Equilibrium Dominance in Experimental Financial Markets

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We examine the predictive power of equilibrium dominance in experimental markets where firms with investment opportunities have an informational advantage over potential investors and are permitted to purchase a money-burning signal. Equilibrium dominance often fails to predict well when a Pareto-superior sequential equilibrium is also available. Instead, equilibrium selection appears to be related to the potential earnings of a more valuable firm that can signal its type successfully by defecting from the sequential equilibrium. Potential investors

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formulate their bids for firm equity based primarily on expectations formed adaptively in response to signaling choices made by firms.

Much attention has been devoted to the effects of informational asymmetries in finance. In such asymmetric information models, there are often multiple Nash equilibria. The appropriate interpretation of models with multiple equilibria is a matter of some controversy. Theorists have reacted in a variety of ways to the problem. Some focus attention on a favorite equilibrium in their model, ignoring all others. More commonly there is an attempt to justify an equilibrium selection by appeal to one or more "refinement" concepts.[1] Different analysts seem to prefer different refinements.

In this article we provide experimental evidence concerning the predictive power of one particularly popular refinement, namely equilibrium dominance, also known as the intuitive criterion, developed by Cho and Kreps (1987). We examine equilibrium dominance in the context of simple financial markets in which the proposed refinement makes clear, testable predictions. These predictions are then compared to the actual behavior of agents in a controlled setting. The objective is to determine the extent to which equilibrium dominance successfully predicts equilibrium selection.

This article focuses on equilibrium dominance for several reasons. First, it is one of the most commonly invoked of the many available refinement concepts used in theoretical finance models [e.g., Hirshleifer and Png (1989), Berkovitch and Khanna (1990), Eckbo, Giammarino, and Heinkel (1990), Chemmanur and Fulghieri (1994), Chowdhry and Jegadeesh (1994)]. Second, equilibrium dominance has predicted well in some simple two-person matrix games in which a sequential equilibrium satisfying equilibrium dominance coexists with one that does not [Brandts and Holt (1992), Banks, Camerer, and Porter (1994)]. However, it did not do nearly so well when payoffs were explicitly manipulated to discourage previously observed convergence patterns favorable to equilibrium dominance [Brandts and Holt (1992, 1993)]. It is difficult to predict a priori just how it would perform in a financial market context with large numbers of participants. Third, many of the other refinement concepts refine to a subset of the equilibria which satisfy equilibrium dominance and are frequently used to select between several equilibria, all of which satisfy the requirements

[1] A refinement concept is a proposed set of principles used to eliminate some Nash equilibria from consideration as solutions to a model.

of equilibrium dominance. Hence examining the predictive power of equilibrium dominance seems like a good place to start before studying the predictive power of other refinements in experimental financial markets.

The experimental environment that we study is based on an asymmetric information signaling model. Signaling models are often applied in a very specific manner. The researcher begins with some anomalous empirical observation in which it seems that firms are foolishly wasting money. It is then suggested that by apparently wasting money, the firm is actually communicating to the market. Through demonstrating its willingness to waste money, the firm is indicating that it is particularly good. Accordingly this firm should receive better treatment from the market. For the signaling to work, it must be the case that this sort of communication cannot be profitably mimicked. The researcher must confirm that the better treatment by the market is worth more than the money being wasted by the better firm, and also that it is worth less than the cost of mimicry for the worse firm. Daniel and Titman (1995) note that a large class of models in finance theory has this basic signaling structure.

In many models one can construct a signaling equilibrium for a range of parameter values. However, in such cases, there is a second pure strategy equilibrium in which the market refuses to believe that wasting money is rational. If the market believes that wasting money is irrational, then it will not offer better treatment to a firm that wastes money. In that case, it does not pay firms to waste money. One can often construct further equilibria between the two described above. In these further equilibria, some or all of the players use mixed strategies.

Finance theorists often wish to focus on equilibria that involve separation of firms by type [e.g., Berkovitch and Khanna (1990), Eckbo, Giammarino, and Heinkel (1990), John and Lang (1991), Nanda (1991), Chowdhry and Jegadeesh (1994)]. In such cases, the equilibrium in which investors disbelieve the signal is a nuisance because it undermines the proposed explanation of the anomaly. In order to justify focusing attention on the signaling equilibrium and disregarding the nonsignaling equilibrium, the theorist generally makes an appeal to a refinement concept. However, different theorists invoke different equilibrium refinements, raising the question of which, if any, of these refinements possess predictive power in the particular asymmetric information contexts in which they are applied.

There have been a number of experimental studies analyzing the effects of asymmetric information. DeJong, Forsythe, and Lundholm (1985) examined an agency situation, but did not focus on refinement concepts. Similarly, Miller and Plott (1985) examined experimental markets in which signaling was feasible, but did not relate their findings to refinement concepts.

Camerer and Weigelt (1988) tested a model using a two-person game in which some agents were more likely than others to default on their loans. While the sequential equilibrium refinement concept did not account for all of the observed behavior, it worked fairly well. From among the sequential equilibria, the subjects converged to the unique equilibrium that satisfied equilibrium dominance.

Banks, Camerer, and Porter (1994) presented a particularly interesting examination of some matrix signaling games. A wide variety of outcomes were observed, including outcomes inconsistent with any Nash equilibrium, outcomes satisfying a less refined Nash equilibrium, and outcomes predicted by a more refined Nash equilibrium. Equilibrium dominance seemed to be a useful organizing principle when there was only one pure strategy equilibrium that satisfied the criterion. However, when more than one equilibrium satisfied equilibrium dominance, with one or more of those equilibria also satisfying higher order refinements, behavior was less predictable. The more refined equilibrium was often not the one selected. Sometimes participants played a less refined equilibrium which nonetheless satisfied equilibrium dominance. However, non-Nash behavior was also observed quite frequently, typically about one-third of the time.

Brandts and Holt (1992) examined variants of the examples originally presented by Cho and Kreps (1987). Equilibrium dominance predicted the observed equilibrium for a large proportion of the observations. However, the markets did not start out in equilibrium; they gradually converged to it. By altering payoffs to change typical convergence patterns, Brandts and Holt (1992) were able to create examples in which equilibrium dominance failed. Similarly, Brandts and Holt (1993) examined variants of some of the two-person matrix games considered in Banks, Camerer, and Porter (1994). Brandts and Holt (1993) altered the payoff structure of these games in a manner that did not affect the equilibrium configuration. However, as in their earlier article, the altered payoff structure did affect the pattern of adjustment to equilibrium and the equilibrium that was ultimately reached. In particular, some payoff structures were associated with the less refined equilibrium occurring more frequently than the one satisfying an extra refinement. One of their examples involved a failure of equilibrium dominance.

Cadsby, Frank, and Maksimovic (1990) examined experimental auction markets in which equity claims were sold. These markets were patterned on the influential article by Myers and Majluf (1984). The bulk of Cadsby, Frank, and Maksimovic (1990) focused on a case in which no signaling opportunities were available to firms, whose only decision was whether or not to participate in the equity market in order to undertake a value-increasing project. When sequential equilibria were unique, they were observed. When pooling, separating, and semiseparating sequential equilibria coexisted, only the Pareto efficient pooling equilibrium was observed. The selection of the pooling equilibrium was robust to the experimental experiences of the subjects.

Cadsby, Frank, and Maksimovic (1990) also contained one exploratory experiment in which a signaling opportunity was present. In this case, there were two pure strategy equilibria. In one sequential equilibrium, there was pooling with both firm types issuing equity and neither signaling. In the other equilibrium, both types of firms came to market, and the more valuable type signaled. The latter equilibrium satisfied equilibrium dominance. It was this latter equilibrium that was observed. Therefore, in this case, firms did use a signal to break out of a pooling situation in which their equity was being undervalued.

The current article elaborates on that one exploratory experiment, examining further the predictive power of equilibrium dominance in financial markets with signaling opportunities. In contrast to earlier experimental articles which examined equilibrium dominance in the context of a simple two-person matrix game, this article studies its predictive power in the more complicated environment of an experimental financial market. This is important. In experiments based on matrix games, individual players must select their moves from just two or three options. However, in our experimental financial market, potential investors choose from a much larger array of alternative bids. It is the competitive auction market as a whole which determines the one bid that will be put in play as the response of the market to the message sent by a firm. The fact that equilibrium dominance has often (though not always) performed well in two-person matrix experiments is encouraging. However, such experimental evidence is merely suggestive as to how well equilibrium dominance might predict equilibrium selection under the competitive discipline of an actual financial market. Equilibrium dominance is often relied upon to justify focusing on a particular equilibrium in theoretical models of such markets. Therefore, it is particularly important to examine explicitly its predictive performance in the context of a market, the structure of which is motivated directly by finance theory. It turns out that equilibrium dominance often fails in this context. Accordingly, this article goes on to consider what other factors might influence both the adjustment path and the equilibrium ultimately selected by the market.

The rest of the article is organized in the following manner. Section 1 discusses the equilibrium concepts being studied in the context of a signaling game designed to test equilibrium dominance in the laboratory. Section 2 describes the experimental environment. The empirical results on equilibrium selection in experimental financial markets are presented in Section 3. Section 4 develops a framework for examining the adjustment path followed by our markets, and tests that framework using the experimental data. Conclusions are set out in Section 5.

1. Theoretical Issues

Many interactions between a corporation and investors can be modeled as signaling games.[2] A signaling game involves two players: a sender and a receiver. Some aspect of the problem being solved by the sender (the state of nature, or equivalently the sender's type) is not known to the receiver. The sender selects a message after observing the state of nature. Since the receiver cannot observe the true state of nature, he must try to infer it from this message. Having observed the sender's message, the receiver selects an action. The game then ends as each player receives a payoff which depends on the sender's message, the receiver's action, and the state of nature.

The appropriate definition of "equilibrium" in a signaling game is an unresolved question. The Nash equilibrium concept is not powerful enough to provide a full answer. The best strategy for the sender depends on the inferences that the receiver makes upon observing the sender's message. There is no generally accepted method for determining what inferences are appropriate in all circumstances. For example, consider a candidate equilibrium in which the sender selects message m. For this to be a best strategy for the sender, his resultant payoff must be at least as high as it would be if he selected instead an alternative message, m'. Whether this is the case depends on what the receiver infers about the state of nature upon observing m' rather than m. However, the Nash equilibrium concept provides no guidance on this issue because in the candidate equilibrium the receiver observes only m. Upon observing m', the receiver knows only that the market is not in an equilibrium in which the sender plays m. There are two possibilities. The market might be in some other equilibrium, or it might not be in equilibrium at all. Different interpretations imply different reactions. If the researcher cannot predict the receiver's actions, it is also difficult to predict what message the sender will initially select.

[2] Examples include Harris and Raviv (1985), John and Williams (1985), Miller and Rock (1985), Shleifer and Vishny (1986), Giammarino and Lewis (1988), Noe (1988), Allen and Faulhaber (1989), and Welch (1989).

One approach to this indeterminacy has been to add further requirements to the definition of equilibrium by restricting how the receiver is permitted to respond when an out-of-equilibrium message is observed. An equilibrium concept that does this, while placing only moderate consistency requirements on the relationship between out-of-equilibrium beliefs and actions, is the notion of sequential equilibrium, developed by Kreps and Wilson (1982).[3] A sequential equilibrium adds to the Nash notion the requirement that responses to out-of-equilibrium messages be optimal, given some set of beliefs regarding sender type.

While the sequential equilibrium concept is useful, there are often multiple sequential equilibria in signaling games. These equilibria differ according to the beliefs that they permit the receiver to form upon observing an out-of-equilibrium message. Some postulated beliefs may seem more plausible than others. One approach to equilibrium refinement has been to assert that particular equilibria can be disregarded because they depend upon implausible belief structures.

Consider a signaling game in which the sender can be of two possible types, high (H) or low (L). Suppose an equilibrium depends on the receiver responding to an out-of-equilibrium message m' with an action consistent with the belief that the sender may be type L with some positive probability. An interesting possibility arises when the payoffs are such that (i) a type L firm would not wish to deviate from the equilibrium strategy and send a message m', because even if this message persuaded the receiver that the sender was type H and the receiver acted accordingly, the type L firm would do worse than in the equilibrium and (ii) a type H firm would find it profitable to deviate under such conditions. In such circumstances, it may not seem reasonable for the receiver to believe that m' is really consistent with a positive probability that the sender is type L. Equilibrium dominance, proposed by Cho and Kreps (1987), bars such beliefs as implausible, thus eliminating sequential equilibria supported by them from consideration as credible model outcomes.[4]

While equilibrium dominance does restrict out-of-equilibrium beliefs, it still permits too many equilibria in many applications. In particular, there are situations in which more than one type of sender might wish to defect from an equilibrium. Again the receiver must try to determine the particular type of the deviator from a candidate equi-

[3] A formal definition of sequential equilibrium is presented in Section A.1 of the Appendix. For a more detailed discussion and examples of sequential equilibrium and its refinements see Fudenberg and Tirole (1991a). Fudenberg and Tirole (1991b) show that in signaling games the set of sequential equilibria and the set of perfect Bayesian equilibria coincide.

[4] A formal definition of equilibrium dominance is presented in Section A.2 of the Appendix.

librium. Several refinement concepts are aimed at capturing this idea.[5] While these ideas are interesting, we deal with them only peripherally in this article.

1.1 A model to test equilibrium dominance

By adding a signaling opportunity to Myers and Majluf (1984), we develop a model that allows us to examine the predictive power of equilibrium dominance in the laboratory. There are 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. There are no transaction costs.

Each firm is initially financed entirely by equity. There are some assets in place, A_i, and an opportunity to undertake a positive net present value project offering a net payoff of B_i. The subscript i refers to the firm's type, which may be either H (high) or 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. The two types are equally likely. The firm knows the true worth of both the assets and the project. The project requires funding, represented by I, to be undertaken, but the firm has neither available internal funds nor the ability to float debt for this purpose.

A firm can either issue new equity or forgo the new project. If the firm undertakes the project, then it also has access to a dissipative signal. In particular, a firm of any type may send a particular message to investors for a type-specific cost of C_i, borne by the original owners of the firm[6] and paid at the end of the game.[7] The message sent is the same for both types of firms and can be thought of as an advertisement claiming that the firm is type H. Investors receive the message before deciding whether to invest in the firm.

The manager of the firm attempts to maximize the terminal value of the original owners' claim to the firm's assets. If the firm does not proceed with the project, this value 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 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.

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[5] Notable here are the concepts of divinity and universal divinity [Banks and Sobel (1987)] and perfect sequential equilibrium [Grossman and Perry (1986)].

[6] This last assumption is not theoretically restrictive. Part of the cost of dissipative signals paid for by the firm after capital is raised is also borne by the original owner, as discussed by Daniel and Titman (1995).

[7] For the parameter values used in the laboratory, the owners' wealth at that time exceeds the cost of a signal in all possible equilibria.

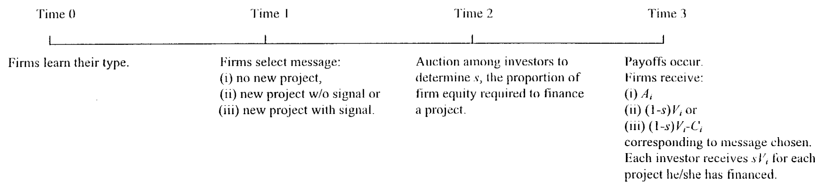

Figure 1
Chronology of events
This figure shows the ordering of events in a single round of an individual experiment.

Then the claim of the original owners will be worth $(1 - s)V_i$ if the project is undertaken. If a signal is purchased, the original owners will also have an expense of C_i, the cost of purchasing the signal. To make the correct decision, the firm needs to know the terminal value of the orginal owners' claim under its various possible strategies. However, this requires a forecast of s. The value of s depends upon the behavior of the investors.

If a firm decides to undertake a project, and thus goes to the market to raise funds, investors must try to infer the probability of the firm being type H versus type L. The estimate will depend on whether or not the firm has signaled, and on the inferences the investor draws from the presence or absence of a signal. The investor's inference will determine the minimum proportion of the firm's equity demanded in exchange for the required funds. A competitive auction is conducted among the investors for the sole right to invest I in the firm. Since I is a fixed number, representing the funding necessary to undertake the project, the auction mechanism must prespecify the amount of money to be transferred to the firm for a proportion of equity, s, determined by the winning auction bid.

Investors determine their bids by comparing I with the expected value of sV_i. Ex post, if $I < sV_i$, the investor will profit, but if $I > sV_i$, the investor will lose. However, the true value of V_i is unknown to the investor when he must decide on his bid for a proportion of firm equity, s. Given many risk-neutral competitive investors, the value of s will be bid down to $I/E(V_i)$, where $E(\cdot)$ is the expectations operator. The two possible values for V_i are known to the investors, but a prediction of the actual value on offer must be formulated based on investor beliefs about the equilibrium being played. The possibilities are discussed below.

After the auction everything is revealed, payoffs are earned, and the game ends. The chronology of events is summarized in Figure 1.

1.2 Four pure strategy sequential equilibria

A sequential equilibrium requires that investors form beliefs about the value of V_i for any firm which issues equity both for the signaling and nonsignaling cases. Given the investors' beliefs and resultant actions, firms must not be able to gain by deviating from the equilibrium. Similarly, given the firms' beliefs and resultant actions, the investors must not be able to gain by deviating.

This game may be consistent with four kinds of pure strategy sequential equilibria.[8] First, a separating equilibrium may exist in which the type H firm neither signals nor undertakes the new project, whereas the type L firm undertakes the project, but does not signal. In the other three equilibria, both types of firms undertake the project. These equilibria are a signaling equilibrium in which type H signals, but type L does not; a pooling equilibrium in which both types signal; and a pooling equilibrium in which neither type signals. The subset of equilibria actually available will depend on the particular parameter values of the problem. From this subset, the equilibrium chosen will involve specific beliefs by investors about the significance of firm actions.

Proposition 1. *A separating equilibrium in which type H firms neither signal nor undertake the project while type L firms undertake the project without a signal is consistent with some set of investor beliefs about firms that deviate by signaling if and only if* $A_H \geq (1 - s_L)V_H$ *where* $s_L = I/V_L$.

In this equilibrium, investors believe that any firm undertaking a project without signaling is type L. The indicated condition guarantees that a type H firm will have no incentive to select type L's equilibrium strategy. It also ensures that for some investor beliefs regarding the significance of a signal, a type H firm will have no incentive to defect by signaling. For example, if investors believe a defecting firm that signals must be type L, it will not pay for a type H firm to deviate in this manner when the stated condition holds. A type L firm will prefer its own strategy for any value-increasing project.

Proposition 2. *A signaling equilibrium in which type H firms undertake the project with a signal whereas type L firms undertake the project without a signal exists if and only if* $\lambda_H \leq (1 - s_H) - A_H/V_H$, $\lambda_H \leq (s_L - s_H)$ *and* $\lambda_L \geq (s_L - s_H)$ *where* $\lambda_H = C_H/V_H$ *and* $\lambda_L = C_L/V_L$.

[8] In general, mixed strategy equilibria also exist, and players may choose to follows mixed strategies. Some of our experimental markets did not converge to a pure strategy equilibrium, possibly reflecting such behavior. However, we believe this to be unlikely. Players were asked to note reasons for their actions during the sessions. We observed no direct evidence of the use of mixed strategies either in the subjects' stated explanations for their actions or in the actions themselves.

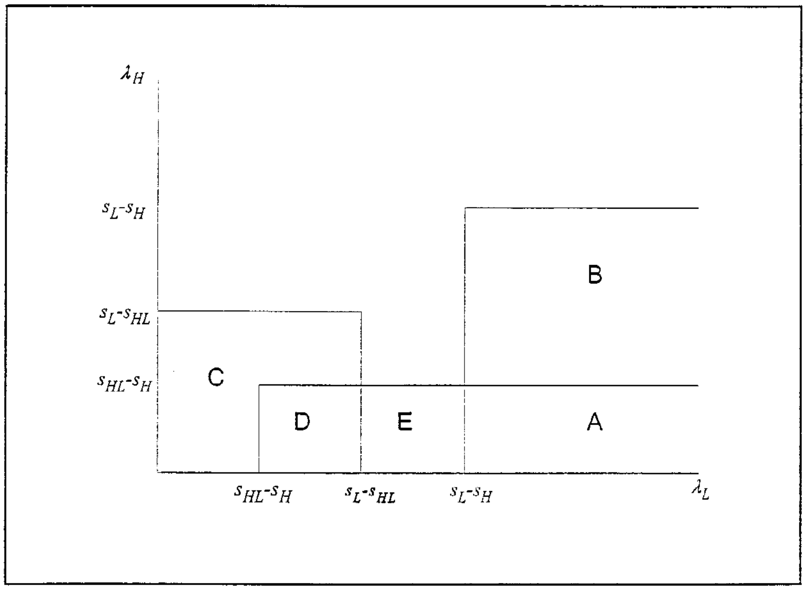

Figure 2
Existence of equilibria
This figure has been drawn on the assumption that V_H is sufficiently high in relation to A_H that the indicated equilibria exist. The pooling equilibrium without signaling exists throughout the diagram. However, it fails equilibrium dimonance in regions A, D, and E. The pooling equilibrium in which both firms signal exists in regions C and D. The signaling-separating equilibrium in which the high type firm signals while the low type does not exist in regions A and B. Experiments G4, G5, G6, GW1, and GW3 used parameter values from region A. Experiments G3, G7, G8, BC2. BC3, BC4, BC5, GW4, BW5, GW6, GW7, GW8, GS2, GS3, GS4, and GS5 used parameter values from region D.

This equilibrium always satisfies equilibrium dominance and higher-order refinements.

In this equilibrium, investors believe that a signaling firm is type H, while a nonsignaling firm is type L. The first condition implies that a type H firm cannot benefit by defecting through abstention from the market. A type L firm can never benefit from such an action. The other two conditions ensure that neither type can gain by selecting the other's strategy. The restrictions imposed by these conditions are illustrated in λ_H, λ_L space by Figure 2, where regions A and B are consistent with this equilibrium as long as the nonabstention condition holds. Since there is no out-of-equilibrium action which requires an investor response, this equilibrium satisfies equilibrium dominance as well as higher-order refinements such as perfect sequential equilibrium.

Proposition 3. *A pooling equilibrium in which both firms signal is* *consistent with some set of investor beliefs about firms that deviate by undertaking the project without a signal if and only if* $\lambda_i \leq (1 - s_{HL}) - A_i/V_i$ *and* $\lambda_i \leq s_L - s_{HL}$ *where* $\lambda_i = C_i/V_i$, $i = H, L$ *and* $s_{HL} = I/(0.5V_L + 0.5V_H)$. *This equilibrium satisfies equilibrium dominance, but not higher-order refinements based on joint deviations such as perfect sequential equilibrium.*

Investors believe a firm that comes to market and signals may be either type H or type L with equal probability in this equilibrium. The first condition implies that neither type of firm has an incentive to defect through abstention from the market. The second condition restricts the cost of signals to be low enough so that it is profitable to continue paying that cost rather than to suffer poorer treatment based on investor beliefs about nonsignaling deviators. It is illustrated by regions C and D in Figure 2. Notice that there is no overlap between the regions consistent with this equilibrium and those consistent with the equilibrium in which only type H signals. Thus these two kinds of equilibria will never coexist for any set of parameter values.

In the context of this signaling-pooling equilibrium, the only out-of-equilibrium move by a firm undertaking the project is to refrain from signaling. Since this move is readily mimicked, it cannot be used to distinguish between the two types of firms. Hence this equilibrium satisfies equilibrium dominance. However, since both types of firm are better off if both simultaneously deviate, this equilibrium fails higher-order refinements based on joint deviations, such as perfect sequential equilibrium.

Proposition 4. *A pooling equilibrium in which neither firm signals is consistent with some set of investor beliefs about firms that deviate by signaling if and only if* $A_H \leq (1 - s_{HL})V_H$. *However, if* $(s_{HL} - s_H) > \lambda_H$ *and* $(s_{HL} - s_L) < \lambda_L$, *it fails equilibrium dominance.*

In this equilibrium investors believe that a firm which comes to market without signaling may be type H or type L with equal probability. When the indicated condition holds, a type H firm will have no incentive to defect by abstention from the market. A type L firm will never have such an incentive for a net value-increasing project. Since signals are costly, any investor belief about the significance of a signal that attributes at least a 0.5 probability to such a deviator being type L implies that deviators lose by signaling. Hence no restrictions on the cost of signaling are necessary to ensure the existence of this equilibrium. It may exist in any region of the parameter space indicated in Figure 2 and coexist with any of the other equilibria.

This equilibrium fails equilibrium dominance if a type H firm would be better off if it signaled and were correctly identified as type H, whereas a type L firm that mimicked it would be worse off. The first of these conditions requires that $(s_{HL} - s_H) > \lambda_H$, and the second requires that $(s_{HL} - s_L) < \lambda_L$. In regions A, D, and E, the above conditions hold. Hence, though pooling equilibria without signaling exist in these regions, they fail the equilibrium dominance refinement.

1.3 Hypotheses about the predictive power of equilibrium dominance

Our tests of equilibrium dominance focus on two different equilibrium configurations. Both of these configurations are consistent with a pooling equilibrium without signaling that is sequential but fails equilibrium dominance. The first configuration employs parameter values that are also consistent with a signaling-separating equilibrium satisfying equilibrium dominance and perfect sequential equilibrium. These two types of equilibria coexist in region A of Figure 2 as long as the nonabstention conditions are satisfied. This configuration is frequently encountered in applied signaling-based theories, and was the one used in the exploratory experiment in Cadsby, Frank, and Maksimovic (1990).

The numbers used in experiment G6 ($A_L = 75$, $V_L = 400$, $C_L = 175$, $A_H = 100$, $V_H = 600$, $C_H = 25$, $I = 300$) provide an example of this configuration. In the pooling equilibrium without signaling, H gets $(1 - s_{HL})V_H = 0.4(600) = 240$ and L gets $0.4(400) = 160$. If H defects by signaling and is believed to be H, H receives $(1 - s_H)(600) - C_H = (0.5)(600) - 25 = \mathbf{275} > \mathbf{240}$. However, if L defects by signaling and is believed to be H, the best possible outcome for L, L gets only $(1 - s_H)(400) - C_L = 0.5(400) - 175 = \mathbf{25} < \mathbf{160}$. Since L loses by defecting even under the best possible scenario, the investor belief that the defector might be L is "unintuitive" and hence barred by equilibrium dominance. However, if a defector is believed to be H, H will gain by defecting and the pooling equilibrium breaks down. Hence it fails equilibrium dominance. In the alternative signaling-separating equilibrium, H earns $0.5(600) - 25 = 275$ and L earns $(1 - s_L)V_L = 0.25(400) = 100$. Since there is no nonequilibrium move to which the investor can react with a belief and resultant action, this equilibrium satisfies equilibrium dominance.

Hypothesis 1. *For parameter values consistent with both (i) a sequential pooling equilibrium without signaling that fails equilibrium dominance and (ii) a signaling-separating equilibrium that satisfies equilibrium dominance and is a perfect sequential equilibrium, refinement theory predicts that (ii) will be observed, but (i) will not.*

The second configuration uses parameter values consistent with a signaling-pooling equilibrium satisfying equilibrium dominance, in addition to the sequential pooling equilibrium without signaling. These two types of equilibria coexist in region D of Figure 2 as long as the relevant nonabstention conditions are satisfied. This double-pooling configuration is particularly interesting because it allows equilibrium dominance to be tested in isolation from refinements such as perfect sequential equilibrium that are based on joint deviations. This equilibrium is also Pareto dominated by the alternative pooling equilibrium without signaling. This allows a comparison between the drawing power of a more efficient equilibrium that does not satisfy equilibrium dominance and a less efficient one that does. This equilibrium configuration has the further advantage that both equilibria being examined involve pooling. We thereby avoid confounding the issue of the efficacy of equilibrium dominance, with the possible dominance of pooling equilibria over separating, or vice versa.

The numbers used in experiment GW4 ($A_L = 50$, $V_L = 375$, $C_L = 70$, $A_H = 100$, $V_H = 625$, $C_H = 70$, $I = 300$) provide an example of this configuration. In the pooling equilibrium without signaling, H gets $(1 - s_{HL})V_H = 0.4(625) = 250$ and L gets $0.4(375) = 150$. If H defects by signaling and is believed to be H, H receives $(1 - s_H)(625) - C_H = (0.52)(625) - 70 = \mathbf{255} > \mathbf{250}$. However, if L defects by signaling and is believed to be H, the best possible outcome for L, L gets only $(1 - s_H)(375) - C_L = 0.52(375) - 70 = \mathbf{125} < \mathbf{150}$. Since L loses by defecting even under the best possible scenario, the investor belief that the defector might be L is "unintuitive" and hence barred by equilibrium dominance. However, if a defector is believed to be H, H will gain by defecting and the pooling equilibrium without signaling breaks down. Hence it fails equilibrium dominance. In the alternative pooling equilibrium with signaling, H gets $250 - 70 = 180$ and L gets $150 - 70 = 80$. If H defects by not signaling and is believed to be H, H gets $0.52(625) = \mathbf{325} > \mathbf{180}$. If L defects by not signaling and is believed to be H, L gets $0.52(375) = \mathbf{195} > \mathbf{80}$. Since it is possible for L as well as H to gain through defection, the belief that the defector could be L is admissible, and the nonsignaling pooling equilibrium passes equilibrium dominance.

Hypothesis 2. *For parameter values consistent with both (i) a pooling equilibrium without signaling that fails equilibrium dominance and (ii) a pooling equilibrium with signaling that satisfies equilibrium dominance but fails perfect sequential equilibrium, refinement theory predicts that (ii) will be observed, but (i) will not. However, if equilibrium dominance fails to predict well, the failure is most likely to occur in this configuration because equilibrium dominance is not backed up by the perfect sequential refinement and because (i) Pareto dominates (ii).*

It turned out that in this double-pooling configuration, some experimental markets converged to the signaling equilibrium satisfying equilibrium dominance, while others converged to the nonsignaling sequential equilibrium. Upon obtaining this result, we considered what factors might be responsible for this dichotomous outcome, developing two plausible hypotheses. Both of these hypotheses are based upon the observation that it is the behavior of the high type firms that is critical in determining equilibrium selection. If high firms refrain from advertising, low firms have no incentive to advertise either. The parameters of the double-pooling case ensure that low firms cannot earn more by advertising, even if they are treated as high types, than in the nonadvertising equilibrium. If, however, the high type firms do advertise, investors will begin to differentiate between high and low type firms, worsening the situation of the nonadvertising low types until they realize they can earn more if they mimic the high firms by advertising.

Since it is the behavior of the high firms that is most instrumental in determining equilibrium selection, it is important to determine what might induce the majority of such firms to defect from the nonsignaling pooling equilibrium by advertising on a persistent basis. The payoff of a high firm is $(1 - s_{HL}) V_H$ in the nonsignaling equilibrium. A high firm that defects from this equilibrium by signaling can at best hope to persuade investors that it is indeed a high firm. In that instance, the payoff of the defecting firm would increase to $(1 - s_H) V_H - C_H$. These payoffs are denominated in a currency created for the experiments called francs. Hence the potential short-term gain from defecting in dollars (PSG) is the exchange rate (e) times the difference between these payoffs:[9]

$$PSG = e[(1 - s_H) V_H - C_H - (1 - s_{HL}) V_H]. \tag{1}$$

Hypothesis 3. *The amount of advertising by high firms and hence the probability of selecting a signaling-pooling equilibrium in the double pooling case will be greater, the higher is PSG, the potential short-term dollar gain that a high firm would achieve if it could successfully signal its type to investors, ceteris paribus.*

The reasoning is straightforward. A high firm pays to advertise. It may or may not be successful at signaling its type. When low firms start to mimic high firms, high firms will be worse off relative to the nonsignaling equilibrium. The prediction is simply that under such

[9] Since the exchange rate from francs to dollars differs between experimental sessions, consistency requires conversion to dollars before comparing the financial incentives associated with individual experiments to each other.

risky circumstances high firms are more likely to go after a large potential short-run prize than a small one.

As mentioned above, a high firm must pay to advertise. The cost of advertising in dollars is eC_H. This cost represents the earnings differential for the high firm of being in the signaling equilibrium satisfying equilibrium dominance versus being in the more efficient nonsignaling equilibrium. Of course, if a high firm successfully signals its type, this cost is overshadowed by the better treatment received from investors. However, once the low types start signaling as well, this better treatment evaporates, and the high firms are left with the same pooling bid as before anyone signaled, together with the cost of advertising. Thus, in the long run, defecting is costly. Hypothesis 4 focuses on this cost.

Hypothesis 4. *The amount of advertising by high firms and hence the probability of selecting a signaling-pooling equilibrium in the double pooling case will be lower, the higher is eC_H, the dollar cost of advertising for the high firm, ceteris paribus.*

2. Experimental Procedures and Design

We created and observed a total of 26 experimental financial markets ("experiments") over four different time periods. Experiments G1–G8, GW1–GW8, and GS1–GS5 were conducted at the University of Guelph in the spring of 1990, the winter of 1991, and the spring of 1991, respectively. The subjects were undergraduate and graduate economics students at the University of Guelph. Experiments BC1–BC5 were conducted at the University of British Columbia in the fall of 1990. The subjects were undergraduate students from the Faculty of Commerce. The number of the experiment in each sequence corresponds to the chronological order in which it was conducted. The numerical parameters used in each experiment are listed in Table 1, while the theoretical predictions are summarized in Table 2.

The experiments employed a currency termed francs. At the end of a session the number of francs earned was converted into Canadian dollars, which were then paid to the subjects. The exchange rates in all experiments were set so that subjects in various sessions earned similar amounts of money.[10] The actual payoffs varied from session to session, averaging about $23 for 2 hours of play. The subjects seemed interested and motivated.

[10] In general, this required different exchange rates for firms and investors in an experimental market. Neither firms nor investors were told the other's exchange rate because we did not want to complicate the decision-making process with information irrelevant to it.

Table 1
Experiment parameter values

	Type *L*			Type *H*					
Experiment (rounds)	No new project	New project	Cost of ads	No new project	New project	Cost of ads	Exchange rate	Number of investors	Blackboard
G1* (10)	250	650	—	400	850	—	0.0047	9	No
G2* (10)	150	480	—	450	810	—	0.0061	9	No
G3 (10)	275	650	75	950	1850	75	0.0024	10	No
G4 (11)	170	500	125	300	750	25	0.0066	8	No
G5 (12)	100	500	175	400	1000	25	0.0049	9	No
G6 (10)	75	400	150	100	600	25	0.0129	9	Yes
G7 (12)	100	500	100	800	1500	25	0.0030	12	Yes
G8 (12)	50	375	70	75	625	70	0.0105	8	Yes
BC1* (8)	250	625	—	500	1250	—	0.0033	14	No
BC2 (10)	275	650	75	950	1850	75	0.0024	10	No
BC3 (10)	50	375	70	75	625	70	0.0105	16	No
BC4 (10)	50	400	50	100	600	50	0.0105	9	Yes
BC5 (10)	100	500	50	300	750	50	0.0070	10	Yes
GW1* (10)	150	600	125	400	1000	50	0.0042	12	Yes
GW2 (10)	240	600	—	880	1400	—	0.0030	6	Yes
GW3 (12)	75	400	150	100	600	25	0.0129	10	Yes
GW4 (10)	50	375	70	100	625	70	0.0160	11	Yes
GW5 (12)	100	500	50	200	750	50	0.0070	12	Yes
GW6 (12)	50	400	60	100	600	30	0.0118	10	Yes
GW7 (12)	50	400	50	100	600	20	0.0115	12	Yes
GW8 (12)	100	450	70	200	750	68	0.0079	10	Yes
GS1* (10)	50	375	—	200	625	—	0.0110	11	Yes
GS2 (12)	50	400	48	300	1600	48	0.0031	12	Yes
GS3 (14)	100	600	150	400	1900	124	0.0024	8	Yes
GS4 (12)	25	400	50	150	750	10	0.0080	10	Yes
GS5 (12)	50	400	55	100	600	55	0.0120	11	Yes

The first column identifies the experimental market and the number of rounds played. Asterisks indicate that most players were inexperienced. The financing provided by the investor who won an auction was 300 francs in each experiment. There were six firms in each experiment. Under "No new project" is the payoff to the firm if it decided not to undertake a new project. Under "New project" is the total payoff if a new project was undertaken. "Cost of ads" refers to the price of purchasing an advertisement. "Exchange rate" gives the rate at which francs were converted into Canadian dollars for the firms. For the investors, the conversion involved subtracting 1050 and multiplying the result by 0.0028 in each experiment. "Blackboard" refers to whether the outcomes of the auctions were written on the blackboard in both rooms at the end of each round.

At the beginning of each sequence, we ran experiments for inexperienced subjects. In most of these experiments (G1, G2, BC1, and GS1), firms were not given the opportunity to signal.[11] This was done to provide the subjects with some experience playing a somewhat simpler version of the game before exposing them to the more complex problem involving a decision about whether or not to signal. Since these experiments were identical in format to those reported in Cadsby, Frank, and Maksimovic (1990), they could also be used to check those results on new subject pools. Another experiment (GW2) used experienced subjects in the same format as a further check on the results of the earlier study.

[11] In experiments G2 and GS1, some of the players were experienced.

Table 2
Equilibrium predictions

Experiment (hypothesis)	Equilibrium	Type *L* Firm action	Type *L* Share	Type *H* Firm action	Type *H* Share	Dominance
G1 (no signal)	Pool	In	40	In	40	—
G2 (no signal)	Separate	In	62.5	Out	—	—
G3 (Hyp. 2)	Both Adv	In, Adv	24	In, Adv	24	Yes
	Pool No Ads	In, No Ad	24	In, No Ad	24	No
G4 (Hyp. 1)	Signal	In, No Ad	60	In, Adv	40	Yes
	Pool No Ads	In, No Ad	48	In, No Ad	48	No
	Separate	In, No Ad	60	Out	—	No
G5 (Hyp. 1)	Signal	In, No Ad	60	In, Adv	30	Yes
	Pool No Ads	In, No Ad	40	In, No Ad	40	No
	Separate	In, No Ad	75	Out	—	No
G6 (Hyp. 1)	Signal	In, No Ad	75	In, Adv	50	Yes
	Pool No Ads	In, No Ad	60	In, No Ad	60	No
G7 (Hyp. 2)	Both Adv	In, Adv	30	In, Adv	30	Yes
	Pool No Ads	In, No Ad	30	In, No Ad	30	No
	Separate	In, No Ad	80	Out	—	Yes
G8 (Hyp. 2)	Both Adv	In, Adv	60	In, Adv	60	Yes
	Pool No Ads	In, No Ad	60	In, No Ad	60	No
BC1 (no signal)	Pool	In	32	In	32	—
BC2 (Hyp. 2)	Both Adv	In, Adv	24	In, Adv	24	Yes
	Pool No Ads	In, No Ad	24	In, No Ad	24	No
BC3 (Hyp. 2)	Both Adv	In, Adv	60	In, Adv	60	Yes
	Pool No Ads	In, No Ad	60	In, No Ad	60	No
BC4 (Hyp. 2)	Both Adv	In, Adv	60	In, Adv	60	Yes
	Pool No Ads	In, No Ad	60	In, No Ad	60	No
	Separate	In, No Ad	75	Out	—	Yes
BC5 (Hyp. 2)	Both Adv	In, Adv	48	In, Adv	48	Yes
	Pool No Ads	In, No Ad	48	In, No Ad	48	No
	Separate	In, No Ad	50	Out	—	Yes
GW1 (Hyp. 1)	Signal	In, No Ad	50	In, Ad	30	Yes
	Pool No Ad	In, No Ad	37.5	In, No Ad	37.5	No
GW2 (no signal)	Pool	In	30	In, No Ad	30	—
	Separate	In	75	Out	—	—
GW3 (Hyp. 1)	Signal	In, No Ad	75	In, Adv	50	Yes
	Pool, No Ad	In, No Ad	60	In, No Ad	60	No
GW4 (Hyp. 2)	Both Adv	In, Ad	60	In, Ad	60	Yes
	Pool, No Ad	In, No Ad	60	In, No Ad	60	No
GW5 (Hyp. 2)	Both Adv	In, Ad	48	In, Ad	48	Yes
	Pool, No Ad	In, No Ad	48	In, No Ad	48	No
GW6 (Hyp. 2)	Both Adv	In, Ad	60	In, Ad	60	Yes
	Pool, No Ad	In, No Ad	60	In, No Ad	60	No
GW7 (Hyp. 2)	Both Adv	In, Ad	60	In, Ad	60	Yes
	Pool, No Ad	In, No Ad	60	In, No Ad	60	No

Table 2
(continued)

Experiment (hypothesis)	Equilibrium	Type *L* Firm action	Type *L* Share	Type *H* Firm action	Type *H* Share	Dominance
GW8 (Hyp. 2)	Both Adv	In, Ad	50	In, Ad	50	Yes
	Pool, No Ad	In, No Ad	50	In, No Ad	50	No
GS1 (no signal)	Pool	In	60	In	60	—
	Separate	In	80	Out	—	—
GS2 (Hyp. 2)	Both Adv	In, Adv	30	In, Adv	30	Yes
	Pool No Ads	In	30	In	30	No
GS3 (Hyp. 2)	Both Adv	In, Adv	24	In, Adv	24	Yes
	Pool No Ads	In, No Ad	24	In, No Ad	24	No
GS4 (Hyp. 2)	Both Adv	In, Adv	52.2	In, Ad	52.2	Yes
	Pool No Ads	In, No Ad	52.2	In, No Ad	52.2	No
GS5 (Hyp. 2)	Both Adv	In, Ad	60	In, Ad	60	Yes
	Pool No Ads	In, No Ad	60	In, No Ad	60	No

This table lists only pure strategy equilibrium predictions. The experiments are listed in the order they were conducted. G*i* represents experiment *i* at Guelph while BC*i* similarly represents experiment *i* at U.B.C. The hypothesis being tests is indicated in parentheses for the signaling experiments, while nonsignaling experiments are so indicated. Under “Equilibrium” the following terms are used. “Separate” means an equilibrium in which high type firms do not undertake new projects. “Pool, No Ads” means that the equilibrium involves both types of firms undertaking the projects but neither type advertising. “Both Adv” refers to an equilibrium in which both types of firms undertake the projects, and both advertise. “Signal” refers to an equilibrium in which both types undertake new projects, and high type firms buy an advertisement while low type firms do not. The predicted firm actions may be any of three varieties. “Out” means that the firm does not undertake a new project (and so does not advertise). “In, No Ad” means the new project is undertaken but an advertisement is not purchased. “In, Adv” indicates that the firm will undertake a new project and purchase an advertisement. “Share” is the predicted percentage of a firm’s equity acquired by the investor in the particular equilibrium. Under “Dominance” we indicate whether the particular equilibrium satisfies equilibrium dominance.

One of the experiments for inexperienced players (GW1) did give the players an opportunity to signal. The purpose of this experiment was to see whether inexperienced players would converge to an equilibrium in the signaling framework. The subsequent experiments in each session were run almost entirely with experienced players. However, on occasion, we had to substitute an inexperienced player when an experienced player did not show up for the session. Experienced players were allowed to play more than once. In one instance, discussed below, we purposely tried to keep a group together through three experiments to determine whether experience encouraged convergence.

Hypothesis 1 was tested by running five experiments (G4, G5, G6, GW1, GW3) using parameters from the equilibrium configuration corresponding to region A of Figure 2. Each of these experiments used different parameters to ensure that nobody would enter a market, having already had experience with identical numbers. In addition to the two pure strategy equilibria always present in this configuration, a separating equilibrium in which type H abstains from the market, as discussed in Proposition 1, was also available in two of these sessions (G4, G5). This extra separating equilibrium did not satisfy equilibrium dominance. Its presence allowed a further check on the robustness of equilibrium dominance as a predictor of outcome when a signaling-separating equilibrium satisfying the refinement is available.

Hypothesis 2 was tested by conducting 16 experiments (G3, G7, G8, BC2, BC3, BC4, BC5, GW4, GW5, GW6, GW7, GW8, GS2, GS3, GS4, GS5) using parameters from the equilibrium configuration corresponding to region D of Figure 2. As in testing Hypothesis 1, identical parameters across sessions were avoided, with the exception of sessions conducted at different universities. In addition to the two pooling equilibria always present in this configuration, a separating equilibrium in which type H abstains from the market was also available in three of these sessions (G7, BC4, BC5). This extra separating equilibrium satisfied equilibrium dominance. In Cadsby, Frank, and Maksimovic (1990), we found, in sessions without signaling, that pooling equilibria dominate separating equilibria of this type. These sessions allowed us to determine whether this would still be the case when signals were available.

The reason we used more market sessions to examine Hypothesis 2 than to examine Hypothesis 1 was our a priori belief that the double-pooling configuration would provide a more challenging test of equilibrium dominance, and thus perhaps provide less definitive results if the number of sessions was restricted to five. Ex post, the extra sessions proved critical in providing us with enough data to test Hypotheses 3 and 4. It must be stressed that we did not design our double-pooling experiments specifically to test these latter two hypotheses. It was only after observing that in the double-pooling context, some markets converged to one equilibrium whereas others converged to another, that we developed these hypotheses as plausible candidate explanations for the different results.

Upon arriving for the session, participants received instruction sheets explaining 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."[12] The subjects were then divided into two groups, known simply as group A and group B. Group A corresponded to firms while group B corresponded to investors. However, words like "investor" or "firm" were not used in the pres-

[12] The instructions and a sample of a projects sheet are presented in Section A.3 of the Appendix.

ence of the participants. Firms were located in one room while investors were 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 8 to 16 investors, depending on the session. This number of auction participants has been found to be large enough to produce competitive equilibria in previous experiments.

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 its own type. Since there were only two smaller envelopes, firms drew either type H or type L with equal probability. The smaller envelopes contained sheets of paper describing each firm's opportunities for the round. After observing its type, each firm could choose either to undertake or not to undertake the available new project. If it chose to undertake the project, it faced the added decision concerning whether or not to purchase an advertisement in the signaling experiments.

To undertake a project required 300 francs in all experiments. A decision to undertake the available project represented a simultaneous decision to raise the required 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 investors. The terminal value of the equity depended upon which type had been drawn. A decision not to undertake the project implied retaining 100% of the equity of the firm and hence receiving a known sum of money. This amount also depended upon which type had been drawn. Those firms which chose to undertake a project could also choose whether or not to purchase an advertisement at a cost which was dictated by firm type.

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

In each round, six envelopes were brought into the investor's room from the other group. The envelopes were opened by the experimenter in random order. After each envelope was opened, the experimenter announced "no new project" or "a new project." In the signaling experiments, the experimenter also indicated whether or not an advertisement had been purchased in each new project case.

The investors were not informed about which of the two situations the firm in question had drawn. The investors did know all the parameter values associated with the two possible firm types, as well as the fact that each type was equally probable.[13]

After each envelope was opened, an oral auction was held if the firm had undertaken a new project. Bidding was conducted in terms of the 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. The winning investor 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%, followed by 81%, etc. Fractional percentage bids were not allowed to avoid the problem of undercutting by an ever-lengthening series of decimal points.

After all envelopes were opened, and all auctions completed for the round, the results were revealed to the winner of each auction and to the firm. In early experiments during the first two sequences (G1–G5 and BC1–BC3), the number of firms of each type was announced at the completion of each round. However, each firm was able to observe the outcome only of its own project and each investor learned whether a particular firm was high or low only if he purchased equity in that firm. In all other experiments, more detailed results of the auctions were written on a blackboard in each room. Specifically, the true type of the firm, whether an advertisement had been purchased, and the fraction of equity exchanged were all recorded in full view. This alteration in procedure was made in response to the nonconvergence of some of the early signaling experiments to determine whether the information presented on the blackboard might facilitate convergence.

Nonsignaling experiments consisted of from 8 to 10 rounds; signaling experiments consisted of from 10 to 14 rounds. Hence the subjects did not know precisely how many rounds would be played or when the experiment would end.[14] Subjects were permitted to record reasons for their decisions which were given to the experimenter at the end of the session.

[13] It is always possible that the subjects did not believe the instructions in any (or all) dimensions. To the extent that this is the case, any individually undominated action is a rational Bayesian action for some arbitrary, and uncontrolled, prior set of beliefs. To the extent that this is true, the theory being examined becomes almost vacuous. In the rest of the article we will work under the maintained hypothesis that priors corresponded to the true distribution outlined clearly to the subjects. While this maintained hypothesis may not always have been true, there is no general nonvacuous alternative that is apparent. Since we do not employ deception, we never do anything to undermine the assumed beliefs.

[14] The number of rounds in each experimental session was determined prior to conducting it, and was not based on decisions made by subjects during that session.

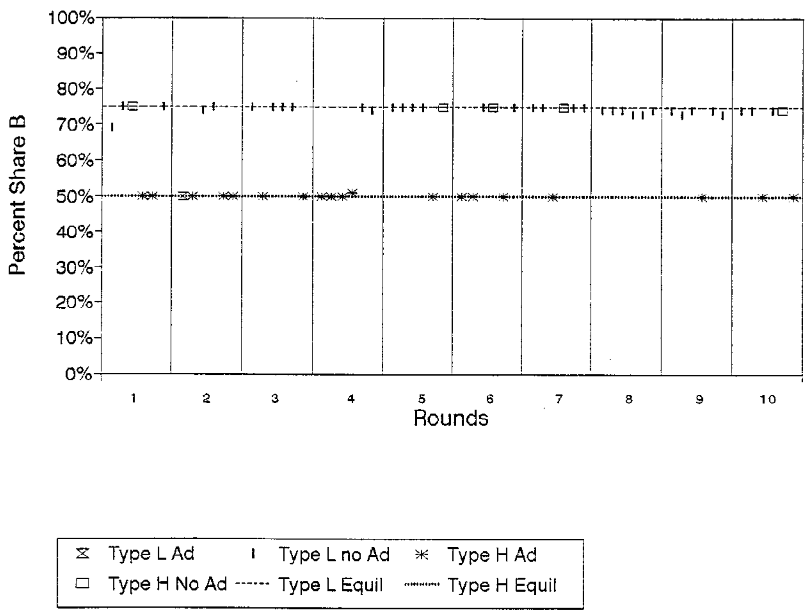

Figure 3
Experiment G6
This figure presents the results for experiment G6, and example of an experiment with a signaling-separating equlibrium in which the high type signals while the low type does not. In this equilibrium, investors (designated group B in the experiment) require 75% ownership to finance a project for a low type and 50% to finance a project for a high type, as indicated on the figure. A pooling equilibrium without any signaling also exists. In this equilibrium, investors require 60% ownership to finance a project. This value is not indicated on the diagram. Projects undertaken by low types are represented by an hourglass for those that signal and by a vertical line for those that do not. Projects undertaken by high types are indicated by asterisks for those who signal and rectangles for those who do not. The position of each symbol indicates the round in which the project was undertaken and the percentage of ownership transferred to the investing member of group B whose bid won the auction.

3. Empirical Results

The results of the last two rounds of each experiment are shown in Table 3. For each experiment, this table indicates the total number of type H and type L firms drawn. For each of those categories, the table also shows the number that advertised and the number that did not, together with the minimum, maximum, and mean proportion of the firm's equity received by investors who won auctions under the various observed scenarios. The results of a few experiments are illustrated in Figures 3–5.

For some of the discussion below, it is convenient to classify experiments into those that converged to an equilibrium and those that did not. Strictly speaking, theory makes point predictions. Any deviation from such a prediction means a failure for the theory. Such a strin-

Table 3
Outcomes of the last two rounds

	Type *L*			Type *H*			Actual share		
Experiment	Total	In, Adv	In, No Ad	Total	In, Adv	In, No Ad	High	Low	Mean
G1	5	—	5				40	39	39.6
				7	—	7	40	39	39.7
G2	5	—	5	7	—	0	60	58	59.4
G3	5	2					24	20	22
			3				24	23	23.7
				7	1		22	22	22
						6	25	23	23.5
G4	3	0	3				48	48	48
				9	4		45	41	42.5
						5	48	48	48
G5	10	0	10				60	51	56.4
				2	1		30	30	30
						1	59	59	59
G6	8	0	8				74	73	73.8
				4	3		50	50	50
						1	74	74	74
G7	8	6					27	21	23.7
			2				59	57	58
				4	4	0	27	22	23.75
G8	6	2					49	49	49
			4				78	75	76.2
				6	6	0	55	48	51
BC1	9	—	9				30	8	25.2
				3	—	3	29	28	28.7
BC2	4	0	4				24	24	24
				8	2		17	17	17
						6	24	24	24
BC3	5	0	5				52	49	51
				7	1		48	48	48
						6	53	48	51.8
BC4	6	0	5				63	60	60.6
				6	1		60	60	60
						5	60	59	59.8
BC5	9	0	1	3	0	0	60	60	60
GW1	7	1					31	31	31
			6				33	31	32
				5	1		31	31	31
						4	33	32	32.8
GW2	6	—	6				29	24	26.3
				6	—	5	29	24	26.4
GW3	9	0	9				76	70	74.9
				3	3	0	51	51	51
GW4	6	0	6				54	53	53.7
				6	0	6	55	53	54.3
GW5	6	0	6				46	45	45.7
				6	0	6	45	44	44.7
GW6	3	3	0				59	57	58
				9	9	0	60	55	58
GW7	5	4					62	55	57
			1				69	69	69
				7	7	0	57	54	55
GW8	7	1					47	47	47
			6				65	55	59
				5	5	0	47	41	43.4
GS1	6	—	6				60	58	59.7
				6	—	6	60	60	60

Table 3
(continued)

	Type L			Type H			Actual share		
Experiment	Total	In, Adv	In, No Ad	Total	In, Adv	In, No Ad	High	Low	Mean
GS2	9	0	9				25	24	24.8
				3	1		19	19	19
						2	25	25	25
GS3	5	3					38	20	29.3
			2				43	40	41.5
				7	7		40	30	34.6
GS4	5	4					45	41	44
			1				70	70	70
				7	7		50	41	45.3
GS5	4	0	4				60	59	59.5
				8	4		55	52	53
						4	59	59	59

"Total" gives the number of players who drew the particular firm type during the last two rounds. "In, Adv" lists the number of players of the indicated type who chose to undertake the new project and to advertise. Similarly, "In, No Ad" refers to those who undertook projects but did not buy advertising. "Actual Share" gives the observed percentage of the firm's equity transferred to the investor as the outcome of the auction. Highest, lowest, and average values are reported.

gent interpretation, however, may miss the genuine power of theory to help organize empirical findings. As a practical matter, we counted an experiment as having converged if in the final two rounds, (i) at least three-quarters of the firms used their signals in the predicted manner, and (ii) the mean bid for equity of firms using their signals as predicted was within 15% of the predicted equilibrium bid (i.e., within 4.5 points of a predicted bid of 30 or within 7.5 points of a predicted bid of 50). In equilibrium, the expected earnings of each investor were $2.10 per round. A winning bid 15% away from the predicted equilibrium bid would result in an expected earnings differential of 12.6 cents or 6% of this amount for the investor.

3.1 Experiments without signals

Five experiments were replications of the framework used in Cadsby, Frank, and Maksimovic (1990) that did not give firms the opportunity to signal. The earlier results were reproduced. The subjects pooled when that was a unique theoretical equilibrium (G1, BC1). They separated when that was a unique prediction of theory (G2). Separation involved gradual convergence, while pooling was almost instantaneous. These experiments also provided corroboration of the central result from our earlier article, in that pooling continued to dominate separating when both equilibria were simultaneously available (GS1, GW2).

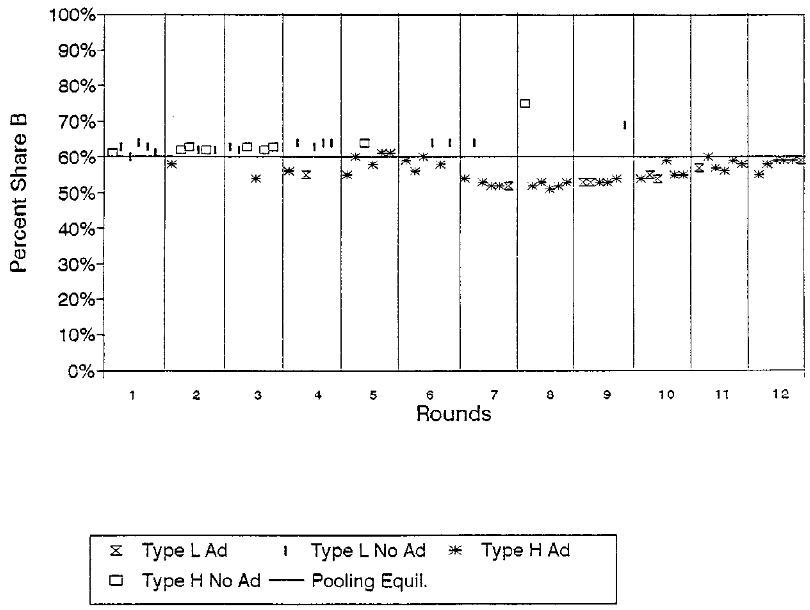

Figure 4
Experiment GW6
This figure presents the results for experiment GW6, an example of an experiment with both a pooling equilibrium without signaling and a pooling equilibrium in which both types signal. In both equilibria, investors (designated group B in the experiment) require 60% ownership to finance a project, as indicated on the figure. Projects undertaken by low types are represented by an hourglass for those that signal and by a vertical line for those that do not. Projects undertaken by high types are indicated by asterisks for those who signal and rectangles for those who do not. The position of each symbol indicates the round in which the project was undertaken and the percentage of ownership transferred to the investing member of group B whose bid won the auction.

3.2 Hypothesis 1

Of the five experimental markets designed to test Hypothesis 1 by using parameters in region A of Figure 2, three (G5, G6, GW3) converged to the signaling-separating equilibrium, while two (GW1, G4) did not converge to any pure strategy equilibrium, according to our criteria. As explained above, the participants in GW1 were inexperienced. Hence G4 was the only experiment with experienced players that did not converge to one of the pure strategy equilibria. Although G4 and G5 were also consistent with a separating equilibrium in which type *H* firms abstain from the market, there was no sign that the availability of this additional sequential equilibrium had any influence on the outcome. In both experiments, all firms came to market in the last two rounds. For this configuration of equilibria, when convergence occurs, equilibrium dominance seems useful in predicting equilibrium selection, corroborating Hypothesis 1.

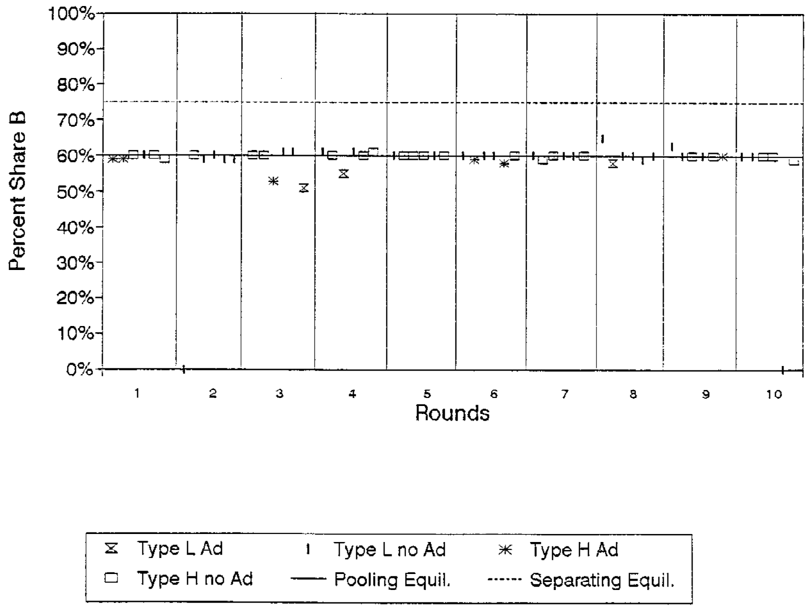

Figure 5
Experiment BC4
This figure presents the results for experiment BC4, an example of an experiment with both a pooling equilibrium without signaling and a pooling equilibrium in which both types signal. In both equilibria, investors (designated group B in the experiment) require 60% ownership to finance a project, as indicated on the figure. A separating equilibrium also exists in which low types undertake projects without signaling, while high types stay out of the market altogether. In this equilibrium, investors require 75% ownership to finance a project, as indicated. Projects undertaken by low types are represented by an hourglass for those that signal and by a vertical line for those that do not. Projects undertaken by high types are indicated by asterisks for those who signal and rectangles for those who do not. The position of each symbol indicates the round in which the project was undertaken and the percentage of ownership transferred to the investing member of group B whose bid won the auction. In two cases, projects were not undertaken, and these are represented by showing 0% as the percentage going to group B.

The sequence of experiments G4, G5, and G6 were conducted with many of the same subjects to determine whether market experience within a particular equilibrium configuration would encourage more rapid convergence to the equilibrium predicted by Hypothesis 1. Experiments G4 and G5 were conducted on adjacent days. In both experiments, the low type firms undertook projects, but did not signal after the first few rounds. However, G4 never reached a conventional equilibirium, while G5 came close to the signaling-separating equilibrium satisfying equilibrium dominance after a long convergence process. Experiment G6, conducted the following week, involved almost no convergence process; rather it essentially jumped to the signaling-separating equilibrium and remained there. Figure 3 illustrates G6, exemplifying the apparent strong pull of the signaling-separating equilibrium satisfying equilibrium dominance among players with considerable experience.

3.3 Hypothesis 2

Equilibrium dominance did not perform well within the double-pooling equilibrium configuration represented by region B of Figure 2. Nine of the 16 markets converged to a pure strategy equilibrium, and of these only three converged to the signaling-pooling equilibrium satisfying equilibrium dominance (GS4, GW6, GW7) as predicted by Hypothesis 2. An example, experiment GW6, is illustrated in Figure 4. The other six experiments which converged achieved the nonsignaling Pareto optimal equilibrium (G3, BC2, BC3, BC4, GW4, GW5). Figure 5 illustrates an example, BC4. Although G7, BC4, and BC5 are also consistent with the separating equilibrium in which type H firms abstain from the market, and these equilibria satisfy equilibrium dominance in this configuration, they were not observed, consistent with the results of Cadsby, Frank, and Maksimovic (1990) where such equilibria were never played when a pooling equilibrium was available.

3.4 Hypotheses 3 and 4

Why did some of the double-pooling experiments converge to the signaling-pooling equilibrium satisfying equilibrium dominance whereas others converged to the more efficient nonsignaling equilibrium? Using data from the nine experiments that converged to a pure strategy equilibrium in the double-pooling configuration, we tested Hypotheses 3 and 4 by running a probit regression with PSG (see Hypothesis 3) and eC_H (see Hypothesis 4) as independent variables. The dependent variable was defined as zero for the experiments converging to the nonsignaling Pareto optimal equilibrium and one for those converging to the signaling equilibrium satisfying equilibrium dominance. PSG turned out to predict equilibrium selection perfectly. Of the experiments that converged, those that had the highest PSGs converged to the signaling equilibrium, whereas those that had the lowest converged to the nonsignaling equilibrium. Of course, our sample is very small. Nonetheless, this result provides evidence in favor of Hypothesis 3 that higher potential short-term gains encourage high firms to advertise, and hence promote achievement of the signaling equilibrium.

Combining data from all of the double-pooling experiments,[15] both those that converged and those that did not, we ran four linear re-

[15] Data from experiment BC5 were not included because, as discussed below, apparent collusion among bidders drove both high and low firms out of the market.

Table 4
Regressions relating advertising to *PSG* and eC_H in double-pooling experiments

Dependent variable	Constant	*PSG*	eC_H	*N*	R^2
propH	0.375	0.970	−0.643	15	0.247
	(0.297)	(0.113)	(0.466)		
propH	**0.348**	**1.014**		15	0.207
	(0.041)	**(0.044)**	—		
propHL	0.247	*1.045*	−0.063	15	0.322
	(0.396)	*(0.059)*	(0.438)		
propHL	0.207	**1.110**		15	0.320
	(0.122)	**(0.014)**	—		

P-values are in parentheses. With the exception of the constant term, they are calculated on the basis of a one-way alternative hypothesis corresponding to Hypotheses 3 (the coefficient on *PSG* is positive) and 4 (the coefficient on eC_H is negative). Entries in bold are significant at the 5% level or less; italicized entries are marginally significant at between the 5% and 10% levels.

gressions in order to test the hypotheses that high *PSG* and low eC_H each encourage first high firms, and ultimately all firms, to advertise. Table 4 reports the results. The first two regressions use the proportion of high type firms that advertise in a given experiment (*propH*) as the dependent variable. The first regression yields the predicted positive coefficient on *PSG* and negative coefficient on eC_H. However, the standard errors are relatively large, and neither coefficient is significant. The *p*-value on the *PSG* coefficient is 0.113, while the *p*-value on the eC_H coefficient is much higher at 0.466. One reason for the high standard errors may be collinearity between the two independent variables which results from the fact that a higher cost of advertising (eC_H) systematically reduces the potential short-term gains from doing so (*PSG*). Since the coefficient on eC_H is nowhere near significance, eC_H is dropped from the second regression. The result is a coefficient which is significantly positive on *PSG*, with a *p*-value of 0.044, providing more evidence in favor of Hypothesis 3. The third and fourth regressions are similar to regressions one and two, except that they employ the proportion of both high and low firms that advertise (*propHL*) as the dependent variable. The results are similar too. The coefficients are once again of the predicted sign. In the third regression, the coefficient on *PSG* is marginally significant with a *p*-value of 0.059. The coefficient on eC_H is again not significant. When it is dropped in the fourth regression, the coefficient on *PSG* achieves significance, with a *p*-value of 0.014. These results support Hypothesis 3, but provide no evidence for Hypothesis 4. This suggests that higher potential short-term gains promote advertising, whereas the level of the longer-term cost of falling into the nonoptimal signaling equilibrium is virtually ignored.

3.5 Nonconvergence

Across many sessions, we have seen that both types of signaling equilibria are sensitive to disruptive influences not predicted by the theory. Equilibria seem more sensitive to such influences than equilibria in experiments conducted under the same setup but without signals. Experiments without signals produced equilibrium convergence in all five cases, and in all but one case in Cadsby, Frank, and Maksimovic (1990). In contrast, 9 out of 21 of our signaling experiments, almost half, did not reach any conventional equilibrium.

A particularly interesting example of an experiment that did not converge was G8. During rounds 5–8 the market seemed to have settled on an equilibrium that satisfied equilibrium dominance. However, it did not stay there. Gradually some of the low types stopped advertising and thus received poorer terms from investors. To some degree, a similar effect may have been at work in G7. However, G7 never clearly settled at an equilibrium.

Experiment BC5 also failed to produce results predicted by theory. This case is revealing from a different perspective. Initially the market went to the Pareto optimal equilibrium not satisfying equilibrium dominance. This seemed consistent with what had happened in other experiments. However, in rounds 4 and 5 the investors attempted to "collude."[16] In so doing, they drove the firms out of the market. The process by which the firms reacted to this disequilibrium behavior is of interest. Initially many acted as if they did not believe that such behavior would persist. Ultimately they faced the facts. The investors were apparently not sensitive to the fact that they might destroy the market. We saw no evidence of such collusion in any other experiments.

4. Dynamics of Bid Adjustment

In discussing equilibrium selection, we found evidence that the extent of signaling depends on the potential short-term gain that a high type firm can expect to obtain if it can persuade the market to bid as though it were indeed high. This process of persuasion is of course what signaling is all about. The process is important because both equilibrium selection and convergence ultimately depend not only on the initial propensity of firms to signal, but also on investor responses to the presence or absence of those signals. How do bids adjust over

[16] The term "collude" is the word some investors used to describe their behavior when debriefed after the experiment. Their actions did not correspond to optimal collusion since they destroyed the incentive of the firms to come to market.

time and in response to the behavior of firms? Our observations of this process in our experimental financial markets suggest the following sort of dynamics.

Initially investors consider the environment they face, and pick bids which may or may not correspond to a theoretical equilibrium. The initial pick is based on some reasoning, but not always theoretically correct reasoning. Then they see what happens. In the subsequent rounds, investors base their predictions concerning firm behavior primarily on observation, rather than on a calculation of optimal behavior in the environment. As the rounds proceed, they pay increasing attention to observed behavior and reduced attention to such calculations. Ultimately the market is trying to optimize against observed, rather than calculated, behavior. Since the environment is stationary, such behavior works well, even though it may not correspond exactly to currently popular theories.

The spirit of this process may be captured by a simple adaptive learning model, which may then be tested against the actual dynamics of the individual signaling experiments.[17] In order to place a bid, investors must formulate an expectation as to the value of each firm offering equity. Since a firm is either high or low and the value of each type of firm, V_H and V_L, is common knowledge, the expected value of a particular firm depends directly on the probability that it is a high type. Investors know whether or not a firm has advertised prior to placing their bids. They must formulate an expectation on the probability that a firm is high, conditional on its selected action. Suppose a firm chooses to advertise. Using Bayes' theorem and the fact that $P(H) = P(L) = 0.5$, we know that

$$P(H \mid Ad) = \frac{P(ad \mid H)}{P(Ad \mid L) + P(Ad \mid H)} \tag{2}$$

where $P(H \mid Ad)$ is the probability a firm is high conditional on it having advertised, $P(Ad \mid H)$ is the probability of a firm advertising conditional on it being high, and $P(Ad \mid L)$ is the probability of a firm advertising conditional on it being low.

We conjecture that investors update their expectations of $P(H \mid Ad)$ adaptively each period by observing the proportion of high and low firms that actually do advertise. As discussed above, in all but a few of the early experiments, this information was made available at the end of each round on the blackboard. The process is assumed to take

[17] We thank the former editor, Chester Spatt, and an anonymous referee for suggesting that we examine the dynamics of learning in our experiments.

the following form:

$$E_t[P(H \mid A)] - E_{t-1}[P(H \mid A)] = \alpha \left[\frac{H_{t-1}^A / H_{t-1}^T}{H_{t-1}^A / H_{t-1}^T + L_{t-1}^A / L_{t-1}^T} - E_{t-1}[P(H \mid A)] \right] \qquad (3)$$

where the time subscripts refer to rounds, H^A/H^T is the proportion of high firms that advertise, and L^A/L^T is the proportion of low firms that advertise.

There is a direct relationship between $P(H \mid Ad)$ and the bid that is made for an advertising firm. Recalling that investors must part with 300 francs in exchange for a proportion of firm equity represented by their bid,

$$Bid_t^A = \frac{R300}{E_t(V_i \mid Ad)} \qquad (4)$$

where Bid^A is a bid for a firm that advertises and R is a factor to take account of risk-loving or risk-averse behavior. If the most aggressive bidder is risk neutral, $R = 1$. If, however, that investor is risk loving, he will bid lower and $R < 1$. Similarly, if he is risk averse, he will not bid as low and $R > 1$. Since $E_t(V_i \mid Ad) = P(H \mid Ad) V_H + [1 - P(H \mid Ad)] V_L$, we may substitute this expression into Equation (4) to obtain an expression for $P(H \mid Ad)$ in terms of observable variables:

$$P(H \mid Ad) = \left(\frac{R300}{Bid_t^A} - V_L \right) / (V_H - V_L). \qquad (5)$$

Substituting Equation (5) into Equation (3) yields an expression that can be estimated to explain the dynamics of bidding behavior for advertising firms in each experiment:

$$\frac{1}{Bid_t^A} - \frac{1}{Bid_{t-1}^A} = \frac{\alpha}{R} \left[\frac{\left(\frac{H_{t-1}^A}{H_{t-1}^T}\right) V_H + \left(\frac{L_{t-1}^A}{L_{t-1}^T}\right) V_L}{300 \left(\frac{H_{t-1}^A}{H_{t-1}^T} + \frac{L_{t-1}^A}{L_{t-1}^T} \right)} \right] - \alpha \left(\frac{1}{Bid_{t-1}^A} \right) \qquad (6)$$

where $0 < \alpha < 1$ is the speed of adjustment of bids for advertising firms.

We derive an analogous expression for the case of nonadvertising firms and estimate it to explain the dynamics of bids for nonadvertising firms, represented by the superscript N:

$$\frac{1}{Bid_t^N} - \frac{1}{Bid_{t-1}^N} = \frac{\gamma}{R} \left[\frac{\left(\frac{H_{t-1}^N}{H_{t-1}^T}\right) V_H + \left(\frac{L_{t-1}^N}{L_{t-1}^N}\right) V_L}{300 \left(\frac{H_{t-1}^N}{H_{t-1}^T} + \frac{L_{t-1}^N}{L_{t-1}^T} \right)} \right] - \gamma \left(\frac{1}{Bid_{t-1}^N} \right) \qquad (7)$$

where $0 < \gamma < 1$ is the speed of adjustment of bids for nonadvertising firms.

Both of these expressions are linear in the parameters to be estimated. This is especially convenient because each signaling experiment yields just 10 to 14 rounds of data, limiting the available degrees of freedom. We use OLS to obtain estimates of α, α/R, γ, and γ/R for each experiment. We also test the null hypothesis of risk neutrality in each case, using a simple *t*-test on the linear restriction that $\alpha = \alpha/R$ for advertising bids and $\gamma = \gamma/R$ for nonadvertising bids. Where risk neutrality cannot be rejected at the 10% level or less, the equations are reestimated with these linear restrictions imposed.

In some rounds of certain experiments, data are missing, either because no firms are advertising, in the case of Equation (6), or because all firms are advertising, in the case of Equation (7). Such rounds are simply dropped. In a few scattered instances, there are rounds in which the random process of picking envelopes produced no firms of a particular type. This meant that investors received no new information on the propensity of the missing type to advertise that they could use to update their expectations for the subsequent round. In such cases, we assume that investors used the latest available information. Accordingly we use the latest available H^A/H^T, L^A/L^T, H^N/H^T, or L^N/L^T as necessary in the regression.

Table 5 reports the results for bids on advertising firms. Table 6 reports the results for bids on nonadvertising firms. Each table is divided into panels, grouping experiments by equilibrium configuration and selected equilibrium. α_f and γ_f refer to the adjustment parameters when the linear restrictions representing risk neutrality are imposed. The reported *p*-values compare the null hypothesis against the predicted one-sided alternative that the parameters be positive. Coefficients that are significant at the 5% level or less are highlighted in bold. Coefficients that are marginally significant at levels between 5% and 10% are in italics.

Overall, the risk neutrality hypothesis is rejected only twice in the case of advertising experiments, and five times in the case of nonadvertising experiments. In discussing the significance of the adjustment coefficients, we refer to the results with the risk neutrality restriction imposed whenever it was not rejected by the data.

In each table, panel A reports results on the three experiments with a signaling-separating equilibrium and a nonsignaling-pooling equilibrium that converged to the signaling-separating equilibrium satisfying equilibrium dominance (G5, G6, GW3). In the advertising case, the adjustment parameters are significant in just one experiment, GW3. The reason for this is that in experiments G5 and G6, advertising was presumed to be the action of a high firm from the very beginning,

Table 5
Dynamics of bid adjustment for firms purchasing advertisements

Experiment	$\frac{\alpha}{\bar{R}}$	α	N	R^2	H_0: $\frac{\alpha}{\bar{R}} = \alpha$ t-statistic	α_f	$\bar{R}_f^2$
Panel A: Experiments with signaling-separating and nonsignaling-pooling equilibria converging to the signaling-separating equilibrium							
G5	0.152	0.144	10	0.066	0.458	0.111	0.042
	(0.242)	(0.246)			(0.659)	(0.274)	
G6	0.004	0.004	8	0.002	0.033	0.004	0.002
	(0.459)	(0.459)			(0.975)	(0.457)	
GW3	**0.243**	**0.245**	11	0.492	0.747	**0.203**	0.461
	(0.011)	**(0.012)**			(0.474)	**(0.008)**	
Panel B: Experiments with signaling-separating and nonsignaling-pooling equilibria converging to neither equilibrium							
G4	−0.179	−0.187	9	0.142	0.466	−0.172	0.115
	(0.826)	(0.833)			(0.655)	(0.831)	
GW1	−0.013	−0.004	5	0.046	0.359	0.014	0.006
	(0.463)	(0.486)			(0.744)	(0.444)	
Panel C: Double-pooling experiments converging to a Pareto optimal nonsignaling equilibrium							
G3	**0.264**	*0.206*	9	0.412	1.189	*0.213*	0.293
	(0.034)	*(0.058)*			(0.273)	*(0.053)*	
GW4	—	—	1	—	—	—	—
GW5	—	—	1	—	—	—	—
BC2	0.007	0.014	8	0.107	0.525	0.017	0.066
	(0.422)	(0.318)			(0.618)	(0.252)	
BC3	−0.006	−0.006	6	0.001	0.041	−0.004	0.001
	(0.525)	(0.525)			(0.969)	(0.523)	
BC4	**0.285**	**0.282**	5	0.725	0.173	**0.283**	0.722
	(0.034)	**(0.034)**			(0.874)	**(0.016)**	
Panel D: Double-pooling experiments converging to a signaling-pooling equilibrium satisfying equilibrium dominance							
GW6	**0.343**	**0.349**	10	0.449	0.519	**0.331**	0.431
	(0.017)	**(0.017)**			(0.618)	**(0.014)**	
GW7	**0.372**	**0.381**	11	0.430	0.441	**0.359**	0.418
	(0.014)	**(0.015)**			(0.670)	**(0.012)**	
GS4	**0.392**	**0.375**	11	0.418	0.788	**0.342**	0.378
	(0.016)	**(0.016)**			(0.451)	**(0.017)**	
Panel E: Double-pooling experiments converging to neither equilibrium							
G7	**0.631**	**0.614**	11	0.450	0.310	**0.604**	0.444
	(0.014)	**(0.012)**			(0.764)	**(0.009)**	
G8	**0.537**	**0.539**	11	0.608	0.105	**0.537**	0.608
	(0.002)	**(0.002)**			(0.918)	**(0.001)**	
GW8	**0.572**	**0.577**	11	0.455	0.249	**0.584**	0.451
	(0.014)	**(0.013)**			(0.809)	**(0.008)**	
GS2	**0.468**	*0.482*	6	0.683	0.226	**0.444**	0.678
	(0.033)	*(0.051)*			(0.833)	**(0.011)**	
GS3	**0.602**	**0.652**	13	0.599	*1.854*		
	(0.001)	**(0.001)**			*(0.091)*	—	—
GS5	**0.249**	**0.258**	11	0.381	0.651	**0.283**	0.352
	(0.050)	**(0.040)**			(0.531)	**(0.021)**	
BC5	−0.135	0.015	4	0.838	*2.981*		
	(0.770)	(0.466)			*(0.097)*	—	—

P-values are in parentheses. For α, α/R, and α_f, they are calculated based on the alternative hypothesis that each of these coefficients is positive. Entries in bold are significant at the 5% level or less; italicized entries are marginally significant at between the 5% and 10% levels.

Table 6
Dynamics of bid adjustment for firms not purchasing advertisements

Experiment	$\alpha/\bar{R}$	α	N	R^2	H_0: $\alpha = \alpha/\bar{R}$ t-statistic	α_f	$\bar{R}_f^2$
Panel A: Experiments with signaling-separating and nonsignaling-pooling equilibria converging to the signaling-separating equilibrium							
G5	**0.249**	**0.248**	11	0.495	0.038	**0.246**	0.495
	(0.029)	**(0.019)**			(0.971)	**(0.005)**	
G6	0.047	0.052	9	0.179	1.029	0.019	0.054
	(0.134)	(0.131)			(0.338)	(0.258)	
GW3	0.009	0.028	11	0.339	0.948	**0.166**	0.273
	(0.482)	(0.436)			(0.368)	**(0.041)**	
Panel B: Experiments with signaling-separating and nonsignaling-pooling equilibria converging to neither equilibrium							
G4	**0.633**	**0.596**	10	0.753	**2.949**		
	(0.002)	**(0.002)**			**(0.019)**	—	—
GW1	**0.784**	**0.680**	8	0.616	**2.574**		
	(0.012)	**(0.012)**			**(0.042)**	—	—
Panel C: Double-pooling experiments converging to a Pareto optimal nonsignaling equilibrium							
G3	**0.346**	**0.338**	9	0.503	0.254	**0.337**	0.498
	(0.017)	**(0.016)**			(0.807)	**(0.011)**	
GW4	0.234	0.207	9	0.226	0.754	0.077	0.164
	(0.159)	(0.148)			(0.475)	(0.123)	
GW5	**0.823**	**0.743**	11	0.445	**2.528**		
	(0.013)	**(0.013)**			**(0.032)**	—	—
BC2	**0.096**	**0.086**	9	0.385	0.854	**0.073**	0.321
	(0.040)	**(0.037)**			(0.422)	**(0.044)**	
BC3	**0.422**	**0.338**	9	0.393	*2.115*		
	(0.040)	**(0.045)**			*(0.072)*	—	—
BC4	0.003	0.003	9	0.000	0.002	0.003	0.000
	(0.483)	(0.482)			(0.999)	(0.481)	
Panel D: Double-pooling experiments converging to a signaling-pooling equilibrium satisfying equilibrium dominance							
GW6	*0.363*	*0.361*	8	0.382	0.106	**0.353**	0.381
	(0.064)	*(0.059)*			(0.919)	**(0.038)**	
GW7	−0.008	−0.006	10	0.003	0.117	−0.010	0.001
	(0.527)	(0.520)			(0.910)	(0.538)	
GS4	0.256	0.262	10	0.245	0.192	*0.293*	0.241
	(0.181)	(0.155)			(0.852)	*(0.062)*	
Panel E: Double-pooling experiments converging to neither equilibrium							
G7	**0.488**	**0.420**	10	0.655	1.266	**0.412**	0.586
	(0.002)	**(0.003)**			(0.241)	**(0.003)**	
G8	**0.211**	**0.249**	9	0.419	1.110	**0.182**	0.300
	(0.035)	**(0.030)**			(0.271)	**(0.050)**	
GW8	*0.379*	*0.367*	10	0.368	0.345	**0.321**	0.358
	(0.067)	*(0.053)*			(0.739)	**(0.026)**	
GS2	*0.214*	0.142	11	0.246	*1.580*		
	(0.095)	(0.155)			*(0.074)*	—	—
GS3	0.261	0.221	12	0.109	0.508	0.167	0.086
	(0.162)	(0.148)			(0.623)	(0.166)	
GS5	0.081	0.080	11	0.139	0.232	0.077	0.134
	(0.130)	(0.129)			(0.822)	(0.121)	
BC5	*0.334*	**0.459**	7	0.467	1.816	0.157	0.115
	(0.061)	**(0.048)**			(0.129)	(0.206)	

P-values are in parentheses. For γ, γ/R, and γ_f, p-values are calculated based on the alternative hypothesis that each of these coefficients is positive. Entries in bold are significant at the 5% level or less; italicized entries are marginally significant at between the 5% and 10% levels.

so that bids started out in equilibrium and simply stayed there. In the nonadvertising case, the coefficients are significant in two of the three cases. Once again, in experiment G6 the coefficient was not significant because the subjects acted as if they believed all nonadvertising firms were low right from the first round, and bidding behavior remained unchanged throughout the game.

Panel B in each table reports results on the two experiments with a signaling-separating equilibrium and a nonsignaling-pooling equilibrium that did not converge to either equilibrium. In both cases, the adjustment coefficients are insignificant for advertising bids, but significant for nonadvertising bids. Bids for advertising firms in experiment G4 started out in equilibrium, and hardly moved as the experiment progressed. In the case of GW1, there was hardly any advertising at all.

Panel C in the two tables reports results for double-pooling experiments that converged to the nonsignaling Pareto optimal pooling equilibrium. In two of the experiments, GW4 and GW5, advertising occurred in just two rounds so that regressions for advertising firms could not be estimated. In two other cases, G3 and BC4, the adjustment coefficients for advertising firms were significant. However, the coefficients were not significant for BC3, in which there was little advertising data. In the other experiment, BC2, investors erroneously assumed that all advertising firms were high, and bid accordingly from the beginning to the end of the game, despite the fact that 42% of advertisers were actually low. Clearly the hypothesized partial adjustment process failed in this instance. The adjustment coefficient for nonadvertising bids was significant in four of the six experiments. GW4 was not far from significance with a p-value of 0.123 on γ_f. BC4 was another example of an experiment that found the equilibrium immediately for nonadvertising bids, and simply stayed there.

In both tables, panel D reports results for double-pooling experiments that converged to the signaling-pooling equilibrium satisfying equilibrium dominance. The adjustment parameter for advertising bids was significant for all three experiments and in two out of three cases for nonadvertising bids. The exception was GW7, in which nonadvertising bids failed to adjust as predicted when high firms abandoned the nonadvertising strategy.

Panel E in the two tables reports results for the seven double-pooling experiments that did not converge to either equilibrium. The adjustment parameter for advertising bids was significant for all experiments except BC5, where, as discussed previously, other factors were at work and where there was little advertising data. For nonadvertising bids, three experiments have estimates of the adjustment parameter that are clearly significant. In GS2, γ/R is marginally significant, but γ is not. In BC5, these two parameters are both significant, but γ_f, estimated with the linear restriction imposed, is not. However, the adjustment parameter is not significant in either GS3 or GS5.

Considering that these adjustment parameters were estimated with very little data, the results are quite supportive of the adjustment hypothesis when the initial bid does not start out in equilibrium. Overall the adjustment parameter is significant for 12 out of 19 advertising bid cases and for 13 out of 21 nonadvertising cases. Several cases of nonsignificance are due to immediate achievement of an equilibrium value. Others are due to lack of data. However, in a few cases, subjects seemed to cling to losing strategies or wander aimlessly, making little use of the feedback provided. Signaling experiments that did not provide detailed information on the blackboard (G3–G5 and BC2 and BC3) did no worse in this regard than those that did.

5. Discussion and Conclusions

A signaling environment was more difficult for the subjects than the same environment without a signaling opportunity. As a result, convergence was generally slower in the signaling environment, and sometimes an equilibrium outcome was not attained at all. It would appear that economic theorists are not the only people who are in some disagreement about what to expect in multiple equilibrium environments.

When an equilibrium was attained, it was not always maintained. In classical usage, the term “equilibrium” refers to a state of rest for a system. Barring an exogenous shock, once in “equilibrium,” the endogenous variables in a system will repeat their values in the next period. We observed several cases in which a session reached a game theoretic equilibrium but did not stay there. These equilibria did not prove to be “equilibria” in the classical sense of the term.

Equilibrium dominance was not always a helpful principle for predicting which equilibrium would occur. When equilibrium dominance was tested against another equilibrium that failed to satisfy equilibrium dominance, but was Pareto superior, both types of equilibria were observed. The particular equilibrium that occurred did not depend on a theoretical refinement. However, it did depend on the potential short-term gains for a high firm that successfully revealed its type by advertising. Thus it was not a refinement at all, but rather the extent to which the payoff structure created an incentive for high firms to try advertising while groping for an equilibrium that mattered for equilibrium selection. This is rather similar to the results of Brandts and Holt (1992, 1993) where it was the effect of the payoff structure on actions taken prior to convergence that seemed to determine equilibrium selection, regardless of whether one equilibrium satisfied more refinements than another.

In markets with an equilibrium satisfying equilibrium dominance, in which both types of firms undertake their projects with the high type alone signaling, as well as a nonsignaling pooling equilibrium which fails equilibrium dominance, the refinement received some support. This equilibrium configuration is close to the usual signaling applications of refinement concepts. However, it is not clear that equilibrium dominance was responsible for this result because these equilibria also satisfied the perfect sequential equilibrium refinement.

The agents in our experiments were much more responsive to market prices than current theory predicts. According to Grossman (1981), a fundamental insight of the rational expectations approach was that traders may use observed prices to learn about their environment and forecast future values of the endogenous variables. This idea seems quite consistent with what we observed. However, its effects seem to be underestimated by currently popular models. Nonequilibrium behavior takes place. Accordingly, people observe responses to out-of-equilibrium actions. They often seem to pay attention to actual prices rather than calculate theoretical prices. In retrospect, it does not seem too surprising that people place more confidence in observed behavior than in delicate reasoning.

Appendix

A.1 Formal definition of sequential equilibrium

Let the sender's type and message and the receiver's action belong to the finite sets T, M, and A, respectively. The sender chooses a message, $m \in M$, which the receiver observes before choosing an action, $a \in A$. The receiver has a prior distribution $p(t)$ over the sender's type, where $t \in T$. The sender's and the receiver's utility functions are $u(t, m, a)$ and $v(t, m, a)$, respectively. A signaling strategy for the sender is a function q: $T \to \delta(M)$, where $\delta(M)$ is the set of all probability distributions over M. The function $q(m \mid t)$ is to be understood as the probability that a sender of type t sends the message m. A strategy for the receiver is a function r: $M \to \delta(A)$, where $\delta(A)$ is the set of all probability distributions over A. The function $r(a \mid m)$ is the probability that the receiver selects action a on seeing the signal m.

A sequential equilibrium consists of strategies q and r and beliefs $\mu(\cdot \mid m) \in \delta(T)$, where $\delta(T)$ is the set of all probability distributions over T, such that

$$\begin{aligned}&\forall\ t \in T,\ q(m' \mid t) > 0 \text{ only if}\\&\quad u(t, m', r(m')) = \max_{m \in M} u(t, m, r(m)).\end{aligned} \tag{A1}$$

$$\forall\ m \in M,\ r(a' \mid m) > 0 \text{ only if}$$
$$\sum_{t \in T} v(t, m, a') \cdot \mu(t \mid m) = \max_{a \in A} \sum_{t \in T} v(t, m, a) \cdot \mu(t \mid m). \qquad \text{(A2)}$$

$$\forall\ m \in M \text{ s.t. } q(m \mid t) > 0 \text{ for some } t \in T,$$
$$\mu(t' \mid m) = \frac{q(m \mid t') \cdot p(t')}{\sum_{t \in T} q(m \mid t') \cdot p(t)}. \qquad \text{(A3)}$$

Equation (A1) states that for all t the sender's strategy is optimal, given the receiver's strategy. Equation (A2) states that the receiver's strategy is optimal for some set of beliefs the receiver has regarding the sender's type, conditional on the sender's message. Equation (A3) restricts the receiver's beliefs by requiring that Bayes' rule be used by the receiver to form beliefs when he sees an action that can occur in equilibrium.

A.2 Formal definition of equilibrium dominance

Consider a sequential equilibrium in which the sender of type t receives $u^*(t)$. Then, for each out-of-equilibrium message, define $T_I(m) = \{t \in T\colon u^*(t) > \max_{r \in BR(\delta(t), m)} u(t, m, r)\}$, where $BR(\mu, m) = \operatorname{argmax}_{r \in \delta(A)} \sum_{t \in T} v(t, m, r(m))\mu(t)$. Then, define $\delta_I(m) = \{\zeta \in \delta(T)\colon \zeta(t) > 0 \text{ only if } t \notin T_I(m)\}$. A sequential equilibrium fails to satisfy equilibrium dominance if for some out-of-equilibrium message m, $u^*(t) < \min_{r \in BR(\delta_I(m), m)} u(t, m, r)$.

A.3 Instructions

This is an experiment concerning the nature of market decision making. Funding for this research has been provided by the Social Sciences and Humanities Research Council of Canada. The instructions are simple and if you follow them carefully and make good decisions you may earn a considerable amount of money.

In this experiment we are going to conduct a market in which there will be two groups of players located in separate rooms. At the start of the experiment you will be randomly assigned to membership in either group A or group B. People in group A will be given an opportunity to carry out a project. If they decide to carry out the project, they will have to raise money from the people in group B. Group A members who choose to undertake a project will also be given the opportunity to purchase an advertisement directed at the members of group B. People in group B will have an auction to determine who will provide the funds to carry out the project.

The type of currency used in this market is francs. All trading and earnings will be in terms of francs. Each participant will be instructed on how to convert these francs into dollars. Do not reveal this to anyone. It is private information. At the end of the experiment your francs will be converted into dollars and you will be paid by check. Notice that the more francs you earn, the more dollars you earn.

A.3.1 Specific instructions to group A. You will be assigned a player number for the duration of the experiment. The experiment will consist of several rounds. At the beginning of each round the experimenter will approach you with a large brown envelope. This brown envelope will contain two smaller envelopes. Without looking into the brown envelope you will choose one of the smaller envelopes. Each of the smaller envelopes contains two sheets of paper; one is labeled "decision sheet" and the other is labeled "certificate."

The decision sheets contain information about the total revenue to be earned if a new project is undertaken as well as the total revenue to be earned if a new project is not undertaken. They also state the cost of purchasing an advertisement attesting to the high value of the total revenue available once money is raised to undertake a new project. After considering all the information you will write down your decision "no new project," "new project without advertising," or "new project with advertising" on the decision sheet. Note that choosing to advertise is costly. However, you are allowed to advertise now and pay later. Specifically you must pay for your advertisement once you have received your proportion of the total revenue. You will then place both sheets of paper back into the small envelope. The experimenter will then collect all envelopes. You may then write down a brief explanation of why you made the decision that you did on the sheet of paper entitled "reasons for decisions." You are not required to write any comments on the reasons for decisions sheet if you would prefer not to do so.

To carry out a new project requires money. Each new project in this game costs 300 francs. This money must be raised from group B. Of course, members of group B will require something in exchange for their 300 francs. Members of group A have only one thing to offer, namely a percentage of the total revenue that will accrue if the project is undertaken. The decision to undertake a new project is thus also a decision to raise the required funds from group B by transferring a percentage of the resulting total revenues to a member of that group.

The actual percentage to be transferred in exchange for the 300 francs will be decided by means of an auction conducted by the experimenter. During the auction the members of group B will bid for the right to supply the francs. Bids are made in terms of the percentage of total revenue desired in exchange for the funds (300 francs) needed to allow the member of group A to undertake the project. Whoever bids the *lowest share* of the total revenue will be the supplier of the funds. After the auction the decision sheet will be returned to you indicating the share of total revenue which now belongs to the supplier of the funds. You will then use this information to calculate your earnings in francs for the round, remembering to subtract any advertising expenditures. Finally, you will calculate your earnings in Canadian dollars.

A.3.2 Specific instructions to group B. This experiment is conducted over a series of rounds. At the start of each round you are given a cash float of 1800 francs which may be used during the round. The cash float for the round is independent of what happened in the previous round. You are also given a score sheet.

In each round a number of envelopes will be brought into the room from the other group. The envelopes will be opened by the experimenter one at a time. After the first envelope is opened the experimenter will announce “no new project,” “a new project with advertising,” or “a new project without advertising.” The details of the information contained in the envelope will not be announced.

If “no new project” is announced the next envelope will be opened. If “a new project” is announced there will be an auction for the right to supply the funds necessary to carry out the project. All projects cost 300 francs to carry out. Bidding will involve raising your hand to be recognized by the experimenter. Upon being recognized you will announce the percentage of total revenue that you would be willing to accept in exchange for the 300 francs needed for the member of group A to undertake the project.

There are two important rules about bidding. First, all bids must be in whole numbers. For example, bids of 77% or 78% are allowable; a bid of 77.5% is not allowed. Second, only bids that lower the percentage of revenue demanded will be permitted. For example, if someone has already indicated that they will provide the funds in exchange for 38% of the revenue then you cannot bid 40%. You can bid any whole number between 38% and 0%. An auction for the project contained in an envelope ends when nobody is willing to further reduce the demanded share.

After all the auctions have taken place, group B participants will receive the certificates containing the information on the projects for the bids which they have won. The experimenter will have already recorded the share of the project revenue that you bid in winning the auction on the decision sheet. You will use the information contained on the certificates you receive to update your score sheet.

A.3.3 Projects. There are two types of situations potentially available to the members of group A. By choosing a letter-size envelope, each member will in effect be selecting the actual type of situation that they are in. Notice that with each new round there is a 50% chance of randomly selecting situation 1 and a 50% chance of randomly selecting situation 2. The two potential situations are as follows:

- Situation 1 (in one envelope)
  - 200 francs total revenue if no new project.
  - 1500 francs total revenue if a new project.
  - 50 francs cost of advertising.
- Situation 2 (in the other envelope)
  - 25 francs total revenue if no new project.
  - 375 francs total revenue if a new project.
  - 50 francs cost of advertising.

Each situation requires a decision by the member of group A who has drawn that situation. In the case of both situations, the decision involves whether or not to undertake the available project. If a new project is undertaken, it is also necessary to decide whether or not to advertise. Remember that if the new project is undertaken, the total revenue produced will be shared with the person in group B who wins the auction for the right to supply the funds. The share that will belong to the person in group B is determined by the auction. In contrast, a decision not to undertake the project means all of the total revenue available without the project accrues to the member of group A.

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