represent our final sample.

For each VC-backed company, we identified the lead investor as either (a) the PE firm that at the moment of the buyout was explicitly mentioned as lead investor or (b) the firm that held the largest equity stake the buyout. We then complemented such information by gathering the following data on all the VC firms investing in nanotechnology: firm name, affiliation (i.e. independent, corporate, financial, public), number of companies in the current portfolio, breakdown of portfolio companies by industry.

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susceptible to make physical, chemical or biological effects available which cannot be achieved above that size without a loss of performance (Scheu, 2005)".

[6] Venture Economics classifies all venture capital and private equity deals in 6 main categories (and several other sub-categories), according to the stage of development of the investee company: seed, early-stage, expansion, later-stage, buyout/acquisition, and other. Since our interest resides in new ventures, we focused exclusively on deals belonging to the first 4 categories, and excluded from the analysis "buyout/acquisition" deals. In order to identify companies operating in nanotechnology, we adopted the classification of Venture Expert, which assigns each company to specific technological areas, including nanotechnology.

In order to construct the patent portfolios of our sample companies, we referred to patent applications at the European Patent Office. We first identified all patents applications at the European Patent Office in the field of nanotechnology over the period 1980-2006. Nanotech patents were identified as showing the code Y01N in the ECLA classification scheme. As of June 2007, the date of data extraction, the European Patent Office register contained 9813 nanotech patent applications.

3.3 Variables

Dependent variable.

VC Financing Amount measures the log transformation of the total amount of VC financing (in million US dollars) obtained by the company at the first investment round[4]. Limiting the study to the initial financing round eliminates the problems related to the causality link between patenting and VC financing. Indeed, previous work has shown that the receipt of VC funding might significantly enhance patent productivity (Kortum and Lerner, 2001; Bertoni et al., 2006). By considering only the initial financing rounds, we could directly assess the impact of the characteristics of patent portfolios on VC investment decisions, our research question, and rule out the "chicken-egg" problem related to the positive impact of VC investments on patenting activity.

Independent variable.

Patents measures, for each company, the stock of patent applications at the European Patent Office at the date of the first financing round. The searches were conducted in June 2007 using the April 2007 version of the Patstat database, realized by the European Patent Office.

For each company, *Nanotech Patents* measures the stock of patent applications at the EPO in the nanotechnology class. Nanotech patents were identified through the "Y01N" code of the ECLA classification, specifically introduced by the EPO to tag this kind of patents.

[4] While Venture Economics identifies for each financing round the date and number of investors, and in most of the cases the amount invested by each investor, it does not track in a systematic way the price paid per share. Given that data on the so called pre-money valuation - the product of the price paid per share in the financing round and the shares outstanding before the financing round - were largely unavailable, we couldn't assess the impact of patent portfolio size, composition and scope on firm value, as in Lerner (1994).

Patent scope captures the average breadth of patents included in the portfolio of the VC-backed company at the year of the first financing round. Ideally patent scope should be measured, for each patent, through the subjective assessment of experts in the nanotechnology field (i.e. researchers, patent attorneys) in order to value the breadth of the claims. However, this is practically impossible for large groups of patents. We thus decided to apply the measure identified and validated by Lerner (1994) in his study of the biotechnology industry. Therefore, for each patent, we measured patent scope by counting the number of IPC classes to which patent examiners assigned each nanotech patent, using the first four IPC digits only. We then computed the average value of this measure for all the patent application included in the company's portfolio at the year of the first financing round. If the company had no patents, we code the average patent scope as zero, as in Lerner (1994).

In order to identify different types of VC firms investing in nanotechnology we used the following dummy variables, which were used to perform "split-sample" regression analyses.

Specialized VC is a dummy taking the value 1 if the company was financed by a lead VC firm specialized in nanotechnology, and 0 in all other cases[5].

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[5] The measure of specialization of the lead VC firm in nanotechnology is adapted from Cressy et al. (2007). For each VC firm included in Venture Expert, we first defined an index, *RIA*, or Revealed Industrial Advantage in nanotechnology, computed as:

$$RIA_{iN} = (C_{iN} / C_{.N}) / (C_{i.} / C_{..})$$

where:
C_{iN} is the number of portfolio companies of VC firm *i* in the field of nanotechnology,
$C_{.N}$ is the total number of companies invested in the nanotechnology field by all VC firms
$C_{i.}$ is the total number of portfolio companies of VC firm *i* and
$C_{..}$ is the total number of companies invested by all VC firms (i.e. across all sectors).

The numerator in this measure ($C_{iN}/C_{.N}$) represents the VC firm *i*'s share of all investments in the field of nanotechnology and the denominator ($C_{i.}/C_{..}$) the VC firm *i*'s share in all investments (i.e. across all sectors). RIA_{ij} therefore measures the VC firm *i*'s *investment focus* in nanotechnology *relative to that of its VC competitors.*

Note that:

$$RIA_{iN} \begin{cases} = 0 \Leftrightarrow C_{iN} = 0 \\ < 1 \Leftrightarrow C_{iN} / C_{.N} < C_{i.} / C_{..} \\ \geq 1 \Leftrightarrow C_{iN} / C_{.N} \geq C_{i.} / C_{..} \end{cases}$$

so that a value of RIA_{iN} less (greater) than one indicates that the VC firm *i* is relatively unspecialised (specialised) in nanotechnology.

We used Venture Economics in order to identify, for each VC firm, the share of its portfolio companies in nanotechnology, as well as the total number of portfolio companies included in each

Corporate VC is a dummy taking the value 1 if the company was financed by a Corporate VC firm, and 0 otherwise, based on the classification provided by Venture Expert.

Control variables.

We included in our analyses also a set of control variables which might affect the total amount of financing obtained by the investee company in the initial round.

Company Age measures the age of the company at the date of the initial financing round, computed as the difference between the investment year and the foundation year of the company[6].

Market scope captures the degree of market diversification of the investee company. Previous research has shown that the size and attractiveness of the product markets in which the target companies operate represent important determinants of the investment decision by VC firms (Tyebee and Bruno, 1984; MacMillan et al, 1985). It is thus likely that companies operating in different markets are characterize by a higher growth potential, thus obtaining higher valuations and financing by VC firms. We proxied the market scope of the investee company with the count of different industries to which the company is assigned by Venture Economics.

Dummy US. is a dummy taking the value 1 for companies located in the United States, and 0 in all other cases. Since the VC industry in the U.S. is by far the most developed in the world in terms of overall amount of funds available, number and experience of VC firms, it is possible that U.S. nanotech ventures benefit from higher investment opportunities than their foreign counterparts.

Dummy Early VC takes the value 1 for investment in the "seed" or "startup" stages of development. Indeed, Gompers (1995) has shown that the amount of financing

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industrial sector over the period 1990-2006. We computed the *RIA* index over the period 1990-2006, consistently with the time period under study.

We then used the *RIA* index to create the dummy variable *Specialized VC*. For each company in the sample, *Specialized VC* takes the value 1 when the company was acquired by a lead VC firm specialized in nanotechnology (i.e. with a *RIA* greater than 1), and 0 in all other cases.

[6] The information on the foundation year of the companies included in the sample was obtained by Venture Expert. In cases were such information was missing, we performed searches on the Internet to gather the relevant data. However, we were not able to find this kind of information for 19 companies out of 332 included in our sample. For such companies, we computed Company Age as the average age at the first financing round of the nanotech companies backed by VC firms in the same stage of development.

received from VC firms tend to be higher, on average, in later rounds as compared to earlier rounds, as a consequence of reduced uncertainty and information asymmetries.

4. Analyses and results

4.1 Descriptive statistics and correlation analysis

Table 1 presents descriptive statistics from the sample of VC-backed companies. On average, the companies included in our sample received 5.01 million US $ in the first financing round by VC firms. At time of first VC investment, they had a mean of 0.84 patents and 0.28 nanotech patents in their portfolio, with a maximum of 15 and 7 patents respectively. Such low figures are due to the fact that only a limited number of companies had obtained a patent before their first financing. More precisely, only 28% (95/332) of the companies had a patent at initial VC financing, whereas this number lowers to 10% (35/332) for nanotech patents. However, it should be noted that such figures are higher than those reported by Mann and Sager (2007) in their study of the software and biotechnology industries. They found that the number of firms with at least one patent before the first financing was just 9% (75/877) in their sample of VC-backed software companies, and 23% (49/212) in their sample of VC-backed biotech companies. Therefore, such results confirm the strategic importance of patenting in the nanotech business. Concerning the breadth of patent protection, the average number of four-digit IPC classes into which a sample patent is classified is 0.46. On average, sample companies operate in 1.7 different industrial sectors, according to the classification of Venture Economics, with a maximum number of 4 different sectors. The mean age of the company at date of the initial VC investment is around 2 years. The large majority of our sample companies is located in the United States (around 86%), followed by Europe (7%), Canada (3%) and Israel.

--- Insert Table 1 around here ---

Table 2 reports the correlation matrix for our variables. We note that whilst most correlations are moderate there is a rather high correlation (0.54) that between *Patents* and *Patent scope,* which might pose problems of multicollinearity. As a robustness

check, we therefore replicated our regression analyses including and excluding *Patent Scope* in the specification model. The results substantially remain the same in all the models estimated concerning the effects of patent portofolios' characteristics on VC financing, with the sole exception of the slit-sample analysis regarding the specialization of VC firms, as discussed in more detail below. For the sake of simplicity, in this paper we report only the tables of the full models with both independent variables.

--- Insert Table 2 around here ---

4.2 Regression analyses and results

We analyzed the relationship between patent portfolios' characteristics of start-up companies and total amount of VC financing in a regression framework, in order to control for the potential influence of other factors. We first adopted an OLS estimator on the full sample including all 332 VC-backed companies. Table 3 (Column 1) shows the results of this first model. The coefficient of the variable *Patents* is positive (0.013), although not statistically significant. The simple number of patents, thus, does not have a significant impact on the amount of funding obtained by VC firms. This evidence is in line with results by Mann and Whitney (2007) in the software industry, showing a little significance of having a patent before the first round of financing on the progress of companies through the VC cycle. It is also consistent with the results of Hsu (2004), who finds no relation between pre-funding patents and various measures of firm performance in his study of a dataset of VC-backed and SBIC startups.

--- Insert Table 3 around here ---

A possible explanation for this evidence resides in the fact that VCs do not simply consider the existence of patents in the process of screening and due diligence of prospective investments, but evaluate in more depth the very nature of the underlying inventions being patented. Indeed, our regression shows that the coefficient of the variable *Nanotech Patents* is positive (0.154) and statistically significant at the 1%

level. This suggests that VCs are sophisticated investors able to evaluate the technological composition of patent portfolios, by placing more relevance on those patents more directly related to the core technological competences of the company, in this specific case related to nanotechnology. This evidence is even more significant if we consider that the EPO publicly reported in its databases the new Y01N code for nanotech patents only in January 2006. Before that date the identification of nanotech patents was an ambiguous and uncertain task, given the inter-disciplinarity and the newness of the field.

On the other hand, we do not find a support in our data for the positive impact of patent breadth on VC financing. Although positive in sign in fact, the variable *Patent Scope* is not statistically significant in our estimates. This evidence, in conflict with the results by Lerner (2004) showing a positive effects of patent scope, might be due to the newness and uncertainty of patenting in the nanotechnology sector, still characterized by a real rush towards strategic patenting. On the one hand, first inventors have strong incentives to stake broad claims in the early days of a technology, in order to safeguard their inventions from infringements and thus increase their innovation's rents (Merges and Nelson, 1990). Early in the history of a technology, there is a higher possibility of obtaining broad patents, due to the absence of competing inventions, the high uncertainty about the market applications, the limited understanding of the prior art landscape by patent examiners. At the same time, however, in the specific case of nanotechnology "[…] the intensifying race to file patent applications has sparked concern that a proliferation of patents, especially broadly defined ones, could hobble innovation and produce a thicket of conflicting legal claims that could eventually drive up costs for consumers" (WSJ, 18/6/04). Therefore, it is not immediate to ascertain the value of large patent scope in this uncertain environment.

Turning to the control variables, only the dummy *Early VC* is statistically significant at the 1% level, and negative in sign. As expected, companies in earlier stages of development (i.e. seed, start-up) tend to receive a lower amount of financing in the initial rounds, also as a way to reduce uncertainty and opportunistic behaviour by entrepreneurs (Gompers, 1995).

We then turn to analyze whether the relation between the patent portfolios of startup firms and the amount of VC financing depends of the characteristics of the VC investor. We first look at the effects of the degree of specialization in nanotechnology

of the lead VC firm investing in the company. In order to do that, we split our observations into two sub-samples depending on whether the lead VC firm is specialized (*Dummy Specialized VC* =1) or not (*Dummy Specialized VC* =0) in nanotechnology. In particular, we have a first sub-sample including all the companies financed by lead VC firms specialized in nanotechnology (253 observations), and a second sub-sample including all the observations by lead VC firms which are not specialized in this field (77 observations)[7].

Table 3 reports in columns 2 and 3 the results of the split sample analysis, showing interesting differences. In fact, the coefficient of *Patents* is positive (0.035) and not significant in the sub-sample of companies backed by VCs specialized in nanotech, whereas it is negative (-0.450) and significant at 1% level in the sub-sample of unspecialized VC firms. On the contrary, the coefficient of *Nanotech Patents* is positive (0.149) and statistically significant at the 1% level in the former sub-sample, whereas it becomes not significant at conventional levels in the latter sub-sample. In addition, in the sub-sample of companies backed by unspecialized VC firms, the coefficient of Patent Scope is positive (1.347) and statistically significant[8].

Such results confirm that VCs having a stronger focus in the nanotech sector tend to accumulate a specific knowledge allowing them to evaluate more effectively those patents tightly related to nanotechnology. On the contrary, not specialized VC firms do not consider the technological composition of patent portfolios in their financing decisions.

Finally, Columns 4 and 5 of Table 3 report the findings of the split sample analysis related to the type of affiliation of VC firms. Column 4 refers to the sub-sample including all the companies financed by Corporate Venture Capitalists (142 observations), whereas Column 5 refers to companies backed only by Independent VC firms (190 observations). In both cases, the coefficients of *Nano Patents* is positive and statistically significant at the 5% level, whereas simple *Patent* counts and *Patent Scope* are not statistically significant. Our analysis therefore does not provide

[7] We were not able to compute the index of specialization in nanotechnology for two companies in our sample, due to missing data.

[8] However, the analysis of the correlation matrix for the subsample of companies financed by VC firms which are *not* specialized in nanotechnology shows the presence of a high correlation (0.81) between *Patents* and *Patent Scope*. We therefore ran further estimates dropping the latter variable from the model. In this case, the coefficient of *Patents* results positive but not statistically significant, whereas *Nano Patents* remains positive and not statistically significant. This analysis provides a more robust confirmation than VC firm specialized in nanotechnology tend to value more nanotech patents in their investment decisions than unspecialized VC firms.

evidence of significant differences in the evaluation of patent portfolios by CVCs and Independent VCs in the course of the selection and financing process.

5. Conclusions

This paper analyzed the impact of the characteristics of patent portfolios by startups - in terms of size, scope and technological composition - on the amount of financing obtained by VC firms. It provides two main contributions to the existing literature on the relationship between patenting and VC investments. First, it moves beyond the simple analysis of patent counts, by claming that VC firms consider the technological relevance of the IPRs possessed by target companies in their selection process. Second, it recognizes that VC firms are not all alike as to the capabilities required to effectively assess the value of startups' technology and intellectual property. In particular, we argued that their degree of specialization in the specific industry of the company under scrutiny and their type of affiliation might influence their evaluation criteria and skills.

We tested our expectations on a sample of 332 VC-backed companies in the nanotechnology sector. Our results show that the simple number of patents applied by the company before the first investment round does not have a significant impact on the amount of financing obtained, controlling for the age, the stage of development, the degree of market diversification, the location of the startup. On the contrary, the startup's stock of patents belonging to the nanotechnology class has a positive and significant effect on VC financing. Such findings help to interpret previous evidence by Mann and Sager (2007) showing no impact patents obtained pre financing and the amount invested by VCs. We show that it is the *type* of patents owned by the startup that matters in the financing decision, in particular for what concerns their technological content, not just their simple number. Overall, our results support the view of VCs as competent investors, able to identify and evaluate the technological capabilities of target companies.

Moreover, it also suggests that this kind of selection skills are not evenly distributed across VC firms. In fact, we showed that VCs relatively more specialized in nanotechnology in their investment strategies tend to value more nanotech patents in their financing decisions than unspecialized VCs. Specialization seems therefore

provide a better understanding and deeper knowledge of the technological specificities of the investee companies' context. This, in turn, might facilitate the correct assessment of new investment opportunities.

On the contrary, we did not find significant differences between Corporate and Independent VCs in the assessment of patent portfolios in the financing decisions. It might be that CVCs retain an evaluation advantage with respect to their independent counterparts only if they possess a sufficient absorptive capacity, in terms of previous technological knowledge stock. Dushnistsky and Lenox (2005) have demonstrated that the marginal contribution of CVC investments on patenting is higher for incumbent firms with higher absorptive capacity. This suggests that the ability of an investing incumbent firm to appropriately identify and transfer knowledge through interaction with a new venture requires that the former has sufficient technical understanding. In this paper we were not able to discriminate CVCs in terms of levels of absorptive capacity, in particular for what concerns the nanotechnology field, an issue which could be directly addressed by future research.

Finally, some qualifications and suggestions for future research.

To begin with, our analysis relied on data from a single sector, nanotechnology, characterized by high degree of newness, uncertainty and inter-disciplinarity. As we have already mentioned, such specificities raise concerns about the generalizability of our results to other contexts, in particular to more mature and established businesses.

Second, it is likely that investment decisions by VCs are influenced also by other characteristics of patent portfolios that we did not consider in our analysis, for instance patent lifetime (as a proxy of the remaining economic usefulness of the patent), family size (as a proxy of the market size of the underlying invention) or patent legal status (i.e. existence of renewal or opposition). There are therefore opportunities to analyze other determinants of patent value that are more directly taken into consideration by VC firms in their investment choices.

Finally, we limited our analysis to the initial financing rounds of the VC cycle, as a way to circumvent the causality problems which limit previous research on patenting and VC investments. Mann and Sager (2007) suggest that patents have their greatest value for companies at the later stage of the investment cycle, whereas in earlier stages other determinants, such as the characteristics of the entrepreneurial team, play a dominant role. However, they do not provide a direct empirical test for such claims. Further research should investigate in more depth the relative importance of the

different criteria adopted by VC firms in the evaluation of startups companies and how they change over the VC cycle.

Tables

Table 1
Descriptive statistics for VC-backed companies

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Log VC financing (mil US $)	332	0.750189	1.47175	-3.21888	4.714562
Patents	332	0.843374	1.975572	0	15
Nanotech Patents	332	0.207831	0.801546	0	7
Patent Scope	332	0.459759	1.083547	0	7.66
Company Age	332	2.03012	2.708217	0	18
Dummy US	332	0.861446	0.346002	0	1
Market Scope	332	1.64759	0.707679	1	4
Dummy Early VC	332	0.331325	0.4714	0	1

Table 2
Correlation Matrix

		1	2	3	4	5	6	7
1	VC financing (mil US $)	1						
2	Patents	0.1046	1					
3	Nanotech Patents	0.0981	0.1179	1				
4	Patent Scope	0.1244	0.5495	0.0157	1			
5	Company Age	0.1467	0.3261	-0.0307	0.2909	1		
6	Dummy US	0.034	-0.0628	0.0061	-0.0874	-0.0439	1	
7	Market Scope	0.0086	0.0857	-0.0729	0.0281	-0.0339	0.0221	1

Table 3
Regressions for patent portfolio characteristics and VC financing: full and split samples

	(1) Full sample	(2) Specialized VC firms	(3) Unspecialized VC firms	(4) Corporate VC firms	(5) Independent VC firms
Variable	*Log (VC financing amount)*	*Log (VC financing amount)*	*Log (VC financing amount)*	*Log (VC financing amount)*	*Log (VC financing amount)*
Patents	.012 (.044)	.035 (.048)	-.450*** (.145)	-.041 (.064)	.031 (.068)
Nanotech Patents	.153*** (.046)	.149*** (.044)	.096 (.223)	.180** (.084)	.139** (.062)
Patent Scope	.071 (.064)	.047 (.065)	1.347*** (.373)	.067 (.110)	.070 (.080)
Company Age	.029 (.032)	.003 (.034)	.119** (.054)	.099** (.039)	.003 (.036)
Dummy US	.061 (.185)	-.012 (.185)	.037 (.547)	.399 (.311)	-.169 (.238)
Market Scope	.054 (.115)	.079 (.135)	-.162 (.258)	.036 (.185)	.055 (.144)
Dummy Early VC	-1.189*** (.170)	-1.475*** (.189)	.372 (.350)	-1.244*** (.255)	-1.134*** (.227)
Constant	.866*** (.280)	.966*** (.304)	1.010 (.661)	.736* (.436)	.921** (.359)
R^2	.178	.239	.178	.223	.161
F ratio for regression	11.63***	11.98***	4.91***	7.46***	5.98***
N. obs in regression	332	253	77	142	190

Robust standard errors are in parentheses.
Level of significance reported: ***; **; * significant at the 1%,5% and 10% levels respectively.

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