

Pooling, Separating, and Semiseparating Equilibria in Financial Markets: Some Experimental Evidence

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This study investigates experimental financial markets in which firms possess more information than do potential investors. Firms were given opportunities to undertake positive net present value projects which they could either forgo or finance by selling equity. Auctions were conducted among the investors for the right to finance the projects. When the theoretical equilibrium was unique, theory predicted well. When theory permitted pooling, separation, and semiseparation, only the more efficient pooling equilibrium was observed. The domination of the pooling equilibrium was robust to different experimental expe-

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riences by participants. When available, signals were used by good firms to distinguish themselves from bad.

Considerable effort has gone into the construction of theoretical models of financial markets in which agents cope intelligently with problems of asymmetric information. This modeling approach has been used to provide intuitively appealing rationales for a wide range of observed phenomena. Examples include leverage ratios, temporal patterns of financing, stock price movements around initial public offerings of securities, and the nature of contracts between firms and investors.

Unfortunately, as stressed by Ross (1987), a corresponding effort has not been put into direct tests of the proposed asymmetric information models themselves. This is a matter of some concern because it is often possible to construct several equally plausible models to serve as candidate explanations for the same empirical observations. The problem is exacerbated by particular difficulties associated with game theoretic modeling. First, equilibria are often qualitatively dependent upon parameters that are unobservable to the researcher, making direct econometric tests difficult, if not impossible, to perform. Second, many game theoretic models of financial markets produce multiple equilibria. When faced with multiple equilibria, there is a natural tendency for theorists to focus on the one equilibrium that is consistent with the stylized facts or empirical results under consideration. This process may become dangerously disjointed because the next researcher may choose a totally different type of equilibrium to explain an alternative set of facts. It may be that neither equilibrium is consistent with both sets of facts occurring simultaneously and yet this may be precisely what is happening in the real world. Thus, the models in question are never really subjected to potentially disconfirming tests.

The present paper investigates the performance of experimental financial markets characterized by asymmetries of information. The reason for using experiments is that they are able to address and overcome some of the difficulties mentioned above. The particular context that we examine is based on the influential paper by Myers and Majluf (1984). Their paper played a major role in the development of the literature on informational asymmetries in financial markets and has been frequently cited to interpret the findings of event studies.¹ Informational asymmetry has also figured prominently in subsequent contributions such as Giammarino and Lewis (1988), Noe (1988), Allen and Faulhaber (1989), and Grinblatt and Hwang (1989).

¹ For example, see Asquith and Mullins (1986), Eckbo (1986), or Masulis and Korwar (1986).

Accordingly, it seems the appropriate place to begin our experimental investigations of the effect of asymmetric information in financial markets.

The questions addressed by our study follow directly from the literature that analyzes the equilibria of financial markets subject to asymmetric information. First, when theory predicts a unique equilibrium, is that equilibrium actually observed? Second, when theory indicates that there are a number of equilibria, one exhibiting separating, a second exhibiting pooling, and a third exhibiting semiseparating, which equilibrium corresponds to the behavior observed? Third, does previous exposure of agents to a unique pooling or separating equilibrium result in a different equilibrium outcome in the multiple equilibrium case? Fourth, will a signal be used to convert a pooling equilibrium into a separating equilibrium?

There are a number of advantages associated with the use of experiments to address corporate finance questions. The researcher has the ability to control directly many of the theoretically important variables. By nesting environments, alternative models of the same phenomena can sometimes be tested against each other. As shown by Camerer (1987), experiments also provide a direct method of checking whether psychological biases disrupt equilibrium predictions.

Perhaps the most important role for experiments arises under circumstances in which theory does not make unique predictions. Experiments can sometimes cast light on matters left open by theory. In our study, this situation arises owing to the theoretical prediction of multiple equilibria. If pooling, separating, and semiseparating equilibria are all subgame perfect, which outcome will occur and will the outcome vary depending on the experiences of agents? The experimental approach allows us to treat these theoretically consistent possibilities as alternative hypotheses to be tested against each other.

Several papers have used experiments to test financial theory. Perhaps surprisingly, more effort has gone into the testing of asset pricing than corporate finance theory. Forsythe, Palfrey, and Plott (1982) demonstrated that the efficient markets hypothesis does a good job of predicting the pricing of two-period assets. Forsythe, Palfrey, and Plott (1984) and Friedman, Harrison, and Salmon (1984) showed that the existence of a futures market enhances the process of market convergence to equilibrium. There has been a sequence of papers examining the informational efficiency of experimental asset markets, including Plott and Sunder (1982), Friedman (1984), Copeland and Friedman (1987), Plott and Sunder (1988), and Smith, Suchanek, and Williams (1988). Kroll, Levy, and Rapoport (1988) used laboratory experiments to test the capital asset pricing model.

There have been relatively few studies using the experimental approach to investigate asymmetric information models. We are familiar with three relevant studies. DeJong, Forsythe, and Lundholm (1985) demonstrated that the presence of moral hazard opportunities leads to theoretically predicted shirking by agents. Miller and Plott (1985) examined a product market in which firms could produce higher or lower quality goods. Their findings indicate that equilibria may be particularly sensitive both to relative costs and to institutional settings. Signaling behavior was quite commonly observed. Camerer and Weigelt (1988) tested a borrowing model in which some agents were more inclined than others to default on their loans.

The rest of this paper is organized in the following manner. In Section 1, we review and recast the theoretical environment of Myers and Majluf (1984). Their paper contains no discussion of multiple equilibria. We show that their setup has multiple equilibria for some parameter values. In Section 2, we discuss the experimental environment, created as a laboratory analog to the theoretical model. In Section 3, we present and analyze the empirical results. In Section 4, we extend the Myers and Majluf (1984) framework to allow signaling to occur. Some conclusions are set out in Section 5.²

1. Theoretical Background

The intuition underlying Myers and Majluf (1984) is very appealing. Consider a situation in which a firm's management has better information than do potential investors concerning both the value of the firm's assets in place and the likely payoffs to new projects. Investors will be faced with an adverse selection problem. The less valuable firms will be willing to sell a higher proportionate claim to their future revenues than the more valuable firms in exchange for needed financing. Investors take into account the presence of less valuable firms in the market when deciding how much to offer for newly issued securities. Thus, the more valuable firms receive worse terms from the market than they would if their quality were known. In some cases, these terms may be so unfavorable that better firms decide to stay out of the market rather than dilute the claim of current shareholders on existing assets. This is unfortunate because such a decision involves forgoing opportunities to undertake positive net present value projects.

In order to test this intuition experimentally, it is necessary to develop a precise statement of the theory in the context of a well-

² Examples of the instruction sheets and other documents used in the experiments are contained in Appendix 1. A detailed presentation of the results is listed in Appendix 2. These appendices are available on request to the authors.

specified market mechanism. Accordingly, we restate the informal model of Myers and Majluf (1984) as a sequential game.³ The model involves two kinds of agents: firm managers acting on behalf of current shareholders ("firms") and potential investors or financiers ("investors"). All agents are assumed to be risk neutral or at least able to diversify away any risk. There are no transaction costs.

Consider the firm's problem first. The firm is initially financed entirely by equity. There are some assets in place, denoted A_i , and a positive net present value project available that offers a net payoff denoted by B_i . The subscript i refers to the firm's type. The firm may either be of type H (high) or of type L (low). The sum of the assets in place plus the net value of the project is greater for type H than for type L firms. The two types are equally likely. The firm knows the true worth of both the assets and the project. The project requires I to be undertaken. However, the firm has neither available internal funds nor the ability to borrow funds for this purpose.

The manager of the firm attempts to maximize the terminal value of the original owners' claim to the firm's assets. There are two strategies available. The firm may choose either to forgo, or alternatively to undertake, the available project. If the firm chooses not to proceed with the project, the terminal value of the original owners' claim is simply A_i .

If the new project is undertaken, the terminal value of all claims on the firm will be $V_i = A_i + B_i + I$. However, V_i does not belong entirely to the original owners of the firm. Rather, it must be shared with the investor who provided the equity funding necessary to undertake the project. Let s denote the share of revenues that will accrue to the equity bought by the investor. Then the claim of the original owners will be worth $(1 - s)V_i$ if the project is undertaken. To make the correct decision, the firm needs to know whether this value will be greater or less than A_i . However, this requires a forecast of s . The value of s will depend on the behavior of the investors.

The difficulties facing the investors are clear. If a firm decides to undertake a project, and thus goes to the market to raise funds, the investor must try to infer the probability of the firm being of type H versus the probability of the firm being of type L . The investor's inference will determine the fraction of the firm's equity s to be demanded. Each investor faces the same inference problem.

An auction is conducted among the investors for the sole right to invest in the firm. Note that I is a fixed number, representing the

³ This restatement of Myers and Majluf (1984) owes much to Giammarino and Lewis (1988). However, Giammarino and Lewis (1988) employ a market mechanism involving firm investor bargaining, whereas we develop the model in the context of the auction market implicit in Myers and Majluf (1984).

funding necessary for the firm to undertake the project. Thus, the auction mechanism must be such as to prespecify the amount of money to be transferred to the firm in exchange for equity. This may be accomplished simply by conducting a descending equity demand auction to determine s . The investor who wins the auction by bidding the lowest value of s , provides the firm with the required I , in exchange for a claim of sV_i on the terminal value of the firm.

Investors must attempt to determine an appropriate value of s by comparing I to the expected value of sV_i . If $I > sV_i$ ex post, the investor will have lost. However, if $I < sV_i$ ex post, the investor will have profited. The problem for the investor is that the true value of i is unknown at the moment when he must decide on the appropriate share s of the firm's equity to bid. Given many risk-neutral competitive investors, the value of s will be bid down to the point at which $I = E(sV_i)$, where $E(\cdot)$ refers to the expectations operator. The two possible values for i are known to the investors. A prediction of the actual value of i for the equity on offer requires knowledge of the equilibrium type.

The literature contains a large number of refinements of the Nash equilibrium concept. An equilibrium notion that captures the intuitions being modeled is the sequential equilibrium concept of Kreps and Wilson (1982). This equilibrium concept was investigated experimentally by Camerer and Weigelt (1988) who found it to describe "actual behavior well enough that it is plausible to apply it to theoretical settings in which individuals make choices." Accordingly, it seems a sensible equilibrium notion for the theory underlying our experiments.

The sequential equilibrium is particularly simple in our environment. The firm has a choice of issuing, or not issuing, new equity at stage 1. Investors bid on issued equity at stage 2. A sequential equilibrium requires that investors form beliefs about the value of V_i , both in the case where the firm issues equity as well as in the case where it does not. Given the investors' beliefs and hence actions, the firm must not be able to gain by deviating from the equilibrium. Similarly, given the firms' beliefs and hence actions, the investors must not be able to gain by deviating.

As in many asymmetric information models, the character of the equilibrium will depend on the precise parameter values of the problem at hand. There are three regions of parameter values to be distinguished: a region of separation, a region of pooling, and a region in which either separation or pooling is consistent with theory. As will be discussed below, semiseparating is also possible in the overlapping region. In the present context, separation means that the type H firm does not undertake the new project. Pooling means that both

types of firms undertake their new projects. In every instance in which both equilibria are available, the pooling equilibrium Pareto dominates the separating equilibrium. The claims in the next three paragraphs follow directly from an application of Propositions 1 and 2 in Giammarino and Lewis (1988).

First, a unique pooling equilibrium in which both type H and type L firms proceed with new projects exists without an accompanying separating equilibrium if and only if $(I/V_L) < (B_H + I)/V_H$. The undertaking of new projects by both types of firms implies that both types of firms are using the financial market to raise funds from investors. Investors in turn will demand a fraction s^* of the firm's equity, where $s^* = I/(0.5 V_L + 0.5 V_H)$.

Second, a unique separating equilibrium in which type L firms proceed, while type H firms do not proceed, with new projects, exists without an accompanying pooling equilibrium if and only if

$$(B_H + I)/V_H < I/(0.5 V_L + 0.5 V_H).$$

Investors recognize this fact and hence demand a share $s^* = I/V_L$ of the firm.

Third, a pooling and a separating equilibrium exist simultaneously if and only if

$$I/(0.5 V_L + 0.5 V_H) < (B_H + I)/V_H < I/V_L.$$

In the pooling equilibrium, both types of firms proceed with new projects and the investors obtain $s^* = I/(0.5 V_L + 0.5 V_H)$ of the firm's equity. In the separating equilibrium, only type L firms proceed with the new projects and the investors obtain $s^* = I/V_L$ of the equity.

The previous three paragraphs are essentially a restatement of the results in Myers and Majluf (1984). The only significant difference is that we recognize the existence of a range of parameter values for which both pooling and separating equilibria exist. Interestingly, the numerical example of pooling given in Myers and Majluf (1984) actually falls within this overlapping region.

A third sort of equilibrium in which semiseparating⁴ takes place also exists if and only if

$$I/(0.5 V_L + 0.5 V_H) < (B_H + I)/V_H < I/V_L.$$

The necessary and sufficient conditions for the existence of a semiseparating equilibrium are identical to those associated with the simultaneous existence of pooling and separating equilibria described

⁴ Note that the semiseparating equilibrium derived here in the context of the Myers and Majluf (1984) setup with auctioned equity differs from the semiseparating equilibria derived by Giammarino and Lewis (1988) in the context of a signaling model where auctions are replaced by a negotiation process between the firm and the investor.

above. A semiseparating equilibrium requires that the type H firm be indifferent between undertaking and not undertaking the new project. Investors expect only a fraction of the type H firms to come to market. This has the effect of increasing investors' equity demands from any firm being financed, relative to such demands in the pooling case where all type H firms come to market. The reason is simple. Investors are less likely to be financing a type H firm because such firms undertake projects only some of the time in the semiseparating case.

Specifically, the manager of the type H firm will be indifferent between undertaking and not undertaking a project when the terminal value of the original owners' claim on the firm is identical regardless of the choice made, that is, when

$$(1 - s^*)V_H = V_H - I - B_H. \quad (1)$$

The value of s^* demanded by investors is a function of the probability of the type H firm undertaking available projects and hence issuing equity in the financial market. Let P denote the probability of the type H firm issuing equity and recall that the type L firm undertakes all projects in the semiseparating equilibrium. Then

$$s^* = I/[V_H P/(1 + P) + V_L/(1 + P)]. \quad (2)$$

Substituting Equation (2) into Equation (1) and solving for P yields

$$P = I/B_H - V_L(I + B_H)/B_H V_H, \quad (3)$$

which is the equilibrium P in the semiseparating equilibrium. Substituting the equilibrium P back into Equation (2) yields the equilibrium s^* under semiseparating.⁵

The preceding analysis assumes that there is no credible mechanism by which a firm might communicate its true value to potential investors. The lack of such a mechanism is damaging to the interests of the type H firm's initial owners. In all three equilibria, their equity is undervalued by the market relative to its true ex post value. If the underpricing is too severe, they simply stay out of the market.

⁵ It is easy to show by algebraic manipulation that, under the stated conditions, $0 < s^* < 1$ and $0 < P < 1$. This demonstrates sufficiency. To show necessity, note that investors will always purchase an equity issue for $s \leq I/V_L$. For all $s < (B_H + I)/V_H$, the owner of a type H firm strictly prefers to issue. Thus, for $(B_H + I)/V_H \geq I/V_L$, a type H firm will issue with probability 1 and a semiseparating equilibrium does not exist. If the probability that a type H firm issues is P and that a type L issues is 1, investors break even if

$$s = I/[PV_H/(1 + P) + V_L/(1 + P)].$$

Since $\partial s/\partial P < 0$, the minimum of s occurs when $P = 1$ and is $2I/(V_L + V_H)$. If

$$2I/(V_L + V_H) \geq (B_H + I)/V_H,$$

Type H is better off by not issuing with any positive probability and a semiseparating equilibrium does not exist.

2. Experimental Environment

In naturally occurring financial markets, participants normally have considerable experience interacting with their environment. In an experimental financial market, participants have much less time to acquaint themselves with their surroundings. It is important, therefore, that the experimental setup be made as transparent as possible to the participants.

In keeping with standard practice, the experiments were conducted in a sequence of independent rounds. There were no links across rounds concerning available actions, objective functions, or public information. What changed from round to round was simply that participants gained experience, becoming familiar with the experimental environment. Since theory pertains to equilibrium, our primary interest is in how markets perform once the subjects develop this familiarity.

In published experimental studies of finance theory, the subjects have usually been either economics or business students.⁶ The participants in our experiments were graduate economics and business students at Queen's University in Kingston, Ontario. We avoided the use of finance students on the grounds that they might be familiar with Myers and Majluf (1984). As in many other studies [e.g., Forsythe, Palfrey, and Plott (1982)], a notional currency was used in these experiments. This currency was known as francs. The participants were instructed on how to convert these francs into Canadian dollars and could use this formula to calculate dollar earnings after each round. Participants were paid by check at the end of the experiment. The earnings of the subjects varied depending both on luck and on how well they played the experimental game. The actual payoffs worked out to an average of \$22.05 and ranged from \$10.61 to \$28.17 for two hours of play. The subjects appeared well motivated and enthusiastic.

Upon arriving for the session, participants received instruction sheets that explained the rules and procedures of the experiment and a projects sheet describing the specific characteristics of the two types of firms, which were referred to as "situations." They were then divided into two groups, known simply as group A and group B. Group A corresponded to owner-managers, while group B corresponded to investors.⁷ We will refer to people in group A as "firms" and those in group B will be termed "investors." However, words such as "man-

⁶ However, Plott (1989) reports that "To date, no subject pool differences which bear on the reliability of economic theory have been reported."

⁷ The fact that each group A player is simultaneously both the original owner and the manager of a firm creates a clear incentive for management to act in the interest of the original shareholder. This identity of interest is one of the critical assumptions of the Myers and Majluf (1984) model.

ager," "investor," or "firm" were not used in the presence of the participants. Firms played in one room while the investors played in another. There was an individual experimenter or research assistant present in each room at all times in order to prevent potentially collusive discussions. There were always six firms and from eight to 12 investors depending on the session. In previous experiments, this number of auction participants has been found to be large enough to produce competitive equilibria.

At the start of each round, the experimenter approached each firm individually with a large envelope. Each such envelope contained two smaller envelopes. By choosing one of the smaller envelopes, each firm randomly selected their own type. Since there were only two smaller envelopes, they drew either type *H* or type *L*.⁸ Clearly, the two types were equally likely. The smaller envelopes contained sheets of paper describing each firm's opportunities for the round.

After observing their type, each firm could choose either to undertake or not to undertake the available new project. To undertake a project required *I*, which was set equal to 300 francs in all experiments. A decision to undertake the available project represented a simultaneous decision to raise these funds from the investors by transferring a percentage of the resulting terminal value of the equity to an investor. The actual percentage to be transferred in exchange for the required 300 francs was decided by means of a subsequent auction among the group of investors. The terminal value of the equity depended on which type had been drawn. On the other hand, a decision not to undertake the project implied retaining 100 percent of the equity of the firm and hence receiving a known sum of money. This amount also depended on which type had been drawn. For example, in experiment F, a type *H* firm would get $(1 - s)$ (1250) francs by choosing to undertake and 800 francs by choosing not to undertake the project. A type *L* firm would get $(1 - s)$ (750) francs by choosing to undertake and 400 francs by choosing not to undertake a new project. In both cases, *s* was an unknown number between 0 and 100% to be determined by auction.

At the start of each round, each investor was given a cash float of 1800 francs to be used during the round. The cash float for each round was independent of what had happened in the previous rounds. The 1800 francs were enough to permit any individual investor to finance all six projects that could theoretically require financing.⁹ In each

⁸ Situation 1 corresponded sometimes to being a type *H* firm and sometimes a type *L* firm. Situation 2 always corresponded to the opposite type. While the experiments were conducted in terms of "situations" 1 and 2, for clarity our discussion will make the conversion into types *H* and *L* as appropriate.

⁹ To ensure that repayment of the float would not disrupt the equilibrium predictions, they were only required to return 1050 francs.

round, six envelopes were brought into the investor's room from the other group. The envelopes were opened by the experimenter one at a time. After each envelope was opened, the experimenter announced "no new project" or "a new project." Apart from two initial symmetric information experiments to be described in more detail below, the investors were not informed about which of the two situations the firm in question had drawn. Note that the investors did know the two possible types of firms, but not the actual outcome for any given firm. An oral auction was then used, with bidding conducted in terms of s , fraction of firm equity demanded. Whichever investor demanded the *lowest* fraction of the firm's equity won the auction. Bidding started high and ended when no investor was willing to undercut the standing bid. Whichever investor won the auction gave up 300 francs to the firm and received the fraction of the firm's equity that the investor had himself bid. All bids were in terms of integer percentages, such as 82 percent followed by 81 percent, etc. Fractional percentage bids were not allowed. This was done to avoid the problem of undercutting by an ever lengthening series of decimal points.

The numerical parameters selected for experiments A–J are set out in Table 1. The letters designating the experiments correspond to the chronological order in which they were conducted. Experiments A and B differed from the subsequent sessions in that the investors were informed as to the type drawn by a particular firm prior to the auctioning of its equity. These symmetric information cases were used to establish a benchmark. It was important to ensure that the basic auction structure was behaving as expected before introducing asymmetric information.

For the first eight experiments, we kept two distinct groups of participants. Specifically, experiments A, C, E, and G were undertaken by the "morning" group, while experiments B, D, F, and H were undertaken by the "afternoon" group.¹⁰ This was an attempt to control for learning that might take place across experimental sessions. Our concern was quite specific. We were particularly interested in the outcomes of experiments in which pooling, separating, and semiseparating were all equilibria. Our conjecture prior to conducting the experiments was that past experience might be crucial. The idea was that people who had just experienced an experiment that separated might continue to expect separation. In such an instance, the decisions taken would tend to validate the separating equilibrium in a subsequent multiple equilibrium experiment. Similarly, subjects who had just experienced a pooling equilibrium would produce a pooling

¹⁰ Participants occasionally missed an experiment or dropped out of a group. However, nobody was permitted to participate in both groups.

Table 1
Experimental parameters

Ex- peri- ment	Subjects	Type <i>L</i>		Type <i>H</i>		Exchange rate for firms	Number of investors
		No new project	New project	No new project	New project		
A	A.M.	250	625	500	1250	0.00330	11
B	P.M.	160	500	620	1000	0.00470	12
C	A.M.	300	750	625	1250	0.00300	11
D	P.M.	80	400	270	600	0.01100	10
E	A.M.	50	375	200	625	0.01100	10
F	P.M.	400	750	800	1250	0.00300	10
G	A.M.	150	480	450	810	0.00610	8
H	P.M.	150	480	450	1050	0.00452	10
I	Mixed	375	750	1875	2250	0.00175	12
J	Mixed	240	600	880	1400	0.00300	10

During experiments A and B, the investors were informed of the firm's type prior to the auction. The financing provided by the investor who won an auction was 300 francs in each experiment. There were always six firms. The heading "No new project" lists the payoff to the firm if no new project was selected. The heading "New project" gives the total payoff if a new project was selected. "Exchange rate for firms" refers to the rate at which francs were converted into real dollars for the firms. For the investors, the conversion formula involved subtracting 1050 and multiplying the resulting number of francs by 0.0028 in all experiments. Exchange rates were chosen so that a good player in either group could expect to earn \$2.10 per round on average.

outcome in a multiple equilibrium environment. This conjecture did not turn out to be correct.

The theoretical predictions are listed in Table 2. The numerical values follow directly from the theoretical discussion in Section 1. Experiments A and B were the only symmetric information cases (i.e., the investors knew the firm's type before bidding). The numerical values for experiment A were such that, if it had actually been a case with asymmetric information, the predicted equilibrium would have involved pooling. Experiment B would have been a case of a separating equilibrium if there had been asymmetric information.

Experiment C used numerical values such that theory predicts a unique pooling equilibrium. The numerical values used in experiments D, G, and I lead to the prediction of a unique separating equilibrium. The numerical values for experiments E, F, H, and J are such that, according to theory, one pooling, one separating, and one semiseparating equilibria all coexist. These sessions are of particular interest. The morning group of subjects in experiment E had recently participated in experiment C, which was theoretically predicted to pool. None of them had previously experienced a separating equilibrium. The afternoon group of subjects in experiment F had recently participated in experiment D, which was theoretically predicted to exhibit separation. None of them had previously experienced a pooling equilibrium. The subjects in experiment J were a mixed group who possessed a variety of previous experiences. However, most of

Table 2
Equilibrium predictions

Experiment	Equilibrium	Type <i>L</i>		Type <i>H</i>	
		Pr(NP)	<i>s</i> *	Pr(NP)	<i>s</i> *
A	SI	1	48	1	24
B	SI	1	60	1	30
C	P	1	30	1	30
D	S	1	75	0	0
E	S	1	80	0	0
E	P	1	60	1	60
E	SS	1	68	0.36 ¹	68
F	S	1	40	0	0
F	P	1	30	1	30
F	SS	1	36	0.20 ¹	36
G	S	1	62.5	0	0
H	P	1	39.2	1	39.2
H	S	1	62.5	0	0
H	SS	1	57.1	0.09 ¹	57.1
I	S	1	40	0	0
J	S	1	50	0	0
J	P	1	30	1	30
J	SS	1	37.1	0.35 ¹	37.1

SI means symmetric information equilibrium, P means pooling equilibrium, S means separating equilibrium, and SS means semiseparating equilibrium. Pr(NP) is the probability of a new project being undertaken by the indicated type of firm in the particular equilibrium. *s** is the predicted percentage of a firm's equity that belongs to the investor according to the particular equilibrium.

¹ In the semiseparating case, the percentage ownerships listed are conditional on having undertaken the project. Otherwise, the original owner retains 100 percent of equity.

them had participated in experiment I, a separating equilibrium case, earlier the same day. The subjects in each of the experiments with multiple equilibria had previous experience in the experimental environment.

Experiment G used numbers taken from the example of separating and experiment H used numbers taken from the example of pooling employed by Myers and Majluf (1984). All numbers were multiplied by 3. However, this does not change the theoretical predictions. Though presented by Myers and Majluf (1984) as an example of pooling, the numbers used in experiment H are actually consistent with pooling, separating, and semiseparating.

3. Empirical Results

The main empirical results for experiments A-J are summarized in Table 3 and Figures 1-10.¹¹ Experiments A and B were cases of sym-

¹¹ In the figures, the type *L* firms are grouped at the start of each round, while the type *H* are grouped at the end of the round. This is for convenience of illustration and does not represent the precise intraround order of the auctions. In Table 3, we focus on the final two rounds because we are mainly interested in the equilibrium. However, there are only six firms in each experiment. By reporting results for the last two rounds, we increase the number of decisions to 12.

Table 3
Last two round outcomes

Ex- peri- ment	Type <i>L</i>		Type <i>H</i>		Actuals for new projects			Predicted <i>s</i>
	Number	New project	Number	New project	Highest	Lowest	Mean	
A	6	6			48	48	48	(48)
A			6	6	24	24	24	(24)
B	9	9			60	60	60	(60)
B			3	3	30	30	30	(30)
C	6	6	6	6	29	28	28.3	(30)
D	8	8	4	0	58	56	57.5	(75)
E	4	4	8	8	60	56	58.3	(60)
F	5	5	7	7	30	28	29.3	(30)
G	6	6	6	0	62	60	61.7	(62.5)
H	6	6	6	6	39	37	37.8	(39.2)
I	4	4	8	0	40	37	38.5	(40)
J	5	5	7	7	30	28	28.8	(30)

Number refers to the number of players who drew the particular firm type during the last two rounds. Under the heading "New project," we list the number of players of the indicated type who chose to undertake the new project. *s* refers to the actual percentage of the firm's equity demanded by the investor as the outcome of the auction. Predicted *s* reproduces the theoretically forecast value of *s*. For the multiple equilibria experiments, we list the value associated with the pooling equilibrium.

metric information. The investors were told whether a particular firm was type *H* or type *L* before each auction took place. The results illustrated in Figures 1 and 2 indicate that theory was a completely accurate guide to the outcomes of these experiments and that convergence to equilibrium occurred very rapidly. Experiment C produced the unique theoretically predicted, pooling equilibrium as shown in Figure 3. Convergence was immediate. The unique separating equilibrium forecast was verified in experiments G and I as illustrated by Figures 7 and 9. However, convergence took considerably longer than in the cases discussed previously. In experiments G and I, many firms and investors tried pooling initially. On finding that separating would result in higher payoffs, the firms separated. As can be seen in Table 4, this process took until round 6 in the case of experiment G and until round 4 in the case of experiment I. Investors moved gradually to the separating equilibrium. In both experiments, convergence was essentially complete by round 7.

Our most important finding concerns the situation in which theory makes an ambiguous prediction due to the existence of multiple equilibria. Pooling, separating, and semiseparating equilibria are all consistent with the numerical values used in experiments E, F, H, and J. However, a glance at Figures 5, 6, 8, and 10 shows that all of these multiple equilibria experiments actually produced outcomes corresponding to the pooling equilibrium, regardless of whether the subjects had previously experienced a pooling or a separating equi-

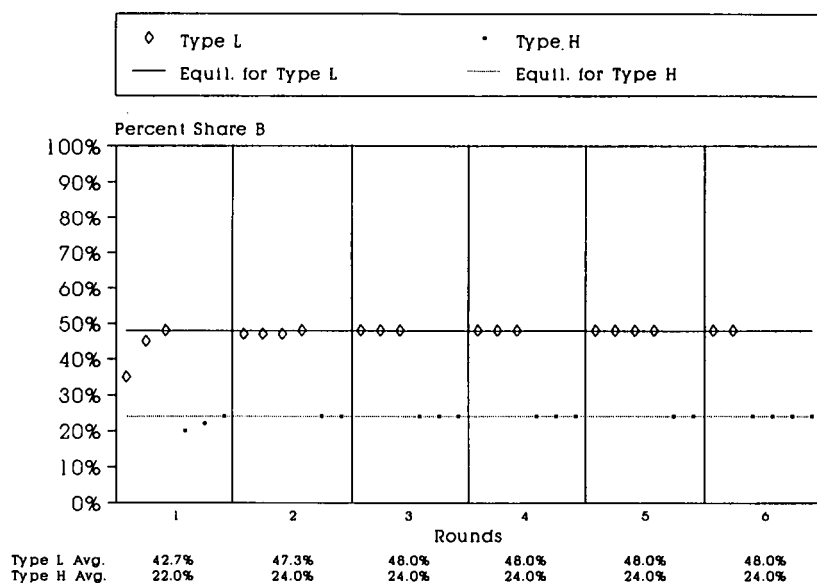


Figure 1
Experiment A (Morning Group)

Information was symmetric in this experiment in that the investors knew the type of each firm before the auction. The symbols indicate outcomes of each individual auction. Convergence to the theoretically predicted equilibrium occurred by round 3.

librium. Price convergence occurred by round 2 in experiments E and F and instantaneously in the later experiments, H and J.

Only one experiment produced a genuine failure for theory, namely, experiment D, illustrated in Figure 4. In that case, the firms separated just as theory predicts. However, type H firms took until round 8 to depart entirely from the market. This slow convergence of the firms to the predicted separating equilibrium was reflected in the failure of the investors to learn that all type H firms had left the market before the experiment ended in round 10. Thus, the investors appeared to price the equity as if the firms were pooling. However, pooling was not an equilibrium for these parameter values. Accordingly, the investors who won the auctions consistently lost money in the later rounds. Because of the surprising nature of this session, we ran an extra session using parameters that theoretically induce separation, namely, experiment I. As already mentioned, the anomaly did not reappear.

During the final two rounds of all ten experiments including the anomalous experiment D, firms undertook new projects when, and only when, the Myers and Majluf (1984) analysis predicted that they would. Even during the earlier rounds, there were not a large number of incorrect predictions.

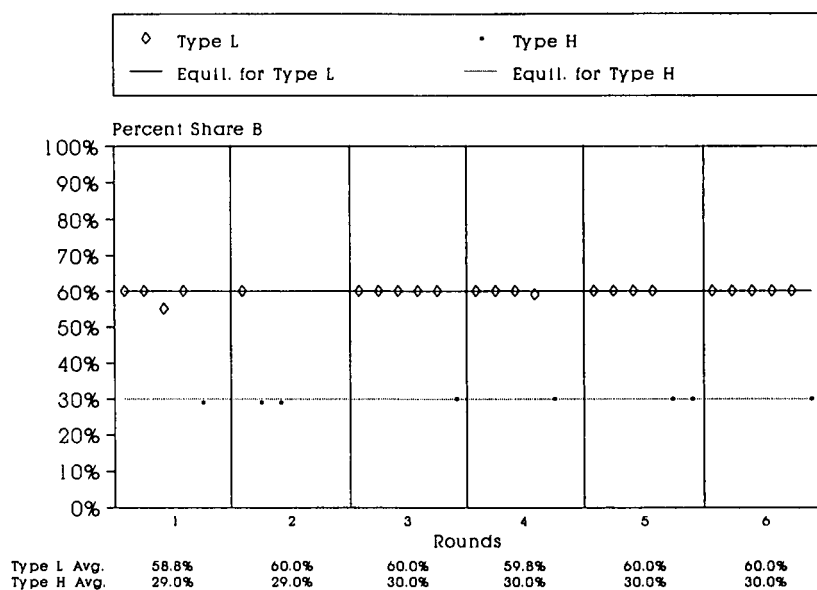


Figure 2

Experiment B (Afternoon Group)

Information was symmetric in this experiment in that the firms knew the type of each firm before the auction. Convergence to the theoretically predicted equilibrium occurred by round 5.

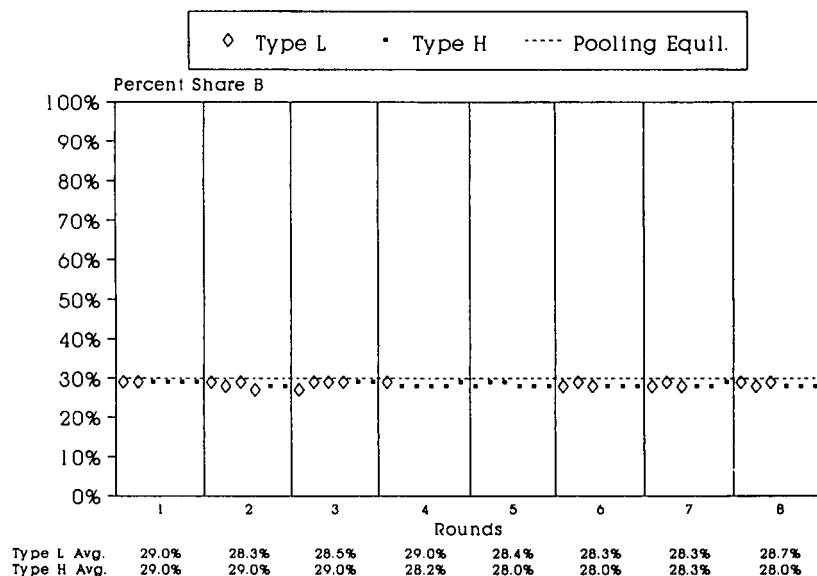


Figure 3

Experiment C (Morning Group)

This was an asymmetric information experiment with a unique pooling equilibrium predicted by theory. Convergence to a point just below the theoretically predicted equilibrium was instantaneous.

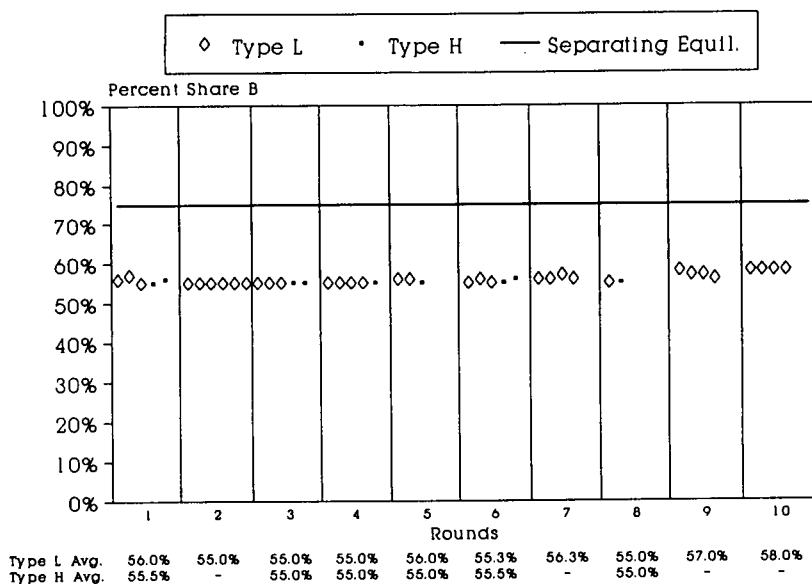


Figure 4
Experiment D (Morning Group)

This was an asymmetric information experiment with a unique separating equilibrium predicted by theory. Spaces left in each column to the right of the symbols represent type *H* firms that did not undertake the available new projects. By round 8, all type *H* firms had left the market as predicted by theory. However, the investors did not converge to the separating equilibrium but continued to bid as if any project on offer involved in equal probability of coming from a type *H* or type *L* firm.

The actions of the investors are quite readily understood. The percentage of equity demanded by the investors corresponded closely to the theoretical predictions. Apart from session D, the largest mean deviation from a theoretical equilibrium prediction in the final two rounds was just 1.7 percent.

There are two distinct approaches taken by theorists to the interpretation of equilibrium theory. One view is that calculations are virtually costless and hence the system jumps instantly to equilibrium. The other interpretation is that equilibrium theory represents the outcome of some as yet unknown process [e.g., Lucas (1986)].

Our findings along with almost all other experiments seem to correspond to the second interpretation. Whenever a pooling equilibrium exists, experimental subjects seem to find it almost instantaneously. However, when a pooling equilibrium does not exist, a process of convergence of the unique separating equilibrium takes place. That process seems to involve some firms trying to pool, learning it is not a profitable strategy and ultimately separating (Table 4).

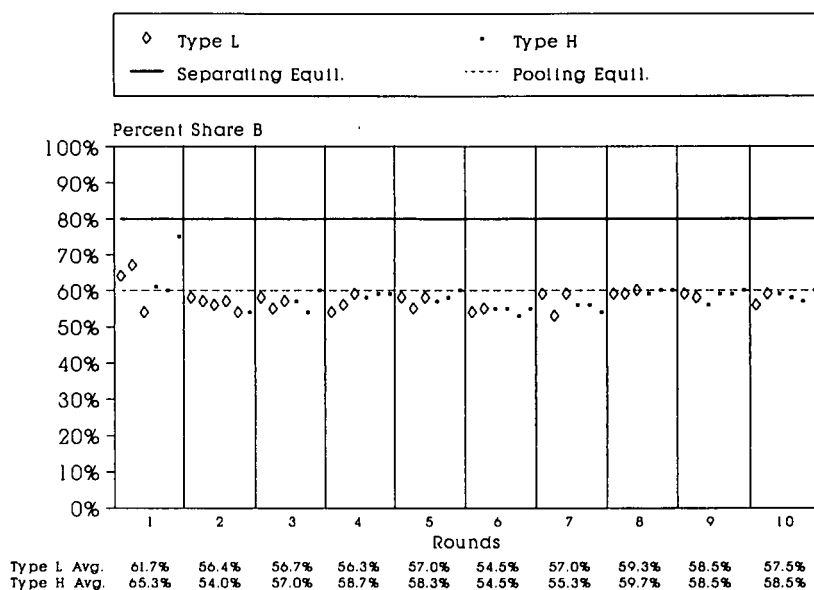


Figure 5
Experiment E (Morning Group)

This was an asymmetric information experiment in which a pooling, a separating, and a semiseparating equilibrium coexist. The semiseparating equilibrium lies in between the separating and pooling equilibria but is not shown in the diagram. Very little was learned between rounds 2 and 10. The players moved very rapidly to a small range of prices just below the predicted pooling equilibrium.

As the firms separate, the investors follow.¹² Our interest focused on the experiments in which theory predicts multiple equilibria. The dominance of pooling over separation did not correspond to our prior expectations. Before running the experiments, we had anticipated that the experience of the subjects participating in any particular session might be the crucial determinant of which equilibrium would actually occur. We were mistaken. Whether a subject had been exposed only to pooling (experiment E), only to separation (experiment F), only to separation and a previous multiple equilibrium case that pooled (experiment G), or to both pooling and separation with separation earlier that same day (experiment J) played no role in determining which equilibrium was selected in the multiple equilibrium case. The more efficient pooling equilibrium was consistently chosen over both other available equilibria.

¹² It is interesting to observe that this is precisely the way Myers and Majluf (1984) present their example, indicating that separation may occur. Firms try pooling, but then realize that separation is more profitable.

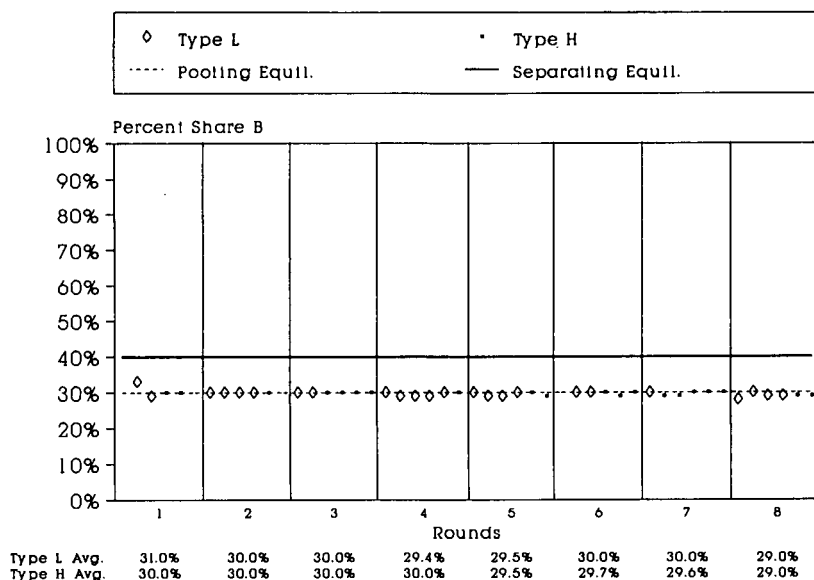


Figure 6
Experiment F (Afternoon Group)

This was asymmetric information experiment in which a pooling, a separating, and a semiseparating equilibrium coexist. The semiseparating equilibrium lies between the separating and pooling equilibria but is not shown in the diagram. Spaces left in each column to the right (left) of the symbols represent type *H* (*L*) firms that did not undertake their available projects. The players converged to a price slightly below the predicted pooling equilibrium by round 2. However, a type *H* firm chose not to undertake a project in round 2 and a type *L* firm chose not to undertake a project in round 6.

Why did pooling dominate separation? A particularly simple interpretation appeals to us. Suppose that different investors expect different types of equilibria; some anticipating separation and others expecting a pooled equilibrium. The investors who expect the pooling equilibrium are always willing to undercut those who expect separation. Accordingly, they set the price of equity because they remain in the auction longer. Two aggressive investors anticipating a pool would suffice to drive the equilibrium to the pooling outcome. We would expect to find many aggressive investors in most naturally occurring financial markets.¹³ Furthermore, it also seems plausible that the more investors there are, the more likely it is that at least two will expect pooling.

¹³ This argument would, however, be disrupted if there are short sales. Aggressive short selling by those who expect a separating equilibrium would leave the outcome unclear. While short sales may be hard to envisage in an initial public offering, in other multiple equilibria situations they may be quite natural. For general environments, it is hard to know what outcome would arise if different investors expect different types of equilibria.

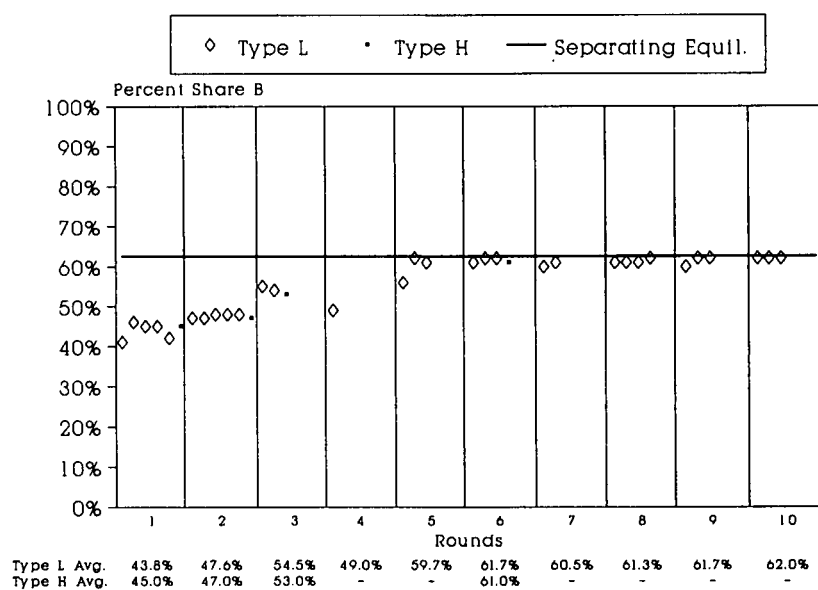


Figure 7

Experiment G (Morning Group)

This was an asymmetric information experiment with a unique separating equilibrium predicted by theory. The parameters of the experiment were taken from an example of separating in Myers and Majluf (1984) and multiplied by 3. Spaces left in each column to the right of the symbols represent type *H* firms that did not undertake their available projects. Convergence to a point just below the separating equilibrium occurred by round 7.

When the equilibrium was unique, the result was not always exactly as predicted. There were fairly small deviations observed. All mean deviations from the equilibrium were slightly on the aggressive bidding side. There are several possible interpretations of this fact. First, it has been suggested to us that the investors derive some, obviously small, amount of utility simply from "winning" the auction. This idea seems unlikely. In the symmetric information case, the observed equity demand was exactly equal to the theoretical prediction. Is winning the auction only prestigious under asymmetric information?

A second interpretation is that the subjects may be slightly risk preferring. A third possibility is that the investors are unwittingly making slight calculation errors in determining their reservation demands. If the calculation errors are unbiased, then those who make an error which leads to an excessively low demand for equity will systematically be the winners. This idea, which is somewhat in the spirit of a trembling hand equilibrium notion, would predict a small winner's curse. The winner's curse is actually observed. Unfortunately, it is not clear how to distinguish this interpretation from risk preferring tastes.

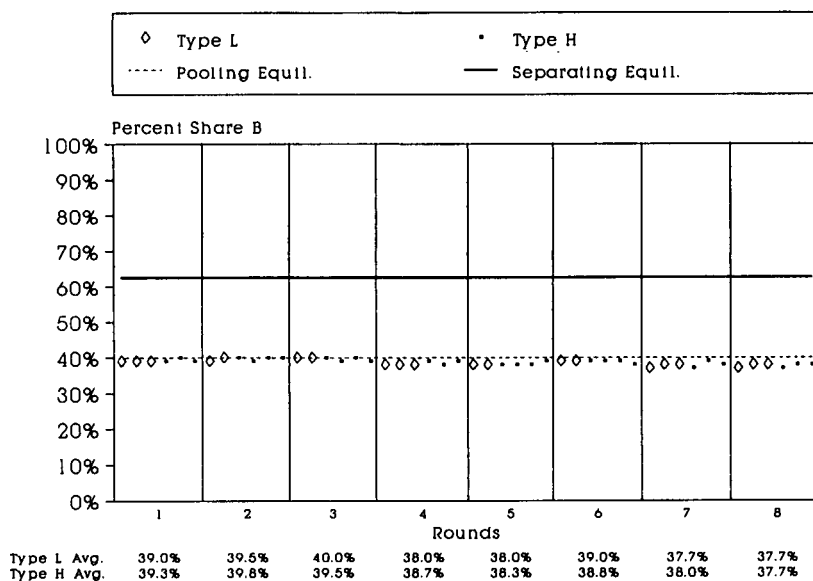


Figure 8
Experiment H (Afternoon Group)

This was an asymmetric information experiment in which a pooling, a separating, and a semiseparating equilibrium coexist. The semiseparating equilibrium lies between the separating and pooling equilibria but is not shown in the diagram. The parameters of the experiment were taken from an example of pooling in Myers and Majluf (1984) and multiplied by 3. The players converged instantly to a point slightly below the predicted pooling equilibrium.

4. Will Firms Use a Signal to Break a Pool?

One quite natural reaction to the Myers and Majluf (1984) model is to argue that good firms will find ways to signal their type. In the pooling equilibrium, the type *H* firm would be interested in finding a way to prove to the market that it is of high quality. We ran one experiment specifically to address this issue.

The corporate finance literature has considered several ways in which firms might try to use signals to reveal their true type to investors. In each case, the idea is for a type *H* firm to find an action that will be unprofitable for the type *L* firm to mimic. By so doing, a type *H* firm reveals its type to the market, thus receiving better treatment. Though the action may provide no direct benefit, it acts as a signal, providing an indirect benefit as a result of its effect on the behavior of others.

Suppose a signaling mechanism is available, requiring a type specific cost of C_i (recall that i is either *H* or *L*) borne by the original

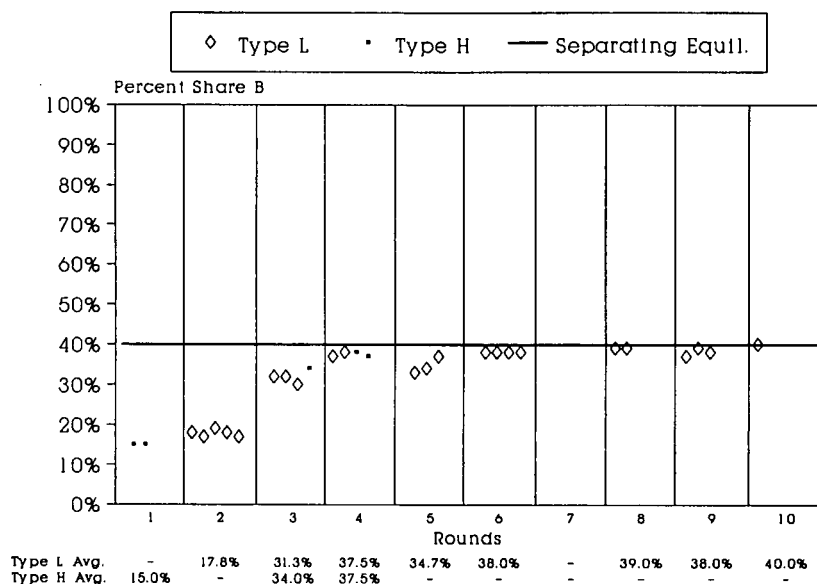


Figure 9
Experiment I (Mixed Group)

This was an asymmetric information experiment in which a unique separating equilibrium is predicted by theory. Convergence to a point just below the separating equilibrium occurred by round 6. In round 7, all firms drew type *H* and they all selected no new project as predicted by theory.

owner of the firm.¹⁴ In a signaling equilibrium, investors believe that the type *H* firm purchases the signal and the type *L* firm does not. Believing this, the investors demand $s_H = I/V_H$ from a firm that has purchased a signal and $s_L = I/V_L$ from a firm that does not signal. In order for these beliefs to be consistent, there are two restrictions that must be satisfied. First, the type *L* firm must have no incentive to purchase the signal. This requires that C_L be greater than $(1 - s_H)V_L - (1 - s_L)V_L$. The second requirement is that the type *H* firm make a positive profit net of the cost of the signal. This requires that C_H be less than $(1 - s_H)V_H - (1 - s_L)V_H$. Our interest in this section is limited to the issue of breaking a pool. Thus, we focus on parameters for which the type *H* firm will be better off in the signaling equilibrium than in the pooling equilibrium. For this to be the case, $(1 - s_H)V_H$

¹⁴ One way to think about the signal is in terms of a voluntary audit. If the firm decides to be audited, the auditor's report will be made public before the equity issue. The firm will only wish to be audited if the auditor's report is going to be favorable. It is easier for a type *H* firm to convince an auditor that it is of high quality than it is for a type *L* firm. However, at some added cost, it is possible for the type *L* firm to arrange matters such that the auditor will be fooled. Under this interpretation, C_L is greater than C_H and all voluntarily undertaken auditor's reports are favorable announcements concerning the firm.

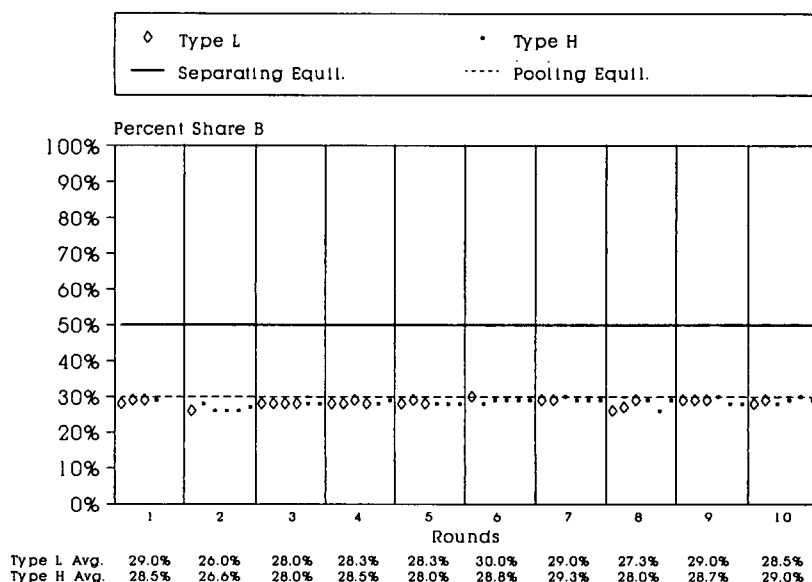


Figure 10
Experiment J (Mixed Group)

This was an asymmetric information experiment in which a pooling, a separating, and a semiseparating equilibrium coexist. The semiseparating equilibrium lies between the separating and pooling equilibria but is not shown in the diagram. Spaces left in each column to the right of the symbols represent type *H* firms that did not undertake their available projects. The players converged instantly to a point slightly below the predicted pooling equilibrium.

— C_H must be greater than $[1 - 2I/(V_H + V_L)]V_H$. The numerical values for experiment K are of this form.

The setting was the same as in the previous experiments with one important change. When the firms opened their envelopes to determine their type, they were also informed of the price of an advertisement (signal). An advertisement worked in the following manner. If the firm bought the signal, the auctioneer announced to the investors that an advertisement had been purchased by that firm. The announcement was made before the auction took place. The cost of the signal for each type was public information. Note that any such signal had to be purchased on credit since the firm had no liquid assets available. The purchase of an advertisement is thus a commitment by the firm to "burn money" from their terminal cash flows. This commitment provides a requisite signal.

The numerical values for a type *L* firm in experiment K provided a payoff of 50 francs if no new project was undertaken and 400 francs if a new project was undertaken. The signal cost the type *L* firm 120 francs. For a type *H* firm, the payoffs were 100 and 600 francs, respectively. The signal for a type *H* firm cost only 30 francs.

Table 4
Issuing decisions by firms

Experiment	D		G		I	
	Type L	Type H	Type L	Type H	Type L	Type H
1	3/3	2/3	5/5	1/1	0/1	2/5
2	6/6	0/0	5/5	1/1	5/5	0/1
3	3/3	2/3	2/2	1/4	3/4	1/2
4	4/4	1/2	1/1	0/5	2/2	2/4
5	2/2	1/4	3/3	0/3	3/4	0/2
6	3/3	2/3	3/3	1/3	4/5	0/1
7	4/4	0/2	2/2	0/4	0/1	0/5
8	1/1	1/5	4/4	0/2	2/2	0/4
9	4/4	0/2	3/3	0/3	3/3	0/3
10	4/4	0/2	3/3	0/3	1/1	0/5
P						
S	1	0	1	0	1	0
SS						

Experiment	E		F		H		J	
	Type L	Type H	Type L	Type H	Type L	Type H	Type L	Type H
1	3/3	3/3	2/3	2/3	3/3	3/3	2/2	2/4
2	5/5	1/1	4/4	1/2	2/2	4/4	1/1	5/5
3	3/3	3/3	2/2	4/4	2/2	4/4	4/4	2/2
4	3/3	3/3	5/5	1/1	3/3	3/3	4/4	2/2
5	3/3	3/3	4/4	2/2	2/2	4/4	3/3	3/3
6	2/2	4/4	2/3	3/3	2/2	4/4	1/1	5/5
7	3/3	3/3	1/1	5/5	3/3	3/3	2/2	4/4
8	3/3	3/3	4/4	2/2	3/3	3/3	3/3	3/3
9	2/2	4/4					3/3	3/3
10	2/2	4/4					2/2	4/4
P	1	1	1	1	1	1	1	1
S	1	0	1	0	1	0	1	0
SS	1	0.36	1	0.20	1	0.09	1	0.35

Experiments A, B, C, and K are not included because, in each case, theory predicts that all firms should undertake the new projects. In 168 out of 174 decisions made by firms in these experiments this prediction was correct. None of the deviations occurred after round 4. The table entries take the form x/y , where y refers to the total number of firms who drew the particular type in the given round of the indicated experiment. x is the number that decided to proceed with a new project. The row beginning with P lists the probability of a particular type of firm proceeding with a new project in the pooling equilibrium. Similarly S refers to the probability in the separating equilibrium and SS refers to the semiseparating equilibrium.

The equilibrium outcome is readily computed for these numerical values. If there were no opportunity to signal, then the equilibrium would be of the pooling type. In that equilibrium, the investors would get 60 percent of each firm's equity, leaving the other side with 40 percent.

The availability of the signal drastically alters the theoretical prediction. The prediction is now that both types of firms will undertake their new projects. Type H firms will buy the signal. The investors

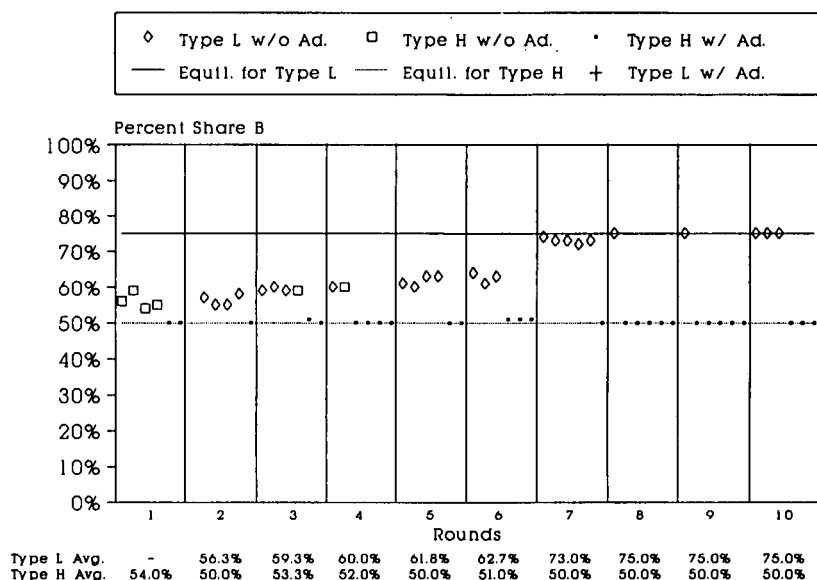


Figure 11
Experiment K

This is an asymmetric information experiment which has an equilibrium in which the type *H* firm could purchase a signal to demonstrate to the investors that the particular firm was really of type *H*. Spaces left in each column to the left of the symbols represent type *L* firms that did not undertake their available new projects. No type *L* firm tried to send a signal by purchasing advertising. Convergence to the equilibrium pricing for each type of firm occurred at round 8.

will demand 75 percent of the equity from the firms that do not signal (type *L*) and only 50 percent from the firms that do signal (type *H*).

The results presented in Table 5 and illustrated in Figure 11 show that the theoretical prediction is exactly borne out. Firms bought the predicted signals and the investors reacted to the signals in the expected manner. However, as can be seen from Figure 11, convergence to the equilibrium took until round 8. As in the other cases of separation, converging to a signaling equilibrium was more challenging than finding a simple pooling equilibrium.

5. Concluding Remarks

We have empirically investigated the problem proposed by Myers and Majluf (1984). Their paper has received a great deal of attention but no direct tests. In order to test their ideas directly, we ran experiments in which subjects faced the actual constraints and reward structures postulated by the theory. More generally, we have demonstrated that game theoretic financial models are amenable to testing, using the

Table 5
Last Two Round Outcomes for Signaling Experiment K

Firm type	Number	New project with signal	New project no signal	Actual <i>s</i> for new projects		Predicted <i>s</i>
				Highest	Lowest	
L	4	0	4	75	75	(75)
H	8	8	0	50	50	(50)

"Number" refers to the number of players who drew the indicated firm type during the last two rounds. Under the heading "New project with signal," we list the number of players of the indicated type who chose to undertake a new project and to purchase a signal. "New project no signal" is defined analogously. "Actual *s*" refers to the actual percentage of firm equity transferred to the investor as a result of the auction. "Predicted *s*" gives the share that is predicted by the signaling equilibrium.

same general methods that have been used previously for testing asset pricing theory.

There are four substantive conclusions to be drawn from this study. First, when the theory predicts a unique equilibrium, that prediction was borne out by the equilibrium actions of the subjects. This is encouraging. If it were not true, one might have questioned the usefulness of game theoretic models of financial markets. Instead, our results suggest that game theoretic ideas are very useful in predicting market outcomes.

The second conclusion concerns situations of multiple equilibria. We show that the Myers and Majluf (1984) setup does have multiple equilibria for a range of parameter values. This fact was not mentioned in their paper. If pooling, semiseparation, and separation are all equilibria, the appropriate theoretical prediction becomes unclear. When theoretical means are unable to answer important questions, it is natural to look for other tools. Experiments represent one such tool.

In this study for every case in which pooling, separation, and semiseparation are all sequential equilibria, the subjects pooled. The fact that this result was robust to variations in the previous experiences of the subjects is important. It is also interesting to note that the chosen pooling equilibrium is always Pareto superior to both the separating and the semiseparating possibilities. To the extent that future theoretical models with multiple equilibria parallel the environment that we have examined, we would argue that priority should be given to the pooling outcome.

The third result concerns the way in which equilibrium is attained. Although the subjects moved almost instantaneously to an available pooling equilibrium, they converged more slowly when only a separating equilibrium was available. It would be difficult to attempt to exploit the convergence processes that we observed for financial profit. This difficulty would be particularly acute in naturally occurring finan-

cial markets, because it might not be clear whether one is in the midst of a convergence process or at a fundamental equilibrium.

The final result concerns the use of signals. Good firms often have an incentive to use signals in order to distinguish themselves from bad firms. If available, such signals can, in theory, often improve the treatment that good firms receive from investors. We have demonstrated that such signals can work, not only in theory, but also in fact. The good firms in our experiment did exploit the opportunity to use a signal to break a pooling equilibrium.

There are two major directions for further experimental research that we regard as particularly interesting. First, we are investigating the role of signals in more depth. One idea that has been frequently suggested is that firms may use their capital structure or dividend policy as signals.¹⁵ The second question of interest to us concerns the institutional structure. Different institutions offer differing degrees of commitment and hence may alter the range of possible equilibria as in Giammarino and Lewis (1988). We are particularly interested in finding out whether pooling will continue to dominate separation and semiseparation in such environments.

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¹⁵ For respective examples, see Noe (1988) and John and Williams (1985).

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