Show Me the Right Stuff: Signals for High-Tech Startups*

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Abstract

We present a model where the founders of a technology startup signal whether their technology has a high or low probability of success, using patents and founders', friends' and family's money (FFF money). These signals convey information about, respectively, the quality of the technology (and the degree of its appropriability) and the founders' commitment. We find that if investors care relatively more (less) about the technologies in which they invest than founders' commitment, then the founders will optimally invest relatively more (less) in patents than FFF money as a signal. If the investors are indifferent about the two attributes, the ratio of investment in the corresponding signals will be inversely proportional to their relative cost. Moreover, independently of the investors' preferences, high quality startups will invest more in both signals relative to a situation of symmetric information. We use a novel data set, which includes information on startups located at the incubator of the Georgia Institute of Technology, to empirically test the model. We find that investment in patents is a signal for Venture Capitalists and Business Angels. However, the impact of patents on Venture Capital investment is greater than on Business Angel investment. Finally, FFF money serves as a signal for Business Angels but not for Venture Capitalists.

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1 Introduction

One of the most important issues facing technology startups is access to capital (Denis, 2004). Because such startups have little or no observable history of performance and there is uncertainty about their technology, attracting funds from external investors is not an easy task (Shane and Stuart, 2002). Thus a major issue for technology startups is finding signals of their value for potential investors. However, investment in signals is costly and not all startups can afford it (Amit et al, 1990). Indeed, the Berkeley Patent Survey shows that while securing funds is one of the most important reasons for startup patenting, the associated cost is the most common reason for not patenting (Graham and Sichelman, 2008; Graham et al. 2009) Moreover, different classes of investors (e.g. business angels and venture capitalists) reputedly vary in the extent to which they value different startup characteristics (Osnabrugge and Robinson, 2000; Graham et al., 2009).

In this paper, we revisit a central topic in entrepreneurial finance, namely the signals technology startups send to external investors in order to convey information about their quality. Our focus is on how signaling costs affect the decision of startups as to the signals they send to investors and on how investors' preferences towards different attributes of a startup affect the latter's investment in signals. We develop a theoretical model that addresses both issues. In the model, the founders of a startup have private information about the technology's probability of success and consider the use of two signals: patents which reflect the quality of the technology underlying the business and investment of their own money, or that of their friends and family (FFF) designed to signal their commitment. We allow the proportion in which the signals are combined to depend on the investors' preferences towards the two startup's attributes signaled by their founders and the costs of investing in the signals. The model yields predictions on the equilibrium amounts of the two signals, depending on the investors' preferences and the signaling costs. We then estimate the parameters of the model using a novel database of 117 technology startups housed in the Georgia Institute of Technology's Advanced Technology Development Center (ATDC) from 1998-2008.

In the theory, we apply the fundamental insights of Spence (1973, 1974), Leland and Pyle (1976), and Engers (1987) to the financing problem of the technology startup with two potential signals. Our theory establishes the conditions under which a separating equilibrium arises and characterizes the latter based on the preferences of a potential investor and the costs of investing in each signal. Our first finding is that the founders of a startup whose technologies have a high probability of success (high quality startups hereafter) find it worthwhile to invest more in both signals relative to a situation of symmetric information, independently of an investor's preferences. However, when an investor places more weight on the quality of a technology being commercialized than the commitment of a startup's founders, high quality startups will provide more patents than FFF money as a means to differentiate from low quality startups. Conversely, when the investor values more the founders' commitment, the investment in FFF money will be greater than that in patents. In both cases, the cost of investing in each signal constrains the choice of high quality startups relative to the amounts of patents and FFF money they provide. Finally, when an investor is indifferent between the two attributes of a startup, the ratio of investment in the two signals will be inversely proportional to their relative cost. In each equilibrium, the optimal investment in patents and FFF money made by high quality startups is negatively affected by the costs of investing in the signals.

We use a novel database to empirically test the theory. This database builds on the data on startups at the Georgia Institute of Technology's incubator in Rothaermel and Thursby (2005a, 2005b) and includes information on the rounds of Business Angels' and Venture Capitalists' (VCs) founding, the amount founders, friends' and family's money invested by the founders, as well as the number of patents they filed. Further information was collected with a survey we of the founders and from the startups' business plans.

We estimate a structural equation model that relates the amount of patents and FFF money to the costs of investing in these signals, and the amount invested in signals to the financing provided by VCs and Business Angels. We find evidence that, *having taken into account the costs of making a patentable invention*, the number of patents filed is positively associated with greater investments made by both Venture Capitalists and Business Angels. However, the impact of filing a patent is greater on VCs' than on Business Angels' investment. Moreover, *having taken into account the opportunity costs of investing founders', friends' and family's money*, the latter has a positive and statistically significant impact on Business Angels' investment, whereas its impact on VCs' investment is not significant. We believe these results provide some evidence that VCs and Business Angels have different preferences towards the signals that are sent by the founders of a startup. In particular, while VCs do not seem to consider founders', friends' and family's money as a signal, the reverse is true for Business Angels. Moreover, VCs seem to appraise more than Business Angels the investment in patents by the founders.

While informational issues and quality variation among startups is well documented in the literature on entrepreneurial finance, much of the emphasis has been on the value added that VCs 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 (2001), Hsu (2004) and Bottazzi, Da Rin and Hellmann (2008)). While Hsu (2004) shows that startups are willing to pay a price for VC 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) and Haeussler et al. (2009) have concentrated on the signaling value of patents. Hsu and Ziedonis (2008) using a sample of US semiconductor firms find that the greater the number of patents filed, the higher the pre-money valuation by VCs. Moreover, the signaling value of patents is greater in early financing rounds and when funds are secured from prominent investors. Haeussler et al. (2009), using a sample of German and British biotechnology companies, find similar results. Moreover, they show that patent oppositions increase the likelihood of receiving VC, but ultimate grant decisions do not spur VC financing, presumably because they are anticipated. Both of these studies, however, focus on signals in the sense that they are positively correlated with performance.

We contribute to the literature both by endogenizing the startup's decision to signal or not and by considering the role of multiple signals (in our case patents and FFF money). This study is also among the few that 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.'s (2009) examines Business Angel and VC data to examine the relation between control rights and investor composition, finding that the former tend to have weaker control rights. DeGennaro (2009) estimates expected returns on Angel investment and find that Angel investors earn similar returns to those earned by VCs on their investments.

Wong (2002) provides an agency model of funding in which Business Angels force entrepreneurs to hold a large stake in the firm in order to align the interests of the entrepreneur and the firm. None of this work, however, examines startup decisions regarding signals.

The remainder of the paper is organized as follows. Section two introduces the setup of the model. Section three describes the solution of the signaling game. Section four presents an empirical estimation of the theory. Section five concludes.

2 Setup of the Model

We build a simple model in which the founders of a startup company are better informed about the probability of success of a technology than a potential investor. Whether a technology has a high or low probability of success defines the type of a startup. As in Leland and Pyle (1976), given this asymmetry of information, there is an incentive for the company to signal its type to potential investors, who for our purposes exclude friends and family members.

As in Engers (1987) and Grinblatt and Hwang (1989), we consider two potential signals, each of which conveys information on different aspects of the firm's type. The two signals we consider are the number of patents filed (or granted), and founders', friends' and family's 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. In line with existing literature on family finance (Parker, 2009; Casson 2003), our model assumes that family members and friends have private information about a startup because they are close to their founders. This implies that a startup's founders do not need to signal their type to family and friends. Moreover, the investment made by the founders, family members and friends is a signal for external investors, who do not have any private information on the startup's type.

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 addition to allowing the startup to earn rents from its inventions, patents generate value by facilitating the sale of rights to interested parties or by increasing the startup's bargaining position in negotiations with other patent holders or established firms with complementary assets (Cohen, Nelson, and Walsh, 2000; Arora, Fosfuri and Gambardella, 2001; and Gans, Hsu, and Stern, 2004). The role of FFF money is threefold. In fact, in addition to signaling founders' commitment, it also generates value by increasing the startup's bargaining position in negotiations with other potential investors. Finally, it complements the funds provided by other investors.

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 $\theta_H > \theta_L$[1]. Each type generates a value, $V(p, M; \theta)$, which depends on the investment of the founders in patents, p, the amount the founders, their friends and families,

[1] θ_H and θ_L are also referred in the text as high quality and low quality startups, respectively.

invest in the startup, M, and the technology, θ. 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, respectively, about the quality of the technology and the founders' commitment to the startup.

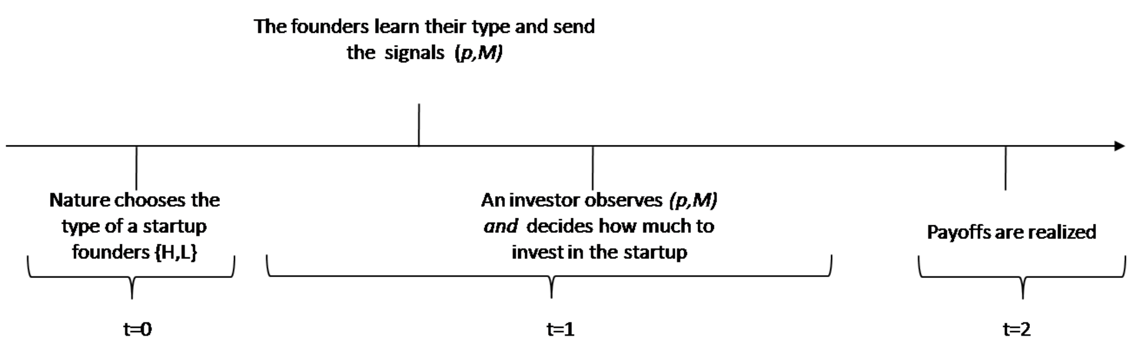
We assume that $V(p, M; \theta)$ is an increasing strictly concave function of p and M. In each point, the derivatives of $V(p, M; \theta)$ with respect to p and M are the same for both types. Moreover, p and M are complements in the realization of $V(p, M; \theta)$, thus, $V_{Mp}(p, M; \theta) > 0$, 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 in 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. Note that $r(p)$ is the cost of a patented invention, inclusive of the opportunity cost of the effort made to develop the invention. 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, $\rho > 0$, is the opportunity cost of investing M in a startup, which we assume is the same for both type of founders. The second is the risk premium required for each dollar of FFF money obtained. Our assumption here is that friends and family have private information about the startup type. Thus we can represent the premium as zero for 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.

Figure 1: **Time Line**



The founders' utility is a function of their 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:

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

where $\alpha \in (0, 1)$ is the fraction of equity retained by investor j, V^j is investor $j's$ expectation of the value of startup with productivity θ. $M \geq \underline{M} \geq 0$, is founders', friends' and family's investment in the startup, which is at least equal to a minimum amount $\underline{M}$ required to start the business.

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

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

3 Solution of the Game

In what follows, 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 attributes of a startup: the quality of a technology being commercialized (QT) and the commitment of the founders (C). For the purposes of our model, we first consider a case in which all external investors share the same preferences. In this setting, if an investor values QT more highly than C, then she will believe that the founders are of type H, if the latter have invested an amount of p greater than a threshold p_s, and the increment in p relative to a situation of symmetric information is at least equal to the increment in M. The threshold p_s is the level of p at which L-type founders are indifferent between mimicking and H-type and revealing their true type, for a given M. The reverse occurs, if an investor values C more highly. Then, the investor will believe that the founders are of type H if $M \geq M_s$, and the increment in M relative to a situation of symmetric information is at least equal to the increment in p. M_s is the investment which makes L-type founders are indifferent mimicking the H-type and revealing their true type, for a given p. Finally, if an investor is indifferent between the two attributes, her beliefs will not be affected by the relative levels of M and p, as long as L-type founders do not find it profitable pretend they are of type H.

Hence, the investor's beliefs can be formalized as:

[2] An objective function that takes into account present and future values of a firm is used, for instance, by Bhattacharya (1979).

$$
\begin{aligned}
b(H \mid (M,p)) &= 1 \text{ if } M \geq M_s \text{ and } \Delta M \geq \Delta p, \text{ provided that } C \succ_I QT \\
&= 0 \text{ otherwise} \\
\\
&= 1 \text{ if } p \geq p_s \text{ and } \Delta M \leq \Delta p, \text{ provided that } C \prec_I QT \\
&= 0 \text{ otherwise} \\
\\
&= 1 \text{ if either } M \geq M_s \text{ or } p \geq p_s, \text{ provided that } C \sim_I QT \\
&= 0 \text{ otherwise}
\end{aligned}
$$

ΔM and Δp are the increments in M and in p, respectively, relative to a situation of symmetric information. 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 of 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^* are the amounts solving L-type founders' maximization problem.

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

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

s.t.:

(i) $U^H \geq 0$

(ii) $\alpha V(M_H, p_H; \theta_H) + (1-\alpha)V(M_H, p_H; \theta_L) - k b_H p_H - (\rho + g_L)M_H \geq V(M_L^*, p_L^*; \theta_L) - k b_H p_L^* - (\rho + g_L)M_L^*$

(iii) $V(M_H, p_H; \theta_H) - b_H p_H - \rho M_H \geq \alpha V(M_L^*, p_L^*; \theta_L) + (1-\alpha)V(M_L^*, p_L^*; \theta_H) - b_H p_L^* - \rho M_L^*$

(iv) $\overline{M} > M_H^* \geq 0$

(v) $\overline{p} > p_H^* \geq 0$

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 founders 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, $V^j(M,p;\theta)$, has to 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 the investors, The following separating equilibria arise:*

(i) If $C \succ_I QT$, then H-type founders will choose M such that the IC constraint of type L-founders holds as equality and p such that the first order condition is satisfied.

(ii) If $C \prec_I QT$, then H-type founders will choose p such that the IC constraint of type L-founders holds as equality and M such that the first order condition is satisfied

(iii) If $C \sim_I QT$, then H-type founders will choose M such that the IC constraint of type L-founders holds as equality and p such that the first order condition is satisfied, provided that $\Delta > 0$. Conversely, if $\Delta < 0$, then H-type founders will choose p such that the IC constraint of type L-founders holds as equality and M such that the first order condition is satisfied. Δ is the difference between the utility H-types would achieve if they were to choose p from the corresponding first order condition and M so as to satisfy the IC constraint of type L-founders and the utility they would achieve if they were two choose M from the corresponding first order condition and p so as to satisfy the IC constraint of type L-founders. Moreover, $\frac{\partial \Delta}{\partial b_H} < 0$ and $\frac{\partial \Delta}{\partial \rho} > 0$.

All these equilibria survive the elimination of all separating Nash equilibria that are equilibrium-dominated and to the elimination of all pooling equilibria.

Proof. See Appendix. □

If an investor places more weight on founder commitment, then H-type founders will invest an amount of M such that the IC constraint of L-type founders holds with equality. As it is shown in the Appendix, this amount is greater than that under symmetric information. Moreover, its increment relative to a situation of symmetric information is greater than that of p. The intuition is the following. Because $V_{Mp}(p,M;\theta) > 0$, and therefore, $\frac{dp}{dM} > 0$, an increase in M relative to the optimal amount under symmetric information leads p 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 p relative to a situation of symmetric information is lower than that of M. The rationale for this result is that if an investor values founder commitment more highly, she will be inclined to believe that the founders are of type H provided that the latter invest relatively more in M in order to signal their quality. As it is standard in signaling theory, amounts of M that are greater than M_s

are not chosen by H-type founders because they are equilibrium dominated. If an investor values the quality the technology more highly, then the reverse occurs. Finally if an investor's beliefs are such that he is 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 a relatively more in the signal that costs the least, in order to signal their type.

We now consider, the comparative statics distinguishing between the three cases highlighted in Proposition 1.

Proposition 2. *Provided that the solutions of p and M are interior, then:*

(i) if $C \succ_I QT$: $\frac{\partial M_H^*}{\partial \rho} < 0$, $\frac{\partial M_H^*}{\partial g_L} < 0$, $\frac{\partial p_H^*}{\partial b_H} < 0$;

(ii) if $C \prec_I QT$: $\frac{\partial p_H^*}{\partial b_H} < 0$, $\frac{\partial p_H^*}{\partial k} < 0$, $\frac{\partial M_H^*}{\partial \rho} < 0$;

(iii) If $C \sim_I QT$ and $\Delta > 0$: $\frac{\partial M_H^*}{\partial \rho} < 0$, $\frac{\partial M_H^*}{\partial g_L} < 0$, $\frac{\partial p_H^*}{\partial b_H} < 0$. Conversely, if $C \sim_I QT$ and $\Delta < 0$: $\frac{\partial p_H^*}{\partial b_H} < 0$, $\frac{\partial p_H^*}{\partial k} < 0$, $\frac{\partial M_H^*}{\partial \rho} < 0$.

Proof. See Appendix. □

In case (i), an increase in the opportunity cost, ρ, of investing in M and in the cost of investing in p, b_H, reduce the optimal amounts M_H^* and p_H^* H-types are willing to invest in the project. Moreover, an increase in the risk premium, g_L, L-type founders have to pay to their friends and families for each dollar they lend makes more onerous for L-type founders to mimic H-types. This, in turn, induces H-type founders to reduce the amount of M they provide as a signal. In case (ii), as before, an increase in ρ and b_H triggers a reduction in M_H^* and p_H^*. Furthermore, an increase in k reduces the incentive for L-type founders to cheat, and, therefore, H-type founders' investment in signaling. Finally, case (iii) is identical to case (i) if $\Delta > 0$, and to case (ii) if $\Delta < 0$.

4 Empirical estimation

We have built a signaling model in which startup founders are more informed as to the probability of success of their technology than their potential investors, and for this reason, they need to signal their type to potential investors in order to attract their funds. We have considered as quality signals the amount spent in filing patents and founders', friends' and family's money. As argued above, the amount of money spent in filing patents conveys information about the quality of a technology and the degree of its appropriability, as well as contributing to the value of a startup. The second signal, in addition to affecting the value of a startup, reveals information on the commitment of a startup's founder. Moreover, it is a complementary source of financing relative to the funds made available by other investors.

In this section, we test the model's implication that the founders of a high quality startup use filed patents and FFF money as signals for two types of investors, Venture Capitalists and Business Angels. In line with Proposition 2 of the theory, we control for the costs the founders of a startup have to afford when sending signals to potential investors. To this scope, we exploit a novel database on startups that spent time at the incubator of the Georgia Institute of Technology. This database contains information on the number of patents filed by the founders, the amount of FFF money as well as the investment provided by Venture Capitalists and Business Angels. We integrate this information with that available from the business plans of these companies as well as from survey evidence and other sources.

4.1 Description of the Dataset

We use data on technology startups made available by the incubator of the Georgia Institute of Technology, the Advanced Technology Development Center (ATDC). The ATDC provided information on 226 startups that spent time at the incubator during the period 1998-2008. The population of startups includes spinoffs from the Georgia Institute of Technology as well as spinoffs from other universities. Of these startups, the ATDC gathered information on the amount of money the received from Business Angels and VCs, over the period they spent at the incubator, the amount of FFF money invested by the founders and the number of patents they filed.

For 80 startups we integrated the information provided by the ATDC with that available from the business plans of these companies submitted to the ATCD, at the time of entry in the incubator. These 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.

For the companies for which we did not have the business plans we sent a survey to at least one of their founders with the aim of gathering the same information as that we found in the business plans of the 80 startups. Specifically, we asked questions on the founders' education background and the sectors in which their technology were to be commercialized. The response rate was 29%, with 42 answers. We gathered the remaining information thought the web sites of the founders, and using in some cases their profiles on the linkedin network.

We excluded from our sample those companies that joined ATDC more than ten years after they were created. In fact, for these companies the information provided by ATDC was incomplete. In total we have 471 firm-year observations relative to 117 startups that spent at least a year in the incubator at the Georgia Institute of Technology during the period 1998-2008. On average a company spent 4.5 years, with a minimum of 1 and a maximum of 8 years. Almost half of the startups in the sample had at least one founder who had studied either at the Georgia Institute of Technology or at Emory University.

As it is shown in table 1, the startups in our sample had received on average a greater amount of investment by Business Angels and VCs than the whole population of startups housed at ATDC. The average amount of Business Angel investment received by a startup in our sample over the period it spent at the incubator amounts to 87,498 USD[3], whereas the average amount of VC investment is 454,419 USD. The corresponding figures for the whole population are 54,012 and

[3] All figures are expressed in real terms

290,601, respectively. Moreover, 54% of the startups in our sample and 65% of the whole startup population did not receive any Business Angel funding. The corresponding percentages for VC funding are 57% and 68%. Consistent with the findings of DeGennaro (2010) and Shane (2009), only 20% of the startups in our sample and 15% of the whole startup population had received funding from both VCs and Business Angels.

The startups in our sample had also filed a greater amount of patents and invested a larger amount of FFF money than the whole population. The average number of patents filed each year by a startup's founders in our sample during the time spent at the incubator is 0.65. 44% of the companies did not file any patent while at the ATDC. As for the whole population, the average amount of patents filed is 0.312 and 29% of the startups did not file any 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. The corresponding figures for the whole population are 27% and 20,028, respectively.

Table 1: VC Investment, Business Angel Investment and Founders' Investment in FFF money and patents

	Firm-Year N=471			**Firm-Year N=998**		
	Mean	**Std. Dev.**	**Max**	**Mean**	**Std. Dev.**	**Max**
VC investment	454418	1608483	23500000	290601	1313687	23500000
Angel investment	87498	348511	4473386	54012	261268	4473386
FFF money	27890	155968	2673797	20028	134628	2673797
Filed Patents	0.654	2.677	45	0.312	1.868	45

4.2 Methodology

In order to test the first proposition of our theory relating to the existence of a separating equilibrium, we estimate four equations. The first relates the amount of VC investment (VC FUNDS) to the number of patents filed every year (FILED PAT) by the founders and other variables of interest. The second links VC FUNDS to founders', friends' and family's money (FFF MONEY), and other variables of interests. The third and the fourth are identical to the first and the second except that the dependent variable is now the amount invested by Business Angels (ANGEL FUNDS).

FILED PAT and FFF MONEY are potentially endogenous as each of these signals, on one side, and the amount invested by VCs and Business Angels, on the other, may be subject to correlated unobserved shocks, even after controlling for a variety of exogenous regressors. For this reason we estimate a structural equation model for VC and Business Angels' funds which consists of two stages. The first stage begins with a regression that links each signal with a series of instrumental variables and other exogenous regressors, the latter in common with the second stage regressions. Finally, in the second stage, we regress VC FUNDS and ANGEL FUNDS on the signals' estimated values and other exogenous variables.

In the first stage regression for FFF MONEY, we use as instrument a count variable (CLOSENESS) that takes the value of four if the founders had family connections, three if they were in the same class during either their master or PhD, two if they studied at the same university but not in the same class, one if they studied in Atlanta but not in the same university, and zero otherwise. CLOSENESS is a measure for the opportunity costs of investing founders', friends' and family's money, the parameter ρ in our theory. In fact, the closer are the relational ties among the founders, the less costly it is for them to risk invest own money. As in our theory, we expect that the impact of these ties on the costs of investing FFF affects in the same way H- and L- type founders. As second instrument we use the average number of years (AV_WORK_YS) the founders worked prior to founding the startup. This variable captures the "pockets' size" of the founders. Hence, the greater is the average number of years the founders have been working after their graduation, the greater the amount of money available to invest in the company. As additional instruments, we include three dummies that control for the time interval between the foundation year and the entry year at ATDC. The first, D_NO_LAG, is equal to one if the year of foundation and that of entry in the incubator coincide. The second dummy, D_2_5, is equal to 1 if a startup joined the incubator between the sixth and the tenth year after foundation. The third dummy, D_6_10, is equal to 1 if a startup joined the incubator between the second and the fifth year after foundation. Moreover, we control for the life cycle of a startup starting from the entry year at ATDC, with a discrete variable, CYCLE, that takes increasing values the longer the time spent at ATDC. Our prior is that FFF investment occurs in the first years a startup has joined ATDC, when the uncertainty over the value of a startup is greater. Therefore, FFF investment should be greater in the first years a startup has joined the incubator, provided that the time lag between the foundation year and the year of entry in ATDC is short enough.

As exogenous regressors, we include the number of full time employees (FT) and a dummy (TIME AT ATDC) that takes the value of one if a startup remained at the incubator for more than six years. The greater the number of full-time employees, the greater is the amount that has to be paid for the employees' salaries. Therefore, we expect that FT affects positively the initial investment made by the founders, their friends and families. TIME AT ATDC is a proxy for the value of a startup. In fact, the time spent at the incubator is likely to be correlated to the time interval between a startup's creation and either exit event, IPO or acquisition. It is commonly believed, that the longer it takes for a startup to either be acquired or go public, the lower its value is. Finally, we control for time effects, using year dummies.

In the first stage regression for the number of patents filed, we use as instrument a variable (MASTER SCI)[4] that is defined as the number of founders with a master's degree in science or engineering. With this variable we capture the effort cost of making a patentable invention (the parameter b_H in our theory), the logic being that, with a master in science or engineering, the founders acquire a knowledge background that reduces the costs of making a patentable invention. As before, we include in the regression the dummies D_NO_LAG, D_2_5, D_6_10, and CYCLE.

Finally, as exogenous regressors, we use the dummy TIME AT ATDC and the variable FT. Moreover, we control for time as well as industry effects. For the latter we use a dummy, INFO TECH, that takes the value of one if a startup is intended to commercialize its products in the

[4]In other model's specification we proxied the cost of making an invention with the share of founders with a PhD in science and engineering. This specification delivered very similar results to our preferred one.

information technology sector; a dummy, HEALTHCARE, that takes the value of one if its products are intended for the healthcare industry; a dummy, PHARMA_MDEV, that takes the value of one if its products are for the pharmaceutical, biotech and medical device sectors; and a dummy, OTHER, which include startups operating mainly in the manufacturing sector.

In the second stage, we estimate two equations for the amounts invested by Business Angels and VCs[5], respectively, and use as independent variables, the signals' estimated values from the first stage, the number of full time employees, the dummy TIME AT ATDC, a dummy (PROFESSOR) that takes the value of one if the founders include at least an academic professor, and, finally, time and industry controls. Similar to Higgins et al. (2008), the rationale for the dummy PROFESSOR stands in the fact that having an academic professor among the founders might act as a signal of firm value.

4.3 Descriptive statistics on the controls and instruments

Descriptive statistics on the control variables as well as the instruments are presented in Table 2. 25% of the startups joined the incubator the same year they were founded, while 65% joined the ATDC within the first five years from creation, and the remaining 10% within the 6th and the 10th year. 37% of the companies had spent more than 6 years at the incubator.

The vast majority of the companies operated in the information technology sector (72%), 10% in healthcare, 0.03% in the pharmaceutical, biotechnology, and medical devices sectors, while the remaining were mainly operating in the manufacturing sector.

On average a startup, while at ATDC, had 17 full time employees. The average number of founders is 2, with 34% of the startups having at least an academic professor among the founders.

In the case of 7 startups the founders were connected by family links. 9 startups had founders that had been in the same class during their master and/or PhD studies. Finally, in the case of 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 and, on average, 0.92 founders had a master in science and/or engineering.

4.4 Results

In this section we report the regression results for the impact of the signals, FFF money and patents filed, on Business Angels and VCs. We estimate our systems of equations using a censored regression model with one endogenous regressor[6]. In fact, this estimation method allows to taking into account the realistic case in which an investor finds it optimal not invest in a company (Wooldridge, 2002). The censored regression model with an endogenous variable is derived under the assumption that the errors from both equations are jointly normally distributed and it is estimated using a maximum likelihood method.

[5]All the nominal variables were converted into real terms by dividing for the yearly consumer price index.

[6]In the Appendix, as robustness check, we estimate a similar model specification where all investments are measured as binary outcomes. Moreover, we estimate the same specification but excluding from the sample possible outliers.

Table 2: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
D_NO_LAG	0.238	0.426	0	1	471
D_2_5	0.622	0.485	0	1	471
CYCLE	3.285	2.082	0	8	471
TIME AT ATDC	0.361	0.481	0	1	471
FT	16.831	25.029	0	150	471
INFO_TECH	0.645	0.479	0	1	471
HEALTHCARE	0.072	0.259	0	1	471
PHARMA_MDEV	0.053	0.224	0	1	471
PROFESSOR	0.340	0.474	0	1	471
CLOSENESS	0.380	0.768	0	3	471
AV_WORK_YS	13.577	7.832	1	33	471
MASTER SCI	0.915	1.05	0	4	471

4.4.1 FFF money

Table 3 reports the regressions' results for the impact of founders', friends' and family's investment on VC and Business Angel investment. All variables, except for the dummies and the CLOSENESS index, are expressed in logs.

The results of the benchmark censored regressions for VC and Business Angel investment, where we do not correct for the endogeneity of the signals, are reported in the first and in the second columns, respectively. The reported coefficients are marginal effects for the unconditional expected values of the Business Angel and VC investment, respectively[7]. The impact of FFF investment on Business Angel investment is positive and statistically significant at 10% confidence level, while the impact on VC investment is not statistically significant. The number of full time employees (FT) has a positive and statistically significant coefficient in both equation specifications, indicating a positive relation between the size of a startup and the investment made by both type of investors. This result implies that either larger size startups require more funds from external investors, or, if size is positively correlated to the value of a startup, then higher value startups are positively associated with greater investments by external investors. The dummy TIME AT ATDC has negative and highly significant impact on both the investment made by VCs and that made by Business Angels. Thus, startups that tend to spend a long period at the ATDC incubator receive less funding from external investors. If we posit that the startups that spend the longest period in an incubator are the low quality startups, then again this result suggests that lower quality startups tend to receive fewer investments from external investors. The coefficients of the industry dummies are statistically insignificant in the regressions for Business Angel and VC investment. This seems to suggest that investment by Business Angels and VCs is not concentrated in any of the sectors described by the dummies, relative to the category OTHER. Finally, the coefficient for the dummy, PROFESSOR, is not statistically significant in any of the equations' specifications. This result might be due to the fact that an academic professor can act as a signal of firm quality in ways other than being a firm founder.

[7]Marginal effects are evaluated at the regressors' means.

In the remaining columns, we implement our structural equation model, taking into account the endogeneity of FFF money. In columns 3 and 4 we present the results for Business Angel investment, while in columns 5 and 6 we present the results for VC investment. The reported coefficients in the second stage regressions are marginal effects for the unconditional expected values of the Business Angel and VC investment, respectively. In the first-stage of the Business Angel investment model, FFF investment is a function of our proxy for the opportunity costs of investing, the pockets' size of the investors, the discrete variable CYCLE and the dummies D_NO_LAG, D_2_5, D_6_10, as well as the regressors FT and TIME AT INCUBATOR. As expected, the coefficient of CLOSENESS is positive and statistically significant at the 1% level. The interpretation of this result is as follows. The closer the relational ties among the founders, the lower the costs of investing founders', friends' and family's money, and therefore, the greater the amount invested. The coefficient for AV_WORK_YS is not statistically significant. This result might be explained by the fact that AV_WORK_YS is only a partial measure of the pockets' size of the founders. In fact, while it captures the flow of income earned by the founders, it does not control for the stock of wealth. This implies that we cannot distinguish, for instance, between a dollar invested by a university graduate student backed by a wealthy family and a graduate student that earns the same salary as the first, but who is not economically supported by her family. As expected, FFF investment tends to be made in the first years of existence of a startup. Indeed, the coefficient of the variable CYCLE is negative and statistically significant at the 1% confidence level, suggesting that FFF investment tends to be larger if it occurs within the first years since entry in the incubator. In line with this result, FFF investment is larger the shorter the time lag between a startup's foundation year and the entry year at ATDC. In fact, the coefficient D_2_5 is positive and statistically significant at the 5% level, implying that startups what have joined the incubator within the first five years since their foundation tend to invest more FFF money than those startups that have joined ATDC within the 6th and the 10th year. Finally, the number of full time employees (FT) has a negative and statistically significant coefficient, suggesting a negative relation between the size of a startup and FFF money.

In column four, we report the second-stage regression results for Business Angel investment. Having instrumented FFF money, its coefficient increases in magnitude and becomes statistically significant at the 1% confidence level. When controlling for the endogeneity of the signal, an increase by 1% in FFF money triggers an increase by 0.79% in the unconditional expected value of Business Angel investment, which is larger than the 0.08% increase derived from the baseline regression. These results seem to suggest that having controlled for the factors that affects the decision choice of the agents regarding how much to invest in FFF money, the latter has a large and highly significant impact on the investment made by Business Angels.

In columns five and six, we implement the structural equation model for the impact of FFF money on VC investment. The first-stage regression delivers very similar results to that for Business Angels' investment. Again, the closer the relational ties among the founders the greater the amount of FFF money, the latter occurring in the first years of inception of a startup. Also, the larger the number of full time equivalents, the lower the amount of FFF money. In the second-stage regression, even after controlling for the costs of investing, the founders' pockets' size and the timing of the investment, FFF investment does not have a statistically significant impact on VC financing. This result is in line with the findings by Hellmann and Puri (2002) who show that venture backed startups are more likely and faster to bring in outsiders as CEOs, this latter event often coinciding with the departure of the founders. Therefore, if the founders are to be substituted in case of VC financing, then commitment by the founders is relatively less important for VCs.

The results on FFF money could be the expression of two factors. The first is the signaling value of FFF money. The second is the choice made by either a startup's founders to opt for Business Angel or by a VC to avoid investing in a given startup. In both cases, because Business Angels tend to face greater financial constraints than VCs, the founders who opt for the latter's investment are more likely to match this investment with their own money. Even though we are not able to distinguish between these two factors, survey evidence provided by Van Osnabrugge and Robinson (2000) and DeGennaro (2010), and own interviews conducted with startups' founders provide evidence that FFF money is an important signal for Business Angels. In particular, Van Osnabrugge and Robinson (2000) and DeGennaro (2010) show that Business Angels tend to consider more than VCs founders' characteristics, such us commitment, trust and enthusiasm. Our interviews point to similar conclusions. One of the founders we had interviewed argued that Business Angels are not willing to risk their own money if the founders do not even invest a penny in their own startup. Another founder contended that Business Angels often require the founders to have some "skin in the game" and invest their own money in the startup. Finally, other founders pointed to the importance of founders' commitment for Business Angels.

4.4.2 Patents filed

Table 4 reports the regressions' results for the impact of the number of patents filed by the founder on the investments made by Business Angels and VCs. All variables, except for the dummies, are expressed in logs. In columns one and two, we show the benchmark regression results, without controlling for the endogeneity of the signal, for VC and Business Angel investment, respectively. As before, startups that spend a longer time at the incubator tend to receive less funds from both VCs and Business Angels, the coefficient for TIME AT ATDC being negative and statistically significant at 1% confidence level in both regressions. Moreover, startups with a larger number of full-time employees tend to receive a greater investment by both types of investors, as suggested by the positive and statistically significant coefficient of FT in both regressions. Finally, the coefficient of FILED PATENTS is positive and statistically significant at the 1% level in the regression for VC investment, and positive and statistically significant at the 5% confidence level in the regression for Business Angel investment. This result seems to suggest that the number of patents filed has a positive impact on both VC and Business Angel investment.

In column three, we report the results for the first stage of the structural equation model for Business Angel investment. We regress the number of patents filed by the founders on our proxy for the cost of making a patentable invention MASTER SCI, the dummies D_NO_LAG, D_2_5, the variable CYCLE, as well as the regressors FT and TIME AT INCUBATOR, and industry dummies. Our proxy for the cost of making an invention has a positive and statistically significant impact on the number of patents filed, the coefficient being significant at the 1% confidence level. This implies that the greater the number of founders with master in science or engineering, the lower the costs of making a patentable invention, given the technical knowledge the founders have acquired during their studies. This ultimately has a positive impact on the decision choice of the founders regarding how many patents to file in order to signal their quality, vis-a-vis external investors. Moreover, investment in filed patents tends to be greater during the first years a startup has joined the incubator and if the time lag between foundation and entry in the incubator is short.

Similar to the findings of Graham et al. (2009), the coefficient of INFO_TECH is negative and statistically significant, indicating that startups in the information technology sector tend to file a lower number of patents relative to the baseline sector, OTHER. Finally, also the coefficient of the dummy HEALTHCARE is negative and statistically significant, suggesting a similar story as for INFO_TECH.

Column four presents the second-stage of the two stage model, for Business Angel investment. Having controlled for the costs of filing patents, the marginal effect of the log of FILED PAT on the unconditional expected value of the log of Business Angel investment increases from 0.71 to 4.5, and remains significant at the 5% level. Thus an increment in the number of filed patents by 1% causes 4.5% increase in the unconditional expected value of Business Angel investment. Moreover, the coefficient for the number of full time employees is no longer significant, while that of the dummy, PROFESSOR, is negative and statistically significant at the 10% confidence level.

Columns five and six present the results for the structural equation model applied to VC investment. The first-stage regression delivers very similar results to that for Business Angel investment, the investment in patents occurring mainly in the first years of inception of a startup, and being greater the larger the number of founders with a master in science or engineering. Moreover, as before startups in the sectors of information technology and healthcare file less patents relative to the benchmark sector, OTHER. The second-stage regression results reveal that having controlled for the costs of filing patents, the marginal effect of the log of FILED PAT on the unconditional expected value of the log of VC investment increases from 0.97 to 9.7.

Having controlled for the costs of filing patents, the relative difference in the elasticity of the unconditional expected values of Business Angel and VC investment with respect to the founders' investment in patents increases. This result provides some support to the number of patents filed by the founders having a stronger impact on the VCs' decision on how much to invest in a company than on the Business Angels' investment decision.

The results presented in Tables 3 and 4 reveal two important aspects. The first relates to the importance of controlling for the costs of investing in signals. In fact, the signaling theory suggests that signals are costly to send and, therefore, the agents have to take costs into consideration when deciding whether they want to mimic the H-types, if they are L-types, or whether they want to distinguish themselves from the L-types, if they are H-types. The second aspect points to the importance of distinguishing among types of investors, when deciding which type of signals and how much of each signal to invest in. In fact, these results seem to suggest that VCs and Business Angels have different preferences relative to the signals they observe. In particular, VCs do not appear to consider FFF investment as important, and this might be due to the fact that VC investment is often associated with a departure of the founders from a startup. On the contrary, Business Angels seem to appreciate FFF investment as a signal for founders' commitment. Moreover, the importance VCs and Business Angels attach to the number of patents filed seems to be different, with VCs valuing more than Business Angels the number of patents filed by the founders.

Table 3: Impact of FFF money on VC and Business Angel Investment

	(1)	(2)	(3)	(4)	(5)	(6)
	ANGEL_FUNDS	VC_FUNDS	FFF MONEY (1st Stage)	ANGEL_FUNDS (2nd Stage)	FFF MONEY (1st Stage)	VC_FUNDS (2nd Stage)
	Mrg. eff.	*Mrg. eff.*		*Mrg. eff.*		*Mrg. eff.*
FFF MONEY	0.076*	-0.019		0.785***		0.817
	[0.041]	[0.038]		[0.286]		[0.528]
FT	0.290**	0.937***	-0.182*	0.576***	-0.180*	1.724***
	[0.123]	[0.151]	[0.096]	[0.211]	[0.094]	[0.334]
TIME AT ATDC	-2.143***	-2.654***	0.359	-2.434***	0.626	-3.668***
	[0.377]	[0.504]	[0.414]	[3.854]	[0.685]	[0.920]
PROFESSOR	-0.138	0.319		-.050		0.530
	[3.162]	[0.442]		[0.561]		[0.633]
INFO TECH	-0.800	0.093		-0.862		0.140
	[0.650]	[0.515]		[0.832]		[0.776]
PHARMA_MDEV	-0.032	1.951		0.277		3.107
	[0.660]	[1.581]		[1.058]		[1.977]
HEALTHCARE	0.366	-0.179		0.632		-0.203
	[0.802]	[0.780]		[1.202]		[1.357]
CLOSENESS			0.653***		0.497**	
			[0.203]		[0.231]	
AV_WORK_YS			0.269		0.247	
			[0.227]		[0.235]	
D_NO_LAG			0.343		1.062*	
			[0.520]		[0.598]	
D_2_5			0.955**		0.883**	
			[0.406]		[0.391]	
CYCLE			-0.639***		-0.671***	
			[0.135]		[0.148]	
YEAR DUMMIES	YES	YES	YES	YES	YES	
Constant			2.100*		2.157*	
			[1.227]		[1.148]	
Pseudo R2	0.064	0.103				
Wald chi2				82.33***		127.29***
Observations	471	471	471	471	471	471

Clustered standard errors by firm in brackets. Marginal effects are calculated for the unconditional expected value of y
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4: Impact of the number of patents filed on VC and Business Angel Investment

	(1)	(2)	(3)	(4)	(5)	(6)
	ANGEL_FUNDS	VC_FUNDS	FILED PAT (1st Stage)	ANGEL_FUNDS (2nd Stage)	FILED PAT (1st Stage)	VC_FUNDS (2nd Stage)
	Mrg. eff.	*Mrg. eff.*		*Mrg. eff.*		*Mrg. eff.*
FILED PAT	0.707**	0.964***		4.508**		9.675***
	[0.290]	[0.245]		[1.984]		[2.345]
FT	0.221*	0.835 ***	0.040**	0.192	0.039**	1.403***
	[0.114]	[0.143]	[0.020]	[0.156]	[0.020]	[0.260]
TIME AT ATDC	-2.056***	-2.203***	-0.004	-1.902***	-0.009	-2.620***
	[0.350]	[0.450]	[0.070]	[0.662]	[0.078]	[0.856]
PROFESSOR	-0.370	0.061		-0.789*		-0.766
	[0.358]	[0.345]	[0.000]	[0.470]		[0.645]
INFO TECH	-0.659	0.242	-0.217***	-0.073	-0.225***	1.740*
	[0.601]	[0.453]	[0.078]	[0.735]	[0.073]	[0.893]
PHARMA_MDEV	-0.237	1.312	0.160	-0.806	0.139	0.592
	[0.630]	[1.424]	[0.151]	[0.916]	[0.162]	[2.171]
HEALTHCARE	0.557	0.113	-0.225***	1.542	-0.244***	2.459
	[0.895]	[0.932]	[0.079]	[1.432]	[0.082]	[2.661]
MASTER SCI			0.184***		0.187***	
			[0.063]		[0.057]	
D_NO_LAG			0.267***		0.330***	
			[0.102]		[0.088]	
D_2_5			0.230***		0.211***	
			[0.080]		[0.071]	
CYCLE			-0.084***		-0.076***	
			[0.016]		[0.017]	
YEAR DUMMIES	YES	YES	YES	YES	YES	
Constant			0.400**		0.379**	
			[0.171]		[0.173]	
Pseudo R2	0.070	0.121				
Wald chi2				106.05***		77.05***
Observations	471	471	471	471	471	471

Clustered standard errors by firm in brackets. Marginal effects are calculated for the unconditional expected value of y
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

5 Concluding Remarks

We built a signaling model where the founders of a technology startup use their investment in patents and founders', friends' and family's money as signals for two different attributes of their company.

We find that if an investor values relatively more 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 than that in founders', friends', and family's money; both investments being greater than that under symmetric information. Moreover, the equilibrium investment in patents will be smaller, the greater the cost of making a patentable invention. Similarly, the equilibrium amount of founders', friends', and family's money will be lower the greater the investment's opportunity costs and the greater the cost for a low quality startup to mimic the investment in founders', friends', and family's money of a high quality startup.

The opposite occurs if an investor values relatively more the founders' commitment. We find that there exists a separating equilibrium where the founders of a high quality startup will make an investment in founders', friends', and family's money that is larger than that in the number of patents filed. Again, both investments are greater than that under symmetric information. Moreover, the equilibrium investment in patents will be smaller, the greater the cost of making a patentable invention and the larger the costs for a low quality startup of mimicking the corresponding investment made by a high quality startup. As before, the equilibrium amount of founders', friends', and family's money will be smaller the greater the investment's opportunity costs.

Finally, 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.

We empirically estimated the theory implication on the existence of a separating equilibrium, using a unique database on technology startups based at the incubator of the Georgia Institute of Technology. The information provided was integrated with a survey we sent to the startups' founders and with the companies' business plans. We find that having taken into account the opportunity cost of founders', friends', and family's investment, the latter is positively associated with the investment made by Business Angels but not with that made by VCs. Moreover, having taken into account the costs of making a patentable invention, the investment made by the founders in terms of the number of patents filed is positively associated with both Business Angel and VC investment. However, the impact of the number of filed patents on VCs investment is greater than on Business Angel investment. We believe these 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 VC financing, then it is not surprising that the commitment of the founders is relatively less important for VCs. Moreover, these results are also consistent with discussions we had with startup founders at ATDC who claimed that Business Angels often require the founders to have some "skin in the game" and invest their own money in the startup.

Our empirical results have two important implications. The first is that, because investing in signals is a costly activity, 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. Once we take into account these costs, the impact of each signals on the investment made by Business Angels and VCs increases substantially. The second implication is that the founders of a startup when deciding which signal to invest in and how much to invest they need to consider the preferences of the investors they want to target. Our results, in fact, seem to suggest that VCs attach more importance than Business Angels to patents, as a signal for a technology quality and its appropriability. Viceversa, Business Angels seem to attach more importance than VCs to founders', friends' and family's investment, as a signal for founders' commitment.

A few caveats are in order. First, the information available from ATDC incubator does not allow us to assess how investors' characteristics affect their preferences. Except for the distinction between VCs 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. We thus cannot consider the possibility that startups with different attributes match with investors with different preferences towards these attributes. Extending the analysis to include investors' characteristics and the latter's influence on their preferences remains a subject for future research. Second, while our empirical estimations take into account that the investment made by VCs or Business Angels in a startup might be sequential, we do not explicitly model the effect of the investment by one type of investor on that by the other type. However, similarly to DeGennaro (2010) and Shane (2009), only a small percentage of companies in our sample received funds from both Business Angels and VCs. Finally, our empirical analysis is based on data from a unique institution, the Georgia Institute of Technology. Therefore, the results we found may not generalize to other academic institutions. Extending the analysis to other universities is a venue for future research.

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A Appendix

Proof of Proposition 1 (i) There exists a separating equilibrium whose characteristics are: if $C \succ_I QT$, H-type founders will choose M such that IC constraint of type L-founders hold as equality and p such that the first order condition is satisfied.

The utility maximization problem of H-type founders is defined as:

$$\underset{M,p}{Max}\ V(M,p;\theta_H) - b_H p - \rho M$$
s.t.:

(i) $C \succ_I QT$

(ii) $U^H \geq 0$

(iii) $\alpha V(M_H, p_H; \theta_H) + (1-\alpha)V(M_H, p_H; \theta_L) - kb_H p_H - (\rho + g_L)M_H \geq V(M_L^*, p_L^*; \theta_L) - kb_H p_L^* - (\rho + g_L)M_L^*$

(iv) $V(M_H, p_H; \theta_H) - b_H p_H - \rho M_H \geq \alpha V(M_L^*, p_L^*; \theta_L) + (1-\alpha)V(M_L^*, p_L^*; \theta_H) - b_H p_L^* - \rho M_L^*$

(v) $\overline{M} > M_H^* \geq 0$

(vi) $\overline{p} > p_H^* \geq 0$

Given the preferences of the investors, a candidate for a separating equilibrium is obtained as follows. M_H^* is derived from condition (iii) being binding and p_H^* is derived from the first order condition for p_H. This amounts to reducing the problem to a utility maximization in one variable, p_H, while allowing M_H to be derived from (iii). As mentioned in the the paper, we will only consider interior solutions for p_H and M_H. We need to show that a) this solution to p is a maximum; b) H-type participation constraint is satisfied; c) H-type IC constraint is satisfied; d) p_H^* and M_H^* are greater than the corresponding amounts under symmetric information and $\Delta M \geq \Delta p$; and e) the solution to this maximization problem delivers a separating equilibrium that rules out all pooling equilibria and all other separating Nash equilibria that are equilibrium-dominated, *given the beliefs of the investors.*

a) The proposed solution for p is indeed a maximum because $\frac{\partial^2 V(pM_H^*, p_H^*; \theta_H)}{\partial p_H^2} < 0$.

b) H-type participation constraint is met. In fact:

$V(M_H^*, p_H^*; \theta_H) - b_H p_H^* - \rho M_H^* >$
$\alpha V(M_H^*, p_H^*; \theta_H) + (1-\alpha)V(M_H^*, p_H^*; \theta_L) - kb_H p_H^* - (\rho + g_L)M_H^* = \overline{U}_L^* > 0$

c) H-type IC constraint is met.

In fact, from (iii) we have

$\alpha V(M_L^*, p_L^*; \theta_L) + (1-\alpha)V(M_L^*, p_L^*; \theta_L) - kb_H p_L^* - (\rho + g_L)M_L^* = \alpha V(M_H^*, p_H^*; \theta_H) + (1-\alpha)V(M_H^*, p_H^*; \theta_L) - kb_H p_H^* - (\rho + g_L)M_H^*$

Rewriting we obtain:

$\alpha V(M_L^*, p_L^*; \theta_L) = -(1-\alpha)V(M_L^*, p_L^*; \theta_L) + kb_H p_L^* + (\rho + g_L)M_L^* + \alpha V(M_H^*, p_H^*; \theta_H) + (1-\alpha)V(M_H^*, p_H^*; \theta_L) - kb_H p_H^* - (\rho + g_L)M_H^*$

Inserting this expression into (iv) and rearranging, we obtain:

$\alpha V(M_H^*, p_H^*; \theta_H) + (1-\alpha)V(M_H^*, p_H^*; \theta_H) - b_H p_H^* - \rho M_H^* \geq$
$\geq -(1-\alpha)V(M_L^*, p_L^*; \theta_L) + kb_H p_L^* + (\rho + g_L)M_L^* + \alpha V(M_H^*, p_H^*; \theta_H) + (1-\alpha)V(M_H^*, p_H^*; \theta_L) - kb_H p_H^* - (\rho + g_L)M_H^* + (1-\alpha)V(M_L^*, p_L^*; \theta_H) - b_H p_L^* - \rho M_L^*$

The expression above can be rewritten as:

$(1-\alpha)[V(M_H^*, p_H^*; \theta_H) - V(M_H^*, p_H^*; \theta_L)] + [b_H(kp_H^* - p_H^*) + g_L M_H^*] \geq$
$\geq (1-\alpha)[V(M_L^*, p_L^*; \theta_H) - V(M_L^*, p_L^*; \theta_L)] + [b_H(kp_L^* - p_L^*) + g_L)M_L^*]$

This condition holds as a strict inequality. In fact:

$[b_H(kp_H^* - p_H^*) + g_L M_H^*] > [b_H(kp_L^* - p_L^*) + g_L M_L^*]$

And:

$[V(M_H^*, p_H^*; \theta_H) - V(M_H^*, p_H^*; \theta_L)] - [V(M_L^*, p_L^*; \theta_H) - V(M_L^*, p_L^*; \theta_L)] = 0$

d) The amounts M_H^* and p_H^* are greater than those under symmetric information p_H^+, M_H^+. Under symmetric information, the "envy" condition in the model ensures that L-type founders find it profitable to cheat and invests the same amounts of M and p as H-types would invest. Therefore, the latter need to invest a greater amount of at least one of the two signals, M and p, relative to a situation of symmetric information in order to differentiate from L-type founders. We will show that indeed both signals are provided in greater quantities but that $\Delta M \geq \Delta p$.

Deriving the IC constraint for the L-type founders with respect to M, we obtain:

$$\alpha \frac{\partial V(M, p; \theta_H)}{\partial M} + (1-\alpha)\frac{V(M, p; \theta_L)}{\partial M} - (\rho + g_L) = 0 \quad (1)$$

Under symmetric information, the first order condition implies that $\alpha\frac{\partial V(M,p;\theta_H)}{\partial M}+(1-\alpha)\frac{V(M,p;\theta_L)}{\partial M}=\rho$. Using this result into (1), we obtain:

$$(\rho+g_L)-\rho=0 \Longrightarrow g_L\neq 0$$

Thus, at the amount of M that meets the first order condition under symmetric information, for $p=p_H^+$, (1) is not satisfied. Because, at this amount, the left-hand side of (1) is greater than zero, this implies that $M_H^*>M_H^+$.

As for p, the first order condition derived from the H-type maximization problem yields:

$$\frac{\partial V(M,p;\theta_H)}{\partial p}-b_H=0$$

Deriving this expression with respect to M, at $\{M_H^*,\ \mathrm{p}_H^*\}$, we obtain:

$$\frac{\partial^2 V(M_H^*,p_H^*;\theta_H)}{\partial p^2}\frac{dp}{dM}+\frac{\partial^2 V(M_H^*,p_H^*;\theta_H)}{\partial p\partial M}=0$$

Solving for $\frac{dp}{dM}$, we obtain:

$$\frac{dp}{dM}=-\frac{\frac{\partial^2 V(M_H^*,p_H^*;\theta_H)}{\partial p\partial M}}{\frac{\partial^2 V(M_H^*,p_H^*;\theta_H)}{\partial p^2}}>0$$

This implies that relative to the optimal quantities under symmetric information, an increase in M_H^* leads to an increase of p_H^*. Thus, $p_H^*>p_H^+$. However, because $\min\{|V_{pp}(p,M;\theta),V_{MM}(p,M;\theta)|\}>V_{Mp}(p,M;\theta)$, then $\left|\frac{\partial^2 V(M_H^*,p_H^*;\theta_H)}{\partial p^2}\right|>\frac{\partial^2 V(M_H^*,p_H^*;\theta_H)}{\partial p\partial M}$. This implies that a unit increase in M causes p to increase by less than a unit.

e) The solution to this maximization problem delivers a separating equilibrium that rules out all pooling equilibria and all other separating Nash equilibria that are equilibrium-dominated, *given the beliefs of the investors.*

We apply the intuitive criterion proposed by Cho and Kreps (1987). An equilibrium is said to violate the intuitive criterion if there are some founders of type $i\in\{H,L\}$ who have a deviation that yields a greater payoff than the equilibrium payoff, provided that the investors do not assign a positive probability to the deviation having being made by the other type of founders, for whom this action is equilibrium dominated.

Under this criterion, if H-type founders were to invest any amount of p and M greater than the equilibrium amounts, they would still successfully differentiate themselves from L-type founders but they would not earn a greater payoff. Because, M and p are costly to provide, any amount of p and M greater than the equilibrium amounts would yield a lower utility to H-type founders. Moreover, any amounts of p and M smaller than the equilibrium amounts would yield a lower payoff to H-type founders because it would lead the investors to believe that the founders are of type L. Finally, given the preferences of the investors and the lower bound on α, any equilibrium amount of p and M respectively obtained from the IC constraint of L-types and the first order condition for M, would yield a lower payoff to H-type founders because it would lead the investors to believe that the founders are of type L.

As for L-type founders, any positive amounts of p and M lower than the equilibrium amounts M_H^* and p_H^* would not change an investor's belief that the founders are of type L. Because the signals are costly, L-type founders' best strategy is to provide the same amounts as under symmetric information: M_L^* and p_L^*. Moreover it is not profitable for L-type founders to provide amounts of p and M greater than the equilibrium amounts.

Finally, this criterion also eliminates all possible pooling equilibria. Any pooling equilibrium with p and M smaller than the equilibrium amounts would be subject to deviations by H-type founders. Similarly, any pooling equilibrium with p and M greater than the equilibrium amounts would be subject to deviations by L-type founders. Finally, any equilibrium amount of p and M respectively obtained from the IC constraint of L-types and the first order condition for M, would would be subject to deviations by L- and H-type founders.

Proof of Proposition 1 (ii) Same as Proof of Proposition 1 (i)

Proof of Proposition 1 (iii) Same as Proof of Proposition 1 (i). In addition $\frac{\partial \Delta}{\partial b_H} < 0$ and $\frac{\partial \Delta}{\partial \rho} > 0$ are straightforwardly derived by comparing the utility H-types would achieve if they were two choose p from the corresponding first order condition and M so as to satisfy the IC constraint of type L-founders and the utility they would achieve if they were two choose the M from the corresponding first order condition and p so as to satisfy the IC constraint of type L-founders.

Proof of Proposition 2 (i) If $C \succ_I QT$: $\frac{\partial M_H^*}{\partial \rho} < 0$, $\frac{\partial M_H^*}{\partial g_L} < 0$, $\frac{\partial p_H^*}{\partial b_H} < 0$;

$\frac{\partial M_H^*}{\partial \rho} < 0$:

Deriving the IC constraint for type L-founders with respect to M, at $\{M_H^*\ , p_H^*\}$, we obtain:

$$\alpha \frac{\partial V(M_H^*, p_H^*; \theta_H)}{\partial M} + (1-\alpha) \frac{V(M, p; \theta_L)}{\partial M} - (\rho + g_L) = 0 \tag{2}$$

Deriving (2) with respect to ρ and rearranging yields:

$\frac{\partial^2 V(M_H^*, p_H^*; \theta_H)}{\partial M^2} \frac{\partial M}{\partial \rho} - 1 = 0$

Solving for $\frac{\partial M}{\partial \rho}$, we obtain:

$\frac{\partial M}{\partial \rho} = \frac{1}{\frac{\partial^2 V(M_H^*, p_H^*; \theta_H)}{\partial M^2}} < 0$

$\frac{\partial M_H^*}{\partial g_L} < 0$:

Deriving (1) with respect to g_L and rearranging yields:

$\frac{\partial^2 V(M_H^*, p_H^*; \theta_H)}{\partial M^2} \frac{\partial M}{\partial g_L} - 1 = 0$

Solving for $\frac{\partial M}{\partial g_L}$, we obtain:

$\frac{\partial M}{\partial \rho} = \frac{1}{\frac{\partial^2 V(M_H^*, p_H^*; \theta_H)}{\partial M^2}} < 0$

$\frac{\partial p_H^*}{\partial b_H} < 0:$

Deriving the first order condition for p with respect to b_H, at $\{M_H^*\ ,\ p_H^*\}$, yields:

$\frac{\partial^2 V(M_H^*, p_H^*; \theta_H)}{\partial^2 p_H^*} \frac{\partial p_H^*}{\partial b_H} - 1 = 0$

Solving for $\frac{\partial p_H^*}{\partial b_H}$, we obtain:

$\frac{\partial p_H^*}{\partial b_H} = \frac{1}{\frac{\partial^2 V(M_H^*, p_H^*; \theta_H)}{\partial^2 p_H^*}} < 0$

Proof of Proposition 2 (ii) Same as Proof of Proposition 2 (i)

Proof of Proposition 2 (iii) Same as Proof of Proposition 2 (i)

B Robustness Check: Appendix

In this section we present a robustness check analysis. We first consider VC and Angel investment as well as investment in signals as binary outcomes. This is important because the distribution of these investment is highly skewed. We follow Angrist (2001) and estimate a linear first stage. This estimation procedure, presented in tables 5 and 6, delivers similar results as the ones in tables 3 and 4. Successively, we estimate the same model as in tables 3 and 4, having excluded those startups whose external investment (either VC or Business Angel) falls within the 99th percentile. Similar to the results shown in table 3, FFF money has a positive and statistically significant impact on Business Angel investment but not on VC investment. Moreover, similar to the results shown in table 4, the number of patents filed has a positive and statistically significant impact on VC and Business Angel investment, and the impact on the first type of investor is larger than that on the second type.

Table 5: Impact of whether FFF investment has occurred on the probability that VCs and Business Angels Invest

Marg. Eff.	VC_BINARY (1)	ANGEL_BINARY (2)	VC_BINARY (2-Stage) (3)	ANGEL_BINARY (2-Stage) (4)
FFF_BINARY	-0.020	0.109	0.480	0.753***
	[0.038]	[0.069]	[0.326]	[0.110]
FT	0.086***	0.026**	0.097***	0.036***
	[0.014]	[0.011]	[0.017]	[0.013]
TIME AT ATDC	-0.232***	-0.189***	-0.221***	-0.153***
	[0.042]	[0.033]	[0.042]	[0.042]
PROFESSOR	0.029	-0.017	0.059	0.029
	[0.042]	[0.038]	[0.048]	[0.050]
INFO TECH	0.009	-0.071	0.020	-0.048
	[0.049]	[0.059]	[0.052]	[0.059]
HEALTHCARE	-0.015	0.034	-0.009	0.036
	[0.076]	[0.076]	[0.090]	[0.080]
PHARMA_MDEV	0.154	-0.011	0.167	0.004
	[0.120]	[0.058]	[0.142]	[0.065]
YEAR DUMMIES	YES	YES	YES	YES
Observations	471	471	471	471
Wald chi2	82.24***	67.93***	119.11***	131.08***

Clustered standard errors by firm in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Impact of whether patent investment has occurred on the probability that VCs and Business Angels Invest

Marg. Eff.	VC_BINARY	ANGEL_BINARY	VC_BINARY (2-Stage)	ANGEL_BINARY (2-Stage)
	(1)	(2)	(3)	(4)
PAT_BINARY	0.198***	0.124***	0.767***	0.573***
	[0.053]	[0.045]	[0.063]	[0.170]
FT	0.087***	0.022**	0.098***	0.024**
	[0.013]	[0.011]	[0.012]	[0.012]
TIME AT ATDC	-0.190***	-0.174***	-0.139***	-0.119***
	[0.039]	[0.032]	[0.050]	[0.045]
PROFESSOR	0.012	-0.034	-0.018	-0.052
	[0.034]	[0.035]	[0.034]	[0.038]
INFO TECH	0.021	-0.057	0.080	-0.009
	[0.044]	[0.057]	[0.050]	[0.056]
HEALTHCARE	0.002	0.046	0.081	0.083
	[0.087]	[0.081]	[0.118]	[0.090]
PHARMA_MDEV	0.121	-0.025	0.075	-0.049
	[0.106]	[0.055]	[0.074]	[0.061]
YEAR DUMMIES	YES	YES	YES	YES
Observations	471	471	471	471
Wald chi2	99.34***	78.39***	346.46***	132.24***

Clustered standard errors by firm in brackets

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Impact of FFF money on VC and Business Angel Investment: Excluding startups whose VC or Business Angel investment falls within the 99th percentile

	(1)	(2)	(3)	(4)	(5)	(6)
	ANGEL_FUNDS	VC_FUNDS	FFF MONEY (1st Stage)	ANGEL_FUNDS (2nd Stage)	FFF MONEY (1st Stage)	VC_FUNDS (2nd Stage)
	Mrg. eff.	*Mrg. eff.*		*Mrg. eff.*		*Mrg. eff.*
FFF MONEY	0.066*	-0.014		0.696**		0.901
	[0.035]	[0.037]		[0.280]		[0.539]
FT	0.222**	0.877***	-0.195**	0.471**	-0.169*	1.733***
	[0.106]	[0.151]	[0.097]	[0.189]	[0.093]	[0.351]
TIME AT ATDC	-1.749***	-2.614***	0.285	-2.144***	0.647*	-3.824***
	[0.329]	[0.515]	[0.453]	[0.605]	[0.387]	[0.970]
PROFESSOR	-0.116	0.222		-0.123		0.374
	[0.331]	[0.422]		[0.468]		[0.620]
INFO TECH	-0.041	0.030		0.162		-0.016
	[0.463]	[0.509]		[0.662]		[0.821]
PHARMA_MDEV	-0.261	2.598*		0.053		4.099*
	[0.573]	[2.050]		[1.085]		[2.421]
HEALTHCARE	1.084	-0.135		1.691		-0.151
	[1.007]	[0.755]		[1.488]		[1.395]
CLOSENESS			0.699***		0.501**	
			[0.205]		[0.227]	
AV_WORK_YS			0.228		0.234	
			[0.262]		[0.224]	
D_NO_LG			0.220		0.973*	
			[0.556]		[0.580]	
D_2_5			0.794**		0.914**	
			[0.397]		[0.386]	
CYCLE			-0.631***		-0.666***	
			[0.145]		[0.142]	
YEAR DUMMIES	YES	YES	YES	YES	YES	YES
Constant			2.373*		2.225*	
			[1.330]		[1.152]	
Pseudo R2	0.072	0.100				
Wald chi2				74.69***		103.70***
Observations	446	458	446	446	458	458

Clustered standard errors by firm in brackets. Marginal effects are calculated for the unconditional expected value of y
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Impact of the number of patents filed on VC and Business Angel Investment: Excluding startups whose VC or Business Angel investment falls within the 99th percentile

	(1)	(2)	(3)	(4)	(5)	(6)
	ANGEL_FUNDS	VC_FUNDS	FILED PAT (1st Stage)	ANGEL_FUNDS (2nd Stage)	FILED PAT (1st Stage)	VC_FUNDS (2nd Stage)
	Mrg. eff.	*Mrg. eff.*		*Mrg. eff.*		*Mrg. eff.*
FILED PAT	0.537*	0.984***		3.107*		10.386***
	[0.275]	[0.265]		[1.882]		[2.797]
FT	0.173*	0.793***	0.032*	0.149	0.024	1.519***
	[0.101]	[0.141]	[0.019]	[0.130]	[0.017]	[0.270]
TIME AT ATDC	-1.761***	-2.135***	0.033	-1.775***	-0.003	-2.693***
	[0.340]	[0.456]	[0.070]	[0.560]	[0.070]	[0.927]
PROFESSOR	-0.361	0.020		-0.683*		-0.774
	[0.293]	[0.324]		[0.387]		[0.649]
INFO TECH	-0.034	0.143	-0.159**	0.252	-0.195***	1.479
	[0.483]	[0.444]	[0.075]	[0.624]	[0.065]	[0.911]
PHARMA_MDEV	-0.385	1.464	0.381***	-0.902	0.199	0.265
	[0.639]	[1.841]	[0.123]	[0.624]	[0.176]	[2.497]
HEALTHCARE	1.233	0.0812	-0.188**	1.891	-0.192***	2.065
	[1.105]	[0.854]	[0.084]	[1.55]	[0.071]	[2.483]
MASTER SCI			0.191***		0.166***	
			[0.062]		[0.057]	
D_NO_LAG			0.306***		0.268***	
			[0.115]		[0.072]	
D_2_5			0.220***		0.203***	
			[0.067]		[0.066]	
CYCLE			-0.074***		-0.076***	
			[0.016]		[0.016]	
YEAR DUMMIES	YES	YES	YES	YES	YES	YES
Constant			0.387**		0.322**	
			[0.174]		[0.137]	
Pseudo R2	0.072	0.120				
Wald chi2				103.42***		70.91***
Observations	446	458	446	446	458	458

Clustered standard errors by firm in brackets. Marginal effects are calculated for the unconditional expected value of y
*** p<0.01, ** p<0.05, * p<0.1