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**EXPERIMENTAL RESEARCH ON ASSET PRICING**

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# Experimental Research on Asset Pricing

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## Abstract

This paper selectively surveys some of the more prominent laboratory experimental studies on asset market behavior. The strands of literature considered are market microstructure, pari-mutuel betting markets, characteristics of participants, the effect of information release, and studies of the CAPM pricing model.

JEL Classification: C9, G10

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## 1. Introduction

This article reviews some of the more extensive and productive lines of experimental research on asset market behavior. The ability of experimental researchers to observe and exogenously control key aspects of a market, such as the information that traders and dealers possess, the fundamental value of the asset, and the microstructure of the market, have attracted numerous researchers to the method. This article does not purport to be an exhaustive survey, but rather an attempt to concisely distill some of the more influential results, and to illustrate to the non-specialist reader the diversity of topics that have been pursued. Our choice of topics to cover also reflects an attempt to minimize overlap with two other articles that consider closely related topics. The article by Palan (2013) surveys work that uses and extends a particular paradigm of long-lived asset first studied in Smith et al. (1988). The survey of Deck and Porter (2013) considers prediction markets, a special type of contingent claims futures market that is designed with the intention of providing probabilistic predictions about future events<sup>1</sup>.

The scope of the term “*asset market experiments*” has some ambiguity. While no one property always distinguishes an asset from other goods, one of the following two features typically exists in the experimental studies of asset markets that appear in the literature, including those discussed same individual can both purchase and sell, and whether an agent is a buyer or a seller can depend on prevailing market conditions at the moment and her beliefs about future conditions. Speculation can either take place within a market period, or between periods in cases where the assets traded have a

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<sup>1</sup> For surveys of early work in this area, see Sunder (1995) or Duxbury (1995).

life extending over multiple periods. This feature contrasts with markets for perishable goods, with a life of one period, which cannot be resold after they are purchased. The second feature is that asset markets often trade a good that has a value that is not common knowledge at the time that trade takes place. In some studies, traders may have different information about this value than others, and some may have more accurate information than others. These two features generally distinguish asset market paradigms from the experiments surveyed in the other articles in this special issue, with the exception of the two articles mentioned in the first paragraph.

This survey is organized as follows. Section 2 describes the early experimental work in which the basic methodology and baseline findings for later work were established. Section 3 discusses a very productive line of research involving issues related to market microstructure. Section 4 considers parimutual betting markets, a special type of contingent claims market. Section 5 focuses on studies documenting the heterogeneity of the participants in the experiments. Section 6 explores the effects of releasing public information on market activity. Section 7 discusses experimental work relating to the Capital Asset Pricing Model, and section 8 consists of a few concluding remarks.

## **2. Early work**

Forsythe et al. (1982, 1984) and Friedman et al. (1984) describe the behavior of experimental markets for assets with a life of two and three periods (a period is defined as a unit of time between two dividend payments.)<sup>2</sup> Though these horizons are short, traders do face a situation where they have incentives to arbitrage intertemporally and to form expectations about prices in future periods. After a number of replications of two-or three-period asset markets, prices in the last period converge to approximately the rational expectations equilibrium level. However, convergence is slower and less reliable for period prices, the farther the period in question precedes the final one. The rational expectations equilibrium prices cannot be discovered until the price for the last period stabilizes, and the price discovery process unravels backward. The presence of futures markets aids and accelerates convergence to rational expectations equilibrium (Forsythe et al, 1984, and Friedman et al., 1984). The limits of the robustness of these findings are highlighted by Anderson et al. (1991) who replicate the Friedman et al. experiment with slight changes to the operationalization of the environment. They observe support for the rational expectations equilibrium only when traders are highly experienced.

Markets for longer-lived assets have a strong tendency to generate price bubbles and crashes, prolonged deviations from fundamental values, typically at prices that are greater than fundamentals.

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<sup>2</sup> The continuous double auction trading institution, first subject to laboratory investigation by Smith (1962), allows any individual to trade with any other. Any player wishing to make a purchase or sale may submit an offer to the market, which is then made public. Then any player may conclude a trade by accepting one of these offers. This system is conducive to price-taking behavior (Smith, 1982).

A crash is a sudden and rapid fall in prices. This result is originally due to Smith et al. (1988), but it has been widely replicated and shown to be robust to numerous modifications of the experimental design. In the original design of Smith et al., markets are created for assets with a life of a finite number of periods (usually 15 or 30 periods). The asset pays a dividend in each period, which (other than in a few sessions where there is a final fixed terminal value for the asset) is the only source of intrinsic value. The dividend payment is identical for all traders and the distribution of dividends is common knowledge to all traders. The time series of transaction prices in markets with this structure does not track the fundamental value, but rather is characterized by price bubbles and crashes. However, as in markets for shorter-lived assets, futures markets lead to closer adherence of spot prices to fundamental values (Noussair and Tucker, 2006). This literature is reviewed in detail by Palan (2013).

In many asset markets, some traders have better information about the value of the asset than others. One function of a market, and indeed the primary purpose of a prediction market, is to reveal this information with the market price. Several early experimental studies indicate that markets have a strong tendency to disseminate private information provided that enough individuals hold the information. For assets that have a life of only one period, and have a common though uncertain value, Plott and Sunder (1982) observe that when insiders who know the true value of the asset are present, prices in continuous double auctions reveal the insider information. This result shows that there exist conditions where it is possible to use a decentralized market to disseminate privately held information. This is consistent with the efficient market hypothesis (Fama, 1970), the notion that any privately held information is revealed in the asset price.

Later studies illustrate the limits of the ability of markets to reveal information as the informational environment becomes more complex and the task the market must accomplish becomes more complex. Plott and Sunder (1988) study the issue of whether markets can aggregate privately held information. They endow insiders with a portion of the information needed to determine the true value of the asset. Only the aggregation of all of the information held by insiders would allow the state of nature, and therefore the fundamental value of the asset, to be deduced with certainty. The results on information aggregation are mixed in this relatively challenging environment. In a setting in which there are markets for contingent claims and dividends differ between agents, prices tend toward the level corresponding to rational expectations. However, when only one security is exchanged, prices do not correctly reflect the available information. Forsythe and Lundholm (1990) show for the same environment, however, that sufficient trader experience, in conjunction with common knowledge of payoffs, enables the market to reliably aggregate and reveal the inside information.

Copeland and Friedman (1987, 1991) consider the effect of sequential, in contrast to simultaneous, information arrival in a double auction market for an asset with different values in

different states. They consider both a homogeneous setting in which one random event determines whether the state is good or bad for all types, and another, heterogeneous environment, in which different events determine the payoffs for different individuals. Copeland and Friedman (1987) find that models postulating strong-form efficiency are more accurate predictors of prices than some alternatives, i.e., semistrong, ordinary rational expectations, private information, and clairvoyant rational expectations models. They also find that sequential information arrival is less conducive to accurate pricing than simultaneous arrival. They confirm that models that assume rational expectations outperform models that assume that private information is not reflected in prices. Copeland and Friedman (1991) propose a model of partial information revelation, and show that it outperforms full information revelation models. The model they propose assumes that traders can extract some, but not all, private information from market prices. More precisely, the key assumption is that prices allow agents to infer that the state is one member of a set rather than a single state.

Huber et al. (2008) study the value of private information from another aspect. They consider the relationship between information and higher returns, that is, whether individuals with better information about the asset's value earn more than those with less precise information. They study three settings. One is a call market, in which the intrinsic value of the asset in each period is determined by 10 random draws from a binary distribution. The degree of insider information is varied by having different individuals know differing numbers of draw outcomes (the least informed knowing one draw, the most informed knowing nine out of the ten draws). The second treatment is the same except that a double auction trading mechanism is used to trade the asset. The third treatment also has a double auction system, but differs from the second in that the value of the asset is determined by a sequence of dividends determined via a random walk process. The degree of insider information is the number of future dividends known (the least informed knowing one future dividend, the most informed knowing nine future dividends with a total market length of 30 periods). The information is cumulative so that there is an ordering of agents with respect to how informed they are. They find that more information is not always better from the point of view of the individual trader. Rather, only those insiders who are much better informed than others can outperform other traders.

Another type of failure of markets to aggregate information arises when the price behaves as if it is revealing information that is not actually held by any traders. If the presence of insiders is uncertain, market activity can lead to convergence of prices to levels that are consistent with the presence of insiders, even when no insiders actually exist. This occasional failure of markets to reveal the absence of information is termed an information mirage (Camerer and Weigelt, 1991). Individuals may trade on the basis of inferences they make from the market activity they observe, generating prices that appear to reveal insider information that does not actually exist. Camerer and Weigelt usefully distinguish between mirages, which are caused by uncertainty about the information of others, and bubbles, which appear to be caused by uncertainty about the rationality of others.

### 3. Market Microstructure

The studies above all allowed for direct trade between buyers and sellers of securities. However, many asset markets involve designated market makers who act as intermediaries. The interaction between these market makers and informed as well as uninformed traders has been the subject of a rich theoretical literature, with early seminal contributions by Kyle (1985) and Glosten and Milgrom (1985). The predictions of their models initially motivated a line of experimental work which has continued for the last decade and a half.

Schnitzlein (1996) studies an environment in which there are three types of agents, i.e., three market makers, four liquidity traders, and a single insider. The liquidity traders are computerized and trade independently of the asset value, their demand and supply determined according to a Poisson arrival process. The asset value is drawn from an approximate normal distribution, and the actual realized value is known to the insider, but not to market makers. He studies behavior under call and continuous auction trading (a distinct system from the continuous double auction markets described earlier) mechanisms. Noise traders experience losses, and these losses are greater under the continuous auction. Insiders make more trades under the continuous auction and dealer profits are greater in the continuous auction. The insider trading increases price efficiency, indicating that some information leakage occurs. As a consequence, the continuous auction exhibits greater price efficiency.

Lamoureux and Schnitzlein (1997) study a similar setting, in which in some treatments, traders can bypass dealers and trade with each other through a bilateral search mechanism if they so choose. Their markets are also characterized by four liquidity traders, one trader with inside information, and three dealers. Liquidity traders are required to make net purchases and sales up to a certain level to avoid penalties. The distribution of the asset value is normal. Dealers cannot observe activity in, and may not participate in, the search market. The results show that when traders cannot bypass dealers, dealer profits are high. These dealer profits decrease to very low levels when traders can trade with each other directly. In all treatments, liquidity traders lose money on average and insiders make high profits because their information is very valuable. Market efficiency is similar whether or not there are private two-party trades that take place in the search market.

Theissen (2000), in related work, compares call markets, continuous double auctions, and dealer markets in terms of informational efficiency, in a setting with sequential information arrival. He finds that, while opening prices in the call market are closest to the true value of the asset, the call market underreacts the most to new information. The dealer market demonstrates the lowest price efficiency at the unit of the individual transaction, but is nonetheless very efficient at the level of average period price, as the deviations tend to average out. Thus, from the point of view of choice of

market institution, there is a tradeoff between the cost of operating the institution and the informational efficiency of the resulting prices, since the dealer market is the most informationally efficient, but also has the highest costs.

The question of what disclosure requirements to impose on dealers has also been investigated. Bloomfield and O'Hara (2000) report two experiments in which they consider whether transparent markets are competitive with non-transparent markets. In the first experiment, there are two high-transparency dealers who are required to report their trades, and two low-transparency dealers who are not. In the second experiment, dealers can endogenously select whether or not to be transparent. They advance five hypotheses, based on a dynamic game-theoretic model. These assert that in the first period, low-transparency dealers are more likely to set the inside spreads than high-transparency types and thus clear more of the order flow, while earning lower profits that period. However, after the first period, they earn greater profits and estimate the true value of the security with greater accuracy.

In the experiment, the values of the securities are random over a uniform distribution. In each round, four dealers set bid and ask prices for the securities. Additionally, there are four traders of three different types, i.e., one informed trader, one active trader, and two computerized liquidity traders. The results show that low-transparency dealers outperform high-transparency types. They can set prices to make it more likely that they have the inside spread, while high transparency dealers are constrained by their informational disadvantage. A paradox arises in that all dealers would be better off if they were all transparent, but each individual dealer has an incentive to defect to low transparency. Thus dealers would collectively benefit from an environment with a regulatory requirement for transparency.

Flood et al. (1999) consider pre-trade, as distinct from post-trade, transparency. They construct a market in which there are seven competing dealers who trade a single security with informed and liquidity traders. They compare relatively transparent with more opaque markets. In their transparent market setting, all bids and asks are presented on the trading screens of every market maker, and in the opaque treatment, they are not. The market takes place in continuous time, and uses professional security traders rather than a traditional student subject pool. They find that transparent markets have the effect of increasing volume by a factor of three. Search costs have a great impact in the opaque market, and in addition to reducing volume, also lead to dealers making trades at prices that are not the best currently available for them. Dealer spreads narrow to attract informed traders. Dealer spreads are wider in markets without public information than those with such information, but the differences decrease over time. Strikingly, however, markets with no disclosure are more efficient than those with public disclosure, though transparent markets are more liquid.

Krahen and Weber (2001) consider the effects of market maker competition and adverse selection on market behavior. They compare monopolistic markets, in which there is one specialist

per asset, with more competitive organizations. There are informed buyers who receive a noisy signal about the value of the asset. They adapt the design of Plott and Sunder (1988), originally developed to study information aggregation. Some traders receive private information that one of three possible states is not the true state. While no individual knows the true state, the private information given to all traders would allow an individual with access to all of the information to determine the state, and thus the asset's value, with certainty. Within this structure, they compare both monopolistic and competitive market maker regimes to a continuous double auction in which traders conclude trades with each other directly. They also vary how much information market makers have relative to traders. They find that market maker competition reduces the size of the bid-ask spread and increases trade volume. Competitive market makers often lose money, while monopolistic ones earn considerable rents. Inside information on the part of traders translates into greater profits, in particular when market making is competitive.

Schnitzlein (2002) studies an environment where there is uncertainty about the number of insiders in the market. This is a challenging environment for theoretical models to explain. The markets constructed for this experiment are order-driven dealer markets. In both treatments, the probability that any given trader has inside information indicating the true value of the asset is  $1/2$ . In one treatment, the actual number of insiders is made public (ND), and in the other treatment it is not (NI). Schnitzlein finds that insiders behave strategically. In the setting without disclosure, the insiders compete less aggressively than under disclosure. Monopoly insiders delay their trades more under NI than under ND, presumably to conceal their presence, and trade profitably with noise traders. Insider behavior changes as a function of the number of insiders, under ND, but not under NI. Insiders trade off the size of profit opportunities with waiting time: the greater the opportunity, the more quickly they take it. This strategizing is effective and dealers seem to have difficulty telling whether there are insiders and how many there are. A larger number of insiders slows convergence to efficient pricing. Price efficiency is lower when there is uncertainty about the number of insiders than when the number of insiders is public. When the number of insiders is publicly known, they compete aggressively. They thereby tend to reveal their information, and dealers adjust their behavior. Dealers are unable to make such inferences when the number of insiders is not known.

Cason (2000) considers the effect of allowing dealers to communicate with each other. He also studies the consequences of allowing the traders, rather than the dealer, to submit price quotes. As in the other studies in this section, he employs a setting in which trade must go through dealers, some traders are informed, and some others are uninformed. He finds that in the baseline setting in which communication is not possible, bid-ask spreads are small and prices are informationally efficient. When dealers can communicate, they succeed in colluding and realize much greater profits. The resulting prices are uninformative, so there is a large impact on market efficiency. However, even if dealers can communicate, the ability of traders to submit limit orders restores dealer competition



and informational efficiency. Allowing traders to initiate orders makes bid-ask spreads tighten to the same level as in the case without dealer communication in which dealers submit quotes. Dealers make negative average profits, as the bid-ask spread they get is not large enough to make up for their losses on transactions with informed traders.

Kirchler et al. (2011) consider the influence of market microstructure on the effectiveness of the imposition of a Tobin tax. A Tobin tax is a tax on financial market transactions, imposed with the goal of reducing speculation, on the presumption that such speculation increases price volatility. Kirchler et al. consider whether the tax has differential effects on market activity when there are market makers compared to when market makers are absent. Their design, which has currency markets as its motivation, consists of two markets that operate simultaneously. In contrast to the studies described in the rest of this section, the fundamental value process evolves over time and follows a geometric Brownian motion. The Tobin tax is very small, at 0.1% of the transaction value. They find that in a market with no market makers, the imposition of the Tobin tax in one market increases volatility. In a market with market makers, it has the opposite effect. If both markets are taxed, there are no effects of the tax on volatility. Efficiency is similar in all treatments. The Tobin tax reduces trade in the taxed market and increases it in the simultaneously operating untaxed market. Trading volume exhibits a modest and insignificant drop when the tax is introduced in both markets. Tax revenue is greater when there are market makers.

These results are consistent with earlier work of Hanke et al. (2010) who find that a Tobin tax reduces volume of trade in the taxed market, shifts some volume to other untaxed markets, and is ineffective at raising revenue if there are alternative untaxed markets. This study also reports that market efficiency in taxed markets is reduced when tax havens exist, and that the tax appears to reduce speculation. A higher tax rate leads to a corresponding increase in tax revenue by roughly the same proportion, but otherwise does not exert an effect any different from a lower tax rate.

DeJong et al. (2006) consider the simultaneous operation of an asset and a derivative option market in the presence of an insider. The option has a strike price equal to the expected value of the asset. The option market is open concurrently with a market for the underlying traded asset. Treatments with and without the traded option are compared. Because the stock return is normally distributed, the option value has a skewed distribution. Some traders have inside information about the actual value. The results indicate that the insider trades aggressively in both the stock and the option markets, leading to feedback effects between the two markets. Price convergence takes place in both markets simultaneously. When the intrinsic value of the option is positive, informational efficiency is higher in the market for the stock, and volatility is lower.

#### 4. Parimutuel Betting Markets

A number of interesting experiments have explored the behavior of parimutuel betting markets. These are markets in which individuals have an opportunity to place bets on one of more outcomes, and the bets determine the betting odds. Once bets are placed, they cannot be revoked. Most of the studies focus on settings in which individuals have private information that is correlated with the eventual outcome. As in the studies on asymmetric information described earlier, a major focus is on the extent to which this private information is aggregated into market prices. In these markets, these are expressed as the odds on each outcome. At the level of individual decision making, a primary focus is to study the conditions under which players engage in herding and in contrarian behavior.

Herding is defined as betting in disagreement with one's private signal but in favor of the consensus based on prior bets. This is optimal in cases when the informational content of the prior bets weighs in favor of one outcome to a greater degree than one's private signal weighs in the favor of another outcome. However, it can also be incorrect to herd if the information implicit in others' bets does not outweigh the information contained in the private signal for a rational agent. Contrarian behavior involves betting against one's own private information and against the consensus. Contrarian behavior is of special interest, because it can generate or accentuate the favorite long-shot bias.

This bias is the tendency for betting odds to overstate the probability of a long-shot being the outcome, making it more profitable in expectation for other bettors to bet on a favorite than on a long-shot. This is because the market odds reflect contrarian bets and overprice long shots as well as underprice favorites. Along with contrarian behavior, various plausible betting heuristics, such as betting with equal probability on each outcome regardless of payout and perceived winning probability, or betting based on idiosyncratic tastes for the outcome (favorite number, preferred color of horse, acquaintance with jockey, etc...), can also accentuate the favorite long-shot bias. A favorite long-shot bias can also arise as a consequence of the transformation of probabilities (Kahneman and Tversky, 1979; Prelec, 1998), risk-seeking preferences, or the presence of utility for beating the odds by betting on a successful longshot.

The source of the favorite long-shot bias has been the specific topic of a number of experimental studies. Piron and Smith (1995) report an experiment that they interpret as supporting the idea that the transformation of probabilities, rather than the existence of utility from beating the odds, is a cause of the favorite long-shot bias. Hurley and McDonough (1995) consider whether the favorite long-shot bias is a result of the fact that the racetrack earns a fraction of the amount bet. They present a model in which, with zero take for the market maker, there is no bias, but a positive take generates a bias. However, their experiment, which compared treatments with markets with and

without market maker costs, yielded no difference between the two treatments, and thus their model was not supported. That is, they concluded that the favorite long-shot bias is not driven by costly information and transaction costs.

Drehmann et al. (2005) conduct a large internet-based field experiment, in which players play a betting game with the structure of a parimutuel betting market. Players endowed with private information are offered, sequentially, one opportunity to place a bet on one of two possible outcomes, or to refrain from betting. The odds, the prices for a bet on each outcome, are updated after each bet so that they reflect the conditional probability of each outcome. Thus, the price equates the expected payoff of betting on each of the two available alternatives based on the public information only. Therefore, it is always optimal to bet in agreement with one's private information. There are a number of treatments that vary the displays that bettors are presented with, whether an option not to bet is available, and whether prices are set assuming the presence of error in the bets of prior bettors. However, all of treatments have in common the feature that it is always optimal, in terms of maximizing expected value, to bet on the outcome that is in agreement with one's private signal. Despite this, only 2/3 of decisions are consistent with private signals. There is little herding, but abstention from making a bet, as well as contrarian behavior, is common.

Similar results are obtained by Cipriani and Guarino (2005). They also report an experiment, in which each bettor in a sequence possesses some private information about whether an asset's value is likely to be 0 or 100. They can bet on the outcome, by either buying or selling based on the information they have and (in some treatments) on the history of betting decisions of prior bettors in the sequence. They conduct one treatment in which the price is fixed at 50, and one in which it is flexible, varying according to prior betting activity in a manner analogous to Drehmann et al.'s (2005) experiment. In the flexible price treatment, it is always optimal to bet in favor of one's private signal. Indeed, they find that the flexible price condition leads to a lower incidence of herding than the fixed price treatment. However, they observe a high incidence of abstention from betting as well as of contrarian behavior. The results are similar whether or not the history of preceding bets is provided. In both this study and in Drehmann et al. (2005), contrarian betting impedes the ability of the market to aggregate information.

Koessler et al. (2012) introduce a design feature that greatly reduces the incidence of contrarian behavior. They construct a pari-mutuel market, in which players move in a fixed sequence, as in the last two studies. However, at the time each individual makes a bet, all players must submit a belief assessment about the state. That is, they must assess the probability that each of the two outcomes will be realized. Beliefs are remunerated based on how far they are from the actual outcome, according to a function that ensures that it maximizes expected payoff for an agent to truthfully report his actual belief. Koessler et al.'s experiment has three treatments. In the Bet

treatment, individuals only submit bets. In the ObsPred treatment, one group of players submits bets, and another group of observers, endowed with private signals and who can observe the history of trades, submits beliefs. In the BetPred treatment, the same players make bets and submit beliefs. When bettors submit beliefs, in BetPred, contrarian behavior decreases sharply compared to the other treatments. Under BetPred, the market also aggregates more information, primarily by reducing contrarian betting, and exhibits a much smaller favorite long-shot bias. Beliefs are also more accurate when bettors, rather than observers, are submitting them. It appears that eliciting beliefs from bettors directs more of their attention to the probability of each outcome eventually being realized. This may cause relatively less weight to be placed on the high payout associated with the long-shot in the (unlikely) event that it wins, reducing the tendency to bet on it.

The parimutuel market experiments described above are highly structured in terms of the precise sequencing of bets, and the constraint that each individual can only submit one bet. Such structure facilitates the study of individual decisions and the testing of theoretical models of decision-making. In many parimutuel betting markets in the field, however, such specific structure is not present. Rather the market is open-ended, and an individual can place many bets at the timing of her choosing. The laboratory experimental study of open continuous parimutual betting markets was initiated by Plott et al. (2003). In their experiment, they conduct several markets that operate simultaneously. In each market, the experimenter sells contingent claims on a different outcome. Individuals are endowed with some private information about the likelihood of the outcomes and a fixed budget with which they can purchase tickets. While the market is open, any individual can at any time purchase as many tickets he wishes at a fixed price per ticket. All ticket purchases are public information, each market shows the number of tickets it has left for sale, and the odds are posted periodically. Tickets purchased cannot be resold. There are two treatment conditions, “Not Sets,” in which individuals’ private information would allow them to eliminate some outcomes with certainty, and “PIC,” where private information allows updating of probabilities, but not the elimination of any of the possible outcomes. A favorite long-shot bias appears in both settings, though information aggregation is better in Not Sets than in PIC. Strategic behavior, in the form of waiting until late in the period (including the submission of bets just before the market close) and attempts to bluff and mislead early in the market period, are common and appear to accentuate the favorite long-shot bias.

Alexrod et al. (2009) modify the Plott et al. (2003) design in two ways. They impose a cost of delay, to encourage earlier betting, with the goal of reducing early-period strategic waiting and bluffing. This is done by increasing the price of each bet at a constant rate over the course of the market period. They also divide the period into two rounds of betting, and after the first round, the current interim odds are posted. The authors find that the process of information aggregation is more rapid with these modifications. The favorite long-shot bias is present in the first round, but largely

disappears in the second round, suggesting that it is a disequilibrium phenomenon, that is, a transitory pattern that fades away if the process of market clearing is permitted to continue unimpeded.

Roust and Plott (2005) propose and test a further enhancement of this system. In their betting markets, there are two stages. In the first stage players can buy contingent claims on each outcome with fixed budgets of fiat money (which has no value other than as a means to purchase the claims). Prices are constant over the course of this stage. Because the money has no other use, there is an incentive for individuals to spend all of their budgets. The number of claims purchased is not disclosed until the stage ends, so there is no incentive to bluff and mislead within stage one. The second stage of the market is a parimutuel betting market with price that increase regularly over time, as in Axelrod et al. (2009). This two-stage system reduces the incidence of bubbles and information mirages relative to, and achieves better values of measures of information aggregation than, the systems studied by Plott et al. (2003) and Axelrod et al. (2009).

## **5. Participant characteristics**

### **5.1. Behavioral traits**

The behavior of markets is influenced by characteristics of traders. One of the factors that has been associated with asset mispricing in the field is trader overconfidence. Deaves et al. (2009) consider the role of overconfidence in price determination in laboratory markets. They measure three types of decision biases related to overconfidence in a sample of participants in experimental markets. These are calibration-based overconfidence, the better-than-average effect, and the illusion of control. They find that the measures are only weakly correlated with each other, and that the calibration-based measure is the one that correlates most strongly with the number of trades an individual concludes. Men are not more overconfident than women, but there are cultural differences. Women and men trade the same amount in Canada, but women trade less than men in Germany. In general, overconfidence leads to poorer performance.

Biais et al. (2005) consider the relationship between overconfidence, defined as the tendency to overestimate the precision of one's own information, and trading activity. They also look at self-monitoring, which is a form of social awareness, and its connection to trading behavior. They consider the environment of Plott and Sunder (1988) with the addition that they allow short selling. They conduct both call markets and continuous double auction markets. A confidence interval task is employed to measure miscalibration. They ask participants ten questions, requiring subjects to provide upper and lower limits for their answer so that there would be a 90% chance that the true numerical value lies between the two limits. They find that the extent of miscalibration is uncorrelated with the IQ of participants. In their markets, prices depart considerably from full information levels. When the true liquidation value is high, the relatively high transaction prices reveal the state.

However, when prices seem to indicate a convergence to the value associated with the middle state (the second highest of the three possible liquidation values), the price pattern reflects the true state in only 52% of cases.

In the experimental market, men trade more than women. Miscalibration is correlated with poorer performance in men, but not in women. On the other hand, greater IQ is correlated with higher earnings for women, but not for men. The authors hypothesize that miscalibrated people make the price shoot toward one of the states more quickly, and this leads miscalibrated traders to earn lower profits. Self-monitoring, the awareness of one's own actions, is presumed to be correlated with a better ability to trade, and greater earnings. This is also measured in this study, using survey questions. The authors find that miscalibration does lower trading profits, and self-monitoring improves profits for men, but not for women. The effect appears to mostly be due to miscalibrated and poorly self-monitoring individuals falling into the trap of falsely thinking that prices are in the middle state.

Weber and Camerer (1998) construct an experiment to study the disposition effect. The disposition effect is a tendency, first identified in field data by Shefrin and Statman (1985), for individuals to sell assets that have increased in value more readily than those that have declined in value. Weber and Camerer hypothesize that subjects would sell more shares when the sale price is above the purchase price than when it is below, and that they would sell more when price has increased since the preceding period, than when it has decreased. They further hypothesize that the disposition effect would be smaller when the asset is automatically sold, than when the trader makes a conscious decision to sell, and that trading volume is positively correlated with the size of price changes. The rationale for this last hypothesis is derived from a theory of Andreassen (1988) that a large price change focuses trader attention on the stock, and the fact that the pattern is observed in field data. They support all four hypotheses in an experiment in which there are six asset markets operating simultaneously.

Bossaerts et al. (2010) report an experiment in which ambiguity aversion can have a direct measurable impact on market behavior. In their setup, ambiguity aversion has an impact that is distinguishable from that of risk aversion. Ambiguity is created by making the state probabilities (governing the actual value of the asset) unknown. Ambiguity-averse individuals are those who gravitate toward portfolios for which the state probabilities are known. The experiment of Bossaerts et al. consists of a sequence of periods in which two assets, stocks and bonds, each with a life of one period, trade. Bonds pay a fixed dividend and stocks have two possible terminal values, depending on the state of the world, which is unknown at the time the market is operating. Short-selling is permitted.<sup>3</sup> There are two endowment configurations, one of which is chosen to make a reversal in the

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<sup>3</sup> Short-selling, given a sufficiently large capacity to take short positions, tends to reduce price levels (see for example Haruvy and Noussair, 2006)

state probability/price ranking relatively likely. Sessions in which probabilities are known are paired with session in which they are unknown.

The market data confirm that ambiguity aversion is widespread. Many individuals refuse to hold an ambiguous portfolio, and there is a great deal of heterogeneity in the level of ambiguity aversion that individuals exhibit. One reason that this is important is that asset prices are typically assumed to reflect aggregate beliefs. If people who are ambiguity averse do not participate in the market, their beliefs have no influence on prices. A second reason that heterogeneity in ambiguity aversion is important is that inframarginal ambiguity-averse individuals affect the amount of risk held by other agents, even though they have no direct effect on prices themselves.

## **5.2 Traders' Emotional States**

Three recent studies explore the role of emotions in generating bubbles in experimental asset markets. All three papers consider markets with the structure of Smith et al. (1988), which is discussed in detail in Palan (2013). Andrade et al. (2012) induce mood exogenously with film clips before the market opens. Subjects watch video clips that are (a) exciting and arousing, (b) neutral, (c) fearful, or (d) sad. They find that the high intensity, exciting video clips are associated with larger bubbles than the other three treatments. The other three are not different from each other.

Lahav and Meer (2010) conduct two treatments, which they call the positive and neutral treatments. Like Andrade et al, they induce mood by showing film clips to subjects before the market opens. Positive affect was induced with comedy routines by Jerry Seinfeld, and in the neutral treatment, no clip was shown. They find that the positive treatment is characterized by greater bubbles and higher prices than the neutral treatment. This is the case even though the neutral treatment still bubbled.

Hargreaves-Heap and Zizzo (2011) conduct an experiment in which a bubble market is created and emotions are tracked over the course of the session. They consider the emotions of anger, anxiety, excitement and joy. Their experiment consists of four conditions in which the participants complete two sequential asset markets. In two of the treatments, the participants rate on a Likert scale from 1 – 7 how intensely they current feel each of the four emotions at the beginning of each period. In one of these conditions, subject can engage in non-price chat and in the other they cannot chat. They report that eliciting emotions or the ability to chat does not have an effect on market prices, but they find that the level of excitement reported is positively correlated with price level. They also find that buying assets is linked to excitement and selling assets is connected to anxiety. They do not find a correlation between emotional state and trading profits.

## 5.2 Trader strategies

Haruvy et al. (2012) apply the model of DeLong et al. (1990) to describe data from an asset market experiment with the structure of Smith et al. (1988). The DeLong et al. model postulates three trader types: fundamental value, momentum, and rationally speculating traders. The fundamental value trader makes purchases if prices are below fundamentals and sells if they are above. The momentum trader follows previous trends, purchasing if prices have been increasing in the recent past and selling if prices have been decreasing. The rational speculator anticipates future price movements and purchases (sells) if she expects prices to rise (fall). Haruvy et al. (2012) test whether this structure predicts the observed treatment differences in an experiment in which the experimenter purchases and resells units of asset. The model predicts a reshuffling among traders that induces a repurchase to exacerbate bubbles and a share issue of sufficient size to induce prices to track fundamentals. The predictions are strongly supported in the data both at the market and at the individual levels.

Bhojaj et al. (2008) consider a setting, in which there are both smart-money traders and sentiment traders. The market is conducted under high and low share endowment conditions, as well as high and low cash endowment conditions. In the first experiment reported in the paper, there is one robot sentiment trader and nine human smart money traders. The sentiment trader purchases a fixed quantity each period at the prevailing market price. The humans have the typical incentives to maximize their total wealth. In early periods, humans tend to front-run the sentiment trader by buying early, but then delay selling off, so that prices exceed fundamental value. Large endowments or tight margin restrictions temper the bubble and crash pattern. The traders from the first experiment also participate in a second experimental series where they are endowed with cash but no asset, so that some traders must hold short positions if any trade is to occur. Here, relaxing margin restrictions increases bubble magnitude, since individuals use the borrowed cash to front-run more. The authors conclude that loose margin restrictions impede convergence to the equilibrium outcomes.

In related work, Bloomfield et al. (2009) study whether uninformed traders exhibit distinct patterns of behavior, compared to noise traders. Noise traders are a convenient modeling device that allows dealers to make money to compensate for their losses due to superior information that informed traders have. They have three types of traders in their markets, i.e., liquidity, informed and uninformed. Liquidity traders have a requirement to buy and sell a certain number of units, generated randomly each period. Uninformed traders are the same as liquidity traders except for the transactions requirements. Lastly, informed traders have perfect information as a group, but individually know the true state plus/minus a random number. They find that uninformed traders act like contrarian traders, taking positions on the opposite side of the market from the informed, and therefore lose money. Their willingness to engage in trade increases the volume in the market. They thus effectively serve as the noise traders specified in theoretical models. Due to their contrarian bidding strategies, market



efficiency is reduced. In this study, a Tobin tax is also considered. In contrast to the work of Hanke et al. (2010), the tax is implemented in a market with asymmetric information. Bloomfield et al. find that the Tobin tax reduces the trading activity of informed and uninformed types by the same proportion. The tax does not affect market efficiency.

## **6. Public Information Release**

In addition to being able to endow individuals with private information, and studying the endogenous dissemination of the information through trading activity, an experimenter can make information public exogenously and study the impact of the information release. A number of studies have investigated related issues. Gillette et al. (1999) study how information release affects prices, transaction volume, and traders' dividend expectations. They consider both markets using double auctions and call market mechanisms. There is a terminal liquidation value for the asset that is common to all units and traders, but is unknown during the time the market is open. Public signals that allow the final value to be estimated with greater precision, are released every third period over the total 15-period horizon. As the information is released, incentivized expectations of the final dividend are elicited. The authors find that information release fails to homogenize expectations. Instead, expectations and prices underreact to the information signals. Average forecasts are unbiased, but are quite heterogeneous. They do tend to reflect an extrapolation of prior trends. This is consistent with data from markets in which prices exhibit bubbles and crashes, in which traders' own price forecasts (Smith et al, 1988; Haruvy et al., 2007) also reflect an anticipation of the continuation of future trends. Prices deviate from fundamentals more than forecasts do, because expectations adjust too slowly. Trading volume is positively correlated with trader heterogeneity.

Kirchler et al. (2010) consider the framing of information and its potential effect on asset prices. In their market, the asset fundamental is drawn from a normal distribution. In some treatments, however, subjects are given some additional percentile information about the distribution, with different subjects sometimes receiving different information. In some conditions, this information is positive. This is the case, for example, when the information indicates that there is a 5% chance that the value of the asset would exceed a given amount (this level is considerably greater than the mean value). In contrast, in a negatively framed information release, the information given is a probability that the asset return would be lower than a certain amount. This information is redundant, since it can, in principle, be calculated from the normal distribution that participants already know. Nevertheless, the percentile information affects subjects' decisions and market prices considerably. Positively framed buyers purchase assets, while negatively framed buyers sell them. The data also confirm the disposition effect identified in earlier work. The overall conclusion is that irrelevant information can influence asset prices.

Gneezy et al. (2003) consider the effect of the frequency with which information is released and the frequency with which a portfolio can be adjusted. They measure the effect of these variables on the performance of an individual's investment portfolio. The asset traded has a life of one period and can pay a fixed positive dividend in each period with probability  $1/3$ , independently drawn each period. Trading follows double auction rules. There are 15 total period in the experiment. There are two treatments. In the High Frequency (H) treatment, traders can adjust their portfolio in each period, and traders are informed at the end of each period about the value of the asset in that period. In the Low Frequency (L) treatment trading can only take place every third period, and then only in blocks of three units. They find that more information and more flexibility result in less risk taking, and lower prices. Prices are greater than the expected dividend value in all treatments.

Corgnet et al. (2013) consider the effect of ambiguous, and sequentially released, information regarding the dividend distribution. Their markets consist of three periods where information was provided at the conclusion of the first and second periods about the asset's dividend that would be determined at the end of the third period. In their control treatment, the distribution of the dividend is made known via public observation of the randomization devices, and thus their associated probabilities. Conversely, in the ambiguous treatment, the dividend distribution is not made known. Rather ambiguity is created using a process similar to Ellsberg (1961). Differently colored marbles are drawn from an opaque bag and the distribution of colors is not announced. Their results do not support the existence of an ambiguity premium and more surprisingly, the markets with ambiguity exhibit smaller deviations from the asset fundamental value.

## **7. Studies of the Capital Asset Pricing Model**

The standard model relating the return/risk profiles to market prices is the capital asset pricing model (CAPM). Bossaerts and Plott (2004) construct an experimental environment in which the model can be applied. In their setup, there are two risky securities, A and B, as well as one risk-free asset called notes. There are separate markets for each of the three securities. Notes can be sold short, while the other two assets cannot. There are three possible states and no traders have inside information. Trade proceeds according to a process in which agents can submit limit orders at any time the market is open, and the orders are entered in the order book. If a limit order crosses the best limit order on the other side of the market, it is converted to a market order, and a trade is concluded. Both risky securities yield greater expected return than the safe asset, while security A has greater mean and variance of dividend payment than B. The asset has a life of one period and the environment is repeated under stationary conditions for up to eight periods within the same session. A large number of traders (by experimental standards) participate in each market: usually a number between 30 – 60 individuals.

The authors test three predictions of the CAPM model. The first is that prices would reflect risk premia. The second is that the ranking of state price probabilities would be the inverse of the ranking of aggregate wealth in those states. Under the CPAM model, which assumes quadratic utility, the risk premia are proportional to the covariance between a security's return and the return of the market portfolio. This corresponds to the condition that the portfolio's Sharpe ratio, the ratio of mean return to variance of return, be as great as possible. Thus, the third prediction for the experiment is that the observed Sharpe ratio would be at the greatest feasible level.

The data show substantial risk premia, indicating that agents are risk averse. A session conducted in Bulgaria at very high stakes relative to the outside income of the subject pool yields similar results. The second prediction receives some support from the direction of price movements over time. The third prediction is also consistent with the pattern of convergence. Nonetheless, two sessions yield considerable mispricing. A second treatment, in which the realization of the state is drawn without replacement, reveals that the cause of the mispricing is a belief on the part of some traders that the state probabilities are not independent. Rather, some participants are subject to the gambler's fallacy that realizations that have not occurred for a long time are due to occur. An augmented CAPM model (CAPM +  $\epsilon$ ) is proposed (Bossaerts et al., 2007), that reconciles some key features of the data from this line of research. Whether the CAPM, a competitive model that assumes price taking, predicts well in a thinner market is taken up by Bossaerts et al. (2002). They find that convergence to the CAPM predicted portfolio holdings and prices is slower in thin than in thicker markets.

Asparouhova et al. (2003) consider the dynamics of market adjustment in this type of market. They organize their analysis around five conjectures. The first is that the excess demand for a security is positively correlated to the change in its transaction price. The second is that there is an absence of indirect effects of complementarity or substitutability between assets, which means that a price change in one of the securities is uncorrelated with price changes in the other two securities. The third is that a Walrasian system of stochastic differential equations can characterize the process of mean reversion to equilibrium pricing. The fourth is that the order book contains information that correlates with the level of excess demand. The fifth is that order book would contain information that correlates with transaction prices, but which cannot be accounted for by excess demand. Asparouhova et al. find strong support for the first conjecture, but also observe a negative relationship between excess demand for one security and the transaction price change on the other. Stability conditions are satisfied in the experimental data. The order book does contain information about excess demand conditions.

## **8. Conclusion**

We have reviewed several of the most longstanding lines of research in experimental finance. This survey is not intended to be exhaustive, but rather to provide a sampling of some of the more important developments in the area. While data sets from non-laboratory financial markets are very extensive and detailed, there remain some key parameters that are unobserved and thus must be estimated. Experimental methods offer a complementary methodology that allows some key underlying determinants of prices, such as fundamental values or insider information, to be observed and varied exogenously. Thus, in our view, experimental studies can complement empirical work, particularly in the area of theory testing and development. We also believe that in the future experimental finance will push into the areas of financial engineering and market regulation.

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