Coordination in the Presence of Asset Markets[1]

Shimon Kogan • Anthony M. Kwasnica • Roberto Weber

Tepper School of Business, Carnegie Mellon University
Smeal College of Business, The Pennsylvania State University
Department of Social and Decision Sciences, Carnegie Mellon University
kogan@andrew.cmu.edu • kwasnica@psu.edu • rweber@andrew.cmu.edu

---

Abstract

We study the relationship between an economic production activity, modeled by a minimum-effort coordination game, and asset markets in which securities values correspond to outcomes in the activity. We explore both theoretically and experimentally how final prices and asset holdings in the market influence and forecast outcomes in the coordination game. We vary the incentives from the market relative to payoffs from the game, the number of players playing the game, and whether traders payoffs are influenced by outcomes in their own game or another game. In our experiments, markets lead to significantly lower (and inefficient) group outcomes across all treatments. Prices are informative about group outcomes and the market helps avoid wasted effort in which players make choices higher than the group minimum.

Keywords: Equilibrium Selection; Coordination Games; Experimental Economics.

1 Introduction

Markets are central to economics. Markets aggregate widely dispersed information and direct resources to where they produce the greatest value (Hayek 1945, Smith 1776). An important feature of most markets is their relationship to some underlying economic activity. For example, the value and effectiveness of insurance markets depends crucially on the behavior of those purchasing contracts (Shavell 1979). The value and effectiveness of "prediction markets" depends on their ability to forecast economic events on which the value of assets is based (Wolfers & Zitzewitz 2004).

---

[1]We would like to thank seminar participants at Boston College, Caltech, University of Austin, Texas, University of Texas, Dallas, University of Toronto, University of Iowa, 2007 Informs Meetings, 2007 North American ESA Meetings.

This paper explores the relationship between asset markets, in which the value of traded assets depends on the realization of an economic outcome, and the underlying activity that produces the outcome. We use a laboratory experiment, where we can control important features of both the market and the underlying activity.

The economic activity in our setting consists of a coordination game with Pareto-ranked equilibria, in which the payoff to each player is a function of her own choice and the minimum choice of all players (see Van Huyck, Battalio & Beil (1990), Crawford (1995)). In these games, multiple players choose among several ordered strategies, with pure-strategy equilibria consisting of outcomes in which all players select the same strategy. Players all do better if they coordinate on the highest (most efficient) equilibria, but they also prefer to select lower choices if they believe others will do so. Such games have been applied widely to model economic activity, from the relationship between beliefs and output in macroeconomic models (Cooper 1999), to public good provision (Hirshleifer (1983)), to firm production (Camerer & Knez (1997), Brandts & Cooper (2006)).

Given the extent to which financial markets are often linked to the above kinds of economic activity, we study the relationship between economic performance, measured by outcomes in the game, and a corresponding market in which participants trade assets with value contingent upon the outcome in the coordination game. More precisely, in each period of our experiment participants play the coordination game and receive payoffs from the outcome in the game. However, prior to playing the game, participants trade in a market with Arrow-Debreu securities, each corresponding to one of the possible outcomes (minima) in the game.

Our primary purpose is to explore the extent to which markets may influence outcomes in the underlying economic activity. Our experiment is thus informative about the relationship between markets and such activity.

For instance, in previous experiments using similar games, pre-play communication among players helps reassure them of their mutual intent to pursue the efficient equilibrium and is thus effective for obtaining the efficient outcome (Blume & Ortmann (2007), Cooper, DeJong, Forsythe & Ross (1992)). Thus, the pre-play market might be one mechanism through which players engage in such mutual reassurance and coordinate on the efficient equilibrium (see also Van Huyck & Battalio (1993)). More generally, perhaps asset markets can allow economic agents the opportunity to communicate their intent to pursue efficient outcomes, thus directing economic activity towards efficiency.

The strategic uncertainty in coordination games means that players of-

ten mismatch their choices at least when playing initially. These out-of-equilibrium outcomes imply wasted effort on the part of economic agents. Therefore, another important possible benefit of paring market trading with the economic activity is that it might eliminate such wasted effort. That is, even if the market has no positive effect on aggregate outcomes (higher minima), it may improve efficiency by coordinating agents' actions on a particular equilibrium (i.e., resulting in fewer choices above the group minimum).

While communication through the market might allow groups to achieve greater efficiency, the market also creates incentives for traders / players to decrease the group's output in the coordination game. Since group output is determined by the lowest action by any group member, any single player can lower the output statistic unilaterally (assuming it is not already at the lowest possible value). Therefore, a market with sufficiently high payoffs creates a possible incentive to engage in such opportunism, thereby harming the underlying economic activity.

We explore the above relationships between markets and economic activity by varying the incentives of the market relative to the game. When market incentives are high, the possible influence of opportunism is considerable the effect of markets on economic behavior might simply result from modified individual incentives. However, when market incentives are low such a direct influence is less likely, and any influence of markets on economic behavior is likely to result from influences on beliefs, communicated through prices.

As we describe above, our research contributes to understanding the relationship between markets and underlying economic activity. This knowledge is particularly valuable in light of the recent proliferation of information markets, which often yield valuable predictions of future economic outcomes (Forsythe, Palfrey & Plott (1982), Plott & Sunder (1988), Berg & Rietz (2003), Wolfers & Zitzewitz (2004)). However, understanding whether such markets can accurately forecast the outcome of strategic interactions among many individuals as in much economic activity is an important question. Moreover, the possible influence of such markets on the underlying economic activity is also an issue that merits attention.

In every period of our experiment subjects simultaneously trade shares in four markets, each corresponding to one of the possible outcomes of the subsequent coordination game. To explore different ways in which markets and economic activity interact we vary several treatments in our experiment. First, as we mention above we vary the incentives in the market relative to the coordination game. We also vary the number of players in the coordi-

nation game since this is perhaps the most important factor in determining outcomes in the game (Van Huyck et al. (1990) and Weber (2006)). Finally, we vary whether the coordination game is played absent any market (*Control* condition), is directly linked to the market (Insiders treatment), or is indirectly linked to the market by having players in the game trading in a market whose values are determined by another groups game (Outsiders treatment).

In what follows, we first present a model of the environment in which players first trade in a market and then play the coordination game. This model motivates several hypotheses regarding the relationship between the market and outcomes in the game. We demonstrate theoretically (Section 2) that the market may influence outcomes in the game. Our laboratory experiments (Sections 3 and 4) reveal that the presence of markets significantly lowers the groups minimum effort (output), which is true across *all* our treatments, even when the market incentives are very weak (Market-L treatment) or when the outcome of the game is unrelated to market payoffs (outsiders). However, the market predicts such behavior and, perhaps as a result of such communication, there is generally less wasted effort or choices above the group minimum. We discuss our results and compare them to previous research in Section 5.

2 The Model

Players participate in a two-stage game consisting of an asset market followed by a coordination game. The value of the securities traded in the asset market depend upon the realization of the minimum effort chosen in the coordination game for a particular group.

In order to understand predicted behavior in the first stage asset market we must first examine the second stage coordination game. Players participate in an N player minimum effort coordination game. All players simultaneously select an effort level $e_i \in \{1, \ldots, M\}$. Each player's payoff depends upon their effort level and the minimum effort level, $e_{\min}$ chosen by all players:

$$\pi_i(e_i, e_{\min}) = a + be_{\min} - ce_i \tag{1}$$

where $0 < c < b$. In this game, any selection of effort levels such that $e_i = e_j$ for all i and j is a pure strategy 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 dominate 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'; someone who has chosen $e_i = 1$ receives a certain payoff whereas selecting high effort involves lower payoffs when other players select lower efforts. Since the secure payoff from low effort is greater than the payoff when the player select high effort but other players select low effort, 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).

This game was first studied experimentally by Van Huyck et al. (1990).[2] 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 does not emerge as a focal point in the data. Second, group size influences the equilibrium selection. Small groups (with 2-3 subjects) converge to much higher effort levels than large groups (9-16 subjects). Our experiments examined two different group sizes: *Small* groups with three subjects each and *Large* groups with six subjects each.

Prior to the coordination game all players participate in an asset market where security values are based upon the minimum effort level chosen by some group in the subsequent game. There are M state-contingent securities traded with the following payoffs:

$$X_m = \left\{ \begin{array}{ll} \beta & \text{if } e_{\min} = m \\ 0 & \text{otherwise} \end{array} \right. \tag{2}$$

where $\beta > 0$.

There is a considerable literature demonstrating that properly designed markets can provide high-quality information regarding uncertain outcomes. In particular, Arrow-Debreu style securities, like the ones used here can efficiently aggregate information. Using experimental markets, Plott & Sunder (1988) show that markets can aggregate dispersed information. 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. Field studies of asset markets designed to predict uncertain events

---

[2]The original presentation of the game is due to Bryant (1983).

also show that these types of markets provide accurate signals regarding future outcomes. 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 & Rietz (2003) who summarize a decade long evidence on its accuracy over short and long horizons. 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.

2.1 Communication and Equilibrium Selection

One factor that may significantly improve coordination on efficient outcomes in games of strategic complementarities is communication. Pre-play costless communication generally improves the frequency of efficient play even in games with more than two players (Blume & Ortmann 2007, Cooper et al. 1992). Asset markets may serve as an effective pre-play communication device. Van Huyck & Battalio (1993) found that the inclusion of a market in which participants could trade a limited number of certificates which entitled the holder to play in a subsequent coordination game *always* resulted in successful coordination on the Pareto dominant equilibrium.[3] In their experiment, the winning bidders, and thus participants in the game, are those who assign the highest value to the right to play. Therefore, subjects may be signaling via the asset market an expectation of high effort which is in turn observed. The asset markets we study here offer a similar opportunity for participants. By buying assets that only payoff in the highest effort level, subjects can declare their intention to play high effort. Thus, our initial conjecture is that Arrow-Debreu futures markets may result in similar coordination improvements to those observed via pre-play communication and 'right to play' asset markets.

Hypothesis 1 (Pure Communication Effect) *Communication through an asset market will improve coordination for both group sizes.*

On the other hand, the effect of pre-play communication can depend critically on the structure of the communication. For example, one way communication is often less effective than two-way communication at inducing

---

[3]Crawford & Broseta (1998) propose a model of learning dynamics that explains the result in median effort games.

improved coordination (Cooper et al. 1992, Weber, Camerer, Rottenstreich & Knez 2001). Likewise, the asset markets in these experiments are substantially different than those studied by Van Huyck & Battalio (1993). Both the incentives created by the assets and the communication opportunities enabled by the assets may have a substantial impact on their ability to coordinate player choices in the subsequent game.

2.2 Portfolio Incentives and Equilibrium Selection

We begin by examining the direct effect asset markets of this sort may have on the choice of effort levels in the coordination game. In contrast to the right to play asset market of Van Huyck & Battalio (1993), where the result of the asset allocations are sunk at the time players make effort choices, player actions in the asset market studied here can directly affect the incentives to play various effort levels in the game. No matter what concept of equilibrium is imposed on the asset markets, 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 $x_i = (x_{1i}, x_{2i}, \ldots, x_{Mi})$ be player i's *portfolio* at the end of trading. Since these assets payoff based upon the outcome of the game, the original payoffs from Equation 1 are modified to be:

$$\overline{\pi}_i(e_i, e_{\min}; x_i) = a + be_{\min} - ce_i + \beta \sum_{m=1}^{M} \delta_m x_{mi} \tag{3}$$

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 is 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 pure strategy Nash equilibrium if and only if asset portfolios are such that for all $\ell < m$,*

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

for all i.

Proofs are provided in the Appendix.

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:

1. For all asset positions, the lowest effort choice, $e_i = 1$, by all players is a Nash equilibrium outcome.

2. In order for higher effort choices to be Nash equilibria, it must be that asset positions of the players are not too *diverse*.

3. When comparing asset positions, it takes more diverse assets for lower effort to be preferred to higher effort.

4. The asset portfolios that induce certain Nash equilibria depend upon the relative payoff of the asset market (β) to the coordination game $(b - c)$.

Thus, while we should expect the asset position of the players at the end of trading to affect the subsequent choice of strategies in the game, the strength of such an effect should depend upon the payoffs in the market and coordination game. If β is large relative to $(b - c)$ then even small differences across a single player's state-contingent holdings may eliminate the high effort choices as an equilibrium. On the other had, if β is small relative to $b - c$, large (potentially infeasible) cross-asset holdings differences will be necessary to change the set of the equilibria from those of the original game.[4]

In order to examine this potential effect, we systematically varied the payoffs. In the *Market H* variant $(b - c)/\beta = 2$ and in the *Market L* variant, $(b - c)/\beta = 40$. Thus, the *Market L* treatment significantly lowered the relative payoff of the market. In order to see the potential strength of this treatment consider the differences in asset holdings that would be necessary to induce an individual to be unwilling to play the effort level $e_i = 4$. In the *Market H* treatment, the individual would have to hold greater than 2, 4, or 6, more units (than units of the X_4 asset) of the X_3, X_2, or X_1 assets respectively. Whereas, in the *Market L* treatment, the required minimum differences are 40, 80, and 120.[5] Since the set of Nash equilibria in the

---

[4]It should be noted, however, that even if the set of equilibria have not been changed by asset market holdings the payoffs in the coordination game have changed and become potentially asymmetric. Brandts & Cooper (2006) and Goeree & Holt (2005) study the effect of changes in payoffs on equilibrium selection in coordination games.

[5]The payoffs for the *Market L* treatment were selected after completion of the *Market H* treatment in such a way that, given the observed asset positions of players from the

modified coordination game is always a subset of the set of Nash equilibria of the original game, we are lead to our next hypothesis.

Hypothesis 2 (Portfolio Incentive Effect) *The presence of an asset market will lower coordination in the* Market H *treatment and will have little or no effect in the* Market L *treatment for both group sizes.*

While this hypothesis suggests coordination will be more difficult as a result of the inclusion of an asset market, it is important to note that the asset market as conducted does not preclude efficient outcomes. The total endowment of each state-contingent asset is the same so a uniform portfolio of the same unit holdings for each asset was always possible for every agent.[6]

2.3 Markets and Communication

We present here one possible model of equilibrium in the market. There are many obvious shortcomings of the model we propose but we also believe it adequately captures the essential 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 that is consistent with the stylized details of strategic uncertainty in the coordination game. Suppose that each player has some beliefs about the minimum effort that will be chosen by the $N-1$ other players where μ_{mi} indicates player i's belief that the the minimum choice of the other players will be m. The typical story of coordination failure due to strategic uncertainty in this game is that each player recognizes that high effort is the Pareto dominant equilibrium, but due their beliefs about the choices of others players find it rational to player $e_i < M$. Specifically, a player's expected utility from their effort level choice given this strategic uncertainty is given by:

$$\Pi_i(e_i) = \sum_{m=1}^{M} \mu_{mi}\overline{\pi}_i(e_i, m; x_i) \tag{5}$$

Market H variant, under these new payoffs no effort choice would have been ruled out as a potential equilibrium. Only two occasions (out of 828) were observed such that subjects ended with asset positions that would have eliminated some effort level choices from the set of Nash equilibria under the *Market L* payoffs.

[6]The asset market might offer an opportunity to offset some of the risk associated with other players playing lower effort. However, in this setting hedging or insurance opportunities are limited for two reasons. First, as agents attempt smooth allocations across minimum effort levels, the asset allocations become inconsistent with Proposition 1. Second, the cost of acquiring these assets in the market further limits hedging.

If players maximize their expected utility with respect to these preferences, then they may decide to play effort levels other than the Pareto dominant equilibrium. Let $\mu = (\mu_1, \ldots, \mu_N)$ be beliefs for each agent. Then we say that $e^* = (e_1^*, \ldots, e_N^*)$ is an *equilibrium given beliefs* μ if e_i^* maximizes Equation 5 for all i. Players maximizing with respect to these beliefs provide an explanation for the two forms of inefficiency in coordination games. First, if beliefs regarding low effort minima of other players are sufficiently high, a player will prefer to play low effort herself. Second, players' initial effort choices may fail to be *ex post* best responses to the *ex post* choices of the other agents resulting in wasted effort. Of course, via repeated interaction players will refine their beliefs to be consistent the observed history of play and we expect that players will converge to a particular Nash equilibrium.[7]

The market, like any communication device, may provide an opportunity for players to refine their beliefs prior to playing the game. Let p_m be the market price for the asset X_m that pays β in the event that minimum effort chosen is m. In order to properly define a notion of a market equilibrium we must have two features. First, agents' asset buying/selling choices must be consistent with their expected effort choices and their beliefs about other agents. Second, the actual effort choices must be the result of maximizing behavior in the second-stage modified coordination game. The following definition of a market equilibrium incorporates both of these features.

Definition 2 (x^*, p^*, e^*) *is a* rational expectations equilibrium *if there exist beliefs* μ *such that:*

1. x_i^* *maximizes* $\sum_{m=1}^{M} \mu_{mi} \overline{\pi}_i(e_i, m; x_i) - p_m x_{mi}$ *for all* i.

2. e^* *is an equilibrium given beliefs* μ.

This notion of a market equilibrium places few restrictions on the set of beliefs that are allowed for players. Thus, there are likely to be many potential rational expectations equilibria. As is typical in discussion of rational expectations type equilibria, we allow for prices to reveal information to the agents. In particular, we say that a rational expectations equilibrium is *revealing* if the beliefs which support the equilibrium are given by $\mu_{mi} = p_m / \sum_{\ell=1}^{M} p_\ell$ for all i, or beliefs are simply given by the observed normalized prices. Further, the equilibrium is said to be *fully revealing* if there exists an effort level m such that $p_m = \beta$ so $\mu_{mi} = 1$ for all i. In the event of a fully revealing equilibrium, all strategic uncertainty is resolved and the

---

[7]Crawford & Broseta (1998) propose a model that formally interacts learning dynamics with strategic uncertainty.

resulting effort choices must constitute Nash equilibria of the game. If markets are an effective communication tool they should admit fully revealing rational expectations equilibria that result in high effort for the players. In fact, we find that any Nash equilibrium can be supported as a fully revealing rational expectations equilibrium.

Proposition 3 *Given an effort level m, there exists a fully revealing rational expectations equilibrium with $p_m^* = \beta$ and $p_\ell^* = 0$ for all $\ell \neq m$ and $e_i^* = m$ for all i.*

The intuition behind this result is obvious. Let $e_i^* = m$ for all i and notice that, given these prices, for all players $\mu_{mi} = 1$. However, this means that each player has identical preferences and the marginal benefit of another unit of $x_{i\ell}$ is β if $\ell = m$ and 0 otherwise. Thus, setting p_ℓ equal to β for $\ell = m$ and 0 otherwise insures that each agent is indifferent between more units of each of the asset and the equivalent amount of cash. Given this indifference between cash and assets, portfolios can be assigned in order to ensure that $e_i^* = m$ remains a Nash equilibrium (the conditions of Proposition 1 are satisfied); the allocation $x_{im} = x_{i\ell}$ for all ℓ and i will trivially satisfy this condition given any equilibrium effort level.

Proposition 3 suggests that information revelation that results in efficient outcomes is possible, which could be taken as further support for our original Hypothesis 1. However, any pure-strategy Nash equilibrium is also possible under this proposition. Therefore, we need to investigate whether any of these potential equilibria are more likely to be observed. The attainment of a particular rational expectations equilibrium is fundamentally a dynamic process where agents begin with differing beliefs and some how converge to a consensus opinion regarding the minimum effort that will be observed. If small perturbations in equilibrium beliefs result in dramatically different equilibria then we would expect that these equilibria would be unlikely to be observed. We say that a fully revealing rational expectations equilibrium (x^*, p^*, e^*) is *stable* if for all $\epsilon > 0$ and for all i if there exists an x' such that (x', p^*, e^*) is a rational expectations equilibrium given beliefs $\mu_{mj} = 1$ if $p_m^* = \beta$ and 0 otherwise and $\mu_{mi} = 1 - \epsilon$ if $p_m^* = \beta$ and $\epsilon/M - 1$ otherwise. If even one agent assigns some small amount of strategic uncertainty of the choices of other players, and this uncertainty induces either market or game behavior that moves the group away from the particular game outcome, then this equilibrium is extremely fragile. The following proposition shows that only one of the fully revealing rational expectations equilibria identified earlier is stable.

Proposition 4 *The unique stable fully revealing rational expectations equilibria is given by $p_1^* = \beta$ and $p_m^* = 0$ for all $m \neq 1$ and $e_i^* = 1$ for all i.*

In order to see why the lowest effort is stable consider a player who now places some small probability on others choosing a higher minimum. While the difference between beliefs and prices might create opportunities for trade, given the player's effort plan $e_i^* = 1$, the marginal value of any asset that pays off in the event of higher effort is still 0 and so the agent's trading preferences are unchanged and allocations can be adjusted slightly to insure that $e_i^* = 1$ remains maximal. To see why higher effort levels are unstable consider a player who originally planned to play $e_i^* = M$ but now assigns some small probability to other players selecting a lower effort. The marginal value of an increase in holdings of these lower effort assets is now given by $\epsilon\beta > 0$ and the player's demand for these assets is unbounded given the price of 0. Thus, the player will buy all feasible units of the assets $X_1, X_2, \ldots, X_{M-1}$ which, assuming feasibility is not overly binding,[8] will induce them to take a different expected utility maximizing effort choice and the equilibrium is unstable.

The previous result demonstrates how the strategic uncertainty inherent in the coordination game may infect the market equilibrium. Players who plan on playing high effort but have some uncertainty about the play of others are easily encouraged by market prices to take lower actions whereas players who plan on playing low effort and are similarly uncertain remain unwilling to invest in higher effort assets. This hypothesis stands in direct contrast to the earlier Hypothesis 1 which predicts more efficient coordination due to communication. Unlike the asset market of Van Huyck & Battalio (1993) where players' buying decisions helped to resolve strategic uncertainty by demonstrating that the set of game participants were those that expected high effort, this asset market contains the opposite incentive. It is easy for the low effort players to declare their intentions by buying the low effort asset and easier still for the previously high effort players to follow their signals.

Hypothesis 3 (Market Communication Effect) *The process of communication through asset market prices will lower coordination for both group sizes and both market payoff treatments.*

---

[8]The experiments conducted allowed nearly unlimited short sales so feasibility constraints were rarely binding.

If markets can serve to communicate the eventual minimum effort, we would expect that market prices will accurately predict such effort choices. Proposition 3 identifies fully revealing rational expectations equilibria that precisely predict the game outcome. Since the literature on information aggregation suggests that markets can be very effective at revealing such information, we hypothesize that the market will provide a reasonably good predictor of actual outcomes in the game.[9] However, there are at least two reasons to expect the accuracy of prices in the *Market H* condition to be greater than in the *Market L*. First, it is often argued that markets must be financially relevant in order to encourage active trading. We expect trading activity to be lower under the *Market L* condition and thus the market prices will not be as accurate at predicting subsequent behavior. Second, given that asset holdings significantly reduce the set of viable equilibria in the *Market H* condition, it may be easier to anticipate the equilibria that will be played in the *Market H* compared with *Market L*.

Hypothesis 4 (Market Price Accuracy Effect) *Market prices will more accurately forecast group outcomes in the* Market H *treatment than in the* Market L *treatment.*

In coordination games, there are typically two forms of inefficiency that arise: (1) players fail to coordinate on the high effort Nash equilibrium, which Pareto dominates other lower effort Nash equilibria, and (2) players fail to play a best response to the effort choices of the other players. We term the second type of inefficiency "wasted effort" since it involves players selecting a higher effort level than the observed minimum which only serves to increase the cost to that player. A perhaps hidden benefit of the market is that it might result in more coordinated effort choices (more players selecting the minimum number chosen) so that the inefficiency generated by playing something other than the minimum effort might be mitigated.

Hypothesis 5 (Wasted Effort Effect) *The presence of an asset market will diminish wasted effort for both group sizes and both market payoff treatments.*

Importantly, wasted effort can be diminished even if the markets have resulted in lower effort outcomes due to either the market incentives or market communication effects hypothesized above.

---

[9]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.

2.4 Outsiders and Equilibrium Selection

The number of traders was kept constant in the markets across the Small and Large group treatments in order to control for liquidity and the possibility that market size might affect the performance of the market. This required that some traders in both treatments were *Outsiders*, or the liquidation value of their assets depended upon another group's minimum effort choice. In order to observe the pure effect of market participation on effort choice, we allowed Outsiders to participate in the second-stage coordination game as well. Since Proposition 1 only applies to *Insiders* where their effort choices affects the liquidation value, the set of Nash equilibria for the Outsiders is unaffected by the presence of an asset market.

Hypothesis 6 (Outsiders Behavior Effect) *The presence of a market will not significantly affect group outcomes for Outsiders.*

One might expect, however, that Outsiders could still be affected by the potential communication effects of the market; they observe market prices and assume that those prices also provide information about the intended play in their group. Given that other Outsiders are also participating in the same market, it is possible that some communication may occur through the market. There may also be an "observation effect" in the sense that, if markets result in lower effort levels of the Insiders, then these low effort choices may have a contagion effect of inducing lower effort choices even in those not directly impacted by the asset values. In order to at least partially control for this effect, the participants in the *Control* treatment were allowed to observe the distribution of effort choices of another group.[10] While observation in the *Control* treatment occurred with a lag, we would expect that observation would be qualitatively similar to observation of another groups behavior via a market. Thus, any additional changes in Outsider behavior can be directly attributed to communication effects of the market.

3 Experiment Design

As discussed earlier, three distinct treatment conditions were examined in order to analyze the interaction between markets and coordination in games with multiple equilibria. The three variants were: *Control* where all subjects

---

[10]For example, the group most likely to be adversely affected by this effect, Small groups, were allowed to observe the choice of a Large group in both the *Control* and *Market* treatments.

participated only in the coordination game, *Market H* and *Market L* where all subjects participated in the coordination game preceded by an asset market and the relative payoff of the asset market was altered.

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). A typical session divided subjects into groups as follows: groups A and C were Small groups, and group B and D were Large groups. Each session consisted of eight periods, all identical in structure. In each period, every subject submitted a number, corresponding to her effort choice. Effort choice took one of four values: $e_i = \{1, 2, 3, 4\}$. The payoff function was was the same as in Equation 1. The parameters used were $a = \$1.20$, $b = \$.40$, and $c = \$.20$. Thus, the payoff for the Pareto dominant equilibrium in the coordination game was \$2.00 under all variants.

In the market variants, subjects first traded in an asset market in which securities' liquidating values depended upon the minimum effort game outcome.[11] In the *Market H* treatment, $\beta = \$.10$ whereas in the *Market L* treatment $\beta = \$.005$ in order to reflective the decreased market incentives.[12] Prior to trading, subjects were assigned to markets such that the number of traders per market was fixed at nine. This 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. Market 1 included members from groups A and B, trading securities linked to the minimum effort of group A, and Market 2 included members from groups C and D, trading securities linked to the minimum effort of group D. Each market contained both Insiders - subjects who traded on

---

[11]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.

[12]The parameter amounts were expressed to subjects in 'experimental dollars' and the appropriate exchange was selected so that, in both treatments, the liquidation values of the assets were exactly 1 experimental dollar. This allowed prices to potentially directly reveal probabilistic information in both *Market* treatments.

outcomes that they could directly influence - as well as Outsiders - subjects who traded on an exogenous outcome; groups A and D were Insiders and groups B and C were Outsiders. 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.

At the beginning of each trading stage, subjects were endowed with units of the different asset 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 per market. In each period two subjects in each market had an endowment of 24 units of a particular asset and none of the other assets; one subject in each market had an endowment of six units of each asset. The choice of asymmetric endowments (across subjects) is standard in these types of asset markets and is designed to stimulate trading by providing rebalancing motives to participants. Also, the aggregate endowment did not constrain further trading; subjects could sell each asset short.[13] At the end of the trading stage, subjects participated in the coordination game. Then, subjects' positions in the securities were liquidated according to the appropriate group's minimum effort.

After choosing their own effort level, subjects observed the distribution of effort choices but not the identity of the effort choices. In addition to receiving information about their group's effort choices, each group also observed the effort choice of one other group such that a Small group was matched with a Large group. The feedback provided to subjects in all variants of the experiment was the same. In the market variants, subjects were informed of the minimum effort of their group as well as the other group participating in their market.

The experiment consisted of 17 sessions conducted at the Smeal College of Business, The Pennsylvania State University, between the October 2006 and October 2007. Normally, eighteen subjects participated in each session.[14] 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 $13.52 (ranging from $7.00 to $28.40) for a session lasting around 2 hours.

---

[13]A margin requirement was used to ensure that no subject's short sales exceeded the amount of their cash loan.

[14]In a few sessions, due to a limited number of show-ups, only nine subjects participated. All these sessions happened under the *Market L* treatment.

4 Results

4.1 Minimum Effort Choice

We begin by discussing the observed effort in the coordination game and the role of the market in these results. To do that, we compare the average minimum effort of groups in the *Control* treatment and the *Market H* and *Market L* treatments. Figure 1 depicts the level of effort choice under these treatments over the eight periods of the experiment while separating the data into Small groups (Panel A) and Large groups (Panel B). First, we find that the results under the *Control* treatment are in line with those reported by previous studies (e.g., Van Huyck et al. (1990)); Small groups generally coordinate on high effort levels, close to 4, and there is little decline over time. In contrast, Large groups find it difficult to maintain high effort coordination and experience a steady decline in minimum effort chosen, hovering around effort levels of 2.

Compared with the *Control* treatment, minimum effort in the *Market* treatments is substantially lower for both Large and Small groups. For Small groups, the effort level falls from 3.66 in the *Control* treatment to 1.84 in the *Market* treatment (averaged across the *Market H* and *Market L* treatments). For Large groups, average minimum effort falls from 2.44 to 1.10. Minimum effort is not only lower overall but also on a period by period basis.

These results are not only economically but also statistically significant. Table 1 reports ordered probit regression results of groups' minimum effort regressed on group size and main *Market* treatment. These regressions take into account the ordinal nature of effort choices. The results suggest that minimum effort is lower for Large groups (across both treatments) by at least 0.9 units. The main *Market* treatment lowers effort level by at least 1.6 units (across both group sizes) compared with the *Control* treatment. Nesting both variables (column 3) suggests that Large and Small groups are affected almost identically by the presence of the market, as the interaction term is small and not statistically different from zero.

Another result that emerges from Figure 1 and Table 1 is the comparison between *Market H* and *Market L* treatments. Group minima in the *Market L* treatment appears to be somewhat higher than in the *Market H* treatment. At the same time, in *both* market treatments, group minima is lower than in the *Control* treatment (see columns 4 and 5 in Table 1). Given that payoffs from portfolio holdings in the *Market L* treatment are very low compared to the payoffs from the coordination game, this result is surprising.

17

Since effort choice appears to trend over periods and since the measure used above may mask interesting difference in distribution of effort levels, we examine an additional measure: the median of groups' effort level over the final periods of the experiment. This measure captures the effort the group spent "most of its time" in. Table 2 reports the distribution of median effort levels, across groups, during the latter part of the session (period 4 through 8). We see that in the *Control* treatment, Large groups' effort level is almost evenly distributed with half of the groups selecting low effort levels (of 1 and 2) and the other half selecting high effort levels (of 3 and 4). The distribution of effort shifts dramatically in the *Market* treatment; virtually all Large groups move to the lowest effort level. Small groups' effort in the *Control* treatment is high, with all groups selecting 3's and 4's. Once again, in the *Market* treatment, the distribution of choices shifts toward lower level effort.

These results suggest that the presence of an asset market in conjunction with a coordination game results in selection of an equilibrium that is substantially less efficient. For all group sizes and periods, coordination appears to be lower in the *Market* treatment compared with the *Control* treatment. The effect is not only statistically but also economically significant. This allows us to reject Hypothesis 1, which suggested that the communication afforded by the asset market would result in higher coordination. These results stand in contrast with the findings of Blume & Ortmann (2007), Cooper et al. (1992) and Van Huyck & Battalio (1993), which show that other forms of pre-play communication increased coordination.

To better understand what drives these results we next turn to study the two asset market dimensions that can influence behavior. First, we look at the effect portfolio incentives have on subsequent play. In that part, we focus on the ways in which the liquidating value of security holdings influence individual and collective effort choices. Second, we look at the role prices play in aggregating and disseminating players' beliefs.

4.2   Portfolio Incentives

As we demonstrated in Section 2, players' asset positions can affect the set of Nash equilibria in the coordination game. Before turning to see whether portfolio incentives can account for the difference between the results obtained in the *Control* and the *Market* treatments, we ask whether individuals' effort choices are affected by their portfolio holdings. Table 3 shows the results obtained from a marginal probit regression of individuals' effort choices and their end-of-period portfolio holdings of assets X_1, X_2, X_3, X_4.

The results show how the probability of choosing a given effort level changes with an increase in holdings of each of these securities. For example, column 1 of the table measure how the probability of a subject selecting effort level 1 is related to her security holdings.

We find that subjects that choose effort level m held more m security units and less non-m security units. For example, column 1 Table 3 suggests that subjects who choose effort level of 1 where 1.4% more likely to do so with every additional unit of asset X_1 holding. In this case, increased holdings of assets X_2, X_3, and X_4 have a negative effect (although not statistically significant). Similar patterns emerge if we look at subjects who chose other effort levels; all diagonal elements are positive, and statistically significant, while all off-diagonal elements are negative.[15]

Given that individuals' choices appear to be related to their portfolio holdings, we turn to test the implications of Proposition 1 to determine the set of Nash equilibria after trading in the market. To do that, we compute for each group and period the set of equilibria that are incentive compatible with subjects' security holdings and the modified payoffs of the game. Recall that in the *Control* treatment, the set of equilibria is $\{1, 2, 3, 4\}$. Table 4 presents the observed distribution of group minima sorted into the different sets of equilibria. For example, the first column, labeled "$\{1\}$" reports the frequency of group minima when only effort level 1 satisfies Proposition 1. Likewise, the second column, labeled "$\{1,2\}$" refers to all instances in which effort levels 1 and 2 satisfy this condition. Panel A reports the results for Small groups while Panel B reports the results for Large groups. For comparison, we include the distribution of minimum effort in the *Control* treatment in the last column.

While the theory does not allow us to select among equilibria, it suggests which equilibria *will not* be played. We find that when all groups are predicted to select effort level of 1 (the first column), 82% of the small groups and 98% of the Large groups do so. Likewise, only 22% of the Small groups violate this condition when they are predicted to chose effort levels of 1 or 2, and 33% of the Small groups violate this condition when they are predicted to chose effort levels of 1, 2, or 3. While groups' behavior is not entirely consistent with the incentives induced by security holdings, these results suggest an important role for portfolio incentives.

However, we suggest that the presence of markets lowers efficiency in

---

[15]These results are inconsistent with the idea that subjects would use the asset market to hedge. If that was the case, we should have found the opposite pattern; diagonal elements in Table 3 should have been negative.

a way that cannot be explained by portfolio incentives. To see that, we compare the distribution of group minima when portfolio incentives *do not* eliminate any of the equilibria (column labeled "{1,2,3,4}") with the distribution of group minima in the *Control* treatment. Comparing the two, we find that for both Small and Large groups, group minima are substantially higher in the *Control* treatment. For example, 70% of the groups in the *Market* treatment for which portfolio holdings did not eliminate any of the equilibria selected minima of 1 compared with 33% in the *Control* treatment. More formally, using the Kolmogorov-Smirnov test for equality of distribution functions, we reject the null that distributions of minima are the same across the two sub-samples at the 1% level (separating observations into Large and Small groups).

In summary, the results regarding the portfolio incentive effects provide partial support for Hypothesis 2. We find that individual and group effort levels are influenced by their portfolio holdings. At the same time, we find that portfolio holdings cannot alone account for the full set of findings. In particular, the results obtained from the *Market L* treatment stand in contrast to the hypothesis.

4.3   Price Informativeness

If portfolio holdings alone do not fully account for the effect markets have on play in the coordination game, we turn to study the role prices play. First, we examine the informativeness of market prices about the subsequent outcomes of the game and the ability of subjects to use these prices as a coordination device. In what follows, we use the average price over the last five trades (in each period) as our measure of *market prices*; utilizing other measures such as the median of the last trades, the average of all trades, or the closing trading price yield similar results.[16] We measure price errors as the absolute difference between the observed market price and the realized payoffs. 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 2 depicts the average price error in the *Market H* and *Market L* treatments for both Small and Large groups. We see that price errors drop considerably in the course of the experiment. For example, markets trading the outcomes of Small group effort start with an average price error of .395 in period 1 and drop to an average error of .119 by period 8. While

---

[16]When less than five trades are completed, we average all the trades conducted in that market and period.

the distribution of minimum effort in Small and Large groups was very different, we find that the level of price errors are very similar across the two sets. This similarity is preserved across periods. Next, we observe that price errors in the *Market L* treatment are somewhat higher than in the *Market H* treatment – particularly for Small groups. These results provide supports for Hypothesis 4.

Further evidence on the connection between prices and effort choices can be obtained from Table 5. The table reports results obtained from estimating a marginal probit regression of individual effort choice on the closing prices of securities X_1, X_2, X_3 and X_4. In these regressions we control for subjects' portfolio holdings of these securities. We do that to isolate the effect prices have from the previously documented impact portfolio holdings have (see Table 3).[17] As we can see, low effort level (of 1) is more likely to be undertaken when the price of security X_1 is high and the price of security X_4 is low. Likewise, high effort level (of 4) is more likely to be undertaken when the price of security X_1 is low and the price of security 4 is high. This suggest that subjects' effort choices are related to security prices prevailing in the trading round.

Since prices appear to be informative about subsequent group play, it is natural to ask whether subjects in the *Market* treatment are less likely to mis-coordinate by choosing effort levels that are higher than the minimum in their group. That is, conditional on minimum effort being less than 4, subjects are better off choosing effort levels no higher than the minimum. We denote that as "wasted effort" – the extent to which group members select choices above the minima, and measure it by averaging the absolute difference between subjects' individual effort choice and the minimum the group.

The mean wasted effort, conditional on minimum effort choice, is depicted in Figure 3.[18] For all effort choices and groups sizes, wasted effort is lower under the *Market* treatment compared with the *Control* treatment. This is true for both Small and Large groups. Some of these differences are large in magnitude. For example, when group minimum effort is 2, wasted effort is 40% lower in the market condition (across both group sizes) compared with the *Control* treatment.

We test for the statistical significance of these patterns in Table 6. The dependent variable is group's average wasted effort. The first regression

---

[17]Repeating the same set of regressions while excluding subjects' holdings yields very similar results.

[18]Figure 3 deliberately omits group minimum effort of 4 since, by construction, the wasted effort in that case is zero.

reveals that the wasted effort is slightly higher in the *Market* treatment. However, this result 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 (columns 4 and 5), we see that the wasted effort is significantly lower in the *Market* treatment. Not surprisingly, wasted effort is lower when group minima is higher and when groups are Small. Thus, consistent with Hypothesis 5, holding the group outcome (minimum) constant, we find that subjects are significantly better able to coordinate on that minimum in the *Market* treatment than in the *Control*.

In summary, we find strong support for Hypothesis 3. First, we show that prices convey information. Second, we find that this information affects individual and group effort choices. Prices seem to play two roles. Prices allow subjects to communicate doubt, which has negative effect on group minima. At the same time, prices serve to coordinate beliefs thus resulting in more frequent equilibria play and less effort waste.

4.4   Outsiders' Behavior

Recall that in the *Market* treatment each market is populated by one group of Insiders and one group of Outsiders. Both groups proceeded to participate in the coordination game after trading in the market. However, only Insiders' groups had their payoffs from the market related to their decisions in subsequent coordination game. Therefore, if portfolio holdings are the driving force behind the effect markets have on the behavior in the coordination game, Outsiders should be unaffected by the presence of markets and therefore should select effort levels similar to those observed under the *Control* treatment. Table 7 estimates the difference in minimum group effort between the Insiders and Outsiders while controlling for group size and market incentives. The results suggest that contrary to the hypothesis put forth, Outsiders' groups do not appear to select different minimum effort level than Insiders' groups. Interacting group size with Insider/Outsider treatments does not yield statistically significant differences associated with Outsiders. Crossing *Market H/Market L* and Insider/Outsider treatments yields marginally significant results for the interaction term (column 3) but not for the main effect. Thus, Outsiders seems to be affected by the presence of the market – thus reducing their group effort minima – almost to the same extent as Insiders.

These results, which stand in contrast to Hypothesis 6, are anomalous if one holds the view that the presence of markets affects behavior through

portfolio holdings. However, they can be rationalized if Outsiders use market prices as a focal point for coordination or if Outsiders are unable to verify that observed prices reflect beliefs of Insiders and therefore should be disregarded. One way or the other, these results suggest that the coordination in the presence of an asset market can give rise to a linkage of behavior across strategically independent groups.

5 Conclusion

In this paper we explore the relationship between asset markets and underlying economic activity modeled by a coordination game. We find that incentives and beliefs created by the market influence aggregate behavior in strong and potentially negative ways. We show that:

- The presence 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 and for groups not directly influenced by the market.

- Market trading prior to play of the game reduces "wasted effort" in the form of choices above the group's minimum. Thus, even though overall efficiency is reduced by the inferior group outcomes, this is somewhat mitigated by decrease in mismatched effort choices.

- Despite its negative effect on group effort choice, markets are accurate in forecasting the uncertain outcome.

These results are relevant for domains in which underlying economic activity and asset markets are linked. While markets have enticing information aggregation and forecasting possibilities in regard to some economic activity, it is important to recognize that in some settings the markets themselves might influence the eventual realization of the economic outcome and may do so negatively.

Field studies of prediction markets for election outcomes, movie sales, or the weather do not typically suffer from this problem because each trader's 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 the context in our experiment. There are likely to be relatively few traders and those traders are likely to also have some influence on the eventual observation in question. Additionally, many macroeconomic models rely upon some relationship between expectations and productivity, as

in our underlying game. Given markets' role in communicating and influencing these expectations in our experiment, it is possible that real-world markets may play an important role in contributing to shifts into inefficient equilibria.

It is also worth comparing our results to those of Van Huyck & Battalio (1993), who find that a pre-play asset market improves coordination. We believe the key difference between our experiment and theirs to be the symmetry in our asset market that is not present in their study. In their experiment, the market creates jointly-held positive expectations of group outcomes by eliminating those players who do not hold such beliefs. Therefore, the end result is the resolution of strategic uncertainty and mutual reassurance among those selected by the market to play the game (Crawford & Broseta 1998). In our setting however, the market creates *both* positive and negative signals to players, and in addition does not exclude players with beliefs that correspond to the inefficient outcome. Thus, our markets convey strategic uncertainty to players and allow it to "snowball" into negative expectations about the likely final outcome.

The difference between the two experiments also helps make an important point about the general relationship between markets and coupled economic activity. While Van Huyck & Battalio (1993) demonstrate that such a relationship can enhance efficiency, we demonstrate the opposite. Therefore, these can be viewed as contrasting existence results about how markets impact economic outcomes. Real economic contexts in which markets and economic activity are coupled will often resemble one experiment more than the other, and features of both our experiments may be present in many situations outside the laboratory. Our results suggest that considering the precise influence of markets on economic behavior is of significant importance.

References

Berg, J. E. & Rietz, T. A. (2003), Information systems frontier, *in* 'Prediction markets as decision support systems', Vol. 5, pp. 79–93.

Blume, A. & Ortmann, A. (2007), 'The effects of costless pre-play communication: Experimental evidence from games with pareto-ranked equilibria', *Journal of Economic Theory* **132**, 274–290.

Brandts, J. & Cooper, D. (2006), 'Observability and overcoming coordination failure in organizations: An experimental study', *Experimental Economics* **9**(4), 407–423.

Bryant, J. (1983), 'A simple rational expectations keynes-type model', *The Quarterly Journal of Economics* **98**(3), pp. 525–528.

Camerer, C. & Knez, M. (1997), Cambridge series on judgment and decision making, *in* Z. Shapira, ed., 'Organizational Decision Making'.

Cooper, R. (1999), *Coordination Games*, Cambridge University Press.

Cooper, R., DeJong, D., Forsythe, R. & Ross, T. W. (1992), 'Communication in coordination games', *Quarterly Journal of Economics* **107**(2), 739–70.

Crawford, V. (1995), 'Adaptive dynamics in coordination games', *Econometrica* **63**, 103–143.

Crawford, V. & Broseta, B. (1998), 'What price coordination? the efficiency-enhancing effect of auctioning the right to play', *American Economic Review* **88**(1), 198–225.

Forsythe, R., Nelson, F., Neumann, G. R. & Wright, J. (1992), 'Anatomy of an experimental political stock market', *American Economic Review* **82**(5), 1142–1161.

Forsythe, R., Palfrey, T. R. & Plott, C. R. (1982), 'Asset valuation in experimental market', *Econometrica* **50**(3), 537–567.

Goeree, J. K. & Holt, C. A. (2005), 'An experimental study of costly coordination; special issue in honor of richard d. mckelvey', *Games and Economic Behavior* **51**(2), 349–364.

Harsanyi, J. C. & Selten, R. (1988), *A general theory of equilibrium selection in games*, MIT Press.

Hayek, F. A. (1945), 'The use of knowledge in society', *American Economic Review* **35**(4), 519–530.

Hirshleifer, J. (1983), 'From weakest-link to best-shot: The voluntary provision of public goods', *Public Choice* **41**(3), 371–386.

Knez, M. & Camerer, C. (1994), 'Creating expectational assets in the laboratory: Coordination in 'weakest- link' games', *Strategic Management Journal* **15**, pp. 101–119.

Plott, C. & Sunder, S. (1988), 'Rational expectations and the aggregation of diverse information in laboratory security markets', *Econometrica* **56**, 1085–118.

Shavell, S. (1979), 'Risk sharing and incentives in the principal and agent relationship', *Bell Journal of Economics* **10**, 53–73.

Smith, A. (1776), *The Wealth of Nations*, Modern Library, New York.

Spann, M. & Skiera, B. (2003), 'Internet-based virtual stock markets for business forecasting', *Management Science* **49**(10), 1310–1326.

Sunder, S. (1992), 'Markets for information: Experimental evidence', *Econometrica* **60**, 667–95.

Van Huyck, J. B. & Battalio, R. C. (1993), 'Asset markets as an equilibrium selection mechanism: coordination failure, game form auctions, and forward induction', *Games and Economic Behavior* **5**(3), pp. 485–504.

Van Huyck, J. B., Battalio, R. C. & Beil, R. O. (1990), 'Tacit coordination games, strategic uncertainty, and coordination failure', *American Economic Review* **80**(1), pp. 123–248.

Weber, R. A. (2006), 'Managing growth to achieve efficient coordination in large groups', *American Economic Review* **96**(1), 114–126.

Weber, R., Camerer, C., Rottenstreich, Y. & Knez, M. (2001), 'The illusion of leadership: Misattribution of cause in coordination games', *Organization Science* **12**(5), pp. 582–598.

Wolfers, J. & Zitzewitz, E. (2004), 'Prediction markets', *Journal of Economic Perspectives* **18**(2), 107–126.

A Proofs

Proof of Proposition 1: In order for $e_i = m$ for all i to be a Nash equilibrium it must be that

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

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

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

and

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

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

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

∎

B Tables

Table 1: **Group Minimum Effort**

	(1)	(2)	(3)	(4)	(5)
	Group Minimum Effort				
Market	-1.586***		-1.979***		
	[0.384]		[0.527]		
Market H				-2.235***	-2.796***
				[0.470]	[0.601]
Market L				-1.050**	-1.255**
				[0.458]	[0.615]
Large Group		-0.893**	-1.378***		-1.424***
		[0.367]	[0.514]		[0.529]
Market x			0.13		
Large Group			[0.754]		
Market H x					0.174
Large Group					[0.788]
Market L x					-0.208
Large Group					[0.877]
Period	-0.011	-0.013	-0.014	-0.015	-0.019
	[0.022]	[0.019]	[0.026]	[0.024]	[0.029]
Observations	288	288	288	288	288
R^2	0.1679	0.0591	0.2701	0.2113	0.3251

This table presents ordered probit regression results of groups' minimum effort (across periods) on the following independent variables. *Market* treatment (*Control*(*Market*) treatment observations are coded as 0(1)); *Market H* treatment (*Control*(*Market H*) treatment observations are coded as 0(1)); *Market L* treatment (*Control*(*Market L*) treatment observations are coded as 0(1)); group size (*Small*(*Large*) groups observations are coded as 0(1)); interaction between *Market*, *Market H*, *Market L*, and group size; period number. Outsider groups are not included in the analysis. Standard errors (reported in brackets) are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 2: **Distribution of Group Minimum Effort**

| Median Effort | Panel A: Small Groups | | | |
	Control	Market-All	Market H	Market L
4	0.750	0.100	0.000	0.250
3	0.250	0.200	0.167	0.250
2	0.000	0.100	0.000	0.250
1	0.000	0.600	0.833	0.250
Observations	8	10	6	4

| Median Effort | Panel B: Large Groups | | | |
	Control	Market-All	Market H	Market L
4	0.250	0.000	0.000	0.000
3	0.250	0.000	0.000	0.000
2	0.125	0.100	0.000	0.250
1	0.375	0.900	1.000	0.750
Observations	8	10	6	4

The table presents the distribution of groups' minimum effort choices. Each observation represents the median minimum-effort over the last 5 period of the session. Panel A reports results for Small groups and Panel B reports results for Large groups. Outsider groups are not included in the analysis.

Table 3: **Individual Portfolio Holdings and Effort Choices**

Holdings	(1) Effort = 1	(2) Effort =2	(3) Effort = 3	(4) Effort = 4
Security 1	0.014***	-0.005***	-0.004***	-0.004**
	[0.002]	[0.001]	[0.001]	[0.002]
Security 2	-0.003	0.007***	-0.001	-0.004***
	[0.002]	[0.001]	[0.001]	[0.001]
Security 3	0	-0.006***	0.006***	-0.001
	[0.002]	[0.002]	[0.002]	[0.001]
Security 4	-0.001	-0.001	-0.001	0.004**
	[0.002]	[0.001]	[0.001]	[0.002]
Observations	720	720	720	720
R^2	0.0908	0.0977	0.1084	0.0339

This table reports marginal probit regression results of individual effort choice and portfolio holdings of securities 1, 2, 3, and 4. In column (1) the dependent variable is coded as 1 if the subject selected effort level of 1 (and 0 otherwise), in column (2) the dependent variable is coded as 1 if the subject selected effort level of 2 (and 0 otherwise), in column (3) the dependent variable is coded as 1 if the subject selected effort level of 3 (and 0 otherwise), and in column (4) the dependent variable is coded as 1 if the subject selected effort level of 4 (and 0 otherwise). Outsider groups are not included in the analysis. Standard errors (reported in brackets) are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 4: **Portfolio Holdings and Equilibrium Selection**

	Panel A: Small Groups					
	{1}	{1,2}	{1,2,3}	{1,2,3,4}	Overall	Control
Min Effort = 4	0.03	0.00	0.00	0.29	0.13	0.72
Min Effort = 3	0.09	0.11	0.33	0.26	0.16	0.23
Min Effort = 2	0.06	0.11	0.00	0.26	0.14	0.03
Min Effort = 1	0.82	0.78	0.67	0.19	0.58	0.02
Observations	34	9	3	31	80	64

	Panel B: Large Groups					
	{1}	{1,2}	{1,2,3}	{1,2,3,4}	Overall	Control
Min Effort = 4	0.00	0.00	0.00	0.00	0.00	0.23
Min Effort = 3	0.00	0.00	0.00	0.00	0.00	0.30
Min Effort = 2	0.02	0.00	0.00	0.30	0.10	0.14
Min Effort = 1	0.98	1.00	0.00	0.70	0.90	0.33
Observations	46	2	0	23	80	64

This table reports the distribution of groups' minimum effort choices sorted by treatment ("All" denotes all *Market* treatment observations and "Control" denotes *Control* treatment observations) and with the *Market* treatment into sub-groups based on the set of equilibria that are consistent with subjects modified payoffs and their collective portfolio holdings. Panel A reports results for Small groups and Panel B reports results for Large groups. Outsider groups are not included in the analysis.

Table 5: **Security Prices and Effort Choices**

Ave Closing Price	(1)	(2)	(3)	(4)
		Subject's Min Effort		
	Effort = 1	Effort =2	Effort = 3	Effort = 4
Security 1	0.759***	0.123	-0.096	-0.656***
	[0.257]	[0.099]	[0.118]	[0.222]
Security 2	0.003	0.059	0.117	-0.121
	[0.293]	[0.150]	[0.127]	[0.228]
Security 3	0.205	0.014	-0.111	-0.098
	[0.297]	[0.161]	[0.084]	[0.246]
Security 4	-0.565***	0.063	-0.004	0.445**
	[0.204]	[0.129]	[0.122]	[0.214]
Observations	363	363	363	363
R^2	0.2134	0.1388	0.0947	0.2048

This table reports marginal probit regression results of individual effort choice and the average closing price of securities 1, 2, 3, and 4. In column (1) the dependent variable is coded as 1 if the subject selected effort level of 1 (and 0 otherwise), in column (2) the dependent variable is coded as 1 if the subject selected effort level of 2 (and 0 otherwise), in column (3) the dependent variable is coded as 1 if the subject selected effort level of 3 (and 0 otherwise), and in column (4) the dependent variable is coded as 1 if the subject selected effort level of 4 (and 0 otherwise). The estimation also includes subjects' security holdings as independent variables; these coefficients were omitted from the table. Outsider groups are not included in the analysis. Standard errors (reported in brackets) are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 6: **Wasted Effort**

	(1)	(2)	(3)	(4)	(5)
		Groups' Average Wasted Effort			
Market Treatment	0.328*** [0.127]			-0.916*** [0.176]	-0.926*** [0.163]
Large Group		0.220* [0.127]			-0.095 [0.111]
Group Min Effort			-0.265*** [0.046]	-0.612*** [0.183]	-0.636*** [0.189]
Group Min x *Market* Treatment				0.469** [0.211]	0.470** [0.209]
Period	-0.036*** [0.012]	-0.034*** [0.012]	-0.052*** [0.016]	-0.050*** [0.017]	-0.050*** [0.017]
Observations	288	288	288	288	288
R^2	0.1146	0.0629	0.377	0.4764	0.4813

This table presents ordered probit regression results of groups' average wasted effort (across periods) on the following independent variables. Wasted effort is defined as the absolute difference between subject's effort choice and the minimum effort in her group during that period. *Market* treatment (*Control*(*Market*) treatment observations are coded as 0(1)); group size (*Small*(*Large*) groups observations are coded as 0(1)); group minimum effort; interaction between *Market* and group minimum effort; period number. Outsider groups are not included in the analysis. Standard errors (reported in brackets) are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 7: **Group Minimum Effort – Insider and Outsider Groups**

	(1)	(2)	(3)	(4)
		Group Min Effort		
Insider	0.102	-0.211	0.736	0.174
	[0.346]	[0.478]	[0.494]	[0.337]
Large Group		-1.326**		-0.866***
		[0.558]		[0.324]
Insider x		0.908		
Large Group		[0.698]		
Market H			-1.264**	-0.670*
			[0.563]	[0.344]
Insider x			-1.207*	
Market H			[0.707]	
Period	-0.037	-0.042	-0.043	-0.049
	[0.027]	[0.029]	[0.030]	[0.031]
Observations	320	320	320	320
R^2	0.0035	0.0725	0.0645	0.0931

This table presents ordered probit regression results of groups' minimum effort (across periods) on the following independent variables. Insider treatment (Outsider(Insider) treatment observations are coded as 0(1); *Market H* treatment (*Control*(*Market H*) treatment observations are coded as 0(1)); group size (Small(Large) groups observations are coded as 0(1)); period number. *Control* treatment groups are not included in the analysis. Standard errors (reported in brackets) are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.
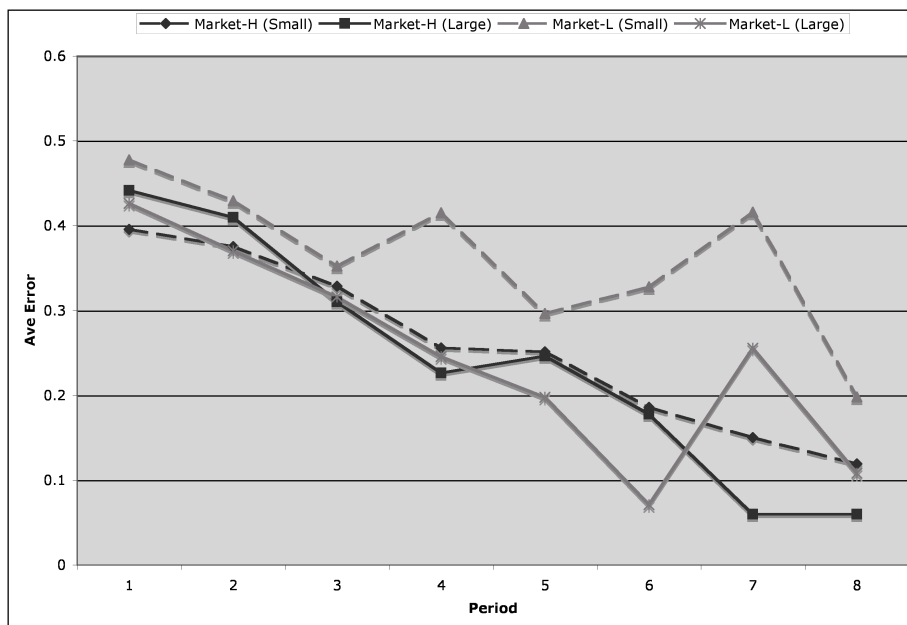
C Figures

Figure 1: **Group Minimum Effort by Period and Treatment**
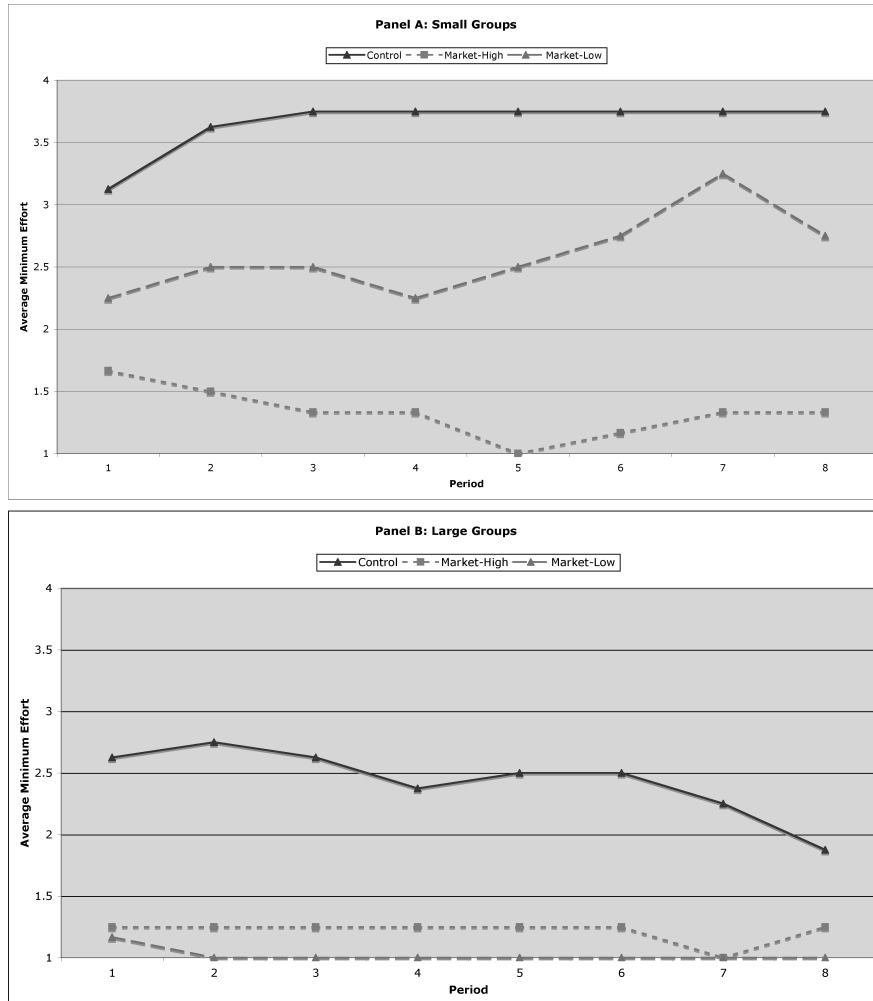
The figure depicts average minimum effort levels (across groups) for Small (Panel A) and Large (Panel B) groups. The solid line corresponds to observation collected in the *Control* treatment, the dotted line corresponds to observations collected in the *Market H* treatment, and the dashed line corresponds to observations collected in the *Market L* treatment.

Figure 2: **Average Absolute Error of Market Prices**

The figure depicts the average price error across periods and treatment cells – market incentives (High and Low) and groups size (Small and Large). For each period and group, price error is computed as the sum of deviation across the four securities between the average of last traded prices and realized security value (which is either 0 or 1). For example, consider the hypothetical case where closing prices for securities 1, 2, 3, and 4 are 0.6, 0.2, 0.1, 0.1 (respectively) and imagine that group minimum effort was 1. The price error, in this example, is 0.9 (= 0.4+0.3+0.1+0.1).

Figure 3: **Mean Wasted Effort**
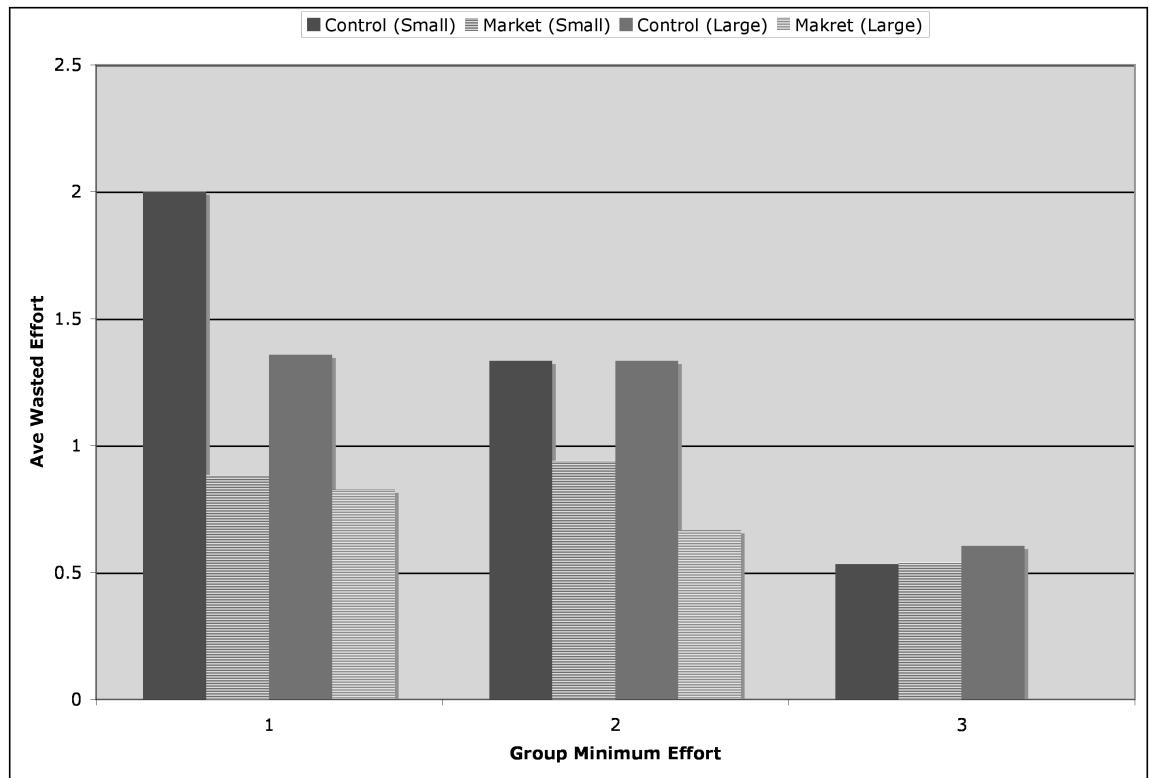
The figure depicts the average wasted effort across treatments (*Control* and *Market*), group sizes (*Small* and *Large*) and groups' minimum effort levels. Wasted effort is defined as the absolute difference between subject's effort choice and the minimum effort in her group during that period. Group minimum effort of 4 is omitted since by definition wasted effort in that case is equal to zero.