

SHOW ME THE RIGHT STUFF: SIGNALS FOR HIGH-TECH STARTUPS

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We present a theoretical model of startup signaling with multiple signals and potential differences in external investor preferences. For a novel sample of technology incubator startups, we empirically examine the use of patents and founder, friends, and family (FFF) money as such signals, finding that they are jointly endogenous to venture capital and business angel investment in the startups. For this sample, venture capitalists appear to value patents more highly than FFF money, while the reverse is true for business angels. Moreover, the impact of patents on venture capitalists is larger than the impact of FFF money on business angels.

1. INTRODUCTION

One of the most important challenges facing entrepreneurs in technology startups is access to capital (Denis, 2004; Shane and Stuart, 2002). With little or no observable history of performance and uncertain technology, a major issue for these entrepreneurs is how to signal their company's value to potential investors. One such signal is an entrepreneur's own investment (Leland and Pyle, 1976). For technology startups, patents are also a potential signal. Indeed, the Berkeley Patent Survey finds that one of the most important reasons for startups to patent is to secure funds (Graham and Sichelman, 2008; Graham et al., 2009).¹ There is also empirical evidence that alliances (Stuart et al., 1999;

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1. On average, "improving chances of obtaining financing" ranked second in importance among the seven reasons considered. Startups in the software sector also rated "enhancing the firm's reputation" more highly

Hsu, 2004), Nobel laureates as advisors (Higgins et al., 2011), and founder attributes (Burton et al., 2002) as well as patents (Hsu and Ziedonis, 2008, 2011; Haeussler et al., 2009) are correlated with startup value, suggesting they could serve as signals.

With multiple such mechanisms, how should managers choose signals? We address this topic in the context of two signals, patents and investment of founders, friends, and family (FFF) funds. We provide theoretical and empirical results on investment in these signals as a function of the cost of signaling and investor preferences. The theoretical model considers a situation of asymmetric information in which the founders of a startup have private information about the technology underlying their business. The value of the startup is a function of the probability of success of the technology, but also the founders' commitment. In seeking external investment, the founders consider using patents as a signal of the probability of success and FFF money as a signal of their commitment. In our model, both signals have other uses as well, and so they are productive signals in the sense of Spence (1974). The theory also incorporates the observation that different classes of investors (i.e., business angel and venture capitalists) vary in the extent to which they value startup characteristics (Osnabrugge and Robinson, 2000; Graham et al., 2009). Investor preferences are known to the founders when they choose their investment. Thus optimal investment is a function of both cost, which is well documented as important (Amit et al., 1990) and investor preferences. We then examine our predictions in the context of technology startups incubated in the Advanced Technology Development Center (ATDC) from 1998–2008.

We provide conditions under which it is worthwhile for startup founders whose technologies have a high probability of success to signal their company's "quality," and we characterize the investment in patents relative to FFF money in terms of their cost and investor preferences. Independent of investor preferences, founders of these startups (high-quality startups hereafter) optimally invest more in patents and FFF money than they should in a situation of symmetric information. However, when a potential investor places more weight on the quality of the technology than founder commitment, high-quality startups should invest more in patents than FFF money relative to the symmetric information case. Conversely, when a potential investor values founder commitment more highly, the startup should invest relatively more in FFF money. Finally, when the potential investor is indifferent between the two attributes, the signal ratio is inversely proportional to the ratio of their costs. Thus, what distinguishes our model from prior models of multiple signals (Milgrom and Roberts, 1986; Engers, 1987; Grinblatt and Hwang, 1989) is that the investment in the signals, in equilibrium, depends on the preferences of the external investors.

Empirically, we consider the impact of patents filed and FFF money on venture capitalist and business angel investments, respectively. To this scope we use novel data which builds on the startup database examined by Rothaermel and Thursby in their analysis of university ties and incubator startup performance (2005a, 2005b). These data include information on the investment of business angels and venture capitalists, the amount of FFF money invested in the firm, and the number of patents filed, which we augmented with information from the startup business plans and a survey of the founders.

Our empirical estimation addresses whether patents and FFF money are endogenously determined variables with regard to startup financing. Understanding this is

than firms in other sectors. Thus the authors interpret signaling as a primary reason for software patenting (Graham and Sichelman 2008, p. 161).

important since otherwise patents and FFF money are simply attributes correlated with the value of a startup because of their productive value to the firm. In that case, they might be strategic choices with regard to output competition or other goals, but they would not be endogenous to the financing problem. One of our major findings is that, for this sample of firms, patents and FFF money are jointly endogenous to venture capital investment and business angel investment.

Accordingly, we estimate two structural equation models, one for each type of investor, which take this endogeneity into account. Having taken into account the costs of investing in the signals, the number of patents filed by a startup has a large, statistically significant effect on venture capitalist investment while FFF money is not statistically significant. In light of our theory, this suggests that venture capitalists care more about the quality of the technology of startups than founder commitment. In the case of business angels we find that FFF money has a positive statistically significant impact on investment while patents filed does not. Moreover, we find that the impact of patents on venture capitalists is stronger than the impact of FFF money on business angels: a 1% increase in the number of patents filed increases the likelihood of venture capital financing by 46%, while a 1% increase in FFF money increases the likelihood of business angel financing by 5%.

Both the theory and empirics contribute to the literature on entrepreneurial finance (see, for instance, Leland and Pyle, 1976; Grinblatt and Hwang, 1989; Denis, 2004; Shane and Stuart, 2002; Kaplan and Per Strömberg, 2004; Cumming, 2008; and Cumming and Johan, 2008), which with the exception of seminal work by Leland and Pyle (1976) and later that of Grinblatt and Hwang (1989), has abstracted from signaling choices by startup founders. While informational issues and quality variation among startups is well documented, much of the emphasis has been on the value added that venture capitalists provide in terms of selecting better quality startups in addition to their role in providing funds, advice, and contacts (Sahlman, 1990; Stuart et al., 1999; Hellmann and Puri, 2002; Hsu, 2004; Bottazzi, Da Rin and Hellmann, 2008). While Hsu (2004) shows that startups are willing to pay a price for venture capitalist certification in the form of equity discounts, he does not examine the startup's decision to invest in signals, *per se*.

More recently, Hsu and Ziedonis (2008, 2011) and Haeussler et al. (2009) have examined the relation between patents and firm valuation. Hsu and Ziedonis (2008, 2011) use a sample of US semiconductor firms and find that the greater the number of patents filed, the higher the pre-money valuation by venture capitalists. They interpret this result in terms of signaling since the effect of patents is greater in early financing rounds, as one would expect if patents worked as a signal. Haeussler et al. (2009) find similar results for a sample of German and British biotechnology companies. In their study, patent oppositions increase the likelihood of receiving venture capital, but ultimate grant decisions do not, presumably because they are anticipated. However, neither study examines patents as a costly signal nor accounts for the endogeneity of the signal.

We contribute to this literature in two ways—we endogenize the signaling decision and consider multiple signals. Our study is also one of the few to consider business angel investment. Kerr et al. (2010) is a notable exception which uses a regression discontinuity approach and finds a positive impact of business angel funding on startup survival and growth. Goldfarb et al. (2009) examines business angel and venture capitalist data to examine the relation between control rights and investor composition, finding that business angels exert weaker control rights. DeGennaro (2012) estimates expected returns on business angel investment and find that Angel investors earn similar returns to

those earned by venture capitalists. Wong (2010) provides an agency model of funding in which business angels force the founders to hold a large stake in the firm to ensure the alignment of their interests with the firm. None of this work, however, examines startup decisions regarding signals.

2. SET-UP OF THE MODEL

We build a simple model in which the founders of a startup company have private information about the probability of success of a technology as well as their own commitment to developing it. Potential investors observe these startup attributes only with noise. As in Leland and Pyle (1976), the asymmetry of information gives the founders an incentive to signal the company's type to potential investors, who for our purposes exclude friends and family members. We shall define the startup's type by whether its technology has a high or low probability of success.

We consider two potential signals which convey information about the quality of a company: number of patents filed and founders, friends, and family money (hereafter "FFF money"). Patents reveal information on the quality of the firm's underlying technology, while FFF money reflects the founders' commitment to the startup. The model differs from other models with multiple signals (see for example Grinblatt and Hwang, 1989; and Milgrom and Roberts, 1986) by our inclusion of the preferences of external investors, which, in equilibrium, affect the founders' investment in the signals.

In line with the existing literature on family finance (Parker, 2009; Casson, 2003), our model assumes that family members and friends have private information about a startup given their proximity to the founders. Thus their investment can be used as a signal for external investors, who do not have private information on the startup's type. While we do not expect family members and friends to be informed about the technology, they are likely to have information about founder attributes, such as dedication, which affect the startup's value.

As in the case of signaling with productive education (Spence 1974), the number of patents filed and FFF money directly affect the value of a startup. In the case of patents, the Berkeley Patent Survey examined six reasons, in addition to attracting financing, for startups to patent their inventions (see, Graham and Sichelman, 2008, p. 154). In general, patents generate value for firms by excluding competitors from practicing their inventions, facilitating licensing to interested parties or by increasing the startup's bargaining position in negotiations with other patent holders or established firms with complementary assets (Cohen et al., 2000; Arora and Ceccagnoli, 2006; and Gans et al., 2002). The role of FFF money is threefold. In addition to signaling founder commitment, it generates value by increasing the startup's bargaining position in negotiations with other potential investors. Finally, it is a source of capital which complements the funds provided by other investors (Agrawal et al., 2011; Parker, 2009; Cumming and Johan, 2009).

2.1 BASIC ASSUMPTIONS

The game is played in three periods. In the first period, Nature chooses each startup's type, H or L , depending on whether its underlying technology has a high or low probability of success, respectively, θ_H or θ_L , with $\theta_H > \theta_L$. Each type of startup generates a value, $V(p, M; \theta)$, which depends on the founders' investment in patents, p , the

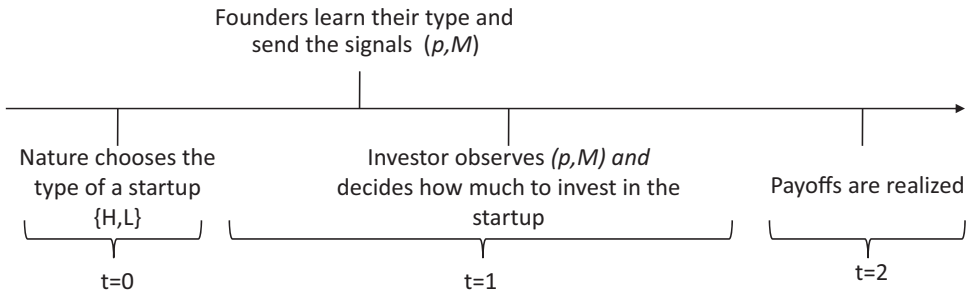


FIGURE 1. TIME LINE

investment by the founders, their friends and families in the startup, M , given the probability of success, θ , of the underlying technology. As discussed above, patents and FFF money are “productive” in the sense that they are inputs to a startup’s value function. A startup with a high probability of success θ_H generates a greater value for any given p and M , thus $V_\theta(p, M; \theta) > 0$. In addition to contributing to the value of a startup, the investments in p and in M convey information about the quality of the technology and the founders’ commitment to the technology, respectively. We assume that $V(p, M; \theta)$ is an increasing strictly concave function of p and M . For each value of p and M , the derivatives of $V(p, M; \theta)$ with respect to these signals are the same and do not vary across types. Moreover, p and M are complements in the realization of $V(p, M; \theta)$, thus, $V_{Mp}(p, M; \theta) > 0$, where $V_{Mp}(\cdot)$ is a cross-partial derivative.

In the second period, the founders learn their type and choose the amounts p and M to send as signals, incurring a cost $c(p, M; \theta)$, which we assume is an additive function of the costs of patents and FFF money, $r(p)$ and $q(M)$, respectively. Importantly, $r(p)$ is the opportunity cost of the effort necessary to develop a patentable invention. This definition of cost is not only more reflective of the true cost of patenting, but also for a patent to provide a signal in the economic sense, it must be more costly for L-type founders than for H-type founders. Indeed, the fee to file for a patent does not depend on startup type, but the opportunity cost does. Hence, we assume that for H-type founders $r(p)$ is a linear function of the investment in patents, $b_H \times p$, where $b_H > 0$ is the marginal cost of effort, while for L-type founders, $r(p)$ is $k \times b_H \times p$, with $k > 1$. This specification ensures that both the total and marginal costs of making a patentable invention are higher for L- than for H-type founders.

There are two components of $q(M)$. The first, ρM , with $\rho > 0$, is the opportunity cost of investing M in a startup, which we assume is the same for both type of founders. Thus, ρM can be viewed as the forgone returns from investing M in projects other than the startup. The second is the risk premium required for each dollar of FFF money obtained. Our assumption is that friends and family have private information about the startup type. Thus, we represent the premium as zero for a high-quality startup and $g_L > 0$ for a low-quality startup.

Based on the amount of each signal observed, an investor decides an amount to invest in the startup. We assume there are at least two investors potentially interested in financing the startup, but that only one eventually makes the investment. Finally, in the third period, the value of the startup is realized and both the founders and the investor receive their payoffs. All players are risk neutral and have a unitary discount rate.

Investor's j utility is equal to $\alpha V(p, M; \theta) - F$, where $\alpha \in (0, 1)$ is the fraction of equity retained by investor j and F is the amount paid to the founders for retaining α . Because there are at least two investors potentially interested in financing the startup, F is equal to $\alpha V^j(p, M; \theta)$, where V^j is investor j 's expectation of the value of a startup with productivity θ and it coincides with that of the other potential investors.

Founder utility is a function of wealth in $t = 1$ and in $t = 2$, net of the costs of investing in M and in p^2 :

$$U_i = W_1(p, M; \theta) + W_2(p, M; \theta) - c(p, M; \theta).$$

Wealth in $t = 1$ is equal to:

$$W_1(p, M; \theta) = \alpha V^j(p, M; \theta) + M.$$

$M \geq \underline{M} \geq 0$, is FFF investment in the startup, which is at least equal to a minimum amount \underline{M} required to start the business. $W_1(p, M; \theta)$ is the sum of the amount received by the founders from external investors, after selling a portion α of their equity, and the amount M lent by friends and families or diverted by the founders to the startup, from alternative uses. W_1 is used to finance part of the venture, including the fees required to file a patent.

The founders' expected wealth in $t = 2$ is equal to:

$$W_2(p, M; \theta) = (1 - \alpha)V(p, M; \theta) - M.$$

That is $W_2(p, M; \theta)$ is the return to equity, after the value of the startup is realized, net of the debt repayment to friends, families and to the founders themselves, who can now reassign to alternative uses the amount they had initially subtracted.

3. SOLUTION OF THE GAME

We are interested in a separating equilibrium of this game. In order to find such an equilibrium, we need to define the system of beliefs and strategies of a potential investor. We allow the system of beliefs to depend on an investor's preferences over two startup attributes: the quality of a technology being commercialized and the commitment of the founders. We assume that investor preferences are known by the founders. In this setting, if an investor values the quality of a technology more highly than founder commitment, she will believe that the founders are type H if the ratio of patent investment to FFF money is greater or equal than k , with $k > 0$. The reverse occurs, if an investor values founder commitment. Then, the investor will believe that the founders are type H if $p/M < k$. If the external investor is indifferent between the two aspects of a startup, then she will believe that the founders are type H either if $p/M \geq k$ or if $p/M < k$.

The corresponding investor's strategy will be to invest an amount $\alpha V^j(M_H^*, p_H^*; \theta_H)$ if she believes that the founders are type H and an amount $\alpha V^j(M_L^*, p_L^*; \theta_L)$ otherwise. M_H^* and p_H^* are the amounts that solve H-type founders' constrained maximization problem. Similarly, M_L^* and p_L^* solve the L-type founders' maximization problem.

Given the beliefs' and strategies of an investor, the H-type maximization problem is as follows:

$$\text{Max}_{M, p} V(M, p; \theta_H) - b_H p - \rho M,$$

2. A very similar objective function is found in Bhattacharya (1979) and Leland and Pyle (1976).

s.t.:

- $U^H \geq 0$,
- $\alpha V(M_H, p_H; \theta_H) + (1 - \alpha)V(M_H, p_H; \theta_L) - kb_H p_H - (\rho + g_L)M_H \geq V(M_L^*, p_L^*; \theta_L) - kb_H p_L^* - (\rho + g_L)M_L^*$,
- $V(M_H, p_H; \theta_H) - b_H p_H - \rho M_H \geq \alpha V(M_L^*, p_L^*; \theta_L) + (1 - \alpha)V(M_L^*, p_L^*; \theta_H) - b_H p_L^* - \rho M_L^*$,
- $\bar{M} > M_H^* \geq 0$,
- $\bar{p} > p_H^* \geq 0$.

The first constraint is the participation constraint of H-type founders. The second is the incentive compatibility constraint (IC constraint) for L-type founders, while the third is the IC constraint for H-type founders. The IC constraints show that a type of founder can mimic the other type only in $t = 1$ because, in $t = 2$, the true type will be revealed. We assume that with asymmetric information, L-type founders find it profitable to mimic H-type founders. This implies that the equity share, α , retained by an investor has to be high enough in order for L-type founders to find it profitable to invest an amount of p and M equivalent to that which maximizes H-type founders utility. This “envy” condition is crucial for the signaling game, because, if this were not the case, H-type founders would not need to differentiate themselves from L-type founders.

In any separating equilibrium, the expected value of a startup, $V^j(M, p; \theta)$, must equal its actual value $V(M, p; \theta)$. Indeed, the IC conditions require the utility of both types of founders being maximized, subject to the market correctly believing that each startup’s value equals its true value. The upper bound on M embodies the assumption that the founders, their family, and friends are wealth constrained. The upper bound on p stems from the fact that the founders of a startup can only dedicate a limited amount of effort to the production of patentable inventions. We assume that $\min\{|V_{pp}(p, M; \theta)|, |V_{MM}(p, M; \theta)|\} > V_{Mp}(p, M; \theta)$, where p and M are evaluated at $\{M_H^*, p_H^*\}$. This ensures that while an additional investment in one of the two signals affects the impact of the other signal on $V(p, M; \theta)$, this effect is not too strong.

We restrict our attention to interior solutions of the game and examine how the different structures of an investor’s belief affect these solutions.

PROPOSITION 1: *Given the system of beliefs and strategies of an investor, the following separating equilibria arise:*

- (i) *If an external investor values the quality of a startup’s technology relatively more than founder commitment, then the founders’ investment in p and M will be such that $p/M = k$*
- (ii) *If the external investor values the founder commitment relatively more than quality of a startup’s technology, then the founders’ investment in p and M will be such that $p/M = z$, with $z < k$.*
- (iii) *If the external investor is indifferent between the quality of a startup’s technology and founder commitment, then the founders’ investment in p and M will be either $p/M = k$ or $p/M = z$, depending on the values of b_H and ρ . All of these equilibria are characterized by the external investor investing $\alpha V(M_H^*, p_H^*; \theta_H)$, if a startup is of high value, and $\alpha V(M_L^*, p_L^*; \theta_L) < \alpha V(M_H^*, p_H^*; \theta_H)$, if a startup is of low value. Moreover, a startup of type θ_H invests greater amounts of both M and p than in symmetric information.*

Proof. The proof of Proposition 1 is available in the online appendix. \square

If external investors place more weight on the quality of the founders' technology, then k is equal to the ratio of patent investment, p , which is derived from the IC constraint of L-type founders holding with equality and the investment in FFF money, M , which is derived from the first-order condition of the founders' maximization problem. Intuitively, if an external investor places more weight on p than on M , the founders will use their investment in p to distinguish themselves from the low-type founders, thus leading to over-investment in p relative to symmetric information. Because $V_{Mp}(p, M; \theta) > 0$, and therefore, $\frac{dM}{dp} > 0$, an increase in p relative to the optimal amount under symmetric information leads M to be greater than the optimal amount under symmetric information. However, the upper bound on $V_{Mp}(p, M; \theta)$, ensures that the increase in M relative to a situation of symmetric information is lower than that of p .

If external investors place more weight on the commitment of the founders, then the reverse occurs. The ratio of p over M will be equal to a constant z , with $z < k$. Intuitively, if external investors place more weight on M than on p , then the increase in M relative to a situation of symmetric information, in which the optimal investments in p and in M are independent of the investors' preferences, will be more pronounced than the increase in p . Because, the reverse occurs if the external investors place more weight on the quality of the founders' technology, then z has to be less than k . Finally, if the investors' beliefs are such that the investors are indifferent to combinations of M and p as long as the IC constraint for L-type founders is met, then H-type founders will choose to invest relatively more in the signal that costs the least in order to signal their type.

As we show in the online appendix, the application of the intuitive criterion proposed by Cho and Kreps (1987) leads to the elimination of all pooling equilibria. To provide intuition, under every configuration of an investor's preferences, a candidate pooling equilibrium could be one in which the founders invest amounts of p and/or M that are smaller than those invested by H-type founders in the separating equilibrium we have outlined. However, such a candidate pooling equilibrium would be subject to profitable deviations by H-type founders. Having observed the amounts of p and M invested by the founders, the investor would place a probability of zero on the founders being H types since with constraint (iii) holding with equality, H-type founders would be better off by deviating and providing the equilibrium amounts of p and M . A similar argument can be made for candidate pooling equilibria in which the founders invest amounts of p and/or M that are larger than those invested by H-type founders in our separating equilibrium.

In some instances an external investor might place a relatively high weight on technology value, but at the same time require the founders to invest a positive amount of own money as a signal that they believe in their own venture (Dushnitsky, 2010a; Dushnitsky, 2010b; Lowe and Ziedonis, 2006). In this case, there exists a separating equilibrium such that $p/M' = k'$. Patent investment, p , is still be derived from the IC constraint of L-type founders holding with equality, but this time the investment in FFF money, M , is equal to an amount M' set by an external investor as a guarantee that the founders are not behaving opportunistically. Hence, M' will be greater than the amount that maximizes the founders' value function. The opposite conclusion is reached if the external investor attaches relatively more importance on founder commitment but requires a positive investment in patents as a guarantee that the startup's technology

complies with a minimum standard. In this case, M is still derived from the IC-constraint of L-type founders, while p is equal to an amount p' set by the external investor.

Two final points bear mention before turning to estimation. First, when external investors have different preferences over startup attributes, then the founders need to choose which external investors they intend to target with their signals, and, then, the amounts of M and p consistent with the investor's preferences, as in the separating equilibria depicted in Proposition 1. The founders' choice relative to the category of investors would depend on the fraction of equity α , and the founders' costs of investing in patents and FFF money. Second, while we have focused on FFF money and patents, the logic of Proposition 1 can clearly be extended to other signals, such as sweat equity to signal commitment rather than FFF money. If for instance, founder commitment could be signaled by either FFF money or sweat equity and the external investors have no specific preference regarding which signal the founders should use, then the founders of a startup should pick the signal that costs the least. If, instead, the external investors have specific preferences regarding which signal can better convey information on the commitment of the founders, then the founders should pick that signal.

4. EMPIRICAL ESTIMATION

In this section, we empirically examine the implications of Proposition 1: namely that the founders of high-quality technology startups consider patents and FFF money as signals of their company's value and (i) when they use these mechanisms to signal, the number of patents they file is larger (smaller) than the investment in FFF money according to the investor's preferences for high-quality technology relative to founder commitment, and (ii) the amount provided by an external investor will be larger the greater the founders' investment in the signal the investor values relatively more. We exploit detailed information available on technology startups located in the Advanced Technology Development Center (ATDC) of the Georgia Institute of Technology. Specifically, we use information on startup investment in patents and FFF money as well as the funds provided by business angels and venture capitalists.

Section 4.1 describes the data, Section 4.2 explains the empirical models which take into account endogeneity of FFF money and patents, Section 4.3 gives summary statistics, and Section 4.4 gives the results.

4.1 DATA SET

The ATDC is a technology incubator sponsored by the Georgia Institute of Technology. Founded in 1981, it has hosted a total of 226 startups during the period 1998–2008. In addition to ensuring incubation space on entrepreneur-friendly terms, the ATDC has an important role in providing strategic entrepreneurial advice and key business connections to the member companies. To this scope, it employs a staff of approximately 20 experienced managers. Additionally, ATDC makes equity investments in the member companies alongside angel investors and venture capitalists. Although this incubator is located on the campus of the Georgia Institute of Technology, the member companies need not be spinoffs from the university. Indeed, only 40% of those in our sample are university startups. For admission, applicant companies must pass a two-stage review by ATDC managers and only between 10% and 20% are eventually admitted (Rothaermel and Thursby, 2005b). As admission criteria, a company has to be located

in Georgia, commercialize a technology which is proprietary in nature, and must have the potential for employing a large number of employees. The majority of the member companies in our sample, 79%, were admitted within the first 5 years after founding, 11% were admitted within their fifth and their tenth year, while the remaining joined ATDC more than 10 years after founding. The majority of the companies, 54%, were active in the information technology sector, while only a small minority (about 5%) were in life sciences.

The ATDC provided information on the 226 startups which they gathered from an annual compulsory survey of member companies. This survey asks information on the company links with the university (e.g., such as commercializing a university technology, employee contracts with university students, informal contacts with the university's faculty), the amount of money they received from business angels and venture capitalists, the amount of FFF money invested by the founders, the number of patents they filed, and the number of patents they were awarded. For 80 startups we integrated the information from this survey with information from their business plans submitted to the ATDC at the time of their entry to the incubator. The business plans contain information on the founders, including their age, whether they have family connections, the year, and the university at which they obtained either their bachelor, and/or master, and/or PhD degree. They also include a detailed description of a startup's technology, including the industry sectors in which it should be commercialized. In cases where the business plans were unavailable, we sent a survey to at least one of the founders asking questions on their education background, the stage of their technology at the time of entry in the incubator, and the sectors in which their technology was to be commercialized. The response rate was 25%, with 37 responses. The remaining information was obtained from founder web sites or linkedin profiles.

We exclude from the sample those companies joining ATDC more than 10 years after founding, since for these companies information was incomplete. This, plus eliminating startups for which we had neither business plans nor survey responses, gave a sample of 117 startups and a total of 471 firm-year observations. The startups in our sample spent at least a year in the incubator during the period 1998–2008. On average a company spent 4.5 years, with a minimum of 1 and a maximum of 8 years. More than half of the startups in the sample had at least one founder who had studied either at the Georgia Institute of Technology or Emory University.

4.2 ESTIMATION MODELS

To examine the impact of FFF money and patents on venture capital and business angel investment, we estimate two structural models one for each type of investor in which we relate external investment to the startup's investment in patents and FFF money:

$$VC\ BINARY_{it} = \delta_0 + \delta_1 FILED\ PAT_{it} + \delta_2 FFF\ MONEY_{it} + X'_{it}\xi + \epsilon_{it}, \quad (1)$$

$$ANGEL\ BINARY_{it} = \varphi_0 + \varphi_1 FILED\ PAT_{it} + \varphi_2 FFF\ MONEY_{it} + X'_{it}\gamma + \eta_{it}. \quad (2)$$

$VC\ BINARY_{it}$ is a dummy that takes the value 1 if the startup i received venture capital funding in year t . Similarly, $ANGEL\ BINARY_{it}$ is a dummy that takes the value 1 if the startup i received business angel funding in year t . $FILED\ PAT_{it}$ is the

amount of patents filed (in log) in year t . FFF MONEY $_{it}$ is the amount invested in a startup by the founders, their friends, and families in year t (in logs).³ We also estimate similar equations to those above, using as dependent variables the amount (in logs) invested in year t by venture capitalists in startup i (VC $_{it}$ FUNDS) and the amount (in logs)⁴ invested in year t by business angels in startup i (ANGEL $_{it}$ FUNDS).

As discussed in the theory section, FFF money is an alternative to external funding from either type of investor. If this were its only role, then we should expect a negative impact of FFF money on external founding. In contrast, if FFF money were to have a signaling role, and this role were to outweigh the importance of FFF money as a source of funding, then we should expect FFF to have a positive impact on external investment.

With regard to the patent variable, we use the number of patents filed rather than the number of patents awarded because the latter would conflate founder use of patents as a productive signal with decision-making on the part of the patent office. In actuality, however, there should be little difference in the results from the two measures since 95% of US PTO patents filed are eventually granted (Quillen et al., 2002). We should also note that while we cannot empirically separate the signaling value of patents from their productive contribution, to the extent that the majority of the startups in our sample operate in the software sector, recent studies point to the importance of the signaling role of patent in this sector. For example, Bessen and Hunt (2007) find that patents as a means to increase a firm's bargaining position is less important for small firms than for large ones, and more to the point, the Berkeley survey finds that for software startups the most important reason to patent is as a reputational signal for external investors (Graham et al., 2009).

X_{it} is a matrix of controls. It includes the variable AV WORK YS, defined as the average number of years the founders worked prior to founding the startup. This variable controls for founder work experience, as well as the founders' "pocket size" since the more years worked the more years of possible savings to invest. The dummy STARTUP EXP controls for whether the founders founded *successful* startups in the past. Serial founders are likely to have developed managerial and technical skills, and built a network of contacts of use in seeking external funds (McGrath and MacMillan, 2000; Shane, 2000). We consider only serial founders of successful startups as Gompers et al. (2010) suggest that unsuccessful serial entrepreneurs have substantially lower chances than successful ones of succeeding in the next venture, and, moreover, the chances of the first category of entrepreneurs are similar to those of first time entrepreneurs. To build the dummy, STARTUP EXP, we collected information from the founders' and the ATDC's websites on the name of the startups the founders had founded in the past and, through extensive web searches. We retained only those startups which either had a successful exit event or as of the time of estimation had a website with updated information on their activities. We include a count, MASTER, of the founders who had obtained a master's degree in science or engineering, as a measure of founder quality. We measure the size of a startup with the number of full time employees, FT $_{it}$.

3. Although we only have yearly data and, thus, cannot determine whether, in a given year, the amount of patents or FFF money invested by the founders occurs before or after the investment of the external investors, we feel confident that either investment by the founders occurs just before or simultaneously with the investment of the external investors, and not after. In fact, discussions with ATDC staff as well as with startup founders revealed that external investors require that the founders commit their effort, be it in the form of FFF money or patents or other types of investment, before they invest.

4. We add 1 to every variable in log. All the nominal variables were converted into real terms by dividing for the yearly consumer price index.

The control READY FOR MKT bears special mention. It is a dummy which takes the value of one if a technology was ready to be commercialized or was at a manufacturing feasibility stage at the time the startup joined ATDC. To construct this variable, we employed two master's students with engineering backgrounds to independently code the stage of the startups' technology based on the technology description provided in the business plans. The students could choose among the following options: (i) proof of concept; (ii) prototype; (iii) manufacturing feasibility; or (iv) ready for the market.⁵ For the startups with missing business plans, we used the founder assessment from the survey mentioned above, in which we asked the founder to choose among one of these four options to describe their technology's stage at the time of entry to ATDC. To reduce noise, we combined the four options into the binary alternative ready/not ready for the market.

To control for sector fixed effects, we use a dummy, SOFTWARE, which takes the value of one if a startup were to commercialize a software product. This dummy controls for the fact that 44% of the startups in our sample were offering software products. We also include a dummy, TIME TO ATDC, that controls for whether a startup had joined the incubator within the first 5 years after foundation. Discussions with startup founders revealed that, holding constant sector effects, one of the most important reasons for early year startups to join ATDC is seeking access to external investment. This factor decreases in importance for startups who join ATDC in their later years, relative to factors such as reaching new markets or making contacts. We include a dummy, GT LINK, which takes the value of one if a startup is commercializing proprietary knowledge of the Georgia Institute of Technology based on an exclusive license. As in Rothaermel and Thursby (2005b), we argue that an incubator firm founded to commercialize a technology from the sponsoring university might have greater incentive to exert effort to ensure the success of the venture than a firm with no such commitment. Finally, we include year dummies to control for time effects.

Our central hypothesis is that if FFF money and patents are used as a signal for external investors, then their investment is endogenous to the system. In this case, FFF money and patents are caused by external funding as well as being caused by external funding. This is because the founders of a startup choose their investment in FFF and patents *taking into account* external investors' beliefs and their corresponding investment strategies, and external investors make their investment decisions *based* on the signals they observe. To take the endogeneity of the signals into account we estimate two-stage least squares models. In the case in which the investment by venture capitalists and business angels is treated as a binary outcome we estimate a two-stage least squares linear probability model, which delivers consistent estimates of the average partial effects (Wooldridge, 2002).

Our instruments are measures of the opportunity costs of investing in the signals. Specifically, we include a count variable, CLOSENESS, which takes the value of three if the founders had family connections, two if they were in the same class during either their master or PhD, one if they studied at the same university but not in the same class, and zero otherwise. CLOSENESS is a measure for the opportunity costs of investing a dollar of FFF money (the parameter ρ in our theoretical model), in the sense that the

5. Where the initial student assessments differed, we engaged the students in a discussion to determine a consistent assessment.

closer are the relational ties among the founders, the less costly it is for them to risk invest their own money.⁶

As a proxy for the opportunity cost of a unit of effort devoted to making a patentable invention (the parameter b_H in our theoretical model), we use a variable, PHD, which is defined as the number of founders with a PhD in science or engineering. The underlying logic is that, with a PhD in science or engineering, the founders acquire a knowledge background that reduces the costs of making a patentable invention. This instrument might be correlated to the unobserved quality of the founders and, thus, might not be exogenous. However, discussion with founders as well as with external investors revealed in many instances that good quality technologies are as likely to come from founders with a master's degree -which we account for with our control- as from founders with a PhD's degree. What makes a PhD attractive from the standpoint of producing inventions is that by having access to their laboratory's equipment, PhD students can produce inventions at a lower cost than founders who need to buy the equipment themselves. In our sample, all founders with a PhD degree had founded their startup towards the end of their PhD study, which leads us to conclude that in our case having a PhD degree should principally translate into lower costs of making a patentable invention. Holding a PhD might also mean better access to a network of external investors interested in commercializing university technology, which might affect the likelihood of obtaining external investment. However, to the extent that we observe external investment only for the period in which the startup was located at the incubator and the majority of founders with a PhD had obtained their degree from the Georgia Institute of Technology, then our variable GT LINK is a good control for their network size.

Finally, we include a discrete variable, CYCLE, that takes increasing values the longer the time spent at ATDC and which we use to measure the extent of asymmetric information between startup founders and external investors. The rationale is that, having controlled for the stage of a technology to be commercialized and time effects, the length of time spent at ATDC affects external investors' willingness to finance a startup only indirectly, through the signaling investment decision of the founders.

4.3 DESCRIPTIVE STATISTICS

The descriptive statistics are given in Table I. The average business angel and venture capital investment in our startups during their tenure in the incubator are \$87,498 and \$454,419, respectively.⁷ Moreover, 54% of the startups in our sample received no business angel funding, while 57% of them received no venture capital funding. Consistent with DeGennaro (2010) and Shane (2009), only 20% of the startups in our sample received funding from both venture capitalists and business angels. Further, with regard to funds raised, our sample of firms is not random. For the period we examine, the business angel and venture capital investments of the average ATDC startup are 24,000 USD and 143,633 USD, respectively. These means are statistically different from the average in our sample at the 1% level.

6. There might be downsides to CLOSENESS as doing business with family and friends could sometimes endanger a close relationship (see for instance Noam Wasserman in: <http://founderresearch.blogspot.com/2005/12/thanksgiving-dinner-with-your.html>). However, given that information asymmetries are much lower when relational ties are close, a reasonable assumption is that the costs from endangering a close relationship are still less important than the opportunity costs of investing FFF money when the founders do not know each other well.

7. All figures are expressed in real terms.

TABLE I.
VARIABLE DEFINITION AND SUMMARY STATISTICS

Variable	Description	Mean	Std. Dev.	N
VC FUNDS	Amount of venture capital funds received by startup <i>i</i> in year <i>t</i>	454,419	1,608,483	471
VC BINARY	Dummy =1 if startup <i>i</i> received venture capital funds in year <i>t</i>	0.189	0.392	471
ANGEL FUNDS	Amount of business angel funds received by startup <i>i</i> in year <i>t</i>	87,498	348,511	471
ANGEL BINARY	Dummy =1 if startup <i>i</i> received business angel funds in year <i>t</i>	0.166	0.372	471
FILED PAT	Number of patents filed in year <i>t</i> by startup <i>i</i>	0.654	2.677	471
FFF MONEY	Amount of FFF money invested by startup <i>i</i> in year <i>t</i>	27,890	155,968	471
MASTER	Number of founders that hold a master's degree in science or engineering	1.361	1.254	471
AV WORK YS	Average number of years the founders worked prior to founding the startup	13.577	7.832	471
STARTUP EXP	Dummy =1 if the founders had founded successful startups in the past	0.306	0.461	471
FT	Number of full time employees in year <i>t</i>	16.831	25.029	471
GT LINK	Dummy =1 if a startup is commercializing proprietary knowledge of GeorgiaTech based on an exclusive license	0.202	0.402	471
READY FOR MKT	Dummy =1 if a technology was ready to be commercialized or was at a manufacturing feasibility stage, when startup <i>i</i> joined ATDC	0.340	0.474	471
TIME TO ATDC	Dummy =1 if startup <i>i</i> had joined the incubator within the first five years after foundation	0.860	0.347	471
SOFTWARE	Dummy = 1 if startup <i>i</i> were to commercialize a software product	0.418	0.494	471
CLOSENESS	Variable = 3 if the founders had family connections, = 2 if they were in the same class during either their master or PhD, = 1 if they studied at the same university but not in the same class, and = 0 otherwise	0.380	0.768	471
PHD	Number of founders with a PhD in science or engineering	0.687	1.098	471
CYCLE	Takes increasing values the longer the time spent at ATDC	3.285	2.082	471

The sample comprises 117 startups that joined the GeorgiaTech's incubator during the period 1998–2008.

The average number of patents filed each year by the startups in our sample is 0.65 and the average number of patents granted during the period in question is 0.38. 44% of the companies made no patent applications while in ATDC and 28% were awarded at least one patent. Moreover, 37% of the startups in our sample received at least one round of investment by their founders, and the average amount invested was 27,890 USD.

Software was the most prevalent sector for the startups in our sample (44%) with the remainder in communication (32%), commercialization of hardware products (8%),

TABLE II.
ENDOGENEITY TESTS, F-TESTS OF EXCLUDED INSTRUMENTS, AND
TESTS OF OVERIDENTIFYING RESTRICTIONS

	Likelihood of obtaining venture capital funds		Amount of venture capital funds obtained		Likelihood of obtaining business angel funds		Amount of business angel funds obtained	
	Statistic	P- Value	Statistic	P- Value	Statistic	P- Value	Statistic	P- Value
Endogeneity test	5.720	0.057	5.654	0.059	14.379	0.001	12.862	0.002
F-test of excl. instr. (FFF MONEY)	14.740	0.000	14.740	0.000	14.740	0.000	14.740	0.000
F-test of excl. instr. (FILED PAT)	16.570	0.000	16.570	0.000	16.570	0.000	16.570	0.000
Test of overidentifying restrictions	0.318	0.573	0.271	0.603	0.361	0.548	1.390	0.238

Note: The endogeneity test is an Hausman's specification test which tests for the (joint) endogeneity of FFF MONEY and FILED PAT. The null hypothesis is that the specified endogenous regressors can actually be treated as exogenous.

pharmaceutical, biotechnology, or medical devices (9%), and finally microelectronic products (7%). One hundred and five companies joined ATDC within the first 5 years from inception. For 32% of the companies, their technology was ready for commercialization or manufacturing feasibility was known when they joined the incubator.

The average number of founders is 2, and 35% of the startups have at least one serial founder. For 7 of the startups, the founders were connected by family links. Nine startups had founders who had been in the same class during their masters and/or PhD studies. Finally, for 12 startups, the founders had been in the same university but not in the same class. The average number of working years prior to founding a startup is 13.6. On average, 1.36 founders had at least a masters in science or engineering and 0.69 had a PhD in these fields.⁸

4.4 RESULTS

The first two columns of Table II present the results of endogeneity tests for the number of patents filed and the amount of FFF money invested by the founders, having estimated a regression for the likelihood of receiving venture capital funds and one for the total amount of venture capital funds (in logs). As discussed above, we use as instruments the variables CLOSENESS, PHD, and CYCLE. The endogeneity test rejects the null hypothesis that the regressors are exogenous with a p -value of 0.06, in both the regression for the likelihood of receiving venture capital funds and in that for the total amount of venture capital funds. As reported in the table, the F-statistic for the significance of the instruments is larger than ten in both the equation for FFF money (F -test =14.74) and that for the number of patents filed (F -test =16.57), suggesting that the instruments are not weak. Finally, the results for the Hansen's J test provide an indication that the instruments are valid. Indeed, the results for this test reveal that we cannot reject the null hypothesis that the instruments are valid with and a p -value of 0.57, in the regression for the likelihood of receiving venture capital funds, and a p -value of 0.60, in the regression

8. In online Appendix B we present a correlation table.

TABLE III.
IMPACT OF FFF MONEY AND THE NUMBER OF PATENTS FILED ON
VENTURE CAPITAL INVESTMENT

	VC BINARY		VC FUNDS	
	coef.	se	coef.	se
FILED PAT	0.457***	[0.125]	6.660***	[1.809]
FFF MONEY	-0.006	[0.017]	-0.114	[0.251]
MASTER	-0.050	[0.049]	-0.763	[0.692]
AVG WORK YS	-0.005	[0.026]	-0.025	[0.366]
STARTUP EXP	0.136***	[0.050]	1.902***	[0.691]
FT	0.051***	[0.016]	0.762***	[0.227]
READY FOR MKT	-0.053	[0.048]	-0.777	[0.670]
TIME TO ATDC	0.038	[0.050]	0.600	[0.708]
GT LINK	0.099*	[0.051]	1.337*	[0.702]
SOFTWARE	0.061	[0.051]	0.861	[0.720]
CONSTANT	0.057	[0.057]	0.715	[1.939]
YEAR fixed effects	YES		YES	
Observations	471		471	
R-squared	0.318		0.327	

Notes: The sample consists of 117 startups with 471 observations. Columns I and II report the results of the IV regression of VC BINARY on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. Columns III and IV report the results of the IV regression of VC FUNDS on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. VC BINARY takes the value of 1 if a startup had received venture capital funds. VC FUNDS is defined as the log of the total amount (in real USD) invested in a startup by venture capitalists. FILED PAT is defined as the log of the number of patents filed by the founders of a startup. FFF MONEY is defined as the log of the total amount (in real USD) invested in a startup by its founders, their friends, or their family. As instruments we use the variables CLOSENESS, PHD and CYCLE. CLOSENESS takes the value of 3 if the founders had family connections, 2 if they were in the same class during either their bachelor, master or PhD, 1 if they studied at the same university but not in the same class, 0 otherwise. PHD is defined as the log of the number of founders with at PhD degree in science or engineering. CYCLE takes increasing values the longer the time spent at ATDC. The other exogenous covariates are MASTER, AVG WORK YS, STARTUP EXP, FT, READY FOR MKT, TIME TO ATDC, GT LINK. All regressions include the sector dummy, SOFTWARE, and year dummies. Standard errors are clustered at the company level. They are reported in brackets next to the coefficient estimates. ***, **, * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

for the total amount of venture capital funds. Taken together, these findings provide a first indication that, for the startups in our sample, patents and FFF are endogenously determined and might serve as signals to attract venture capital investment.

In Table III we present the regression results for the impact of FFF money and patents on venture capital investment. The first two columns report the regression results for the equation in which the dependent variable is the binary outcome, VC BINARY, equal to one if a startup had received a positive amount of venture capital funds on a given year. The last two columns report the regression results for the equation in which the dependent variable is the total amount of funds invested by venture capitalists (in logs).⁹ The standard errors we report are clustered by company.¹⁰

The main result that emerges from Table III is that the number of patents filed by the founders has a positive and statistically significant impact on both the likelihood of receiving venture capital funding and the amount of funds received. A 1% increase in the number of patents filed increases the probability of venture capital funding by 46%. Moreover, the elasticity of venture capital funding with respect to the founders' investment in patents is 6.7, suggesting a high sensitivity of VC investment to patent

9. The results of the first-stage regressions are reported in online Appendix C.

10. We attempted to cluster standard errors by company and year. However, the estimated covariance matrix was not of full rank. As a robustness check we proceeded to partialing out the time dummies as suggested by Baum et al. (2007) and obtained the same qualitative results as if we had clustered standard errors by company only.

investment. The high value of the elasticity should not be surprising given that so many companies in our sample had never filed for a patent, and very few had filed for more than one patent. The investment in FFF does not have a statistically significant impact on venture capital funding. Taken together, the results on the number of patents filed and that on FFF money suggest that venture capitalists care relatively more about the quality of a technology than about the commitment of the founders.

As for the other controls, having founded successful startups in the past has a statistically significant impact on venture capital investment. The magnitude of the coefficients reveal that having founded at least one successful startup in the past increases the likelihood of receiving venture capital funds by 14% and the elasticity of the amount of funds relative to the investment in patents is 1.9. This result is in line with Gompers et al. (2010) as well as with anecdotal evidence that venture capitalists attach a high value to the past experience of the founders in assessing the quality of a venture. The number of full time employees is positively associated with funding from external investors. This result implies that either larger size startups require more funds from external investors, or, if size is positively correlated with the value of a startup, then higher value startups are positively associated with the investment provided by venture capitalists. Finally, startups that commercialize proprietary knowledge of the Georgia Institute of Technology, via an exclusive licence, have a higher likelihood of receiving venture capital funds and receive a greater amount. This could be due either to the fact that these companies are better quality on average or that they have better access than other startups to the network of venture capitalists.

Returning to Table II, the last two columns present the results of endogeneity tests for the number of patents filed and the amount of FFF money invested by the founders, having estimated a regression for the likelihood of receiving business angel funds and one for the total amount of business angels funds (in logs). As before, we use as instruments the variables CLOSENESS, PHD, and CYCLE. The endogeneity test of FFF money rejects the null hypothesis that the regressors are exogenous with a p -value of 0.001 in the regression for the likelihood of receiving business angel funds, and with a p -value of 0.002 in the regression for the amount of funds invested. As before, the results for the Hansen's J test provide an indication that the instruments are valid: we cannot reject the null hypothesis that the instruments are valid with and a p -value of 0.55 in the regression for the likelihood of receiving business angel funds, and a p -value of 0.24 in the regression for the total amount of venture capital funds. Again, our findings suggest that FFF money and the investment in patents are endogenously determined.

In Table IV we present the regression results for the impact of FFF money and patents on business angel investment. The first two columns of the table report the regression results for the equation in which the dependent variable is the binary outcome, ANGEL BINARY, equal to one if a startup had received a positive amount of venture capital funds on a given year. The last two columns report the regression results for the equation in which the dependent variable is the total amount of funds invested by business angels (in log).¹¹ Again, the standard errors we report are clustered by company. Clearly, the main message from Table IV is that FFF money has a positive impact both on the likelihood and on the amount of business angel funding. The magnitude of the coefficients suggests that an increase by 1% in the amount of FFF money increases the likelihood of business angel funding by 5%, while the elasticity of the total amount of business angel funding with respect to FFF money is 0.50. If the role of FFF money

11. The results of the first-stage regressions are reported in online Appendix C.

TABLE IV.
IMPACT OF FFF MONEY AND THE NUMBER OF PATENTS FILED ON
BUSINESS ANGEL INVESTMENT

	ANGEL BINARY		ANGEL FUNDS	
	coef.	se	coef.	se
FILED PAT	0.251	[0.128]	3.360	[1.583]
FFF MONEY	0.045***	[0.017]	0.499**	[0.211]
MASTER	-0.044	[0.052]	-0.550	[0.673]
AVG WORK YS	-0.041	[0.031]	-0.422	[0.386]
STARTUP EXP	0.024	[0.048]	0.275	[0.609]
FT	0.013*	[0.012]	0.167*	[0.154]
READY FOR MKT	-0.027	[0.049]	-0.260	[0.619]
TIME TO ATDC	0.030	[0.049]	0.404	[0.632]
GT LINK	-0.031	[0.050]	-0.343	[0.643]
SOFTWARE	0.016	[0.047]	0.150	[0.590]
CONSTANT	0.202	[0.128]	2.159	[1.625]
YEAR fixed effects	YES		YES	
Observations	417		417	
R-squared	0.136		0.146	

Notes: The sample consists of 117 startups with 471 observations. Columns I and II report the results of the IV regression of ANGEL BINARY on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. Columns III and IV report the results of the IV regression of ANGEL FUNDS on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. ANGEL BINARY takes the value of 1 if a startup had received business angel funds. ANGEL FUNDS is defined as the log of the total amount (in real USD) invested in a startup by business angels. FILED PAT is defined as the log of the number of patents filed by the founders of a startup. FFF MONEY is defined as the log of the total amount (in real USD) invested in a startup by its founders, their friends, or their family. As instruments we use the variables CLOSENESS, PHD and CYCLE. CLOSENESS takes the value of 3 if the founders had family connections, 2 if they were in the same class during either their bachelor, master or PhD, 1 if they studied at the same university but not in the same class, 0 otherwise. PHD is defined as the log of the number of founders with a PhD degree in science or engineering. CYCLE takes increasing values the longer the time spent at ATDC. The other exogenous covariates are MASTER, AVG WORK YS, STARTUP EXP, FT, READY FOR MKT, TIME TO ATDC, GT LINK. All regressions include the sector dummy, SOFTWARE, and year dummies. Standard errors are clustered at the company level. They are reported in brackets next to the coefficient estimates. ***, **, * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

were simply to complement business angel funding then we should have observed a negative coefficient. Having found a positive coefficient suggests that FFF money have some signaling value for business angels, while the investment in patents does not.

These findings are in line with survey evidence provided by Van Osnabrugge and Robinson (2000) and DeGennaro (2010), and our own interviews of startup founders. In particular, Van Osnabrugge and Robinson (2000) and DeGennaro (2010) show that business angels tend to consider characteristics such as commitment, trust, and enthusiasm more than do venture capitalists. Our interviews point to similar conclusions. One of the founders we interviewed argued that business angels are not willing to risk their own money if the founders do not invest any funds of their own, that is unless the founders have some “skin in the game.” Finally, other founders pointed to the importance of founder commitment for business angels. As for the other controls, contrary to our results for venture capital investment, neither commercializing proprietary knowledge from the Georgia Institute of Technology nor having past experience as a successful entrepreneur has a statistically significant impact on business angel investment.

Overall, the results in Tables III and IV provide an indication that patents are chosen by the startup founders in our sample to attract venture capital investment but not business angel investment. By contrast, FFF money is used to attract business angel investment but not venture capital investment. More importantly, we find that the impact of patent investment on venture capital investment is very strong and stronger than the impact of FFF money on business angel investment. In the light

TABLE V.
IMPACT OF FFF MONEY AND THE NUMBER OF PATENTS FILED ON
VENTURE CAPITAL INVESTMENT: EXCLUDING STARTUPS WHOSE
VENTURE CAPITAL INVESTMENT FALLS WITHIN THE 99TH PERCENTILE

	VC BINARY		VC FUNDS	
	coef.	se	coef.	se
FILED PAT	0.469***	[0.129]	6.771***	[1.873]
FFF MONEY	-0.006	[0.018]	-0.093	[0.256]
MASTER	-0.055	[0.050]	-0.816	[0.708]
AVG WORK YS	0.001	[0.026]	0.037	[0.372]
STARTUP EXP	0.132**	[0.052]	1.855***	[0.718]
FT	0.053***	[0.016]	0.774***	[0.223]
READY FOR MKT	-0.055	[0.048]	-0.842	[0.667]
TIME TO ATDC	0.045	[0.050]	0.679	[0.710]
GT LINK	0.102**	[0.052]	1.334*	[0.718]
SOFTWARE	0.055	[0.051]	0.769	[0.715]
CONSTANT	0.066	[0.139]	0.856	[1.951]
YEAR fixed effects	YES		YES	
Observations	458		458	
R-squared	0.309		0.314	

Notes: The sample consists of 114 startups with 458 observations. Columns I and II report the results of the IV regression of ANGEL BINARY on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. Columns III and IV report the results of the IV regression of VC FUNDS on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. VC BINARY takes the value of 1 if a startup had received venture capital funds. VC FUNDS is defined as the log of the total amount (in real USD) invested in a startup by venture capitalists. FILED PAT is defined as the log of the number of patents filed by the founders of a startup. FFF MONEY is defined as the log of the total amount (in real USD) invested in a startup by its founders, their friends, or their family. As instruments we use the variables CLOSENESS, PHD and CYCLE. CLOSENESS takes the value of 3 if the founders had family connections, 2 if they were in the same class during either their bachelor, master or PhD, 1 if they studied at the same university but not in the same class, 0 otherwise. PHD is defined as the log of the number of founders with a PhD degree in science or engineering. CYCLE takes increasing values the longer the time spent at ATDC. The other exogenous covariates are MASTER, AVG WORK YS, STARTUP EXP, FT, READY FOR MKT, TIME TO ATDC, GT LINK. All regressions include the sector dummy, SOFTWARE, and year dummies. Standard errors are clustered at the company level. They are reported in brackets next to the coefficient estimates. ***, **, * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

of our theory, this result suggests that venture capitalists care more about the quality of a startup's technology than business angels care about the commitment of the founders.

4.5 ROBUSTNESS CHECKS

As a robustness check, we estimate the same models as in Tables III and IV excluding those startups whose external investment (either venture capital or business angel) falls within the 99th percentile. We present the results in Tables V and VI.

The results are quite similar. As found in Table III, the larger the number of patents filed by the founders, the greater the likelihood that startups receive funding from venture capitalists, and the larger the amount received. Moreover, in line with the results in Table IV, the amount invested by the founders, their friends, and their families, is positively associated with business angel investment. In fact, the coefficient of FFF money is positive and statistically significant at the 1% level in the regression for the amount invested by business angels as well as the likelihood that business angel investment occurs. These results confirm an impact of patents on venture capital investment that is larger than the impact of FFF money on business angel investment.

TABLE VI.
IMPACT OF FFF MONEY AND THE NUMBER OF PATENTS FILED ON
BUSINESS ANGEL INVESTMENT: EXCLUDING STARTUPS WHOSE
BUSINESS ANGEL INVESTMENT FALLS WITHIN THE 99TH PERCENTILE

	ANGEL BINARY		ANGEL FUNDS	
	coef.	se	coef.	se
FILED PAT	0.215	[0.160]	2.735	[1.959]
FFF MONEY	0.045***	[0.017]	0.806**	[0.212]
MASTER	-0.086**	[0.086]	-1.075**	[0.503]
AVG WORK YS	-0.063**	[0.063]	-0.725**	[0.363]
STARTUP EXP	0.010	[0.010]	0.102	[0.551]
FT	0.015	[0.015]	0.195	[0.164]
READY FOR MKT	-0.054	[0.043]	-0.623	[0.526]
TIME TO ATDC	0.013	[0.046]	0.139	[0.566]
GT LINK	-0.011	[0.056]	-0.037	[0.695]
SOFTWARE	0.042	[0.042]	0.516	[0.534]
CONSTANT	0.309	[0.122]	3.651**	[1.504]
YEAR fixed effects	YES		YES	
Observations	417		417	
R-squared	0.120		0.020	

Notes: The sample consists of 112 startups with 446 observations. Columns I and II report the results of the IV regression of ANGEL BINARY on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. Columns III and IV report the results of the IV regression of ANGEL FUNDS on the endogenous variables, FILED PAT and FFF MONEY, and other exogenous regressors. ANGEL BINARY takes the value of 1 if a startup had received business angel funds. ANGEL FUNDS is defined as the log of the total amount (in real USD) invested in a startup by business angels. FILED PAT is defined as the log of the number of patents filed by the founders of a startup. FFF MONEY is defined as the log of the total amount (in real USD) invested in a startup by its founders, their friends, or their family. As instruments we use the variables CLOSENESS, PHD and CYCLE. CLOSENESS takes the value of 3 if the founders had family connections, 2 if they were in the same class during either their bachelor, master or PhD, 1 if they studied at the same university but not in the same class, 0 otherwise. PHD is defined as the log of the number of founders with a PhD degree in science or engineering. CYCLE takes increasing values the longer the time spent at ATDC. The other exogenous covariates are MASTER, AVG WORK YS, STARTUP EXP, FT, READY FOR MKT, TIME TO ATDC, GT LINK. All regressions include the sector dummy, SOFTWARE, and year dummies. Standard errors are clustered at the company level. They are reported in brackets next to the coefficient estimates. ***, **, * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

5. CONCLUDING REMARKS

This paper provides a simple model that can be used to frame the problem faced by founders of a high-tech startup who need to signal the company's value to potential investors. We consider the use of patents and FFF money as signals of the quality of the technology and founder commitment, respectively. We find that if an investor values relatively more (less) the quality of a technology being commercialized, then there exists a separating equilibrium where the founders of a high-quality startup will make an investment in the number of patents filed that is larger (smaller) than that in FFF money, and the amount invested by the investor will be larger the greater the founders' investment in the signal it values relatively more. If an investor is indifferent between the two attributes of a startup, there exists a separating equilibrium where the optimal proportion with which the two signals are combined will depend on the costs incurred by the high-quality startup's founders of investing in each signal. The results of our model can extend to the case of multiple signals. To the extent that the investors' preferences over the different aspects of a startups can be ordered, then the founders of a startup will, in general, invest relatively more in those signals that convey information about the aspect the investors value more highly.

We also provide an empirical analysis using a novel database on technology startups in the incubator of the Georgia Institute of Technology. To evaluate the impact of

FFF money and patents on external investment we estimate two structural equation models, which take into the account the endogeneity of the signals. We find that while patents and FFF money are endogenous to venture capital investment, venture capitalists appear to value patents more highly. By contrast, FFF money is strategically used by the founders to attract business angel investment but not venture capital investment. Moreover, we also find that the impact of the number of patents filed on venture capital investment is larger than the impact of FFF money on business angel investment. This result provides an indication that venture capitalists value more the quality of a startup's technology than business angels value the commitment of the founders.

Our empirical results are consistent with evidence found by Hellmann and Puri (2002) that venture backed startups are more likely and faster to bring in outsiders as CEOs, this event often coinciding with the departure of the founders. Therefore, if the founders are to be substituted in case of venture capital financing, then the commitment of the founders should be relatively less important for venture capitalists. Moreover, they are consistent with our discussions with startup founders at ATDC who claimed that business angels often require the founders to have some "skin in the game" as evidenced by FFF money. Finally, they are in line with findings by Cosh et al. (2009) that there are systematic differences in the characteristics of startups that seek capital from venture capitalists and startups that seek capital from banks. Indeed, their findings provide evidence that the preferences of venture capitalists are well defined and distinct from those of other categories of investors.

Taken together our theory and empirics have two important implications for founders or managers of technology startups. The first is that, because investing in signals is costly, it is important to control for the cost of the signals in order to correctly assess their impact on the investment made by external investors. Our empirical model considers the costs of making a patentable invention and the opportunity costs of investing FFF in a startup. Once we take into account these costs, we find that FFF money has a positive impact on business angel investment and that patents have a signaling value for venture capitalists. The second implication is that the founders of a startup, when deciding which signal to invest in and how much to invest, need to consider the preferences of the investors they want to target. Our results, in fact, seem to suggest that patents have a signaling value for venture capitalists but not for business angels, while FFF investment serves as a signal for business angels but not for venture capitalists.

A few caveats are in order. First, the information available from the ATDC incubator does not allow us to assess how investor characteristics affect their preferences. Except for the distinction between venture capitalists, and business angels, we do not have information on investors' characteristics such as sectors of specialization, reputation, and education background. These and other characteristics are likely to affect the preferences of external investors as well as their interpretation of the signals they receive. Extending the analysis to include investors' characteristics and the latter's influence on their preferences remains a subject for future research. Second, our data do not allow us to distinguish founders from family and friends investment. The two categories of investment might signal different degrees of commitment to external investors.

Our results are conditional on startups being located at an incubator. We know from previous studies (Colombo and Delmastro, 2002; Cumming and Fischer, 2012) that being a member of an incubator is not a random event and member startups have different characteristics from the nonmembers. In our case, we believe that the distinguishing features of the member startups are their willingness to commercialize technology that is proprietary in nature, their concentration in the information technology sector, and

their ties—formal and informal—with the Georgia Institute of Technology. Thus, these results may not generalize to startups located outside of an incubator or to incubators at other academic institutions. Extending the analysis to other university incubators and to a larger sample of startups in general is a venue for future research.

Moreover, for the startups in our sample we observe that they tend to receive either venture capital funding or business angel funding but not both. While this is not a feature unique to our startups (DeGennaro, 2010; Shane, 2009), we believe that it is in part due to the fact that the majority of our startups operate in the information technology sector and, hence, their financial needs are likely to be less stringent than those of startups operating in other sectors, such as life science. We have suggested in our theory that in the case of sequential investment, the founders of a startup would find it profitable to choose the external investors in such a way that they share the same preferences over the attributes of the startup. In fact, this choice would minimize their investment in the signals since the amount invested by the intermediate investor is considered a “credible” signal by the late-stage investors. A last clarification on our results is in order. Van Osnabrugge and Robinson (2000) and Shane (2009) have argued that sometimes it is not easy for the founders of a startup to distinguish between friends’ and family’s money on the one side, and business angel’s money on the other. Our own experience by interviewing a sample of startup founders revealed that they considered any investment from friends or family, no matter how wealthy, as FFF money rather than business angel investment.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher’s web site:

Appendix

Table B1: Correlation table

Table C1: First-stage regressions for the number of patents filed and the amount of FFF money invested by a startup’s founders

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