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Signaling in academic ventures: the role of technology transfer offices and university funds

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Abstract University spinoffs, an important subset of high-tech start-up companies, operate in a context characterized by marked information asymmetries that limit their chances of obtaining financing. Given the uncertainty and imperfect information that characterize these investment opportunities, signals about their potential value deserve further attention. We investigate the relationship between the main stakeholders involved in the process of creating a university spinoff—that is, the academic founders, the university technology-transfer office, and private investors—focusing on the role of public grants as effective signals that attract private venture capital (VC) funding. Using the database of all spinoff companies established to exploit inventions assigned to the University of Michigan from 1999 to 2010, we determine how the funds provided through the university technology-transfer office influence VC follow-on funding and consequent spinoff growth, controlling for the spinoff's technology, the founders' human capital, and the network's resources. The empirical results support a signaling effect of the commercialization funds provided by the university and suggest an indirect impact on the growth of the spinoff's sales through the mediating effect of VC financing.

Keywords University spinoff financing · Venture capital · Technology-transfer office · Funding gap · Signaling theory

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1 Introduction

Academic spinoffs are new, science-based ventures created to exploit economically the findings and innovative ideas that arise from university research by producing goods or services (Chiesa and Piccaluga 2000).

To sustain this process of technology transfer, most universities have established technology-transfer offices (TTOs), which are semi-independent organizations responsible for recognizing the inventions with the greatest potential for making a significant positive impact and choosing the best course of action to support their development. TTOs' role can be described as that of an intermediary between the innovation suppliers (university scientists) and those who have the means to commercialize innovations, such as venture capitalists (VCs) (Siegel et al. 2007). TTOs are also responsible for identifying spinoff companies that are worth receiving university commercialization funds to support their first validation phases.

Beyond those first validation phases, however, the spinoffs' viability in the long term is related primarily to its ability to obtain financing from outside investors (Siegel et al. 2003; Clarysse et al. 2007), which is why the synergy between university funds and venture capital investments is central to academic spinoffs' sustainability. The spinoffs may choose either to ask for public funds and then private investments or to seek private funds directly. In the first case, TTOs must identify a spinoff as promising before endowing it with university funds, so the spinoffs must be willing to work through the assessment phase and reveal private information to the TTO. In that case, private VCs can infer the spinoff's potential based on public information, which will also include the amount of public funds received. In the second case, VCs will have to base their evaluations only on information the spinoffs share with them.

The literature recognizes that investment decisions in new ventures suffer under an information asymmetry problem (Lockett et al. 2002; Hall and Lerner 2010), as the founding team has more information about a venture's prospects than outsiders do. Because of the shortage of information about the firm's market value and its growth potential, investors might be reluctant to sustain these ventures, leaving academic spinoffs with a funding gap. To overcome this problem, spinoffs may undertake actions to signal their potential value to VCs thereby reducing the information asymmetry.

Previous research on startups has focused on young firms and initial public offerings (IPOs), analyzing signals to investors like the make-up of the board and top management team, ownership characteristics, and endorsement relationships (e.g., Bruton et al. 2009; Busenitz et al. 2005; Certo 2003; Cohen and Dean 2005; Filatotchev and Bishop 2002; Gulati and Higgins 2003; Higgins and Gulati 2006; Janney and Folta 2003, 2006; Sanders and Boivie 2004; Zimmerman 2008). However, the amount of ownership equity and personal net worth the founding team members invest in the company does not appear to have a significant relationship with long-term venture outcomes, so it cannot be considered a valuable signal of potential firm value (Busenitz et al. 2005).

In this paper, we take a step forward by focusing on academic entrepreneurship and the role of the public university funds TTOs award in attracting venture capital financing. We provide evidence that, as a result of the information asymmetries between spinoffs and potential investors, TTOs can offer credible signals to VCs regarding spinoff ventures' prospects. More specifically, we add to the literature on signaling by arguing that the signaler (spinoffs), who might send messages unintentionally to the receiver (VCs), may be substituted by a credible party (TTOs) that is more proximal to the signaler and suffers less information asymmetry. We also show that this signal is effective, as it ensures that venture capital funding is linked to spinoffs' future market success (i.e., sales growth).

To make these contributions, we analyzed the database of all spinoffs created to exploit the inventions assigned to the University of Michigan (U-M) from 1999 to 2010, controlling for variables that might influence the signal sent to VCs: the spinoff's technological endowment, the founders' human capital, and the network's resources.

The results indicate that university commercialization funds (also called gap funds) have an indirect effect on a spinoff's performance by influencing follow-on venture capital investments. In other words, these gap funds are an effective signal of the quality and credibility of a new business, and VCs use this information to identify the spinoffs that are most worth financing.

The following sections illustrate the conceptual framework based on the problem of information asymmetry and signaling theory. First, we identify the actors involved in the technology-transfer process and formulate our research hypotheses. Then we describe our sample and the methods and variables used to test our hypotheses empirically. Finally, the results of our analyses are illustrated and their implications discussed.

2 Academic spinoffs: a signaling model in the technology-transfer process

2.1 Main actors and their roles

An academic spinoff is established when the licensee of a university-assigned invention founds a new company to exploit the discovery economically by producing goods or services. The spinoff phenomenon is relatively new for most universities; institutions like MIT and Stanford are exceptions to the rule. The literature has given ample attention to the influence of university policies and procedures on the commercialization of research, particularly the role of TTOs through their resources and the experience in the development of spinoffs (e.g., DeGroof and Roberts 2004; Lockett and Wright 2005).

The main private financial intermediaries that invest in these kinds of new technology companies are VCs, which specialize in raising capital from a variety of institutional and private investors to invest in young companies in the hope of generating a return by selling the firm or floating it on the public equity market. In exchange for the high risk they take by investing in small, immature companies, VCs usually gain significant control over the company's decisions and a significant portion of its ownership.

Venture capital financing is hard for spinoffs to attract. The marked uncertainty and significant monitoring costs of assessing early-stage seed investments in technology and science-based fields mean that few venture capital investments are made before a proof of concept becomes available (Lockett et al. 2002). In addition, Wright et al. (2006) claimed that VCs have a funding bias regarding academic spinoffs that arises from the complexity of advanced scientific research and academic entrepreneurs' shortage of commercial skills. This bias seems to be mitigated only when there is public-sector capital in the VCs' own capital and when some of the investment managers have worked in an academic environment (Knockaert et al. 2010).

The role of TTOs is especially important in helping these new ventures overcome their financial challenges. Behind an academic spinoff is the initiative of an individual or, more likely, a group of researchers who are usually less attentive to the market and less expert as managers than the average entrepreneur. The researchers typically become involved in the commercialization activities of their research because they expect to generate results that will enhance their academic standing, not because of an entrepreneurial inclination (Fini et al. 2009). If they are not supported in their strategic choices, they tend to seek other partners in their technical-scientific environment in order to focus more on research and less on the commercial side of the new venture (Colombo and Grilli 2005). Most TTOs stimulate and support spinoff activities by providing business support services and resources tailored to novel technology and knowledge-based firms, such as legal and managerial advice, information about public financial support programs, and links with networks of business angels and VCs (Clarysse et al. 2007). The best TTOs develop relationships with key VCs and understand their investment criteria so, “when they … reach out to one of these groups with an investment opportunity in an academic spin-out, the investors are likely to consider the new venture seriously” (Lerner 2004: 54).

2.2 Information asymmetries and signals in innovation settings

Signaling theory is mainly concerned with reducing information asymmetry between two parties (Spence 2002). For example, Spence’s (1973) seminal work demonstrated how a job applicant might use costly signals (i.e., formal education) to reduce the information asymmetry that hampers prospective employers’ ability to select the most qualified candidates.

In innovation settings, the information asymmetry problem occurs when the inventor is better informed about an innovative projects’ nature and chances of success than potential investors are (Hall and Lerner 2010; Stiglitz and Weiss 1981). For instance, as in our case, the founding team knows more specifics about early stage research-and-development (R&D) results and potential applications and other confidential information that might affect future growth than investors do. Therefore, the marketplace for financing the development of innovative ideas looks like the “lemons” market modeled by Akerlof (1970), which describes top-quality start-ups faced with the problem of distinguishing themselves in the market. In other words, spinoff companies suffer considerably from information asymmetry, as they usually have more intangible assets than non-technological firms do, considerable value in terms of human resources, marked complexity, and a high level of uncertainty about their true worth.

The level of uncertainty and information asymmetry in our innovation setting interferes with the outside assessment of the technology’s potential and, consequently, with the ability to raise external capital to the point at which it might become either very expensive or impossible to obtain (Lerner 1999). Therefore, signals have crucial importance in this context.

Signaling theory is frequently used in the strategy and entrepreneurship literature, where scholars have examined the signaling value of the characteristics of corporate governance, such as board characteristics (Certo 2003; Sanders and Boivie 2004), top management team characteristics (Cohen and Dean 2005; Higgins and Gulati 2006; Zimmerman 2008), ownership (Bruton et al. 2009; Filatotchev and Bishop 2002; Janney and Folta 2003, 2006), endorsement partnerships and alliances (Gulati and Higgins 2003), and founder involvement (Busenitz et al. 2005). These studies focused on the role of signaling in parties’ (start-ups and investors) resolving information asymmetries about the latent and unobservable quality of the signaler.

This “quality” refers to the underlying, unobservable ability of the signaler (i.e., the firm) to fulfill the needs or demands of an outsider observing the signal. In Spence’s (1973) classic example, quality refers to the unobservable ability of the individual, which is signaled by university graduation. In our case, quality refers to the unobservable ability of the spinoff to generate revenues in the long term by carrying on an effective technology-transfer and commercialization process and transforming the research's results to marketable innovative products/services, which may be signaled by the ability to obtain the university commercialization funds. Simply stated, this private information provides insiders (i.e., inventors) with a privileged perspective on the underlying quality of their venture.

In our signaling model, we can distinguish three main sequential elements: the signaler, which is the spinoff venture characterized by the unobservable quality of potential economic return; the signal, which corresponds to university commercialization funds awarded after the TTOs' assessment and screening; and the receiver, VCs, who decide whether and how much to invest in the spinoff venture based on the perceived signal.

In addition to theoretical arguments, several research findings are in line with this model, supporting the idea that public funding serves as a signal for venture capital. For instance, Shane (2004: 228) observed, "In some cases, the government serves as a catalyst for private sector financing by paying for the initial test that proves the value of a technology and so motivates private investors to make subsequent investments." Lerner (1999), who studied the Small Business Innovation Research (SBIR) program, the largest public program for subsidizing small high-tech firms, found that SBIR awardees were significantly more likely to receive venture financing than were non-awardees. Finally, Zhao and Ziedonis (2012) studied the R&D awards granted by the State of Michigan and found that R&D funding stimulates follow-on financing from other government and sources of venture capital.

Based on both theoretical and empirical evidence, we surmise that the commercialization funds provided through the university TTOs positively influence the likelihood that a spinoff will attract venture capital financing by signaling the spinoff's growth potential.

Hypothesis 1 Receiving university commercialization funds increases the chances that a spinoff company will receive venture capital financing.

According to signaling theory, signals may be "strong" or "weak" (Gulati and Higgins 2003) based on how the receiver detects the signals. Ramaswami et al. (2010) defined signal strength in terms of how salient the signal is to a given signaler, which is akin to signal fit.

University funds' signaling strength varies with the amount of funds, as Lerner (1999) suggested. If the main purpose of public subsidies is to address small firms' inability to capture the surplus generated by their innovations, there should be a positive relationship between the amount of subsidy received and the effect on the firm such that, the more subsidies they receive, the faster they grow. In short, in the case of academic spinoffs and consistent with the signaling mechanism, more funds provided by TTOs will attract more VCs.

Another possible explanation regards the technology life cycle and the potentiality of a technology to become "the next big thing" if it is properly funded, in contrast with the technology's potential if its development is postponed because it does not receive the money required to proceed with the proof of concept, enter the market, and exploit the right moment. The consequent minor market return could stop the VCs from investing high amounts. The spinoff that is not properly funded has also weak power to bargain for high investments in product-related factors because the budget constraints caused by lack of seed funds result in less freedom to invest in the best managers that are well connected and trusted in the venture capital environment.

Hence, our second hypothesis states that there is a positive relationship between the amount of commercialization funds and investments of venture capital.

Hypothesis 2 The higher the amount of university commercialization funds a spinoff company receives, the higher the amount of venture capital financing.

Spinoffs can send a variety of signals to VCs, although not all of these signals are useful. The usefulness of a signal to the receiver depends on the extent to which the signal corresponds with the quality the receiver seeks (i.e., signal fit). Connelly et al. (2011) defined signal fit as the extent to which the signal is linked with an unobservable quality. In our model there is signal fit if university commercialization funds provided through TTOs (i.e., the signal) foster spinoffs' actual sales growth (i.e., the unobservable quality).

According to signaling theory, insiders generally do not send negative signals to outsiders with a view to reducing information asymmetry, but this is often an unintended consequence of the insider's action. Inventors have both positive and negative private information about their companies, and they must decide whether to communicate this information to outsiders. To attract VCs, spinoffs are most likely to communicate positive information in an effort to convey positive organizational attributes. However, since TTOs' assessment considers spinoffs' quality, including positive and negative private information, signal fit is likely to be a factor in our framework.

Furthermore, TTOs' evaluations are not only observable but also costly signals, which guarantees their effectiveness. More specifically, if a signaler does not have the underlying quality associated with the signal but believes the benefits of signaling outweigh the costs of producing the signal, the signaler may be motivated to send a false signal. If this were to happen, misleading signals would proliferate until receivers learned to ignore them. Therefore, to maintain signals' effectiveness, signalers must structure the costs of signals in such a way that deceitful signals do not pay. The cost associated with obtaining university funds is high because the assessment process is time-consuming, and these costs make or false signaling difficult. However, the TTOs' evaluation is less costly for high-quality spinoffs than it is for low-quality ventures because low-quality ventures must implement considerably more change in order to be awarded the funds.

Our reasoning is also in line with other research findings that showed that spinoffs benefit directly from public funding. Lerner (1999) found that SBIR awardees grew more than other matched firms did, and Zhao and Ziedonis (2012) found convincing evidence that R&D awards enhanced the survival of recipient firms from 15 to 25 %. In a dataset of corporate and university spinoffs, Clarysse et al. (2011) discovered that start-up capital had a significant influence on growth only for university spinoffs.

In this sense, signals may increase the underlying quality of the signaler. A startup that is properly funded has more university support and commitment, media visibility, and bargaining power; it is more appealing to and, consequently, has more ability to penetrate the employee market; and it does not have to waste time searching for other funding sources too soon. All these positive effects of the commercialization funds could result in positive financial results.

Hypothesis 3 The university commercialization funds awarded influence positively the spinoff company's sales growth.

3 Methods

3.1 Sample

The dataset analyzed for the purposes of this study consists of 112 spinoff firms established to exploit inventions assigned to U-M between 1999 and 2010. Like many other US universities since the Bayh–Dole legislation, U-M is entitled to commercialize useful inventions developed by faculty staff or students that emerge from any work that makes material use of the university's resources (e.g., laboratory facilities). Despite Michigan's generally poor current economic conditions, U-M is well placed among the top ten North American universities in terms of the number of license agreements and spinoff companies it creates every year (AUTM data). Its spinoffs have a survival rate of 88.6 %, and those created in the last 11 years account for $247 million annually in sales revenues and employ 1,784 people. This sample does not suffer from a survivorship bias because all the spinoffs under U-M licenses were included. One caveat is that it is not a random sample of startups but is restricted to those that chose to go through the U-M TTO's assessment. Academics may create other forms of start-ups (e.g., non-equity-based) to continue their research without the aim of exploiting their research findings economically or decide not to go through TTOs' assessment. While this bias leads to a relatively homogeneous sample of formal startups, it limits the external validity of the results.

The population of spinoff companies was identified from the U-M TTO's database, which collects details on the spinoffs and the gap funds they are granted. Information on the licensed patents was retrieved from the USPTO database. We compared, checked, and integrated the information in the databases using multiple sources: VenturXpert, the Michigan Department of Licensing and Regulatory Affairs (LARA) database, and the Small Business Administration (SBA) TECH-Net database. Data on the spinoffs' sales and number of employees were retrieved from the Orbis database.

The U-M TTO's routine is characterized by a small number of strong ties that feature a high degree of trust and informality (Johansson et al. 2005). When scientists discover a new process, instrument, or material compound, the scientists involved disclose the invention by means of an Invention Report Form to the U-M TTO and to any sponsor partners before its publication. The Invention Report Form, which is protected by a non-disclosure agreement, provides a detailed description of the discovery and suggests the names of companies that might be interested in the invention.

This report prompts an evaluation phase during which the TTO conducts market research to assess the feasibility of protecting the intellectual property and the invention's potential for commercialization vis-à-vis technologies already on the market. The criteria adopted relate to the invention's innovative content and exclusivity, the dimension and growth of the technological field, the amount of investment required, and the timing of the development.

If the invention can be patented and has economic potential, a patent application is developed with the cooperation of patent attorneys and the scientists involved. Then the scientists and the TTO decide whether to license the patent to an established firm or to create an academic spinoff.

Licensing to an existing company is the solution in 90 % of the cases, but a spinoff is usually chosen if there is an opportunity to develop a range of products from the same technology with interesting target markets and the potential for revenues that are capable of sustaining a new company.

A team of specialized consultants and mentors called the Michigan Venture Center supports the spinoff's creation with operational and strategic advice on the legal establishment of the company, preparation of the business plan, and the search for public or private financing opportunities. They also discuss with the inventors the degree to which the inventors are willing to take part in the project in terms of time, commitment, and flexibility. The inventors may perform several roles, from serving as consultants or providing formal scientific support to the advisory board to participating directly in the company's management and ownership. The TTO usually suggests that scientists complement their teams with someone with economic and managerial experience.

We attended a series of meetings concerning a possible future spinoff, from which we grouped the issues discussed into five main categories: business planning (29 % of the time spent), funding (27 %), product development (22 %), academic work (12 %), and company formation (10 %).

In general, the approach taken by the U-M TTO coincides with Degroof and Roberts' (2004) "comprehensive support and selectivity" academic spin-off policy, which requires (1) a proactive opportunity search that stimulates disclosures, (2) highly selective and specific criteria for technology transfer via a spin-off strategy (versus licensing), (3) strong intellectual property rights protection, (4) market research and product development with help from outside consultants to assess start-up feasibility, and (5) support networks with financial partners and discussion with inventors of their possible role in the spinoff.

According to U-M's patent policy, U-M has the right to own any discovery or invention created using university facilities, equipment, or funds it controls or administers.

Once the innovation is on the market, licensing agreements allow new companies to use the invention in exchange for payment of royalties to U-M and reimbursement for patent expenses. When an invention is licensed to industry, the inventors receive royalties based on the university's policies after royalties are received from the licensee.

TTOs that have close relationships with universities can be considered third parties with independence regarding decisions about which inventions have the best commercial promise. In fact, our database reveals that TTOs do not consider all inventions valuable. Funds can also come from a consortium in which other third parties are involved, as we explain in the section about TTO funds (MIIE, MUCI, U-M, and federal funds).

In the following sections, we describe in detail our study variables (see Table 1).

3.2 Dependent variables

Follow-on venture capital funding was measured using both a binary variable, coded as 1 if the spinoff had received any venture support and zero otherwise, and the inverse hyperbolic sine (IHS) transformation of the amount of venture capital obtained by the spinoff in dollars. The spinoffs' economic performance was also measured in terms of the IHS transformation of the sales growth between 2007 and 2010 in dollars:

$$IHS(y_i) = \log\left(y_i + \sqrt{y_i^2 + 1}\right)$$

We computed the IHS transformation because it is an alternative to logarithmic transformation when the distribution of the variables is skewed and some of the variables take on zero or negative values (Burbridge et al. 1988). The marked presence of zero in the venture capital financing and sales growth distributions makes the IHS transformation preferable to the transformation log(y + 1) as a way to avoid altering the regression's beta.

Financing provided by business angels, suppliers or customers, banks, and other third parties (i.e., family and friends) was disregarded.

3.3 Main explanatory independent variable: TTO gap funds

The "TTO gap funds" variable describes the pool of university resources for funding the early commercialization of technologies with strong commercial potential. Projects suitable for gap funding have typically advanced along a commercial path beyond the point

Table 1 Definition of study variables and descriptive statistics

Variable	Description	Mean	SD	Min	Max
Sales growth	Change in sales (in dollars) between 2007 and 2010	1.39 M	4.26 M	0	20.7 M
Firm sales	Spinoff firms' sales in 2010 in dollars	2.90 M	11.8 M	0	38 M
Number of employees	Number of employees in 2010	15.93	39.5	0	285
Firm financed by VC	Dummy = 1 for spin-offs that obtained VC	0.46	0.50	0	1
VC funds	VC obtained by the spin-off in dollars	6.59 M	15.4 M	0	84.0 M
Firm financed by TTO	Dummy = 1 for spin-off firms that received TTO funding	0.66	0.48	0	1
TTO funds	TTO funds obtained by the spinoff in dollars	0.76 M	1.14 M	0	4.75 M
Scientific endowment					
Patent generality	Herfindahl index on technological classes of citing patents	0.32	0.30	0	0.9
Patent originality	Herfindahl index on technological classes of cited patents	0.50	0.28	0	1
Patent scientific base	Measure of the scientific base outside the patent system	0.54	0.35	0	1
Human capital					
Number of founders	Number of founders	2.34	1.23	1	8
Education	Average number of years of founders' university education	8.92	1.79	4	13
Work experience	Average number of years of founders' work experience before the firm was established	17.25	9.01	3	40
Network resources					
Previous experience with VC	Dummy = 1 if one of the founders had relations with VC before the spin-off was established	0.18	0.38	0	1
Previous venture experience	Dummy = 1 if one of the founders had started a business before the spin-off was established	0.39	0.49	0	1
Age and field controls					
Age	Number of years since spin-off was established	5.75	3.36	1	12
Firm founded in 99–01	Dummy = 1 for firms established in 1999, 2000, 2001.	0.21	0.41	0	1
Firm founded in 02–04	Dummy = 1 for firms established in 2002, 2003, 2004	0.23	0.42	0	1
Firm founded in 05–07	Dummy = 1 for firms established in 2005, 2006, 2007	0.21	0.41	0	1
Firm founded in 08–10	Dummy = 1 for firms established in 2008, 2009, 2010	0.35	0.48	0	1
Medical sector	Dummy = 1 for firms classified as 283—"drugs" and 384—"surgical, medical, and dental instruments and supplies" according to the US SIC Code	0.22	0.42	0	1

Table 1 continued

Variable	Description	Mean	SD	Min	Max
IT sector	Dummy = 1 for firms classified as 737—"computer programming, data processing, and other computer related" according to the US SIC Code	0.17	0.38	0	1
R&D sector	Dummy = 1 for firms classified as 873—"research, development and testing services" according to the US SIC Code	0.35	0.48	0	1

where traditional research funding sources are appropriate but have yet to reach the point where they are fully commercially viable.

TTO gap funding is measured using both a binary variable, coded 1 if the spinoff has received TTO support and zero otherwise, and by the IHS transformation of the amount of funds obtained by the spinoff in dollars.

Specifically, TTO funds include funds provided by the Michigan Universities Commercialization Initiative (MUCI) and Michigan Initiative for Innovation and Entrepreneurship (MIIE) and matched by U-M; and federal funds, that is, SBIR (Small Business Innovation Research) and STTR (Small Business Technology Transfer) grants, for which the TTO facilitates the application procedure. None of these funds have private investors.

The MUCI is a collaboration designed to complement and enhance the technology transfer in Michigan's academic and research institutions by supporting the commercialization of intellectual property. The MUCI Challenge Fund provides money at the pre-seed-money stage to help institutions test and validate the market demand for a technology. The MIIE is a consortium of all fifteen Michigan public universities, strategically working together to leverage university assets to enhance Michigan's economic competitiveness and stimulate growth. The consortium supports individual universities and encourages regional cooperation among universities, foundations, economic development organizations, government agencies, and private enterprise. Working with a grant from the C.S. Mott Foundation, the MIIE accepts applications to three funds: Technology Commercialization, Industry Engagement, and Talent Retention & Entrepreneurship Education.

Applications to the MUCI and MIIE must come from its member research institutions' TTOs, and the universities have to match the amount of funding requested. In the application, the funds requested must be justified by means of market research, a commercial assessment, proof of concept, translational and user studies, IP enhancement, prototype development or testing, feasibility studies for scale-up, and/or business plan preparation.

The review committee consists of research administrators and tech-transfer experts from various Michigan public universities, as well as representatives from industry and the VCs community, who are asked to assess the competitive advantage of the technology, market need, the commercialization plan, the likelihood of a new product/process within 3–7 years, validation, and applicability.

Other sources of funding for developing a technology, called translation research programs, were not considered in this research.

SBIR and STTR are programs administered by the U.S. Small Business Administration Office of Technology to ensure that small, high-tech, innovative businesses are a significant part of the federal government's research and development efforts. SBIR, a competitive program that encourages small businesses to explore their technological potential, provides them with an incentive to pursue technological commercialization. Following the submission of proposals, agencies grant SBIR awards based on a small business's qualifications, degree of innovation, technical merit, and future market potential. Small businesses that receive awards obtain up to \$100,000 for approximately 6 months to help them explore the technical merit or feasibility of an idea or technology; then, in a second phase, the funds can be increased to \$750,000 to enable the firms to undertake R&D and assess their commercialization potential.

SBIR and STTR funds accounted for 54.02 % of the total commercialization funds in our sample. We consider these funds together with the MUCI and MIIE funds because the meetings we attended indicated that U-M's TTO specialists strongly supported their application procedure.

Spinoffs in our sample received TTO funds from 3 years before the spinoffs were established to 1 year afterward, but most received the funds around a year before the spinoff was created.

3.4 Other explanatory and control variables

Various features of the new ventures affect the likelihood that a spinoff will obtain financing and, therefore, that the signal will be sent to the VCs.

3.4.1 Technology endowment

Technology endowment for spinoff companies is strongly related to the patent(s) licensed from the university. Shane and Stuart (2002) studied the performance of 134 MIT spinoffs from 1980 to 1996 and showed that spinoffs with more effective patents and stronger social ties with third parties were more likely to obtain financing than were those without these characteristics. In other words, the signals that patents send to potential investors may differ based on the patents' features.

Previous work using measures of the degree to which patents are more or less basic has demonstrated the measures' validity as indications of a patent's impact on later innovation in a field (Henderson et al. 1998; Hall and Jaffe 2001). The degree to which a patent is more or less basic refers to its fundamental innovative features, such as its originality, closeness to science, and generality of research outcomes, calculated as suggested by Henderson et al. (1998, 2005):

$$PATENT\ GENERALITY_i = 1 - \sum_{k=1}^{N_i} \left(\frac{NCITED_{ik}}{NCITED_i} \right)^2$$

$$PATENT\ ORIGINALITY_i = 1 - \sum_{k=1}^{N_i} \left(\frac{NCITED_{ik}}{NCITED_i} \right)^2$$

$$PATENT\ SCIENTIFIC\ BASE_i = \frac{NPCITES_i}{NPCITES_i + NCITED_i}$$

where NCITING is the number of patents citing the originating patent, NCITED is the number of patents cited by the originating patent, and NPCITES is the number of non-patent sources cited by the originating patent. These characteristics discriminate effectively between less and more basic innovations.

Generality is high if subsequent patents that cite a patent belong to a wide range of fields, while it is low if most citations are concentrated in just a few fields. Originality is high if a patent cites previous patents in a wide range of fields, while originality is low if a patent cites patents in a narrow set of technologies. The scientific base measures the predominance of scientific sources, over technological ones.

These measures tend to correlate positively with the number of citations made (for originality) or received (for generality): in fact, often-cited patents tend to have higher generality scores, and patents that cite many others usually display more originality because of a tendency to cover more patent classes (Hall and Jaffe 2001).

3.4.2 Human capital

The characteristics of the founding team may impact the strength of the signal the firm sends; they are not necessarily useful for increasing productivity, but they are means by which to communicate otherwise unobservable characteristics. In this sense, the human capital (i.e., the founding team's characteristics and knowledge) can influence VCs' decisions (Colombo and Grilli 2010) and the venture's growth (Shane and Stuart 2002).

The variables are the number of founders in the team that founded the company, their level of university education, and their work experience in the spinoff's field. Our descriptive data report an average of 2.34 founders, with a mean 8.92 years of university education, and a mean work experience of 17.25 years.

3.4.3 Network resources and previous business experience

According to signaling theory, the relationships of young firms with VCs may positively affect the signaling environment (Gulati and Higgins 2003). Mosey and Wright (2007) emphasized that entrepreneurs with experience in starting a firm can count on a broad, profitable network of relationships and have the ability to increase their relational capital to obtain new resources.

Companies founded by individuals with start-up experience may also have an advantage over organizations created by first-time entrepreneurs, as new ventures can use their own experience to signal the financial potential of their companies to outside investors (Busenitz et al. 2005).

We construct two binary variables, the experience of the VCs (*Previous Experience with VC*) and the experience of the business start-up (*Previous Venture Experience*). *Previous Experience with VC* is coded as 1 if at least one member of the founding team had previously had dealings with VCs, and zero otherwise. *Previous Venture Experience* is coded as 1 if the start-up had already launched a new company, and zero otherwise (Knockaert et al. 2010).

3.4.4 Control variables

The age and industry control variables in our models relate to the year in which the spinoff was founded (*Firms founded in* 99–01, *Firms founded in* 02–04, *Firms founded in* 05–07, *Firms founded in* 08–10). The spinoffs in our sample were relatively young, averaging 5.75 years.

We controlled for the industry by using the US SIC Code classifications.

Our entire sample comes from the set of inventions assigned to U-M, which allows us to rely on parsimonious models and to avoid controlling for factors related to the university (e.g., IP protection, incentive system, culture, status, policy, and experience), and external environmental factors (e.g., availability of venture capital, industrial research support, state-level economic growth, government policies) (Rothaermel et al. 2007). The reputation effect—that is, the benefit from being spun off from a credible university, which helps to guarantee the quality of the knowledge-based companies—applies to the whole sample (Di Gregorio and Shane 2003).

3.5 Models

To test our first hypothesis, we construct three logit models because the dependent variable is coded as a dichotomous variable and the cumulative distribution function is similar to a logistic distribution:

$$F(x) = \frac{1}{1 + \exp(-x)}$$

The second hypothesis is tested using tobit models, which are appropriate when the dependent variable y_i of a linear regression equals the latent and unobservable variable y_i* when the latent variable is above zero, and zero otherwise. The zeroes are left-censored observations of the dependent variable:

$$y_i = \begin{cases} y^* & if \quad y^* > 0 \\ 0 & if \quad y^* \leq 0 \end{cases}$$

Tobit models are appropriate for analyzing the sample because the variables are observed only when they acquire a value greater than zero (corresponding to the cases in which VCs have decided to finance the spinoff; see Table 2).

The model cannot be estimated using ordinary least squares (OLS) because of the presence of numerous observations that equal zero (corresponding to all the spinoffs that received no follow-up venture capital funding).

The variance is not homogeneous along the distribution (heteroskedasticity), so we calculated robust standard errors for all the models.

When both the variables relating to the TTO gap fund are included in the logit and tobit models (not reported), the variables are positive but not significant, a result that is probably due to the high correlation (0.96) between them.

To test our third hypothesis, we analyzed the distributions of the growth in sales between the spinoffs that received TTO gap funds and those that did not. We used the Wilcoxon–Mann–Whitney test (a non-parametric test similar to the independent samples *t* test) to compare them, which is appropriate when we cannot assume that the dependent variable is normally distributed.

We set the dependent variable as the change in sales (in dollars) in robust OLS regressions with the IHS transformation of growth in sales between 2007 and 2010. The

Table 2 Number of spinoffs financed or not by VCs or TTOs

	Firm financed by VC		Total
	No	Yes	
Firm financed by TTO			
No	32	7	39
Yes	28	45	73
Total	60	52	112

variance is not homogeneous along the distribution (heteroskedastic), so we calculated robust standard errors for all models.

We performed all statistical calculations with the Stata/IC 12 software package.

4 Analysis and results

The descriptive statistics in Table 1 show that 46 % of the spinoffs received venture capital financing and that follow-on venture capital funds provided a mean of $6.59 million. The high percentage of venture capital-backed firms among U-M's spinoffs already suggests that public funds have an impact in the venture capital financing process, as usually only 2 % of the companies that apply for venture capital financing succeed in obtaining it.

A mean of approximately $760,000 and a median of $252,000 in TTO gap funds were granted to a large proportion of the spinoffs (66 %).

The average sales achieved by the new ventures was $2.90 million, and the average number of employees was 15.93. The mean growth in sales between 2007 and 2010 was $1.39 million; this figure was highly skewed, varying from a loss of $1.73 million to growth of $20 million.

Table 3 shows the correlations between the variables analyzed. The correlations between venture capital investments and the TTO gap funding variables are high and significant (from 0.40 to 0.44), as are the correlations of venture capital investments variables with sales growth (0.23 and 0.27). The TTO gap funding variables are positive but do not correlate significantly with sales growth.

To examine multicollinearity, we calculated the variance inflation factor (VIF), which was between 1.12 and 1.31—that is, below the rule-of-thumb cut-off of 5—so multicollinearity issues do not seem to be cause for concern.

The comparison between the spinoffs that received TTO gap funds and those that did not (Table 4) shows that the two groups were similar in terms of their patents' characteristics and their founders' education and experience. The groups seem to differ in terms of their experience in seeking venture capital funding and starting up businesses, but the differences were not significant using the Wilcoxon–Mann–Whitney test (data not reported).

On the other hand, there is a significant difference in the industries in which the spinoffs operate, as the TTO gap funding policy seemed to give a higher priority to spinoffs in medical fields, while giving less priority to software companies.

Table 5 shows the results of testing our first and second hypotheses. The table shows the results of the logit model for estimating the factors that affect the likelihood of receiving venture capital financing and of the tobit model for estimating the factors that influence the amount of venture capital obtained. We can see that there is little difference between the models: the logit models can be seen as a particular case of the tobit models, as they convey the same information for the part that relates to the zero values of the dependent variable. To test for collinearity violations, we computed VIFs for each variable (not shown), and all were below 1.47.

Among the controls, the dummy related to the years 1999–2001 and the industry dummies are significant, confirming the boom in investments in the first year and the contraction of the deals in the other 2 years.

Among the variables that are related to the patent's features, originality and science have a positive and significant effect, suggesting the importance of the innovation's novelty. In our opinion, the importance of the scientific background in comparison to the importance of

Table 3 Correlations between study variables

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Firm financed by VC	–												
2. VC funds (ihs)	.99**	–											
3. Firm financed by TTO	.42**	.40**	–										
4. TTO funds (ihs)	.44**	.43**	.99**	–									
5. Patent generality	−.10	−.09	.14	.14	–								
6. Patent originality	.11	.14	.05	.08	−.02	–							
7. Patent scientific base	.21*	20*	.03	.05	−.04	−.00	–						
8. Number of founders	.19*	.19*	.18†	.17†	−.03	.11	−.15	–					
9. Education	−.04	−.04	.17	.18†	−.18*	.03	.10	.07	–				
10. Work experience	−.02	.00	.04	.04	.08	.17†	0.11	−.20*	.01	–			
11. Previous experience with VC	.33**	.34**	.15†	.18†	−.10	−.00	.18†	.21*	−.03	−.03	–		
12. Previous venture experience	.18†	.17†	.15	.17†	−.17†	−.00	.16†	.16†	.06	−0.8	.28**	–	
13. Age	.06	.10	.10	.11	.26	−.05	.00	−.15	.01	.32**	−.14	−.16†	–
14. Sales growth	.23*	.27**	.13	.17†	.12	.02	−.04	−.02	.04	.04	.14	−.02	.22*

† $p < 0.10$

* $p < 0.05$

** $p < 0.01$

Table 4 Comparison between spinoffs that did and did not receive TTO gap funding

	Mean	SD	Min	Max
TTO gap fund = 1				
Patent generality	0.33	0.30	0	0.90
Patent originality	0.51	0.27	0	1
Patent scientific base	0.52	0.33	0	1
Number of founders	2.41	1.28	1	8
Education	9.02	1.94	3.67	14
Work experience	17.34	9.35	0	37
Previous experience with VC	0.21	0.41	0	1
Previous venture experience	0.41	0.50	0	1
Age	5.99	3.34	1	12
Medical sector	0.30	0.46	0	1
IT sector	0.10	0.30	0	1
R&D sector	0.35	0.48	0	1
TTO gap fund = 0				
Patent generality	0.31	0.28	0	0.86
Patent originality	0.52	0.26	0	0.91
Patent scientific base	0.51	0.37	0	0.96
Number of founders	2.15	1.04	1	5
Education	8.28	2.43	3.5	13
Work experience	17.37	8.43	3	35.5
Previous experience with VC	0.15	0.31	0	1
Previous venture experience	0.34	0.46	0	1
Age	5.31	3.38	1	12
Medical sector	0.10	0.31	0	1
IT sector	0.33	0.48	0	1
R&D sector	0.34	0.47	0	1

Table 5 Determinants of VCs' decisions to finance spinoffs and the amount of money invested

Variables	Model 1 Logit[a] Firm financed by VC	Model 2 Logit[a] Firm financed by VC	Model 3 Logit[a] Firm financed by VC	Model 4 Tobit VC funds (ihs)	Model 5 Tobit VC funds (ihs)	Model 6 Tobit VC funds (ihs)
Constant				−6.06 (6.03)	−6.66 (6.98)	−7.99 (8.16)
Firm founded in 99–01	0.37** (0.13)	0.37* (0.16)	0.38* (0.16)	12.50** (4.03)	10.46** (3.87)	11.25** (3.87)
Firm founded in 02–04	−0.12 (0.17)	−0.16 (0.17)	−0.15 (0.17)	−1.12 (4.25)	−1.82 (3.93)	−1.24 (3.93)
Firm founded in 05–07	−0.08 (0.15)	−0.07 (0.16)	−0.05 (0.15)	−2.33 (3.79)	−2.90 (3.14)	−2.03 (3.19)
Medical sector	0.29[†] (0.16)	0.23 (0.18)	0.26 (0.18)	6.74[†] (4.02)	3.74 (3.44)	4.41 (3.54)
IT sector	−0.19 (0.15)	−0.02 (0.11)	−0.01 (0.10)	−6.43 (4.94)	−1.76 (4.73)	−1.57 (4.87)

Table 5 continued

Variables	Model 1 Logit[a] Firm financed by VC	Model 2 Logit[a] Firm financed by VC	Model 3 Logit[a] Firm financed by VC	Model 4 Tobit VC funds (ihs)	Model 5 Tobit VC funds (ihs)	Model 6 Tobit VC funds (ihs)
R&D sector	−0.02 (0.13)	−0.05 (0.15)	−0.03 (0.15)	−0.91 (3.76)	−1.17 (3.39)	−0.93 (3.46)
Scientific endowment						
Patent generality	−0.18 (0.20)	−0.34 (0.24)	−0.34 (0.24)	−7.25 (4.94)	−9.03 (4.57)	−8.86 (4.69)
Patent originality	0.45* (0.21)	0.42† (0.21)	0.46* (0.22)	10.46* (3.89)	9.73* (3.86)	10.81* (3.86)
Patent Scientific base	0.31† (0.16)	0.46* (0.20)	0.47* (0.20)	7.62* (3.63)	8.02* (3.75)	8.65* (3.74)
Human capital						
Number of Founders	0.08 (0.06)	0.07 (0.05)	0.07 (0.05)	1.44 (1.16)	0.95 (0.95)	0.98 (0.96)
Education	−0.03 (0.03)	−0.07 (0.04)	−0.07 (0.04)	−0.95 (0.72)	−1.53* (0.71)	−1.53* (0.73)
Work experience	−0.01 (0.01)	−0.01 (0.01)	−0.01 (0.01)	−0.06 (0.06)	−0.10 (0.16)	−0.09 (0.16)
Network resources						
Previous experience with VC	0.34* (0.15)	0.30* (0.15)	0.31* (0.15)	8.70** (3.22)	7.04* (3.00)	7.33* (2.99)
Previous venture experience	0.13 (0.11)	0.13 (0.13)	0.14 (0.13)	2.80 (3.01)	1.33 (2.74)	1.52 (2.77)
Gap funding						
TTO funds (ihs transformation		0.05** (0.01)			1.07** (0.26)	
Firm financed by TTO			0.51** (0.11)			13.12** (3.64)
Wald χ^2	22.20†	42.16**	39.33**			
F				4.55**	8.07**	7.90**
Pseudo R^2	0.24	0.35	0.34	0.07	0.11	0.11
Observations	112	112	112	112	112	112

Robust standard errors are in brackets

† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

[a] Marginal effect coefficients are shown

references to other patents has to do with the university environment, where star scientists tend to publish rather than patent their findings and, consequently, to refer to their own and their peers' scientific articles. Baum and Silverman (2004) also mentioned the importance of patenting activities in prompting more funding from sources of venture capital.

Human capital does not seem to influence the VCs' decisions; we even found a significant negative effect in models 5 and 6, a result similar to that reported by Colombo and Grilli (2010). These results could be explained by the homogeneity of the human capital in spinoffs, as 75 % of the spinoffs' founders in our sample had more than a mean 8 years of university education and 10 years of work experience. In discussing the "average" human capital of a spinoff, Chiesa and Piccaluga (2000) also made the point that most academic spinoffs are founded by groups of scientists that are highly homogeneous in terms of human capital.

The significant positive impact of founders' having experience in dealing with VCs underscores the importance of the founders' network capital in obtaining the VCs' trust. Having prior experience with a start-up also had a positive, but statistically not significant, effect. The results are not surprising, as Hsu (2004) identified social ties with VCs as an important precursor to the attainment of organizational resources and subsequent performance.

The models support our first and second hypotheses, which propose that TTO gap funds have a positive effect on the chances that a spinoff will receive venture capital financing and on the amount of venture capital funding received. In fact, the coefficients of both the binary variable that relates to the TTO funds and the amount received from the TTO are positive and significant for the likelihood of receiving venture capital financing (respectively, model 2: $\beta = 0.05$, $p < 0.00$; model 3: $\beta = 0.51$, $p < 0.00$) and the amounts invested by VCs (respectively, model 5: $\beta = 1.07$, $p < 0.00$; model 6: $\beta = 13.12$, $p < 0.00$) after controlling for the spinoff's technology, the founders' human capital, and their networking resources.

Tables 6 and 7 show the results of testing for our third hypothesis. First, we compare the TTO gap-funded spinoffs with those that received no financial support from the university. Table 6 shows that the mean sales growth from the end of 2007 to the end of 2010 was higher for the spinoffs that received TTO gap funds ($1.73 vs. $0.77 million). The distribution is highly skewed: for instance, among the spinoffs that were granted funding, only about one in five of the observations were above the mean level of sales growth. This skewness has to do with the financial and operating performance of other small firms, such as VCs' portfolio companies. At each reported percentile, the change in sales is more

Table 6 Comparison of sales growth between spinoffs that did and those that did not receive TTO gap funds

	TTO gap fund = 1	TTO gap fund = 0	*p* value from comparison
Mean	1.73	0.77	
90th percentile	3.06	1.80	
75th percentile	1.45	0.54	
Median	0.36	0.08	
25th percentile	0.13	0	
10th percentile	0.05	−0.02	
Wilcoxon–Mann–Whitney p value			0.001
No. of observations	73	39	
Sub-sample of spinoffs that did not receive VC financing			
Mean	0.46	0.18	
90th percentile	1.61	0.50	
75th percentile	0.60	0.12	
Median	0.24	0.05	
25th percentile	0.10	0	
10th percentile	−0.02	−0.03	
Wilcoxon–Mann–Whitney p value			0.001
No. of observations	28	32	

Table 7 Determinants of spinoff firms' sales growth

Variables	Model 1 OLS Sales Growth (ihs)	Model 2 OLS Sales Growth (ihs)	Model 3 OLS Sales Growth (ihs)	Model 4 OLS Sales Growth (ihs)	Model 5 OLS Sales Growth (ihs)	Model 6 OLS Sales Growth (ihs)
Constant	7.51 (2.09)	4.36 (3.57)	3.87 (4.34)	2.93 (4.34)	4.15 (4.32)	3.26 (4.49)
Firm founded in 99–01	1.75 (1.60)	1.41 (1.64)	0.40 (1.05)	−0.55 (1.48)	0.27 (1.52)	−0.84 (1.46)
Firm founded in 02–04	1.05 (1.76)	0.79 (1.78)	−0.11 (1.16)	0.71 (1.56)	−0.16 (1.67)	0.50 (1.57)
Firm founded in 05–07	−3.85 (2.43)	−4.08 (2.46)	$-4.38^{\dagger}$ (2.40)	$-4.03^{\dagger}$ (2.36)	$-4.51^{\dagger}$ (2.40)	$-4.17^{\dagger}$ (2.37)
Medical sector	4.85* (2.37)	$4.46^{\dagger}$ (2.61)	3.40 (2.47)	2.65 (2.24)	3.17 (2.43)	2.44 (2.22)
IT sector	$4.58^{\dagger}$ (2.36)	$4.49^{\dagger}$ (2.27)	5.42* (2.50)	5.63* (2.38)	5.45* (2.46)	5.61* (2.35)
R&D sector	$4.09^{\dagger}$ (2.22)	$3.86^{\dagger}$ (2.26)	$3.88^{\dagger}$ (2.15)	$3.72^{\dagger}$ (1.98)	$3.76^{\dagger}$ (2.14)	$3.56^{\dagger}$ (1.98)
Scientific endowment						
Patent generality		0.24 (0.57)	0.11 (0.66)	−0.08 (0.61)	0.07 (0.65)	−0.10 (0.61)
Patent originality		−0.03 (0.28)	−0.10 (0.27)	−0.06 (0.28)	−0.10 (0.30)	−0.06 (0.28)
Patent scientific base		$0.13^{\dagger}$ (0.07)	$0.13^{\dagger}$ (0.07)	$0.12^{\dagger}$ (0.06)	$0.12^{\dagger}$ (0.06)	$0.11^{\dagger}$ (0.06)
Human capital						
Number of founders		$2.90^{\dagger}$ (1.69)	$2.90^{\dagger}$ (1.71)	1.36 (1.79)	$2.80^{\dagger}$ (1.68)	1.26 (1.73)
Education		−0.18 (1.52)	−0.20 (1.48)	−0.82 (1.44)	−0.30 (1.47)	−0.79 (1.42)
Funding						
Firm founded by TTO			3.87* (1.77)	2.55 (1.70)		
Firm founded by VC				4.75** (1.36)		
TTO funds (ihs)					0.30* (0.12)	$0.20^{\dagger}$ (0.11)
VC funds (ihs)						0.28** (0.08)
F	$2.00^{\dagger}$	1.54	2.25*	2.62**	2.34*	2.73**
R^2	0.13	0.17	0.22	0.29	0.23	0.29
Observations	112	112	112	112	112	112

Robust standard errors are in brackets

† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

positive for the spinoffs funded by the TTO, and the differences are consistent throughout the distribution. We tested the equivalence of the distributions using the Wilcoxon–Mann–Whitney test and rejected the null hypothesis for the equality of the distributions.

To avoid the risk of the results' being driven by venture capital investments and not the impact of TTO gap funding, we examined only the subsample of spinoffs that did not receive other investments. Here again, for each percentile, the change in sales was more positive for the spinoffs funded by the TTO, and the differences are consistent along all of the distribution. The distributions still differ significantly, as confirmed by the Wilcoxon–Mann–Whitney test, but they are less skewed in this case.

Table 7 shows the results of OLS models that estimate the factors that affect the spinoffs' sales growth. The baseline models (models 1 and 2) show an influence of the founders' work experience and connections with the network of VCs.

The full models (models 4 and 6) have an R^2 of 0.29; they differ statistically from 0, and the coefficients that are significant relate to the software ($\beta = +5.63$, $p = 0.020$), research industries ($\beta = +3.56$ $p = 0.064$), and the founders' work experience ($\beta = +0.12$, $p = 0.098$). Having experience with the venture capital industry loses its significance in the full models only because of an interaction with the venture capital investments' binary variable.

The complete model (model 4) does not support our hypothesis that TTO gap funds have a direct influence on a spinoff's performance, irrespective of any venture capital financing. Model 6 provides some support to the impact of the university's TTO on sales growth, but the influence of TTO gap funds is significant only when the variables that relate to venture capital investments are not entered in the models (models 3 and 5).

This interaction suggests a possible indirect effect of the TTO gap fund on spinoffs' sales, mediated by follow-on venture capital funding.

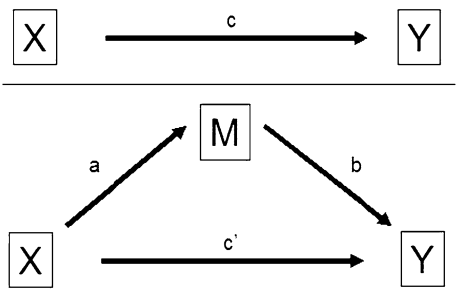
To test the possible mediating effect of TTO gap funding, we adopted Baron and Kenny's (1986) view that

> a variable functions as a mediator when it meets the following conditions: (a) variations in levels of the independent variable significantly account for variations in the presumed mediator [i.e., Path a], (b) variations in the mediator significantly account for variations in the dependent variable [i.e., Path b], and (c) when Paths a and b are controlled, a previously significant relations between the independent and dependent variables is no longer significant, with the strongest demonstration of mediation occurring when Path c is zero. (Baron and Kenny 1986: 1176)

Paths *a*, *b*, and *c* are tested and estimated by three regressions (see Figs. 1, 2), Eqs. 1, 2, and 3:

$$\mathrm{M} = i_1 + a\mathrm{X} + e_1 \tag{1}$$

Fig. 1 Baron and Kenny's (1986) mediation



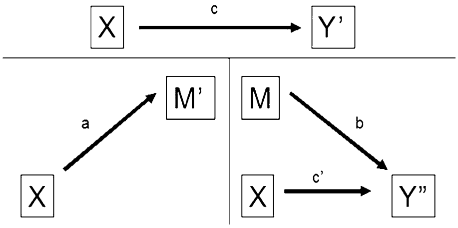


Fig. 2 Baron and Kenny's (1986) mediation test with the mediator being a dichotomous variable

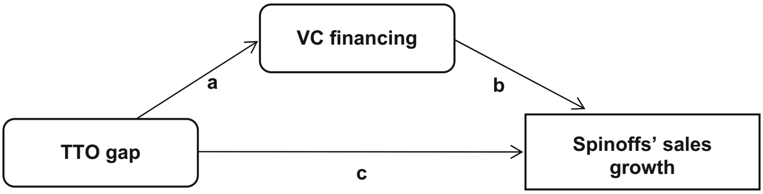


Fig. 3 Model of the relationship between TTO gap funding and spinoffs' sales growth. *Path a* TTO gap funding increases the likelihood of obtaining VC financing. *Path a* + *b* TTO gap funding has an indirect positive effect on spinoffs' performance, through its impact on VC investments. *Path b* TTO gap funding has a direct positive effect on spinoffs' performance

$$\mathrm{Y} = i_2 + c\mathrm{X} + e_2 \tag{2}$$

$$\mathrm{Y} = i_3 + c'\mathrm{X} + b\mathrm{M} + e_3 \tag{3}$$

One way to test the indirect effect is the Sobel test (Sobel 1982), that is, dividing ab by the variance $b^2s_a^2 + a^2s_b^2$ and treating the ratio as a t test. The variance of the test for the binary mediator variable is given using Kenny's (2008) approach. However, if the mediator is a dichotomous variable (Preacher and Hayes 2004), the indirect effect of the degree of mediation must be computed because the coefficients must be transformed.

Four steps are taken to verify the presence of mediation: (1) Model 3 in Table 7 corresponds to Eq. 2 and shows that the TTO gap fund variable is significant ($\beta = +3.87$, $p = 0.029$) when the venture capital variable is absent; (2) We use Eq. 1, which refers to Model 3 in Table 4, to show that the TTO gap fund coefficient has a significant positive influence on the likelihood that a spinoff will receive venture capital financing ($\beta = +0.045$ $p = 0.000$); (3) Model 4 in Table 7 corresponds to Eq. 3 and shows that, in the full model, venture capital financing is the main variable that determines the spinoffs' sales growth, a result that is consistent with many studies that demonstrate the important influence of venture capital financing on the potential growth of new ventures; and (4) TTO gap funding is not significant in model 4 ($\beta = +2.55$ $p = 0.135$).

If either the mediator or the outcome was a dichotomy, the analysis would probably be conducted using logistic regression. The amount of mediation is called the indirect effect, and when added to the direct effect gives the total effect:

$$\text{Total effect} = \text{direct effect} + \text{indirect effect}$$

The effects of the binary mediation are total effect = 0.36, direct effect = 0.24, and indirect effect = 0.12 (also see Fig. 3).

Table 8 Sales growth for spinoffs that received TTO gap funding and VC investments, TTO gap funding alone, or no funding

	TTO gap fund = 1 VC = 1	TTO gap fund = 1 VC = 0	TTO gap fund = 0 VC = 0
Mean	3.38	0.46	0.18
90th percentile	6.40	1.61	0.50
75th percentile	2.14	0.60	0.12
Median	0.49	0.24	0.05
25th percentile	0.17	0.10	0
10th percentile	0.10	−0.02	−0.03
No. of observations	42	28	32

The powerful interaction between TTO gap funding and venture capital investments on spinoffs' sales growth is also apparent from Table 8, where a clear difference emerges among the three groups of spinoffs, supporting the hypothesis that TTO gap funding has a moderate effect and venture capital investments have a strong effect on sales growth.

5 Discussion

As our analysis and results show, the first hypothesis, that gap funding signals a new firm's quality, is supported, suggesting that VCs assume that spinoffs that are awarded commercialization funds by TTOs are the best companies to finance. This finding points to a benefit of public financial support that goes beyond the immediate generation of returns to cover the cost of investment.

The literature has shown that signals may also be unintentional (Janney and Folta 2003). In our case, spinoffs may choose to be evaluated by TTOs in order to receive immediate funds, without the specific aim of attracting VCs. TTOs are more proximal to spinoffs than VCs are, and they arguably act on behalf of the signalers by sending signals to VCs.

The rationale behind this idea lies in the fact that university TTOs suffer from less information asymmetry than VCs do because of TTOs' closer relationship with the scientists and university departments, based on a network of informal relationships. In fact, Johansson et al. (2005) demonstrated that the networks of relationships between spinoffs and universities rely on a few strong, informal links that are characterized by a high degree of trust.

It is reasonable to assume that, when a TTO's financial promotions follow a selection and assessment process, the fact that the TTO provides gap funds and the amount of gap funding it provides to a given invention can play fundamental roles in letting VCs know which spinoffs are good quality. By removing the difficulties involved in funding proof of concept and prototype development, the TTO can effectively close the funding gap between basic research and private sector investments.

In other words, this study adds to the literature on signaling theory by showing that, when intentional and unintentional signals that are sent by another credible party (e.g., the TTOs), the other credible part substitutes in the signaler role.

Our results also support the second hypothesis, that there is a positive interaction between the amount of commercialization funds and venture capital investments, and our third hypothesis concerning sales growth. These results suggest that better performance could be justified, not just by the availability of TTO gap funds alone, but also by the university's commercialization funds' indirect positive effect on the spinoff companies' performance, mediated by the venture capital financing.

The signal TTOs send may vary in strength and be effective not only because it is observable. Visibility is a necessary but not sufficient characteristic of a signal; signal cost is the second characteristic of efficacious signals (e.g., Bird and Smith 2005). The notion of cost in a signaling situation involves the fact that some signalers are in a better position than others to absorb the associated costs. The costs associated with obtaining public funds are high because the assessment process is time-consuming, and these costs make cheating, or false signaling, difficult. However, this assessment is less costly for a high-quality new venture than it is for a low-quality company because a low-quality company will be required to work considerably harder to be awarded the funds. The need for false signaling is also mitigated by the limited information asymmetry between TTOs and spinoffs.

Therefore, the effectiveness of a TTO signal is maintained not only because the costs of the signal is structured in such a way that dishonest signals do not pay, but also because TTOs are in the position to have real information about a spinoff's potential growth. Private investors are more likely to make the right investment decision following these signals than otherwise.

Private investors' decision to syndicate with TTOs could also be explained by other factors such as an interest in collaborating and networking with TTO. The present research does not distinguish the effect of the signal from other factors, although we believe that the limited information available to VCs and their interest in profit constrain all these kinds of complementary effects, making the signaling model the most reasonable.

Over the past 30 years, there has been a growing interest in academic entrepreneurship, which has become an accepted method for exploiting valuable scientific discoveries. Since the Bayh–Dole legislation came into effect, the universities' independence has enabled them to set up TTOs with various systems, personnel, and mechanisms for technology transfer. TTOs play an important role as "bridging institutions" between universities and industry and investors by creating a common knowledge base and a shared language that strengthens the links between these different worlds to exploit the innovation created by scientific research.

Although universities have attempted to commercialize their research, their TTOs soon realized that early-stage venture markets are inefficient and that most university innovation is too risky for investors, so there was a large feasibility and funding gap to fill. The growing separation between VCs, whose business model requires that they invest large amounts, and a sizable number of spinoffs that only need about $200,000 to prove their concepts accentuates the problem. Consequently, we have seen various forms of public support for spinoff companies that compensate for this funding gap, including public venture funds, commercialization grant programs, and seed-capital funds with the participation of governments, universities, and foundations.

Public efforts to improve spinoff firms' chances of success are justified by the conviction that spinoffs generate positive externalities: investments in companies that develop sophisticated technologies and research-derived products have been shown to have positive spillovers that benefit other firms and society as a whole, while firms that make the first investments are unlikely to capture all of the surplus.

The role of US VCs in fostering innovative firms has been well documented (Hellmann 2000), and there is now a broad consensus among economists, business leaders, and policymakers that a vibrant venture capital industry is a cornerstone of America's leadership in the commercialization of technological innovation. Although VCs are supposed to invest more in young, risky companies than in private equity funds, they rarely decide to finance very-early-stage seed investments, preferring instead to join the new venture in the first round of financing.

A properly managed TTO gap fund may not suffice to ensure the consistent economic performance of the spinoffs it supports, but it substantially improves the spinoff's position on the investment markets through its certification role. Therefore, it could have a significant influence on which spinoffs become successful and which merely survive and never become profitable.

Furthermore, the data on sales growth are also of interest because they illustrate a dynamic industrial segment that has been developing and increasing its sales even in times of economic crisis, such as during the 2007–2010 financial crisis in the US.

While we referred to some European research, contextual differences may matter in the model we proposed. These contextual differences could be related to various economic and organizational features. First, public funds in Europe are generally scarcer than in the US, so the assessment process must be highly selective making the TTOs' role more important than it is in the US. However, for the same reason, European TTOs could be less effective in Europe than they are in the US, as European TTOs can provide limited amounts of funds to start-ups. Therefore, TTOs' signal strength and effectiveness might be conditioned by such contextual factors. This scarcity of funds is reflected also in the VCs attitude toward risks. Indeed, European VCs may tend to be more conservative and risk adverse than the American ones.

Second, the academic system in Europe tends to orient research toward academic publishing rather than patenting. Whoever requests a patent usually has an idea about future market applications, making the assessment phase easier for the TTO in the US than it is in Europe and positively affecting the spin-offs' future market potential.

Finally, the organization of the TTOs may differ in these two environments. For instance, the American TTOs usually employ staff with experience in industry who has considerable flexibility in managing budgets. Taken together these factors might favor VCs' investment decisions.

All of these issues could be useful avenues for future research work, because this would show how our signaling model changes according to contextual differences.

We recognize that our results are preliminary and that the main limitation of our study lies in the small size and specific features of our sample. We acknowledge that we cannot generalize from findings obtained from a sample of only the spinoffs created by a single university. On the other hand, considering only one university enabled us to use parsimonious models, fixing the factors that relate to the external environment (industry support, propensity for entrepreneurship, availability of venture capital) and those that relate to the TTO (culture, resources, experience of the personnel). Another limitation is that our analysis did not attempt to assess other social benefits of the "gap funding" program, as this analysis focused exclusively on private returns measured as the spinoff firms' sales growth. We hope that future studies will contribute to establishing a better definition of the signaling role TTOs have in a variety of contextual conditions.

6 Conclusions

Using the database of all spinoff companies related to U-M from 1999 to 2010, this study focused on the signaling role that TTOs assume in the field of academic entrepreneurship. In particular, we show that TTOs send signals to VCs by providing spinoffs with public funds. When a spinoff decides to be assessed by the TTOs in order to be granted funds, the

TTO's action has a major impact on attracting private VCs and critically influences the company's growth prospects. In this sense, we contribute both to the literature about signaling theory and to practical issues.

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