

# Markets, Moral Hazard, and Equilibrium Selection

[Preliminary Draft - UTDallas Seminar]

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## Abstract

We examine the effectiveness of asset markets when the final outcome upon which the asset payout is based maybe affected by the unobservable actions of the traders. Players participate in a minimum effort coordination game preceded by an information market where the asset payoffs are determined by the observed minimum effort level in the subsequent game. We examine both the informativeness of the markets and the effect of the market upon the ultimate outcome in the coordination game. This research provides insights into both equilibrium selection and the application of prediction markets within organizations as a decision support tool.

*(Prediction Markets; Experimental Economics; Coordination Games)*

## 1 Introduction

There is growing interest in the utilization of markets to provide information about uncertain events within an organization. Hewlett-Packard has used markets to more accurately predict sales data, and Microsoft has used markets to provide information on project completion dates. Prediction markets, asset markets designed specifically to provide information about a future event, offer many potential advantages over traditional methods of information acquisition within an organization. The primary advantage is that profit making opportunities in the market may provide individuals the incentive to accurately reveal their private information to the market whereas, without the market, the individuals might be loathe to provide information that is unpopular with management (e.g. low sales data, late project completion, etc.).

Previous studies of prediction markets have typically assumed that the future event of interest is out of the direct control of the market participants; the individuals only have information about the likelihood of the event. However, in markets like those described above, it is likely that the market participants might also have some control over the ultimate outcome. For example, a project team member might put in less effort resulting in delayed project completion. When the ultimate outcome of a project depends upon the hidden actions of the participants, there is said to be *moral hazard*. Therefore, we study the efficacy of prediction markets when moral hazard exists.

We study markets with moral hazard using the tools of experimental economics. Subjects participate in two distinct institutions: a game designed to replicate project completion by members of a team, and a market designed to predict the outcome of the game. The project completion game is the well-known minimum effort coordination game where all agents would prefer to complete the project earlier but the project can only be completed when all members have completed their portion. Thus, the game has multiple potential equilibria. Previous studies have found that the least efficient outcome (late completion) is the most commonly played equilibrium. Our study directly addresses the following questions:

- Does the inclusion of a market result in different outcomes in the coordination game?
- If so, is the outcome more or less efficient?
- Does the market accurately predict the outcome of the game?

We demonstrate theoretically (Section 3) that the outcome of the market can significantly alter the incentives in the eventual game. Using laboratory experiments (Sections 4 and 5), we find that the inclusion of markets significantly lowers coordination. *All* types of groups in our market treatment play lower effort, lower payoff outcomes when the asset market is present. However, the market predicts such behavior, and, perhaps as a result of such communication, there is generally less wasted effort or failure to match the minimum effort level chosen. We discuss the role of market design and game incentives in our results as a direction for future research in Section 6.

## 2 Related Literature

The first strand of literature directly related to this paper studies information aggregation in markets. There has been considerable literature demon-

strating that in many situations properly designed markets can provide high-quality information regarding uncertain outcomes. Using experimental markets, Plott & Sunder (1988) show that markets can aggregate dispersed information. They allowed subjects to trade three Arrow-Debreu securities. Prior to trading, subjects were endowed with private noisy signals (e.g., “the state is *not* X”). While no individual subject could determine the realized state of the world, in aggregate the state was known with certainty. Plott and Sunder show that prices in many of these markets converged to the rational expectation equilibrium, reflecting the fact that private information was aggregated.

Building on these results, many researchers started designing markets to predict outcomes of specific events. These were shown to be surprisingly accurate. Forsythe, Nelson, Neumann & Wright (1992) study the Iowa Political Stock Market, which allows participants to trade securities linked to presidential election outcomes. Forsythe et al. show that the market better predicted ex-post outcomes than professional opinion polls. Further support to the performance of this market is provided by Berg, Nelson and Rietz (2003) who summarize a decade long evidence on its accuracy over short and long horizons.

Given that firms ability to succeed often hinges on their ability to plan ahead in a highly uncertain environment, it is only natural to take advantage of prediction markets. Chen & Plott (2002) report a field experiment of an information aggregation market conducted inside the Hewlett-Packard Corporation. They allow a subset of employees to trade securities whose payoffs were linked to sales of different product lines. Plott and Chen find that these markets were overall more accurate than the official HP forecasts in predicting subsequent sales. The interested reader is referred to Wolfers & Zitzewitz (2004), Sunder (1992), and Spann & Skiera (2003) which provide further details on the study of information aggregation using markets.

The second strand of literature on which we build examines coordination games with multiple Pareto-ranked Nash equilibria and in particular those characterized as minimum effort, or weak link, games first studied experimentally by Van Huyck, Battalio & Beil (1990).<sup>1</sup> In their setup, players are assigned into groups and asked to choose a number representing an effort level. Player’s payoffs are determined by the minimum effort choice of the other players as well as her own effort. Since effort is costly, players have no incentive to contribute more than the minimum effort of the others. Given that payoffs are symmetric, every effort level is a Nash equilibrium, while

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<sup>1</sup>The original presentation of the game is due to Bryant (1983).

the higher effort equilibrium result in higher payoffs. This paper along with a number of other studies (Knez & Camerer 1994) revealed two main regularities. First, while the maximum effort choice is the Pareto dominant equilibrium, it did not emerge as a focal point in the data. Second, group size influences the equilibrium selection. Small groups (with 2-3 subjects) converged to much higher effort levels than large groups (9-16 subjects).

Following up on this work, a number of papers have studied the effectiveness of different mechanisms in improving coordination. In particular, they introduced pre-play communication and altered participation costs. Weber, Camerer, Rottenstreich & Knez (2001) had subjects play the game in large groups while having one player address the others publicly urging them to coordinate efficiently. Chaudhuri, Schotter & Sopher (2002) test different cross-cohort advice treatments for groups participating in this game. In both studies, communication had either no or low impact on coordination. Brandts & Cooper (2006) ask whether changes in the payoffs improve coordination; groups of four subjects participated in multiple rounds of the weak-link game. After a number of rounds, the payoffs were exogenously increased such that coordination was more profitable. They find that this treatment increases efficiency in a way largely independent of the size of the monetary incentives.

Markets introduce similar channels to the one discussed here. First, markets may serve as a pre-game communication device. Van Huyck & Battalio (1993) found that the inclusion of asset markets to determine the participants in the coordination game *always* resulted in successful coordination on the Pareto dominant equilibrium. Second, since trading is payoff relevant, markets may alter incentives for coordination both through insurance and through moral hazard. At the same time, prediction markets are significantly different from previously studied institutions. In all these settings, the helpful coordinating device is payoff irrelevant or the associated costs are sunk at the time of playing the game. With a prediction market, however, each player's asset position from the market affects her final payoff from the play of the game. While the prices paid for the assets are sunk, the payoffs from the assets are not. Therefore, it is possible that the market might actually alter the equilibrium set. Indeed, we show that it is possible that high effort equilibria might cease to exist given particular market outcomes. While this is a potential hazard of a prediction market, the payoff relevance of the assets may also be beneficial. Since a motivating factor for the selection of the low effort equilibria in standard coordination games is that it is of lower risk, the players may be able to insure or *hedge* against that risk by taking a position in the market that pays out well when low

effort is chosen. In theory, this would make the players more likely to play the high effort outcome.

### 3 Theory

We begin by presenting and examining general versions of both the minimum effort coordination game and asset markets based upon the outcome of the game.

#### 3.1 The Coordination Game

Players participate in an  $N$  player minimum effort coordination game. All players simultaneously select an effort level  $e_i \in \{1, \dots, M\}$ . Each player's payoff depends upon their effort level and the minimum effort level chosen by all players:

$$m_i(e) = a + be_{\min} - ce_i \quad (1)$$

where  $c \in (0, b)$  and  $e_{\min} = \min\{e\}$ . See Table 1 for a particular example of the payoff table induced by this payoff function. In this game, any selection of effort levels such that  $e_i = e_j$  for all  $i$  and  $j$  is a Nash equilibrium. The Nash equilibrium with  $e_i = M$  for all  $i$  is the *high effort* equilibrium and Pareto dominates any lower effort equilibrium where  $e_i = m$  with  $m < M$  for all  $i$ . Generally, equilibria with higher effort Pareto dominant those that involve lower effort.

While many equilibrium selection arguments would suggest that the high effort outcome is the natural equilibrium choice in this setting, the low effort outcome ( $e_i = 1$  for all  $i$ ) has some intuitive appeal in terms of risk. The payoff from low effort is 'secure'; no matter what the choices of the other players someone who has chosen  $e_i = 1$  receives a payoff of  $m_i(1, 1)$  whereas selecting high effort involves lower payoffs when other players select lower efforts:  $m_i(M, M) > m_i(M, M - 1) > \dots > m_i(M, 1)$ . Since the secure payoff of  $m_i(1, 1) > m_i(M, 1)$ , if a player assigns enough probability to events such as other players playing lower effort choices, then she will prefer to play lower effort herself. This concept is formalized by saying that the low effort Nash equilibrium is *risk dominant* (Harsanyi & Selten 1988).

#### 3.2 The Market

Prior to the coordination game all players participate in an asset market where asset values are based upon the minimum effort level chosen in the

subsequent game. We assume that the assets cannot be based upon individual effort choices since individual effort likely to be unobservable. In other words, the group's outcome but not its members' efforts are observable. Let there be  $M$  state contingent assets traded with the following payoffs:

$$X_m = \begin{cases} \beta & \text{if } e_{\min} = m \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where  $\beta > 0$ .

No matter what concept of equilibrium is imposed in the market, all players will end with a particular *position* of assets from each market. Let  $x_{mi}$  be player  $i$ 's units of asset  $X_m$  and  $x_i = (x_{1i}, x_{2i}, \dots, x_{Mi})$  be player  $i$ 's *portfolio* at the end of trading. At this time, we place no particular restrictions on the composition of this portfolio (e.g.,  $x_{mi}$  can be any real number). Since these assets payoff based upon the outcome of the game, the original payoffs from Equation 1 are modified to be:

$$M_i(e; x_i) = a + be_{\min} - ce_i + \beta \sum_{m=1}^M \delta_m x_{mi} \quad (3)$$

where  $\delta_m = 1$  if  $e_{\min} = m$  and 0 otherwise. We call this game the *modified minimum effort coordination game*.

It is straightforward that all Nash equilibria of this game also involve identical effort choices since the payoffs from the assets are only affected by the minimum effort chosen. With this in mind, the following proposition characterizes the set of pure-strategy Nash equilibria of the modified minimum effort coordination game.

**Proposition 1** *The selection of identical effort levels  $e_i = m$  for all  $i$  is a Nash equilibrium if and only if asset portfolios in the modified minimum effort coordination are such that for all  $\ell < m$ ,*

$$x_{\ell i} - x_{mi} \leq \left[ \frac{b-c}{\beta} \right] (m - \ell) \quad (4)$$

for all  $i$ .

*Proof:* In order for  $e_i = m$  for all  $i$  to be a Nash equilibrium it must be that

$$M_i((m, e_{-i} = m); x_i) \geq M_i((\ell, e_{-i} = m); x_i)$$

for all  $\ell \neq m$ . Consider  $\ell > m$ , then we have

$$M_i((m, e_{-i} = m); x_i) = a + bm - cm + \beta x_{mi}$$

and

$$M_i((\ell, e_{-i} = m); x_i) = a + bm - c\ell + \beta x_{mi}$$

and obviously  $M_i((m, e_{-i} = m); x_i) > M_i((\ell, e_{-i} = m); x_i)$  for all  $x_i$ . Now consider  $\ell < m$ . Nash equilibrium requires that

$$\begin{aligned} M_i((m, e_{-i} = m); x_i) &\geq M_i((\ell, e_{-i} = m); x_i) \\ a + bm - cm + \beta x_{mi} &\geq a + b\ell - c\ell + \beta x_{\ell i} \\ bm - cm + \beta x_{mi} &\geq b\ell - c\ell + \beta x_{\ell i} \\ \beta x_{\ell i} - \beta x_{mi} &\leq bm - cm - b\ell + c\ell \\ \beta(x_{\ell i} - x_{mi}) &\leq (b - c)(m - \ell) \\ x_{\ell i} - x_{mi} &\leq \left[ \frac{b - c}{\beta} \right] (m - \ell). \end{aligned}$$

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This proposition tell us that the asset market can alter the expected outcomes of the game. In particular, the following observations arise directly out of the proposition:

- For all asset positions, the lowest effort choice by all players is a Nash equilibrium outcome.
- In order for higher effort choices to be Nash equilibria, it must be that asset positions of the players are not too *diverse*.
- When comparing asset positions, it takes more diverse assets for lower effort to be preferred to higher effort.
- The asset portfolios that induce certain Nash equilibria depend upon the relative payoff of the asset market ( $\beta$ ) to the coordination game ( $b - c$ ).

Thus, we should expect the asset position of the players at the end of trading to affect the subsequent choice of strategies in the game. Since the set of Nash equilibria of the modified game is always a subset of the set of Nash equilibria of the original we might expect that coordination on higher effort will be more difficult.

Is it possible that the market asset allocation will affect the game in a positive direction? As mentioned earlier, one rationale for a player to select lower effort levels is that higher effort choices are risky when you suspect that other players will player lower effort. The asset market might offer an

opportunity to offset some of this risk. Suppose a player wants to play the highest effort level  $M$  but she perceives that there is some chance others will play effort less than  $M$ . If this were the case, she could insure against these lower payoff outcomes by purchasing units of assets  $X_1, \dots, X_{M-1}$  in order to increase her payoff in those events. In the extreme, the player might want to *fully insure* or purchase amounts of each asset such that her payoff under all circumstances is identical. If this were the case, lower effort would cease to be risk dominant. For a player considering effort level  $M$  full insurance would require that for all  $\ell < M$ ,

$$\begin{aligned}
 M_i(M, e_{-i} = M) &= M_i(M, e_{-i} = \ell) \\
 a + bM - cM + \beta x_{Mi} &= a + b\ell - cM + \beta x_{\ell i} \\
 x_{\ell i} - x_{Mi} &= \frac{b}{\beta}(M - \ell).
 \end{aligned} \tag{5}$$

However, notice that this full insurance condition is inconsistent with the inequality necessary for effort level  $M$  to be a Nash equilibrium of the modified coordination game given by Proposition 1.<sup>2</sup> A player would never find it in their interest to fully insure and subsequently play that strategy in the game. While this result suggests that insurance opportunities via the market may be limited, it does not preclude the possibility of players partially insuring against the lower effort of others, but the rationality of such a strategy would obviously depend upon the risk preferences of the players, and market prices.<sup>3</sup> It is logical to move next, therefore, to a discussion of what behavior in the market may be expected.

We present here one possible model of equilibrium in the market. There are many obvious shortcomings (lack of dynamic considerations, non-strategic behavior, etc.) of the model we propose but we also believe it adequately captures the essentially elements of rational expectations and strategic uncertainty that are important features of both the market and the subsequent game. We begin by positing a simple model of private information that is consistent with the stylized details of strategic uncertainty in the coordination game. Suppose that each player has a private signal type  $t_i \in \{1, \dots, M\}$  where  $t_i = m$  indicates that player  $i$  believes the *correct* play of the game is effort level  $m$ . A private type draw realization for each

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<sup>2</sup>Nearly identical statements can be made for a player considering a lower effort level and considering insurance against even lower effort choices.

<sup>3</sup>The analysis here ignores the issue of the cost of obtaining assets since, at the time of playing the game, these costs are sunk and should not matter for effort choices. There is substantial experimental evidence that human subjects may not act consistently with this and may actually considered sunk costs in their eventual decision making.

player is then given by the type vector  $t = (t_1, \dots, t_N)$ . Let  $T$  be the (finite) set of all possible type vectors and for notational convenience define  $T(m)$  as the set of type vectors such that for all  $t \in T(m)$ ,  $\min(t) = m$ . Players also have some beliefs over the type draws of other players given by  $\mu_i(t|t_i)$  where  $\mu_i(t|t_i)$  satisfies all the standard assumptions of conditional probabilities. It is important to distinguish between a player's type and her actual actions in the game. We do not require that  $t_i = e_i$ . Rather, the typical story of coordination failure in this game is that even though the type draw is  $t = (M, \dots, M)$  (or each player recognizes that high effort is the Pareto dominant equilibrium) due to some players beliefs about the likely choices of others they find it rational to play  $e_i < M$ . Specifically, a player will prefer to play  $e_i = k$  where  $k < M$  whenever

$$\begin{aligned} \sum_{\ell=1}^M \sum_{t \in T(\ell)} \mu_i(t|M)(a + b\ell - cM) &< \sum_{\ell=1}^k \sum_{t \in T(\ell)} \mu_i(t|M)(a + b\ell - ck) \\ &+ \sum_{\ell=k+1}^M \sum_{t \in T(\ell)} \mu_i(t|M)(a + bk - ck) \\ \sum_{\ell=k+1}^M \sum_{t \in T(\ell)} \mu_i(t|M)b(\ell - k) &< c(M - K) \end{aligned} \quad (6)$$

Intuitively, the right hand side of Equation 6 is the benefit of a lowered effort level in the form of lowered cost and the left hand side is the cost associated with the lowered effort in the form of times when such a strategy results in lowered minimum effort due to the fact that the minimum effort by the other players would have been higher. Define  $e_i(t, \mu_i)$  be player  $i$ 's optimal strategy given her beliefs about every other players type.

Now, let  $\pi_m(t)$  be the market price for asset  $X_m$  given the realization of type draws and  $\pi(t)$  be the price vector given a particular type draw. Also, let  $x_{mi}(t)$  be player  $i$ 's position in asset  $m$  given the type draw. Since we are in a situation of incomplete and asymmetric information, we need to allow for observed prices to refine beliefs about the true state; define  $\Pi(t) = \{t' \in T | \pi(t') = \pi(t)\}$  to be the set of states where price are the same so, after observing prices, if the player originally thought the two states to be possible she has no reason to change her belief. We define a rational expectations equilibrium in the following way.

**Definition 2**  $(x(t), \pi(t))$  is a rational expectations equilibrium if there ex-

ists a plan of action for each player  $e_i(t)$  for all  $i$  such that  $x_i(t)$  maximizes:

$$\left( \sum_{t' \in \Pi(t)} \frac{\mu_i(t'|t_i)}{\sum_{t'' \in \Pi(t)} \mu_i(t''|t_i)} M_i(e_i(t'), t'_{-i}; x_i(t')) \right) - \sum_{m=1}^M \pi_m(t) x_{mi}(t). \quad (7)$$

This definition is generally consistent with previous versions of rational expectations equilibria except that we must incorporate the players effort choice in the game. The definition here expresses that each players purchasing decisions in the market and their eventual efforts must be consistent with expected profit maximization given that they take their beliefs as describing how others will play the game. In this sense, we have left room for ultimate strategies and outcomes in the market to differ.

While there may be many rational expectations equilibria under this definition, it is fairly straightforward to show that there exists an equilibrium that results in the highest possible effort given players beliefs and that prices reveal the information to the market.

**Proposition 3** *There exists a rational expectations equilibrium where  $\pi_m(t) = \beta$  for all  $t \in T(m)$  and  $\pi_m(t) = 0$  for all  $t \notin T(m)$  for all  $m$ .*

Let  $e_i(t) = m$  for all  $i$  and notice that, given these prices, for all players  $\mu_i(t|t_i) > 0$  if and only if  $t \in T(m)$ . However, this means that each player has identical preferences (since  $m_i$  is only measurable with respect to  $T(m)$ ). Thus, setting  $\pi_m(t) = \beta$  insures that each agent is indifferent between one more unit of the asset (worth  $\beta$  for sure) and the equivalent amount of cash. Then asset portfolios can be assigned in order to ensure that  $e_i(t) = m$  remains a Nash equilibrium (the conditions of Propostion 1 are satisfied).

This equilibrium is similar to the fully revealing rational expectations equilibrium that is often the result/objective in information aggregation studies. Importantly, if, as mentioned earlier,  $t = (M, \dots, M)$  then this equilibrium predicts the market will reveal this information and play in the game will be at the high effort, Pareto dominant outcome. Of course, this equilibrium concept is purely theoretical and may ignore many important features of the market process. Therefore, we move next to a discussion of the experimental design.

## 4 Experiment Design

### 4.1 General

The experiment consisted of 10 sessions conducted at the Smeal College of Business Administration, The Pennsylvania State University, during the Fall 2006 and Spring 2007 semesters. Eighteen subjects participated in each session, and no subject appeared in more than one session. Subjects were recruited from a distribution list comprised of primarily economics and business undergraduate students. Participants received a show-up fee of \$6 and an additional performance based pay averaging \$14.37 (ranging from \$1 to \$21) for a session lasting around 2 hours.

All sessions started with subjects being seated in front of computer terminals and given a set of instructions, which were then read aloud by the experimenter. Throughout the session, no communication between subjects was permitted and all choices and information were transmitted via the computer terminal.

At the beginning of the session, each subject was assigned to a group. This assignment did not change throughout the experiment. Each session consisted of two *small* groups (with 3 subjects each), and two *large* groups (with 6 subjects each). Including groups of different sizes is important given the evidence on the dependence of minimum effort game outcomes on the number of participants (see Section 2).

Each session consisted of eight periods, all identical in structure. In each period, every subject submitted an action, corresponding to her effort choice. Effort choice took one of four values:  $e_i = \{1, 2, 3, 4\}$ . The payoff function was the same as in Equation 1 with  $a = 12$ ,  $b = 4$ , and  $c = 2$ .<sup>4</sup> This function gives rise to the payoff table (provided to the subjects in the experiment) presented in Table 1.

After all group members submitted their effort choice, the minimum group effort was announced and payoffs for the period were determined. In addition to receiving information about their group's effort, each group also observed the effort choice of one other group such that a small group was matched with a large group. While the individual effort level choices were revealed on the computer screen, the identity of the effort choices was unknown.

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<sup>4</sup>The payoffs reported here are in 'experimental dollars' which were converted to U.S. dollars at the rate of 10 experimentals for every one U.S. dollar. Thus, the payoff for the Pareto dominant equilibrium was \$2.00.

My Effort	Minimum Group Effort			
	4	3	2	1
4	20	16	12	8
3	–	18	14	10
2	–	–	16	12
1	–	–	–	14

Table 1: Minimum effort coordination game payoff table

## 4.2 Discussion of the design

The experiment was designed around a single treatment divided into two variants: *control* and *market*. In the control variant, subjects participated only in the coordination game. In the market variant, subjects first traded in an asset market based upon the minimum effort game outcome.<sup>5</sup>

Prior to trading, subjects were assignment into markets such that the number of traders per market was fixed at nine. That was achieved by conducting two parallel and separate markets each populated by one small group and one large group. In one market, the value of the securities traded was determined by the minimum effort of a *small* group, and in the second market, the value of the securities was determined by the minimum effort of a *large* group. Specifically, groups were defined as follows:

- Group *A* was a three member group,
- Group *B* was a three member group,
- Group *C* was a six member group, and
- Group *D* was a six member group.

These groups were assigned into markets as follows:

- Market 1 included members from groups *A* and *C*, trading securities linked to the minimum effort of group *A*, and
- Market 2 included members from groups *B* and *D*, trading securities linked to the minimum effort of group *D*.

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<sup>5</sup>In two market treatment sessions, only six market periods were conducted due to time considerations. In both cases, subjects still participated in eight game periods with their initial endowment taken as their payoff from the market.

Each market contained both *insiders* - subjects who traded on outcomes that they could influence - as well as *outsiders* - subjects who traded on an exogenous outcome. The events traded in the two markets were qualitatively different since those were linked to the minimum effort choices of different group sizes. Second, the number of traders was kept constant across the two markets to control for liquidity and the possibility that market size might affect the performance of the market.

Trading was conducted over an electronic double-auction market. The trading stage lasted about 6 minutes. During that time subjects were free to submit limit orders, which were posted to the limit order book, or to accept limit orders submitted by others. There were four securities traded in each market, labeled corresponding to each of the possible minimum effort levels. Each share of a security paid off only if the corresponding minimum effort is obtained and the payoff amount  $\beta = 1$ . At the beginning of each trading stage, subjects were endowed with units of the different securities and with an interest-free loan of cash. The endowments varied across subjects and across periods but the aggregate endowment at the beginning of each trading period was equal across securities at 54 units. In each period two subjects each had an endowment of 24 units of a particular asset and none of the others; one subject had an endowment of six units of each asset. We decided to begin subjects with asymmetric endowments in order to encourage price revealing trading information. Also, the aggregate endowment did not constrain further trading; subjects could sell each asset short.<sup>6</sup> At the end of the trading stage, subjects participated in the minimum effort game. Then, subjects' positions in the securities were liquidated by paying off either 1 or zero, depending on the group's minimum effort. The feedback provided to subjects in the two variants of the experiment was the same. In the market variant, subjects were informed of the minimum effort of their group as well as the other group participating in their market. This design is mirrored in the control variant; by allowing for observation of another group in both variants we control for any effect that observation might have on the play of the minimum effort coordination game.

### 4.3 Hypotheses

We briefly discuss the hypotheses the experiment was designed to test. The most obvious hypotheses are in regard to the expected influence of the market

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<sup>6</sup>A margin requirement was used to ensure that no subject's short sales exceeded the amount of their cash loan.

**Hypothesis 1** *The presence of a market will influence group coordination for ‘insiders’.*

**1a** *The market treatment will generate higher effort levels than the control treatment (communication).*

**1b** *The market treatment will generate lower effort levels than the control treatment (moral hazard).*

In the Section 3 we have provided reasons that one might expect the market to influence behavior in the coordination game. Since markets may serve as an effective communication device to coordinate behavior, it is possible that such pre-play communication will actually induce higher effort. This result would be consistent with previous results such as Van Huyck & Battalio (1993) that suggest that communication can improve coordination. On the other hand, if that communication results in asset positions which remove higher effort equilibria we would expect players to respond to these moral hazard incentive and be more likely to play low effort in the game.

On the other hand, we have no reason to expect that outsiders will change their effort choices as a result of the market. The outcome that is being predicted is exogenous to their eventual play in the game. While it is possible that the market prices might have some communication influence on the outsider traders, we hypothesize that this effect should be limited.

**Hypothesis 2** *The presence of the market will not change effort choices of the ‘outsiders’.*

A perhaps hidden benefit of the market, might be that it might result in more coordinated effort choices (more players selecting the minimum chosen) so that the inefficiency generated by playing something other than the minimum effort might be mitigated. We call any effort above the actual minimum observed ‘wasted effort’ since it does not result in increased benefit and only results in added cost for the player selecting it.

**Hypothesis 3** *Wasted effort will diminish under the market treatment.*

Regardless of the eventual effort chosen, it is interesting to know whether the market will accurately predict such effort choices. Since the literature on information aggregation suggests that markets can be very effective at revealing such information, we hypothesize here that, despite the added

complication of potential moral hazard, that the market will provide a reasonably good predictor of actual outcomes in the game.<sup>7</sup>

**Hypothesis 4** *Market prices will forecast group outcomes in the market treatment.*

## 5 Experiment Results

We begin by discussing the observed play in the minimum effort coordination game and then discussing the role of the market in these results.

### 5.1 Coordination Game Results

The first result relates the effect of the market on the effort choices in the game.

**Result 1** *The presence of a market results in lower effort.*

Average minimum effort choice of the small groups falls from 3.66 (control) to 1.53 in the market treatment. For large groups, average minimum effort falls from 2.44 to 1.16. Figure 1 depicts this change over time. The control data is similar to previous studies; small groups generally manage to coordinate on high effort and there is little decline over time, but large groups find it difficult to maintain high effort coordination and experience a steady decline in minimum effort chosen. Surprisingly, the market treatment seems to have a similar effect upon both the insider and outsider groups; outsider groups averaged a minimum of 1.44 and insider groups averaged a minimum of 1.13.

In Table 2 we report the results of regressions designed to explore the influence of group size and the market treatment on period 1 group outcomes. The regressions are ordered probit, using the group as the unit of observation, and the dependent variable is the minimum in a group. The first regression reveals that minimum choices in period 1 are significantly lower in the market treatment than in the control. Group size exerts a negative, though small and statistically insignificant effect on period 1 group minima. The second regression reveals that there is no interaction between group size and treatment—the coefficient on the interaction term is insignificant

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<sup>7</sup>We do not, however, compare our market outcome with other forecasts of effort so it is impossible to say that markets are a *better* forecast device than other choices.

and the introduction of the term improves fit only slightly. The third regression uses only data from the market treatment and explores differences between insider and outsider groups. The insider groups minima are lower, by about three-quarters of a unit. However, this difference is not statistically significant.

The final two regressions are similar, but use as the dependent variable the median of a group's minima across all periods. This provides us with a good measure of the minimum at which a group spent most of its time. These regressions reveal that the period 1 effects of the market treatment are strengthened over time the coefficients are about twice as large in magnitude and statistical significance. In addition, the effect of group size also increases substantially and becomes statistically significant. (If we also include a regression with a dummy variable for Insider treatment, the coefficient on this variable is again insignificant).

What we can conclude from these regressions is that the market produces a significant negative effect on groups from the outset. These groups start off at minima that are significantly lower, and this does not differ for insider or outsider groups. When we consider behavior over the course of the experiment as a whole, we see that this effect of market treatment is even stronger. These results are consistent with our moral hazard hypothesis but not consistent with the hypothesis that the outsiders should be unaffected by the market.

We can also consider how much "wasted effort" occurred in groups. While lower group minima constitute one source of inefficiency, another important source is the extent to which group members select choices above the minima. While the best outcome for a group is one in which everyone chooses the highest possible choice (4), an outcome in which everyone chooses the lowest possible choice (1) is clearly better than one in which only one person does so and everyone chooses the maximum possible choice. To explore how such wasted effort varies across treatments, we compare the difference between a subject's choice and the minimum in her group. The regressions reported in Table 3 use as the dependent variable the difference between a subject's choice and the minimum choice in that subject's group for that period. The first regression reveals that the wasted effort is slightly higher in the market treatment, though this difference is not statistically significant. However, this is largely due to the increased likelihood of the high effort outcome; if minimum effort of 4 is chosen the deviation must be zero by definition. When we control for the group minimum (regressions 2 and 3), we see that the wasted effort is significantly lower in the market treatment. Not surprisingly, it is also lower for higher group minima.

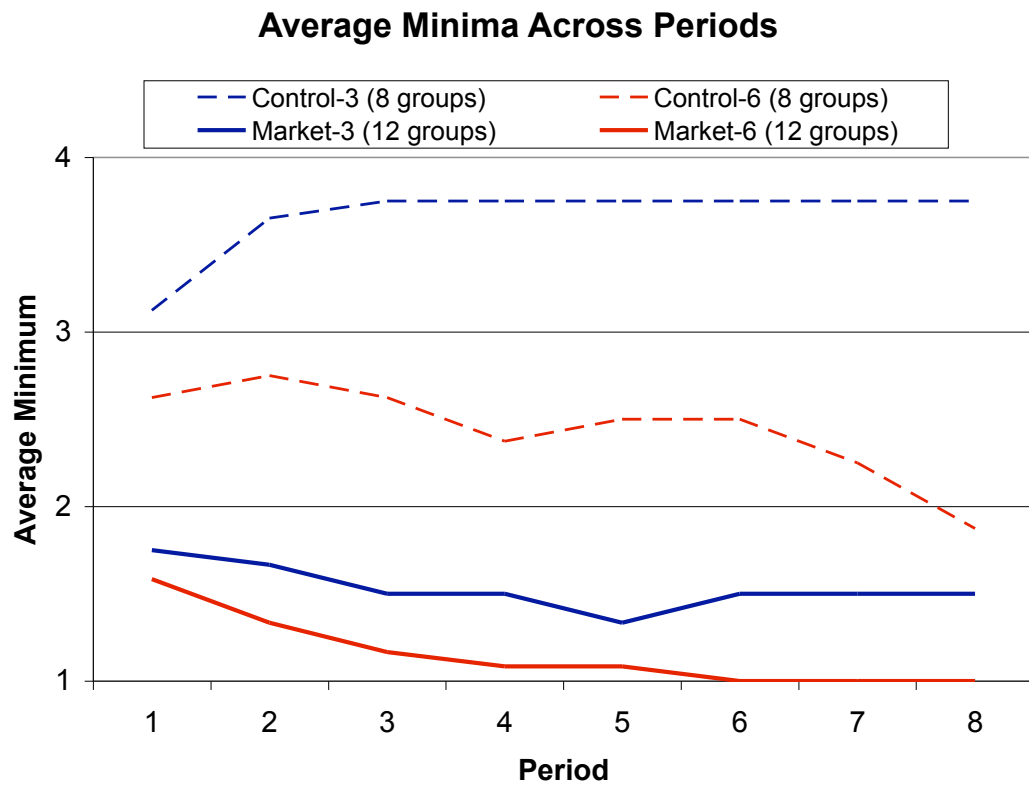


Figure 1: Average Minimum Effort by Period and Treatment

	Period 1 minimum			Median minimum across all periods	
	(1) All groups	(2) All groups	(3) Market treatment	(4) All groups	(5) All groups
Market Treatment	-1.23*** (-0.38)	-1.41*** (-0.53)		-2.46*** (-0.51)	-2.84*** (-0.69)
Large Group	-0.41 (-0.36)	-0.61 (-0.55)	-0.29 (-0.49)	-1.25*** (-0.47)	-1.62 (-0.65)
Market X		0.35			0.78
Large Group Insider		(-0.73)	-0.74 (-0.5)		(-0.9)
Obs	40	40	24	40	40
Log likelihood	-46.56	-46.45	-24.51	-31.67	-31.31
Pseudo $R^2$	0.11	0.11	0.05	0.34	0.35

Table 2: Ordered probit regressions of minimum group effort. Standard error in parenthesis.

Thus, holding the group outcome (minimum) constant, we see that subjects are significantly better able to coordinate on that minimum in the market treatment than in the control.

**Result 2** *Wasted effort is diminished under the insiders treatment.*

The mean deviation conditional on minimum effort choice is given in Figure 2. For all effort choices, other than effort of four, and group sizes, the deviation from the minimum chosen declines under the market treatment. As a result, per player profits from the game only are higher once effort level is controlled for; the average profits are given in Table 4.

## 5.2 Market Results

In this section we examine the performance of the market relative to the eventual outcome of the game. We utilize the average trade price of the last five trades as our measure of *market prices*; utilizing other measures such as the average of all trades, or the closing trading price yield substantially similar results.<sup>8</sup> Figures showing the trading prices from all six insider

<sup>8</sup>When less than five trades are completed, we average all the trades conducted in that market and period.

	(1)	(2)	(2)
	All groups	All groups	All groups
Market	0.25	-0.46**	-0.53**
Treatment	(-0.2)	(-0.19)	(-0.21)
Group		-0.53***	-0.60***
Minimum		(-0.09)	(-0.09)
Period			-0.12***
			(-0.02)
Obs	1440	1440	1440
Log likelihood	-1612.62	-1513.01	-1475.18
Pseudo $R^2$	0.005	0.067	0.09

Table 3: Ordered probit regressions of difference between subject choice and group minimum (Standard errors (in parentheses) are clustered by group.)

$e_{\min}$	Control	Market	$p$ -value
1	11.26	12.25	0.000
2	13.33	14.11	0.005
3	16.83	17.22	0.003

Table 4: Average game profits by minimum effort choice.

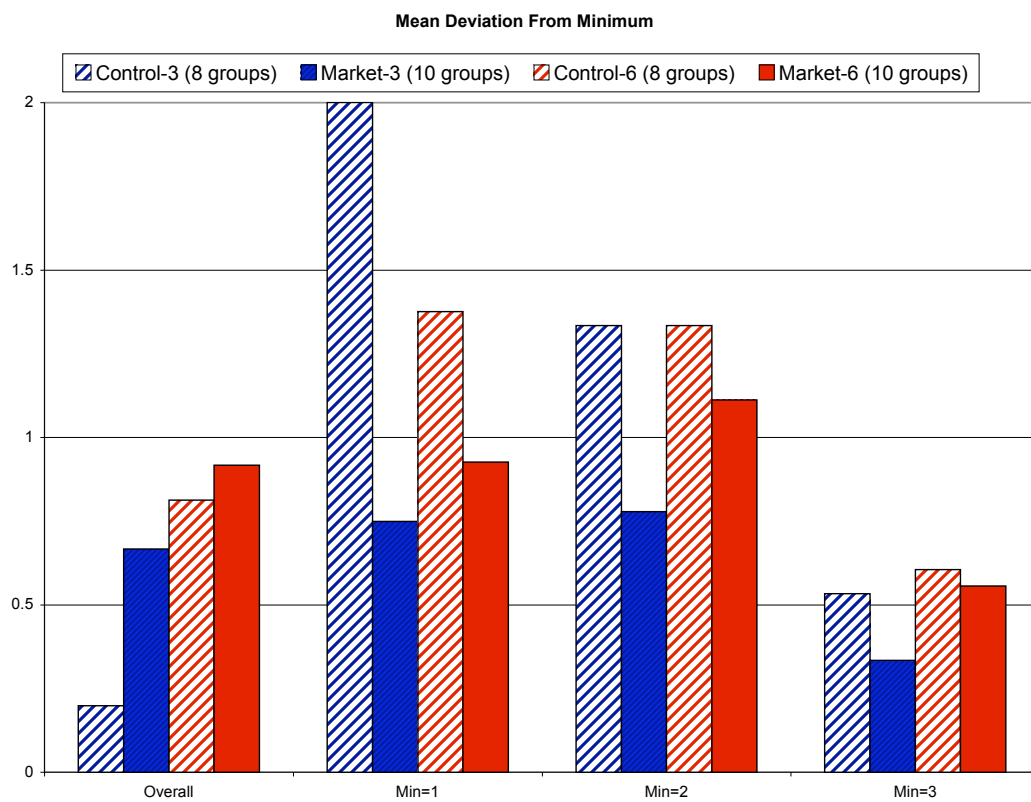


Figure 2: Mean Deviation from Minimum Effort Chosen

sessions are contained in Figures 5-10

**Result 3** *Market prices accurately forecast the group outcomes. Forecast accuracy improves with experience.*

Market accuracy is measured as the absolute difference between the observed market prices and the realized prices.<sup>9</sup> As is evident in Figure 3, the average absolute error drops considerably in the course of the experiment. In period 1, the average error averaged .395 and .447 for the small and large group size markets respectively, but by period 8 the average error had fallen to .119 and .060 for the small and large groups. As further evidence of the accuracy of the market, we can examine how often the maximal market price correctly predicted the outcome (Figure 4). In the final three periods of *all* sessions for *all* groups, using the highest market price as a prediction of the minimum effort would have always predicted the correct game outcome.

As we demonstrated in Section 3, players' asset positions affect the set of Nash equilibria of the game. Since we have observed that behavior changes significantly in the market treatment, we examine whether it is the case that asset positions played a role in this change. We can use the conditions presented in Proposition 1 to determine the set of Nash equilibria after trading in the market. For all group sizes the low effort outcome always remains a Nash equilibrium. For large groups, asset positions after trading were such that efforts of three and four were *never* a Nash equilibrium and an effort level of two was only a Nash equilibrium 4% of the time. Small groups fair only slightly better; the frequency that effort levels two, three, and four remain a Nash equilibrium is 27%, 8%, and 2% respectively.

**Result 4** *Asset positions after the market were rarely such that any higher effort outcomes remained Nash equilibria.*

While this is evidence that the market had a strong influence on the actions of the players, it is still possible that players may have not been responding as the theory predicts. In order to examine this, we need to see whether or not players react in their effort choices to the assets they have. Specifically, they should be more likely to play a particular effort level when they have more (relative to their other asset holdings) of that particular asset.

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<sup>9</sup>Since each period involved observed and realized prices in multiple (four per group) markets, we take the average absolute error of those four markets as our measure of market accuracy in a period.

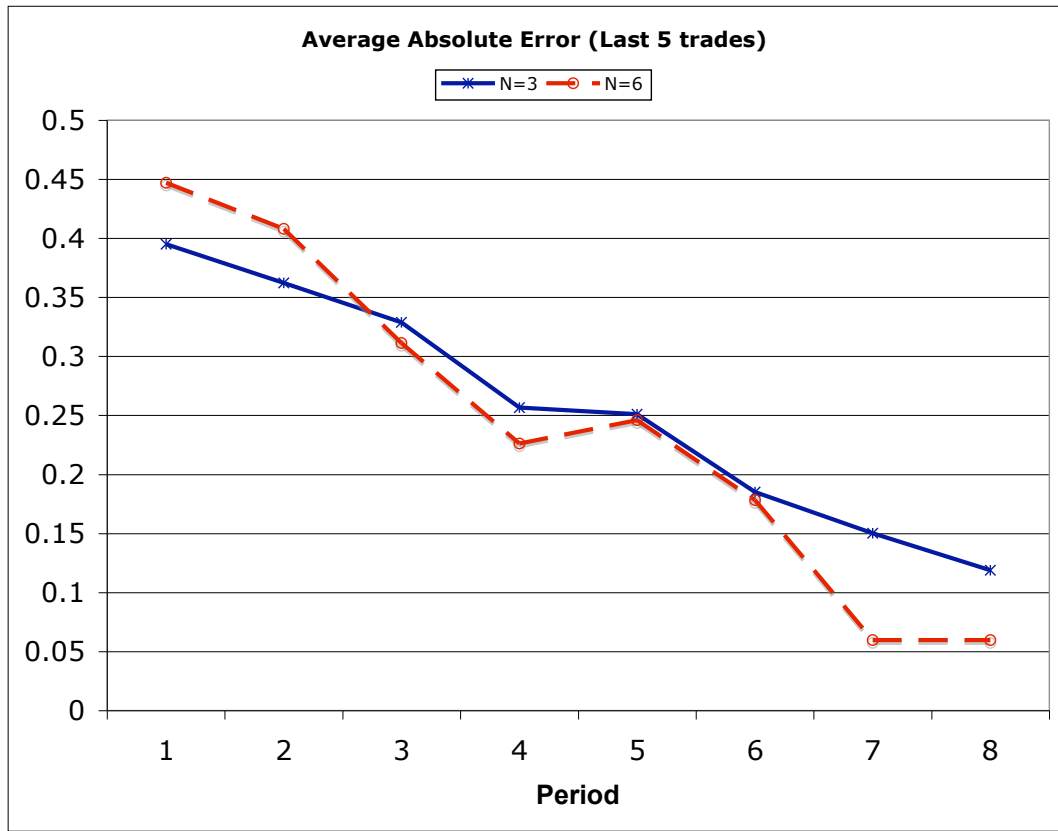


Figure 3: Average Absolute Error of the Market by Period and Group Size

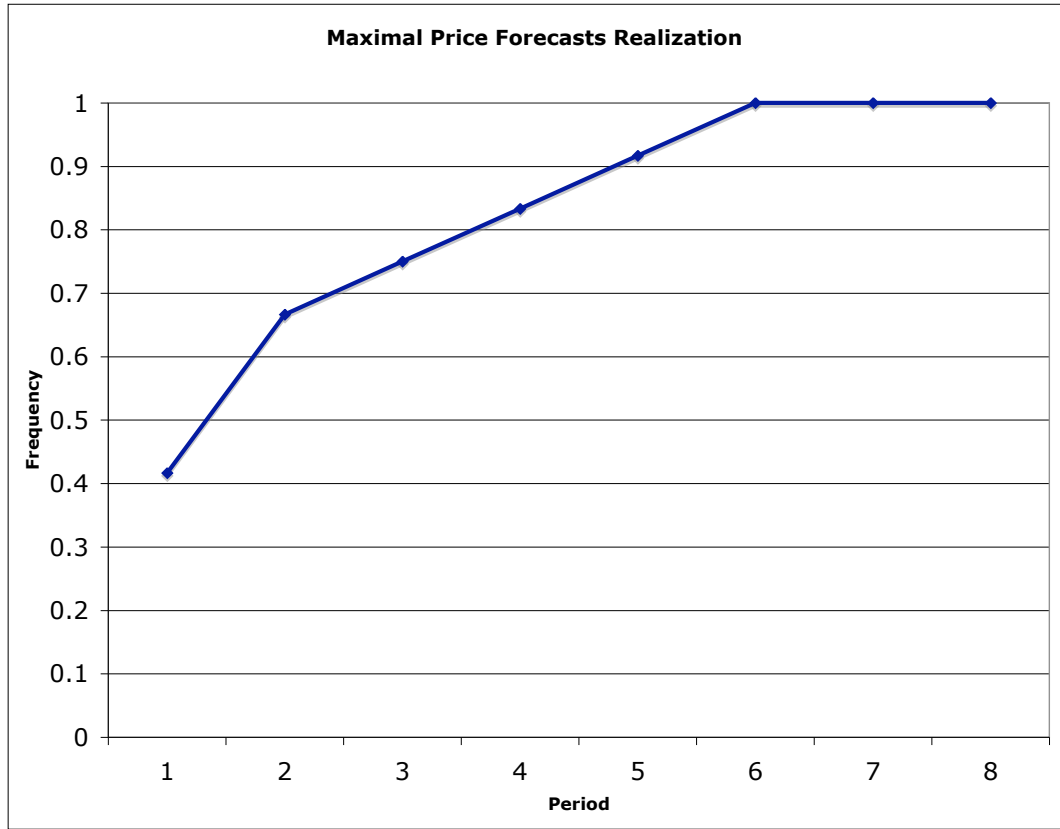


Figure 4: Maximal Prices Predict Market Outcomes

The regression results reported in Table 5 are an attempt to uncover whether individuals behave as expected. Specifically, each probit regression examines individuals' likelihood to play a particular effort level as a function of their asset position at the end of trading. Since only insiders should be influenced in their effort choice by their asset positions, we restrict the observations to only involve the insiders. If subjects are behaving as the theory predicts, then only greater assets for the asset corresponding to the effort level they select should have a positive effect; all others asset levels should negatively influence their likelihood to play that strategy. For the choices of efforts two, three and four the regression results are much as expected where the coefficient is significantly positive for the asset related to that effort level and the other assets often have a significant and negative sign. For the effort choice of one, the sign of asset 1 is not consistent with our expectations. While we are not certain how to interpret this result, we suspect this might be, at least in part, due to the Nash equilibrium pressures on individual effort choices; even if an individual has many assets that payoff if minimum effort equals one, they might decide to play a lower effort because they suspect such low effort to be played by others. Similar probit regression results for outsiders in the market variant find that their is little apparent relationship between asset position and subsequent effort choice, which is also consistent with theoretical expectations.

**Result 5** *Individuals respond in the coordination game as predicted to different asset position*

## 6 Discussion

Our main experimental findings can be summarized as follows:

- The moral hazard effect of markets can be sufficient to induce low effort (Pareto inferior) outcomes in the subsequent game. This is true even for groups who would have coordinated if the market was not present.
- Despite its negative effect on group effort choice, markets are accurate in forecasting the uncertain outcome. This accuracy leads to lower waster effort or inefficiency due to non-equilibrium play.

These results are largely a cautionary tale concerning the application of prediction markets to internal firm decision making. While markets have

	(1)	(2)	(3)	(3)
	Effort =1	Effort = 2	Effort = 3	Effort = 4
Asset 1	-0.015*** (.006)	-.017*** (.005)	-.022 (.006)	-.015*** (.006)
Asset 2	-.009 (.006)	.036*** (.006)	-.006 (.007)	-.009 (.006)
Asset 3	-.006 (.005)	-.009 (.007)	.027*** (.007)	-.006 (.005)
Asset 4	.016*** (.006)	-.002 (.005)	-.005 (.007)	.016*** (.006)
Constant	-.785*** (.170)	-1.05*** (.124)	-1.01*** (.205)	-.785*** (.170)
Obs	864	864	864	864
Log likelihood	-415.44	-367.33	-358.49	-415.44
Pseudo R2	0.037	0.096	0.087	0.037

Table 5: Probit regression results examining the effect of ending asset position on effort choice. (Standard errors clustered by group.)

enticing information aggregation possibilities, in some settings the markets themselves might influence the eventual realization. Field studies of prediction markets for election outcomes, movie sales, or the weather do not typically suffer from this problem because each traders influence on the final outcome is non-existent or at least very small. We believe that applications within firms are more likely to exhibit features similar in nature to our examples. There are likely to be a few traders and those traders are likely to also have some influence on the eventual observation in question.

While this paper has focused on moral hazard concerns in prediction markets, we believe that this issue has broader applicability. Two examples were similar phenomena might be observed are the following. First, in sports betting markets, the incentive for athletes to change the outcome of the game so they (or others) can profit in the betting market is a well-known example of moral hazard and its influence. Second, many macroeconomic models of business cycles and the sort rely upon some notion of expectations. For example, the yield curve, which represent the term structure of interest rates, is largely based upon future expectations of interest rates. It is well-known that an inverted yield curve (interest rate is lower for longer-term debt) is a particularly good predictor of economic recession. When individuals expect an economic recession they will expect lower interest rates

so they will be willing to loan out for longer terms at lower interest rates. However, if one views a recession, as Keynes did, as simply a movement to a ‘bad’ equilibrium, is it that the interest rate markets (and the implied expectations) that are causing a recession or is it in the opposite direction?

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## A Market Graphs

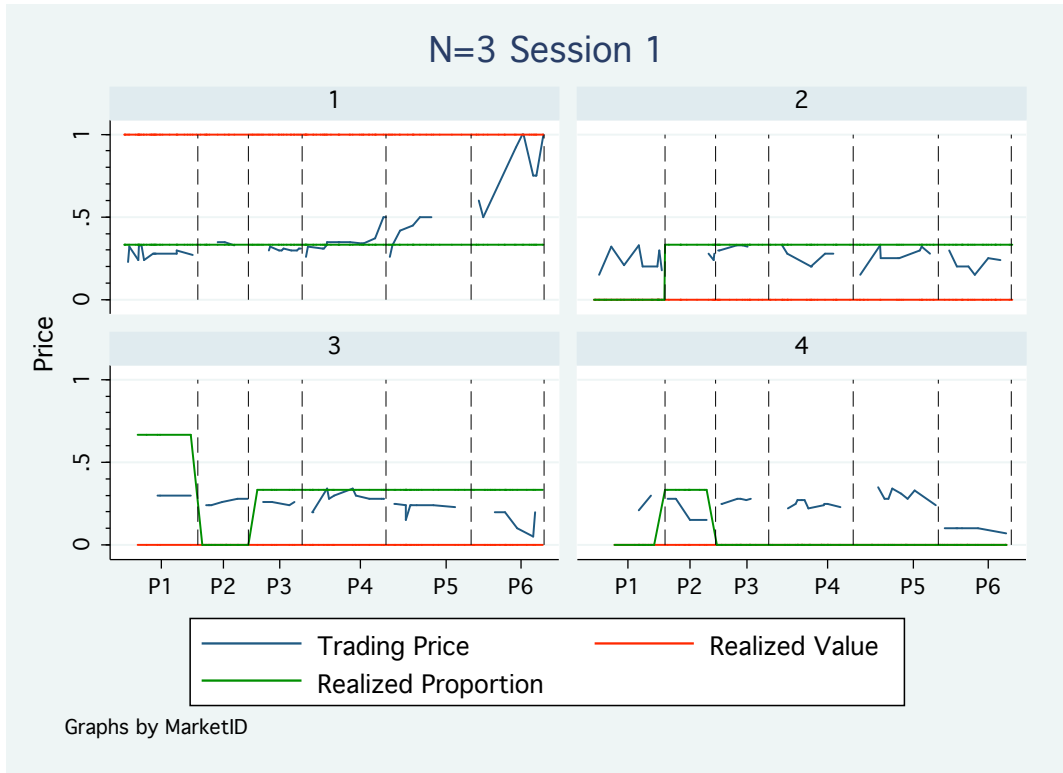


Figure 5: Session 1  $N = 3$

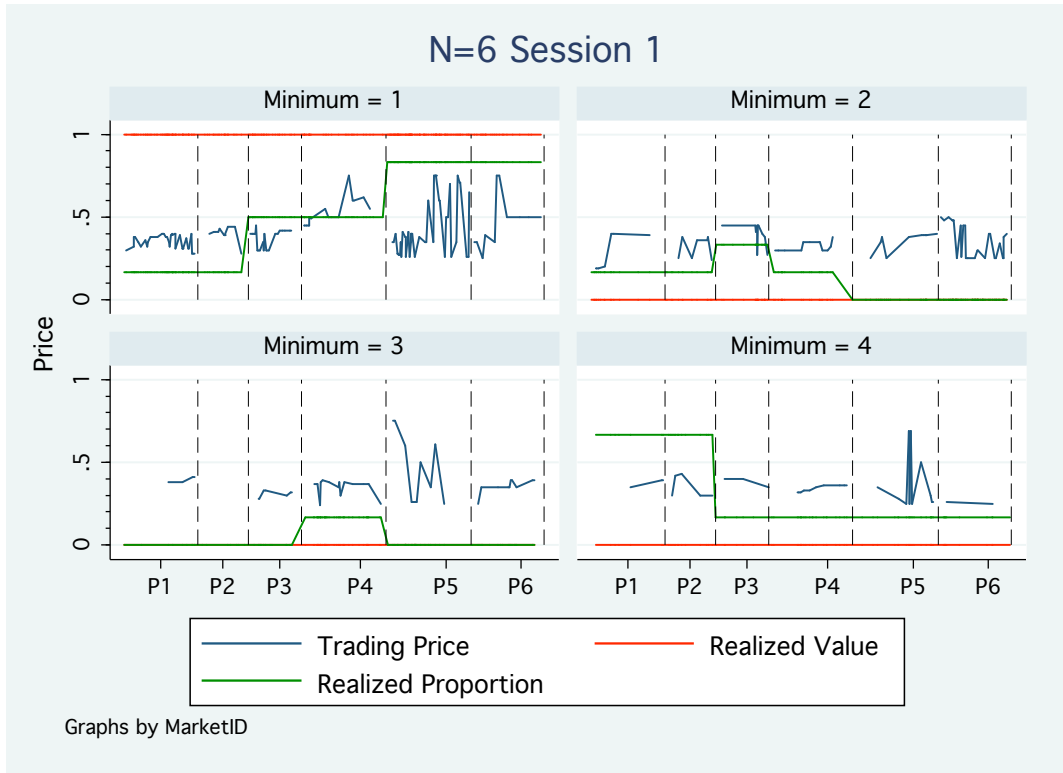


Figure 6: Session 1  $N = 6$

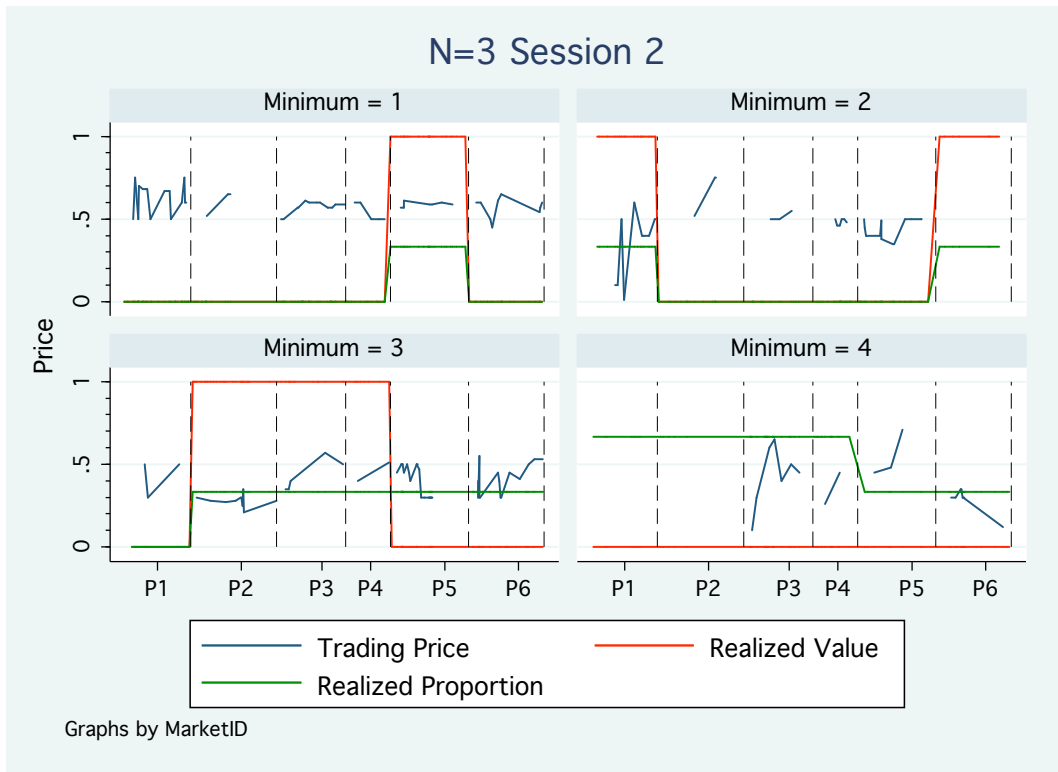


Figure 7: Session 2  $N = 3$

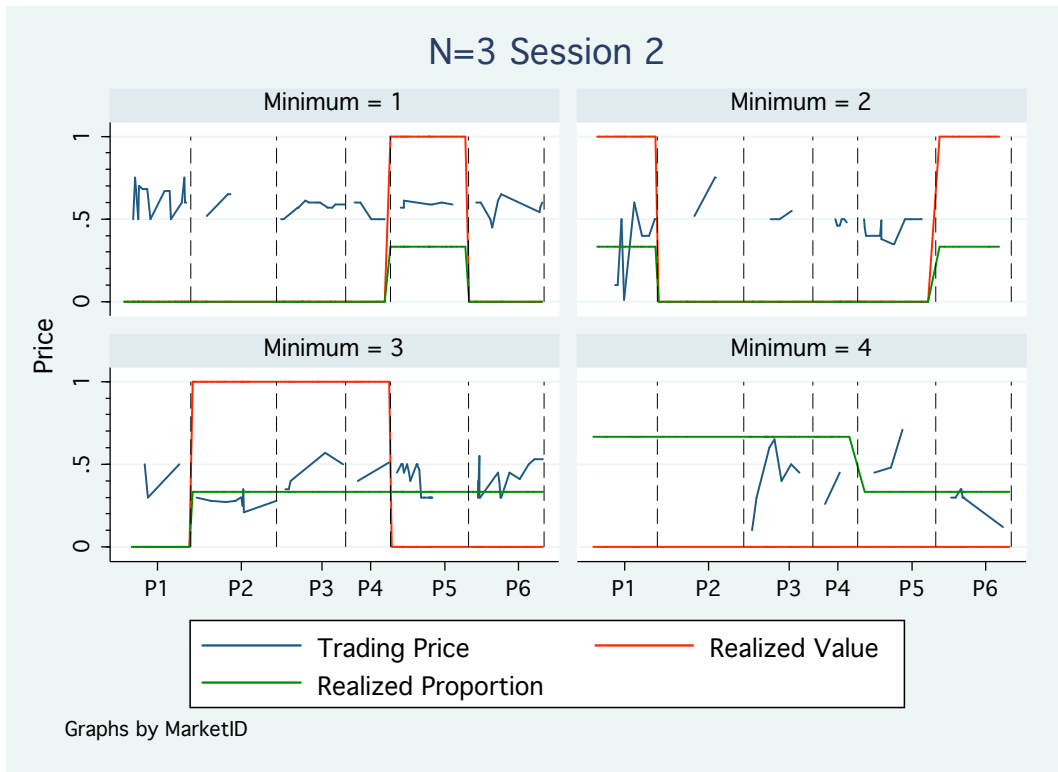


Figure 8: Session 2  $N = 6$

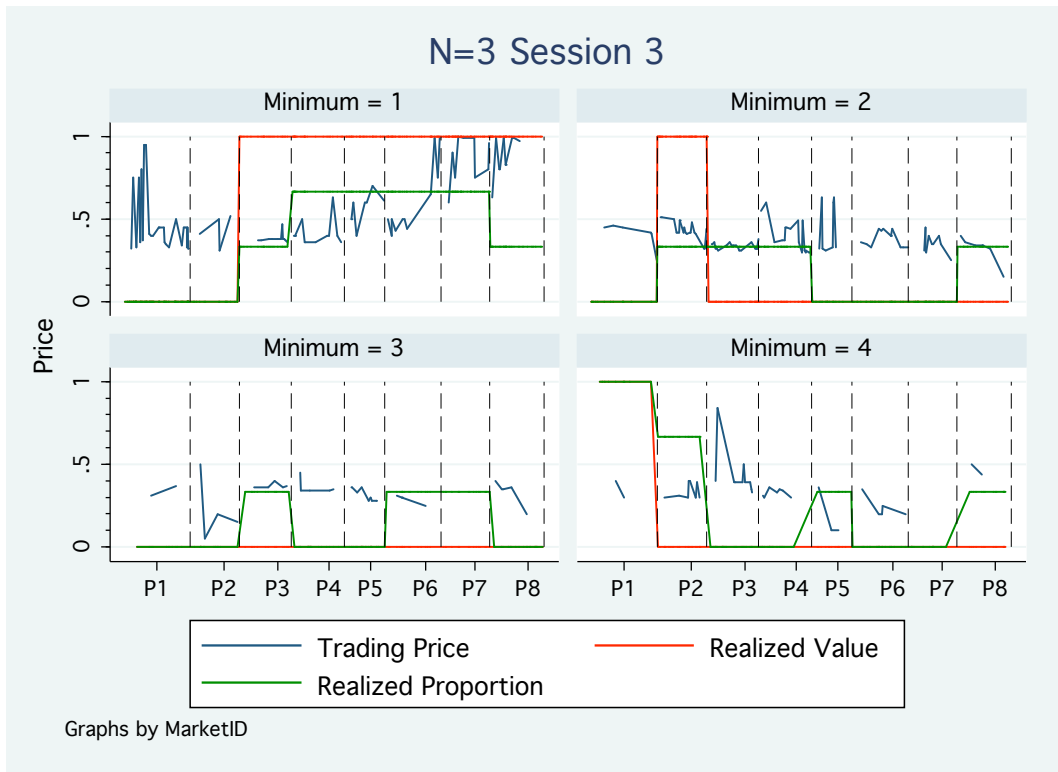


Figure 9: Session 3  $N = 3$

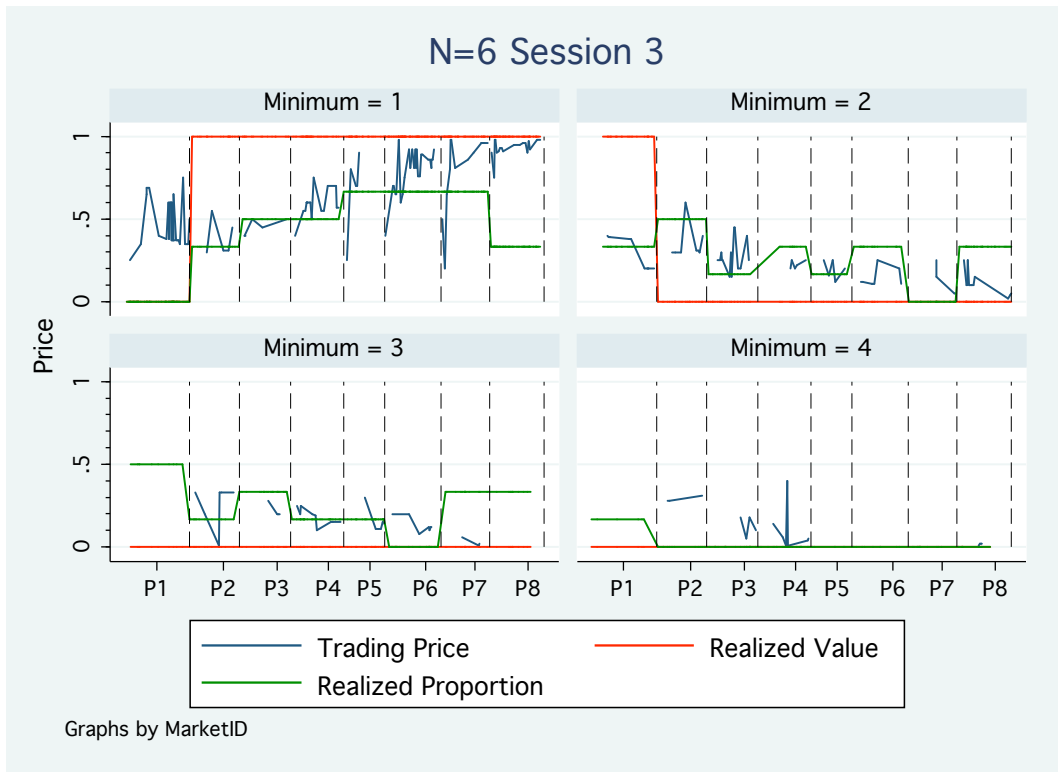


Figure 10: Session 3  $N = 6$