Coordination in the Presence of Asset Markets[1]

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Abstract

We explore the relationship between outcomes in a coordination game and a pre-play asset market in which values are determined by outcomes in the subsequent coordination game. Across two experiments, we vary the payoffs from the market relative to the game, the degree of interdependence in the game, and whether traders' asset payoffs are dependent on outcomes in their own or another game. Markets lead to significantly lower efficiency across treatments, even when they produce no distortion of incentives in the game. Market prices forecast game outcomes. Our experiments shed light on how financial markets may influence affiliated economic outcomes.

Keywords: Equilibrium Selection; Asset Prices; Coordination Games; Experimental Economics.

Coordination in the Presence of Asset Markets

1 Introduction

Markets aggregate widely dispersed information and direct resources to where they produce the greatest value (Hayek 1945, Smith 1776). These dual roles of informational and allocative efficiency help explain why asset markets are often used to guide economic activity such as production and investment.

Many economic contexts involving production and investment are characterized by multiple equilibria (Bryant 1983, Hirshleifer 1983, Cooper 1999, Camerer and Knez 1997, Brandts and Cooper 2006). When asset markets are linked to such contexts, it is important to understand what role they play in aiding coordination and selecting equilibria. If asset markets obtain both informational and allocative efficiency in a multiple-equilibrium context, then they should coordinate the beliefs of economic agents and guide behavior to an efficient equilibrium. Indeed, some evidence suggests that one-sided auction markets may facilitate efficient coordination in an environment with multiple equilibria (Van Huyck, Battalio and Beil 1993, Crawford and Broseta 1998). However, the broader question of whether *all* types of asset markets lead to efficient coordination in environments with multiple equilibria, or under which conditions they do so, remains an open question.

In this paper, we explore the influence of two-sided futures asset markets, similar to markets used in several economic and financial settings, on behavior and outcomes in an economic activity characterized by multiplicity of equilibria. We focus on situations where the outcome of the economic activity is sensitive to the behavior of small numbers of agents. We use laboratory experiments, in which we 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, or input, and group output, which is some order statistic (such as the minimum) of all players' input choices (see Van Huyck, Battalio and Beil (1990), Van Huyck, Battalio and Beil (1991), Crawford (1995)). In these games, players choose among several ordered input actions, with the set of pure-strategy equilibria consisting of outcomes in which all players select the same input. Players all do better if they coordinate on the highest-output (efficient) equilibrium, which is Pareto-optimal, but they also prefer to select a lower input if they believe others will do so.

Coordination games of this kind 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 and Knez 1997, Brandts and Cooper 2006). Financial markets are often linked to these kinds of economic activity. Therefore, we study the relationship between economic performance, measured by outcomes in the coordination game, and a corresponding asset market in which the traded assets' values are contingent on the game outcome. More precisely, in each period of our experiment participants play the coordination game and receive payoffs from the outcome in the game. Prior to playing the game, participants trade in a market with Arrow-Debreu securities, each corresponding to one of the possible outcomes (output levels) in the game.[2] Our primary purpose is to explore the extent to which markets influence outcomes in the underlying economic activity – that is, do markets guide behavior towards more or less efficient equilibria?

There are many ways in which pre-play institutions, such as asset markets, may influence equilibrium selection and coordination in the subsequent game. Previous experiments using similar games demonstrate that pre-play communication among players helps reassure them of their mutual intent to pursue the efficient equilibrium and is thus effective for obtaining

[2]Some markets trade explicit Arrow-Debreu securities, such as prediction markets designed to forecast future outcomes (Forsythe, Nelson, Neumann and Wright 1992) and Chicago Board of Trade binary options for macroeconomic variables (see http://www.clevelandfed.org/Research/data/Fedfunds/index.cfm). Even more markets provide implicit Arrow-Debreu structured securities through the use of derivatives such as S&P 500 index options (Ait-Sahalia and Lo 1998).

coordination on higher (more efficient) output (Blume and Ortmann 2007, Cooper, DeJong, Forsythe and Ross 1992, Devetag and Ortmann 2007). This includes communication that takes place through markets. Van Huyck et al. (1993) show how auctioning off the right to play a subsequent coordination game serves as a way for players to communicate their beliefs about what will happen in the game and, implicitly, their intended strategies (see Crawford and Broseta (1998)). The result is that the one-sided auction markets used by Van Huyck et al. (1993) lead to coordination on the efficient high-output equilibrium of the game. Thus, other kinds of pre-play markets might, more generally, be mechanisms that allows players to obtain mutual reassurance and coordination on efficient equilibria.

However, the kind of implicit communication allowed by two-sided asset markets and the incentives created by such markets may not make efficient coordination in their presence so straightforward. For starters, asset markets of the kind we use here are much more complex and potentially noisy than the more simple kinds of explicit and implicit communication used in the experiments above. There exist separate markets for each equilibrium output level, and players' communication through the asset market may be difficult to interpret. For example, a player indicating a desire to buy assets corresponding to an inefficient equilibrium even at a very low price may create some doubt that the efficient equilibrium will result. Therefore, in contrast with previous results in which communication (including communication through markets) facilitates efficient coordination, pre-play asset markets may also result in an opposite kind of *market communication effect*, one that leads players' beliefs to converge on the inefficient equilibrium.

In coordination games with high degrees of interdependence, as when output is determined by the lowest input choice by any single player, the incentives produced by pre-play asset markets may result in coordination on lower-output (less efficient) equilibria. Through what we term *portfolio incentive effects*, the asset market can create incentives for players to invest in low output assets and then unilaterally decrease the group's output in the coordination game (assuming it is not already at the lowest possible value). A market with sufficiently high payoffs coupled with a coordination game with high input complementarity creates an incentive to engage in such opportunism, thereby harming output in the underlying economic activity.

Our first experiment explores these portfolio incentive effects by using a "weak-link" coordination in game in which group output is determined by the *lowest* input by any player. In such a game, markets should lead to lower input choices, and the resulting inefficient equilibrium. Indeed, we find that, relative to a *Control* condition with no market, the presence of a pre-play asset market significantly reduces output. However, we also find that the distorted incentives produced by the market's presence cannot entirely explain the negative effect of the market on the game – the market lowers players' input choices even when there is no distortion of incentives. This suggests that, aside from any effect the market may have on incentives, it may also negatively affect output through an influence on beliefs.

Therefore, in a second experiment we explore the extent to which asset markets influence outcomes in a coordination game with weaker interdependence among players, and where the portfolio incentive effects are minimal. We use the case where output is determined by the second-lowest input choice in a group, so that the market creates no incentive for any player to unilaterally lower her input choice. In fact, in this "second-order-statistic" coordination game, all of the pure-strategy Nash equilibria to the game are preserved in the presence of a pre-play asset market, regardless of what happens during market trading. But the market may nevertheless yield lower input choices if it pessimistically affects players' beliefs, through a *market communication effect*. Our second experiment confirms this influence of markets – using a second order-statistic game we again find that the presence of an asset market universally lowers input choices and the resulting output levels.

Thus, across both our experiments we find a negative effect of asset markets on output (efficiency) that cannot be explained entirely by a portfolio incentive effect, whereby the market distorts incentives in the game. Indeed, we even find that asset markets decrease output for groups whose game payoffs are *completely independent* of the market (*Outsiders*, who trade in an asset market linked to another group's output). Rather, the overall pattern of effects we find is more consistent with a market communication effect, whereby prices and trading behavior influence beliefs in a way that makes low-output equilibria more frequent. In support of this, we find that prices predict output levels in both experiments, even when controlling for historical output. Therefore, in spite of the prior evidence suggesting that pre-play communication mechanisms, including markets, facilitate efficient coordination, we find that such pre-play institutions may also have detrimental effects, and that such effects are not driven exclusively by distorted incentives. Put differently, in contrast with previous evidence of the beneficial effects of communication in coordination games, we find that communication through a two-sided futures asset market can be harmful.

In the next section, we present a model of a two-stage game involving a pre-play asset market and a linked coordination game, which also serves as the basic framework for our experiments. We leave the formal analysis of the game for the Online Appendix, but refer to the main results in the text. Sections 3 and 4 present our two experiments.

2 Model

Players participate in a two-stage game consisting of an asset market followed by an order-statistic coordination game. The values of the securities traded in the asset market depend upon the realization of the output (order-statistic) in the coordination game.

In the second stage coordination game, each player simultaneously selects an input level $e_i \in \{1, \ldots, M\}$. Each player's payoff depends upon her own input level and the group's output, $m_j(e)$, which is determined by the input choices of all players:

$$\pi_i(e) = a + bm_j(e) - c\,|m_j(e) - e_i| \tag{1}$$

where $m_j(e)$ is the jth order statistic of the n chosen input levels, meaning that if input levels are ordered from low to high or $e_{(1)} \leq e_{(2)} \leq \cdots e_{(n)}$ then $m_j(e) = e_{(j)}$. Assuming

$b, c > 0$, the pure-strategy Nash equilibria are completely characterized by any selection of identical inputs for all players. The Nash equilibrium with $e_i = M$ for all i is the *high output* or *efficient* equilibrium and Pareto dominates any lower output equilibrium where $e_i = m$ with $m < M$ for all i.

When $j = 1$ the coordination game is a version of the well-known "weak-link" or "minimum effort" coordination game first analyzed theoretically by Bryant (1983) and Hirshleifer (1983). Van Huyck et al. (1990) conducted the first experimental study of the game and found two regularities replicated by subsequent studies (Knez and Camerer 1994, Weber, Camerer, Rottenstreich and Knez 2001). First, groups often fail to coordinate on the Pareto-dominant equilibrium. Second, group size exerts a strong influence on equilibrium selection. Small groups of two to three players converge to much higher output levels than larger groups of six or more players.

Other order statistic games where $j > 1$ have also been studied (Van Huyck et al. 1991, Van Huyck, Battalio and Rankin 2007). Generally, higher order statistics facilitate coordination on equilibria corresponding to higher input choices. However, even when $j > 1$ efficient coordination is not trivial. Groups often end up at equilibrium output levels well below M, the result of a strong path dependence whereby initial output outcomes determine subsequent input choices. See Camerer (2003), Chapter 7, for a review of experiments on order-statistic coordination games.

Prior to the coordination game all players participate in an asset market. In the market, the value of a traded security is based upon the output, $m_j(e)$, in the subsequent coordination game. More precisely, there are M state-contingent securities traded with the following payoffs:

$$X_m = \begin{cases} \beta & \text{if } m_j(e) = m \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where $\beta > 0$.

At the conclusion of trading in the asset market, all players possess a particular *portfolio*

$x_i = (x_{1i}, x_{2i}, \ldots, x_{Mi})$ of securities where x_{mi} is player i's units of asset X_m. Since these assets pay off based upon the outcome of the game, the original game payoffs from (1) are modified to be:

$$\overline{\pi}_i(e; x_i) = a + bm_j(e) - c\,|m_j(e) - e_i| + \beta \sum_{m=1}^{M} \delta_m(e) x_{mi} \tag{3}$$

where $\delta_m = 1$ if $m_j(e) = m$ and 0 otherwise. We call this game the *market-modified coordination game*.

We assume that the aggregate endowment for each asset is the same, or $\sum_{i=1}^{n} x_{mi} = k$ for all m. Under this assumption, the market is a constant-sum game, and therefore the efficiency properties of higher matched inputs in the market-modified coordination game are the same as in the original coordination game. However, different *ex post* portfolios can affect individual players' incentives to select particular input levels.

In the Online Appendix, we present a theoretical analysis of how the incentives produced by the market may affect behavior in the modified coordination game. Our two main results (Propositions 1 and 2) show that when output in the coordination game is determined by the lowest input choice ($j = 1$) the asset market distorts players' incentives to the point where equilibria involving input choices greater than 1 can be ruled out, but that for higher order-statistics ($j > 1$) the set of equilibria are unchanged. We discuss these predictions and the intuition behind them in more detail when discussing our experiments in the next two sections.

3 Experiment 1 – Minimum-input coordination ($j = 1$)

Our first experiment explores the special case where $j = 1$ and the output of the coordination game is determined by the lowest input. As we note previously, such a high degree of interdependence means that players may have an incentive to unilaterally decrease output.

One reason this can occur is that a players' portfolio holdings, x_i, at the end of the trading period may modify her incentives in the game. More precisely, following the determination of player portfolios in market trading, an input level m for all players will remain a pure strategy equilibrium of the game only if for all players i and for all lower output levels $\ell < m$,[3]

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

When a player has enough of an asset that pays off under lower output (relative to higher output assets), she has a weakly dominant strategy to play the corresponding lower input, making the higher output equilibrium impossible to support. Thus, the lowest input choice, $e_i = 1$, by all players is the only Nash equilibrium that exists for *every* possible asset portfolio. For higher output outcomes, the relative payoff of the asset market (β) to the coordination game (b) determines the asset portfolios that support equilibria of the market-modified game. This result suggests that the market may lead to lower output in the game, and that the extent to which it does so will be greater when the payoff from the market assets (β) is large relative to the payoffs from the game (b).

In order to examine this potential portfolio incentive effect in our experiment, we systematically varied the payoffs from the market relative to those from the game. In the *Market H* variant we set $b/\beta = 2$ and in the *Market L* variant, we set $b/\beta = 40$. 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 input level $e_i = 4$. In the *Market H* treatment, the individual would have to hold greater than 2, 4, or 6, more units of the X_3, X_2, or X_1 assets respectively (than units of the X_4 asset). Whereas, in the *Market L* treatment, the required minimum differences are 40, 80, and 120. Therefore, the condition in (4) predicts a likely much stronger negative effect of the market in the *Market H* treatment than in *Market L*.

Of course, the above prediction ignores the strategic nature of trading behavior, whereby

[3] See Proposition 1 in the Online Appendix for a proof.

participants in the market know what strategy they are likely to play in the game and the market serves to aggregate this information. Moreover, players most likely jointly determine their trading strategies and game actions in the two stages of the market and game. To analyze this aspect of behavior in the two-stage game, we adopt a rational expectations framework in which the market fully aggregates players' beliefs and behavior in the game is consistent with such beliefs. The only rational expectations equilibrium when $j = 1$ is the inefficient one in which all players select the lowest input choice ($e_i = 1$).[4] Any player can unilaterally assure that the final output is 1 by selecting $e_i = 1$. This means that the only prices that are consistent with an equilibrium in *both* stages of the game must price the low output asset X_1 at β, meaning that low output will occur with probability 1. If the price of the low output asset is lower than β then any player can profit by buying units of the low output asset, and once that player has a sufficient number of these low output assets the player has a weakly dominant strategy to select the low input level $e_i = 1$.

In contrast with prior evidence of the beneficial effects of institutions that allow pre-play communication, including markets, our theoretical analysis predicts that pre-play asset markets will have a negative effect on output levels in the game. Markets can decrease output by providing players with either realized or potential portfolio positions that rule out all but the lowest-output equilibrium.

Our experiment tests the above predictions about the effects of an asset market, relative to a *Control* treatment in which there is no market. We vary several features of the game and the market to better understand the precise relationship between the two. As we mention above, we vary the incentives of the market relative to the game (*Market L* vs. *Market H*). We also vary the group size in which the game is played. Finally, to explore whether the market affects behavior and outcomes in the game even when the two are strategically independent, we include an *Outsiders* treatment in which players trade in a market that is unrelated to their coordination game. This final treatment allows us to determine the extent

[4] See Proposition 2 in the Online Appendix for a formal statement and proof.

to which the market can influence behavior and outcomes in the coordination game, absent any portfolio incentive effect.

3.1 Experimental Design

Each experimental session consisted of eight periods, all identical in structure. In each period, every subject submitted a number, corresponding to her input choice in the coordination game. The input choice took one of four values: $e_i = \{1, 2, 3, 4\}$. The payoff function was the same as in (1) with output determined by the minimum input choice ($j = 1$). The parameters used were $a = \$1.20$, $b = \$.20$, and $c = \$.20$. Thus, the payoff for the efficient equilibrium in the coordination game was \$2.00. These parameters give rise to the payoff table displayed in Table 1, which is identical to the one presented to all subjects.[5]

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 both Small three-person groups and Large six-person groups. A typical session divided 18 subjects into four groups as follows: groups A and C were Small groups, and group B and D were Large groups. All subjects knew their group assignment and the size of their group, as well as well as the structure of the other three groups. Throughout the session, no communication between subjects was permitted and all instructions, choices, and information were transmitted via the computer terminal, utilizing the z-tree program (Fischbacher 2007).[6]

In the *Control* treatment subjects simply played the coordination game for eight periods. In the *Market* conditions, prior to playing the game in a period subjects first traded in an asset market in which securities' liquidating values depended upon the output in the coordination game.[7] Trading took place over an electronic double-auction market. The

[5]The parameterization of the minimum-input game differs from that in Van Huyck et al. (1990) and other coordination game experiments in that there are fewer input level choices available. This was necessary in order to keep the number of traded securities reasonable.

[6]Screen shots of the instructions and market trading platform are provided in the Online appendix.

[7]In two of the 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 for the final two periods.

trading stage lasted approximately six 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. In addition to being able to see the five highest (lowest) current limit orders to sell (buy) for any security, subjects could view the entire trading price history for every security. All activities in the market were anonymous. In order to ensure that subjects understood the market operation, they completed a short quiz and were given the opportunity to ask questions in a practice trading round that was not linked to any game outcome.

Prior to trading, groups were assigned to markets such that the number of traders per market was fixed at nine. We kept the number of market traders constant across the Small and Large group treatments in order to control for the possibility that market size might affect the performance of the market, and to allow a comparison between *Insider* and *Outsider* traders, which we discuss below. This was achieved by conducting two parallel and separate sets of markets, each populated by one Small group and one Large group. In one set of markets the value of the securities was determined by the output of a Small group, and in the second the value of the securities was determined by the output of a Large group. For example, in most sessions Market 1 included members from groups A and B trading securities linked to the output of group A, and Market 2 included members from groups C and D trading securities linked to the output of group D.

At the beginning of each trading stage, subjects were endowed with units of the different assets 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.[8] The choice of asymmetric endowments (across subjects) is common in these types of asset markets and was designed to stimulate trading by providing participants with rebalancing motives. Also, the aggregate endowment did not constrain

[8]In each period two subjects in each market had an endowment of 24 units of a particular asset and none of the other three assets; one subject in each market had an endowment of six units of each of the four assets.

further trading; subjects could sell each asset short.[9]

The *Market H* and *Market L* treatments varied the value of the asset market relative to the game in order to examine the influence of the portfolio incentive effect we describe above. In the *Market H* treatment, we set $b/\beta = 2$ by setting the binary payoff of each asset at $\beta = \$.10$ whereas in the *Market L* treatment we set $b/\beta = 40$ by setting $\beta = \$.005$.[10]

Each market contained two types of traders. *Insiders* were subjects who traded on outcomes that they could directly influence, meaning that their own game determined asset values. *Outsiders* traded on an exogenous outcome, meaning that asset values were determined by the outcome of the other group's game. In a typical session, Groups A and D were Insiders and groups B and C were Outsiders. Our analysis of portfolio incentive effects (see the Online Appendix) only applies to Insiders, whose input choices affect the liquidation value of their asset holdings. For Outsiders, the value of their asset holdings is completely independent of output in their own coordination game. Thus, the set of Nash equilibria for Outsiders is unaffected by the presence of an asset market and, in terms of payoffs and portfolio incentives, Outsiders' coordination game is the same as in the Control treatment. However, Outsiders might still be affected by potential market communication effects; they observe market prices and may assume that those prices also provide information about the intended play in their group (or perhaps believe that others in their group assume so).

At the end of the market trading stage, subjects participated in the coordination game. Then, subjects' positions in the securities were liquidated according to the appropriate group's output. Subjects observed the anonymous distribution of input choices in their own group. Subjects also observed the input choices made by subjects in the other group (of the other size) participating in their market. The feedback from the game provided to

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

[10] The parameter amounts for the game and market were expressed to subjects in 'experimental dollars' and the appropriate exchange rate 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. The values in the coordination game were also varied accordingly so as to keep the same dollar payoff from the coordination game for all treatments.

subjects in all variants of the experiment was the same; in the *Control* treatment, subjects were also informed of the choices in their group as well as those in a group of the other size.

The experiment consisted of 17 sessions conducted at the Laboratory for Economic Management and Auctions (LEMA) at the The Pennsylvania State University, between October 2006 and October 2007. We obtained data for 16 groups in the *Control*, 24 in *Market H*, and 16 in *Market L*. In every condition, half (8, 12, and 8 respectively) of the groups were Large and the other half were Small. In the two *Market* conditions, half of the groups were Insiders and the other half were Outsiders. Thus, in the *Market H* (*Market L*) treatment we have data for 6 (4) groups in each of the four conditions (Large/Small-Insider/Outsider). 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 payment averaging $13.18 (*Control*), $15.17 (*Market H*), and $11.40 (*Market L*). In the *Market* treatments, the payments from the markets contributed on average $4.85 (*Market H*) and $.25 (*Market L*) to this total. *Market* sessions lasted around 2 hours.

3.2 Results

3.2.1 Insider Group Output

We first explore the effects of our market treatments on output for *Control* vs. *Insider* groups. As reported in Table 2, across all 8 periods, mean output differed considerably by treatment. Small Control groups obtained coordination on mean output levels very close to the efficient level, while Large groups coordinated on output of around 2.4.[11] As we

[11] This is higher than is typically the case for large groups, which usually converge to the least efficient equilibrium. However, our experiment differs from most previous experiments in important ways: it uses fewer input choices (e.g., 4 vs. 7 in Van Huyck et al. (1990)), provides subjects with the full history of choices by other players, and also shows players in each Large group the performance of a Small group (Bornstein, Gneezy and Nagel 2002). While these factors may influence behavior in our experiment, relative to other experiments using similar coordination games, they are constant across all our treatments. Also, consistent with previous research, output generally fell (though slightly) across periods in the Control-Large treatment – e.g., by period 8 mean output was 1.9.

predicted, for Insider groups mean output was lower in both *Market* treatments, relative to the *Control*, and this effect was stronger when market incentives were high.

Table 3 tests the relationship between group output, *Market* treatments, and group size.[12] We use ordered probit regressions, which take into account the ordinal nature of output, and estimate a model that includes group random effects. We find that output is lower for Large groups, across both treatments (columns 2 and 3), consistent with prior literature (e.g., Van Huyck et al. (1990)).

The *Market* treatments produce output that is substantially lower across both group sizes compared with the *Control* treatment (columns 1, 2 and 3). Interacting the *Market* treatment with group size (columns 2 and 3) suggests that the effect of markets is somewhat more pronounced for Small groups. We also find that group output in the *Market L* treatment is higher than in the *Market H* treatment (column 3), but still significantly below output in the *Control* treatment.[13]

These findings suggest that, consistent with our predictions, the presence of an asset market in conjunction with a minimum-input coordination game significantly lowers output levels for all group sizes and periods. These results stand in contrast to the findings of Blume and Ortmann (2007), Cooper et al. (1992) and Van Huyck et al. (1993), which show that other forms of pre-play communication, including other kinds of pre-play markets, produce coordination on higher output levels. To better understand what drives these results we turn to study two asset market dimensions that can influence behavior: portfolio incentives and security prices.

3.2.2 Portfolio Incentives

For Insiders, players' asset positions when $j = 1$ may negatively influence output through a distortion of individual incentives. Players who hold enough low-output assets may prefer

[12] Throughout this section, unless noted otherwise, we analyze data obtained from Insider groups only.

[13] We find that markets have similar negative and significant effects when we look at Period 1 results only and when we treat each group as a single observation consisting of that group's median output level over the last five periods of the experiment.

to make low input choices, regardless of their beliefs about others' behavior. This suggests a positive relationship between the amount of an asset an individual Insider holds, and the likelihood that individual will select the corresponding input. Moreover, we expect these portfolio incentives to be stronger when market incentives are high than when they are low.

Table 4 shows the results obtained from probit regressions of individuals' input choices on their end-of-period portfolio holdings of securities 1, 2, 3, and 4, when taking into account market level random effects. We find that subjects who choose an input level m hold more m security units and less non-m security units. For example, column 1 in the table indicates that subjects are more likely to choose an input level of 1 with every additional unit of asset X_1 held. In this case, increased holdings of assets X_2, X_3, and X_4 have a negative, although not statistically significant, effect. Similar patterns emerge if we look at the other input levels; all diagonal elements are positive and statistically significant, while all off-diagonal elements in these columns are negative. Further, these results hold for both the *Market H* and the *Market L* treatments, with the magnitude of the relation between portfolio holdings and input choices being very similar across the two treatments.[14]

Given that individuals' choices are related to their portfolio holdings, we test the implications of the portfolio incentive effect more directly by computing the set of Nash equilibria that persist in the coordination game after trading in the market. For each group and period we find the set of pure-strategy equilibria that are incentive compatible with subjects' *ex post* security holdings and the modified payoffs of the game. Table 5 presents the observed distributions of group output for different realized sets of equilibria remaining in the game modified by *ex post* asset holdings. For example, column 2, labeled "{1,2}" reports the frequency of different output levels observed when only matched input levels of 1 or 2 remain Nash equilibria of the market-modified coordination game following trading (i.e., satisfy the condition in (4)). Panel A reports the results for Small groups while Panel B reports the results for Large groups. For comparison, we include the corresponding distribution of out-

[14]This relationship also generally rules out "hedging" by players who adopt different asset positions than their intended play in the coordination game in order to lower payoff variability.

put choices observed in the *Control* treatment in the last column. Recall that in the *Control* treatment, where game payoffs are not modified by the market, the set of equilibria is always $\{1, 2, 3, 4\}$.

Final portfolio holdings' influence on the set of pure-strategy equilibria also influences behavior; observed behavior rarely falls outside the set of equilibria that are consistent with subjects' holdings (see the first three columns). Thus, portfolio incentive effects can account for some of the decline in output in the presence of asset markets. But we also observe that the presence of markets lowers output in a way that cannot be fully explained by the distortion of incentives ruling out higher-input equilibria. We contrast the distribution of group output when portfolio incentives *do not* eliminate any of the equilibria (column labeled "{1,2,3,4}") with the distribution of group output in the *Control* treatment. Holding the set of equilibria constant, we find that for both Small and Large groups, output levels are substantially lower in the *Market* treatments than in the *Control* treatment. For example, 70% of the Large groups in the *Market* treatments, for which portfolio holdings did not eliminate any of the equilibria, selected output of 1 compared with 33% in the *Control* treatment. If we use ordered probit random-effects regressions (such as the one used in Table 3), using only cases for the *Market* treatments in which all four pure-strategy equilibria remain as equilibria to the market-modified game (i.e., the observations in column "{1,2,3,4}"), we again find a negative and statistically significant effect for the market treatments. Thus, while portfolio incentive effects appear to be at least partly responsible for the decrease in output in the presence of markets, they cannot alone account for the full set of findings. The presence of asset markets leads to significantly lower output, even when the set of equilibria in the market-modified coordination game are unaffected.

3.2.3 Outsiders' Behavior

Recall that the *Market* treatments contained both Insiders and Outsiders. The two groups differ in that Outsiders' incentives in the coordination game are unaffected by the presence of markets. If portfolio incentive effects are the only channel through which markets affect behavior, Outsiders' output levels should resemble those in the *Control* treatment. However, Outsiders' beliefs may be affected by prices and trading in the market that is unrelated to their game, allowing a possible market communication effect to influence their game's output similarly to the effect the market has on Insider groups.

Returning to Table 2, we see that Outsider groups' output is considerably lower than in the *Control*. In fact, they select output levels very close to those observed for Insider groups. Columns 4 through 6 in Table 3 compare output for *Control* and Outsider groups, using ordered probit regressions with random effects. The results confirm that Outsiders' output is significantly lower than that of *Control* groups.

These results are anomalous if one holds the view that the presence of markets affects behavior entirely through portfolio incentive effects. Outsiders' incentives in the coordination game are unchanged by the presence of the asset market, so any explanation for lower output among Insiders that is based only on modified incentives cannot explain why Outsider groups' output changes in a very similar manner.

3.2.4 Price Informativeness

Since portfolio incentive effects alone do not fully account for the detrimental effect of markets on output, we turn to study the role of market prices. Market trading behavior, including prices, could serve as a form of communication, coordinating players' beliefs regarding expected output. Such a market communication effect, which could influence both Insider and Outsider groups, would rely on prices providing information about the subsequent output level. We find that prices affect individual input choices. Indeed, the correlation between the fraction of subjects who choose a given input level m and the average closing price of security m, for all securities, is 0.45, and is statistically different from zero at the 1% level.[15]

[15]While our focus here is on aggregate behavior and outcomes and not on individual behavior, we also examined different bidding strategies used by individual subjects. We created a measure of "optimism signaling", indicating whether in a given period a subject submitted an order to buy asset 4 for a price greater than 0.50. We found such behavior in both Large and Small groups, with some subjects persistently

We also examine the informativeness of market prices about the subsequent group output. We create a measure of price-based expected output by multiplying the standardized prices by the corresponding output associated with that asset.[16] Table 6 shows, using ordered probit regressions of group output on price-based expected output, and a number of treatment and control variables, a positive relationship between market-predicted output and the subsequent actual group output. We account for the possibility that this positive relationship is driven by prices merely adjusting to past outcomes, rather than influencing subsequent outcomes, by including the groups' prior period output in the regressions as a control. While there is a strong (positive) relation between a group's output in period $t-1$ and period t, period t prices additionally predict group output.[17] Thus, prices seem to play a critical role in how the market influences the coordination game, beyond simply reflecting information in past outcomes.[18]

4 Experiment 2: Weaker complementarities in production ($j = 2$)

Our first experiment demonstrates a negative effect of asset markets on efficiency in a linked minimum-input coordination game. Our predictions, based on the property that in such games any player can unilaterally lower output, posit that the market's effects should be based largely on the modified incentives produced either by realized or potential portfolio positions. However, the market's effect in our first experiment appears to go further –

offering to buy asset 4 across rounds. But we also found that in both Large and Small groups the number of subjects trying to signal optimism decreased in the second half of the session.

[16]For example, if the prices of assets 1 and 2 are 0.5 each, the price-based expected output would be equal to 1.5. We use the average price over the last five trades (in each period) as our measure of *market price* for that period. When less than five trades are completed, we average all the trades conducted in that market and period. As is common in the literature, see (Berg and Rietz 2003), we standardize prices such that they add up to one in each market.

[17]Consistent with the idea that subjects use prices to coordinate their behavior, we find that non-equilibrium behavior in the form of input levels that exceed the minimum in the group are lower in the *Market* treatment compared with the *Control* treatment. Thus, markets help reduce "wasted input."

[18]The results are qualitatively similar, though statistically weaker, for Outsider groups.

reducing output even when market incentives are low and when incentives in the game are entirely unchanged, as they are for Outsiders. This finding suggests that, in addition to any portfolio incentive effects produced by markets, there is a market communication effect whereby the market also influences output by negatively affecting players' beliefs.

Our second experiment more directly tests for such a market communication effect by exploring an environment in which the incentive effects produced by the market are very weak. We use a "second-order statistic" coordination game ($j = 2$), in which output is determined by the second-lowest input choice. The portfolio incentive effect when $j = 2$ should be non-existent. For *any* combination of portfolio holdings, all of the matched input outcomes remain equilibria since no single player can unilaterally determine the output level (see Proposition 1 in the Online Appendix). For similar reasons, all equilibria from the game with no market are preserved as fully revealing rational expectations equilibria with the pre-play asset market when $j = 2$ (see Proposition 2). Therefore, any change in output in this case is unlikely to result from portfolio incentives, and is more likely the product of a market communication effect.

4.1 Experimental Design

Sessions for this experiment were identical to those for Experiment 1, except that group output in the coordination game in each period was determined by the second lowest input in the group ($j = 2$, see Table 7). We used the market payoffs from the *Market L* treatment from Experiment 1, and only changed the instructions to reflect that the second-lowest choice would determine payoffs in the coordination game. These sessions were also held at the Laboratory for Economic Management and Auctions (LEMA) at the The Pennsylvania State University, during April 2009. We obtained data for 12 groups in the *Control* treatment and 16 in the *Market L* treatment.

4.2 Results

While the effects are not as strong as in Experiment 1, the presence of asset markets again induces lower output in all treatments – i.e., for both Large and Small groups and for Insider and Outsider groups (Table 8). Table 9 reports ordered probit regressions with group random effects, similar to those for Experiment 1. The results show that output in the *Market* treatment is significantly lower than in the *Control* treatment in all models, and for both Insider and Outsider groups.

We also look at the relationship between prices and outcomes, where a market communication effect would predict a positive relationship between the output level predicted by the market and actual output. As for Experiment 1, we again construct a measure of price-based expected output (see details in Section 3.2.4). Table 10 shows that price-based expected output is strongly related to group output controlling for group size, period number, and previous period output. Notably, the coefficient on expected output is larger than for previous period output. As in Experiment 1, the market forecasts future output, indicating a strong role for market prices in coordinating players' beliefs.

5 Conclusion

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, measured by output in the coordination game, in a significantly negative manner.

In Experiment 1, we find that pre-play asset markets significantly decrease output in an economic environment where the high level of input-interdependence created portfolio-based incentives likely to lead to lower input choices. But in Experiment 2 no player could unilaterally decrease output, and therefore the portfolio incentive effects that potentially exert great influence in Experiment 1 were significantly weaker. We nevertheless find that the market significantly diminishes output in the subsequent coordination game. Thus, across all treatments in both experiments, the presence of an asset markets decreases output, regardless of group size, the degree of interdependence in the game, and the relative incentives in the market and game. Perhaps most surprisingly, this is even true for Outsiders, whose game is strategically independent of the asset market.

These results suggest that, in addition to any incentive distortion effects produced by the market, a great deal of influence is exerted by a market communication effect, whereby prices and trading behavior influence players' beliefs about what will happen in the subsequent coordination game. This is consistent with the fact that in both experiments prices forecast output, and this predictive power goes beyond simply extrapolating from past output levels. Thus, market trading appears informative about likely future output levels, and this kind of implicit communication is self-reinforcing due to the incentive to match others' behavior in the coordination game. In prior research, such communication has generally facilitated coordination on the efficient equilibrium, but here we find quite strong negative effects.

In the Online Appendix, we demonstrate how the presence of a market may exacerbate players' uncertainty and lead to lower output, by examining a particular model of persistent (but small) strategic uncertainty (Proposition 3). We show that if any player has a small amount of "doubt" regarding the actions of the players then even for order statistics higher than the minimum, such as the second order statistic ($j = 2$), any rational expectation equilibrium entailing higher input is unstable. However, this theoretical analysis makes no prediction regarding the direction of influence of a market when $n = 3$ and $j = 2$, where we still find a negative effect of the market on output. Therefore, this theoretical account of our experimental findings is only partial – it explains why the introduction of an asset market may lead to lower output in most of our experimental conditions, but not in all of them. Further work should attempt to more precisely identify *why* the asset markets have a negative influence.

Our 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 kinds of economic activity, in some settings the markets themselves might influence the eventual realization of the economic outcome and, worse yet, may do so negatively. For example, many firms have implemented prediction markets to forecast outcomes such as sales and product quality (Cowgill, Wolfers and Zitzewitz 2008, Wolfers and Zitzewitz 2004). Given that in such settings market traders may have the ability to influence outcomes, our results suggest that the presence of production-linked asset markets may negatively influence outcomes both by creating incentive problems and by pessimistically influencing beliefs. Additionally, many macroeconomic models rely upon some relationship between expectations and productivity, as in our underlying game (Bryant 1983, Cooper and John 1988). Given markets' role in communicating and influencing expectations in our experiment, real-world markets may sometimes similarly play an important role in contributing to shifts into inefficient equilibria. Thus, for example, economic crises may be exacerbated by economic agents focusing their attention on market behavior, which may create self-reinforcing pessimistic beliefs.

It is also worth comparing our results to those of Van Huyck et al. (1993), who find that a pre-play market leads to coordination on higher (more efficient) equilibria. In our experiment, the pre-play asset markets lead to less efficient output levels. This is even true in the particular case in our second experiment where group size is Small ($n = 3$) and the relevant order-statistic ($j = 2$) is therefore the median, as in Van Huyck et al.'s experiment.[19] In this special case we again find that the asset market produces a negative effect on output, providing a compelling comparison of how two different market institutions can lead to very different outcomes when paired with similar games.

We believe the key difference between our experiment and Van Huyck et al.'s to be the symmetry in our asset market that is not present in their study. In their experiment, the

[19] Van Huyck et al. (1993) do not examine such small group sizes, using a group size of 9, but as we note previously smaller groups should generally result in more efficient coordination. Our payoff function is also different than that used by Van Huyck et al. (1993).

market creates jointly-held positive expectations of group outcomes by eliminating those players who do not hold such optimistic beliefs. Therefore, the end result is mutual reassurance among those selected by the market to play the game (Crawford and Broseta 1998). In our setting however, the market allows *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, rather than reducing it as in Van Huyck et al.'s experiment, and allow it to "snowball" into negative expectations about the likely final outcome. The difference between the two experiments 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. We show that considering the precise influence of markets on economic behavior is of significant importance to someone attempting to design a market institution to aid in efficient equilibrium selection.

More generally, our results also stand in contrast to the stylized fact that greater communication facilitates efficient coordination in games like these (Blume and Ortmann 2007, Cooper et al. 1992). We demonstrate that allowing players to interact via asset markets linked to multiple equilibria, which allows rich and costly communication of intentions and beliefs, has a negative influence on which equilibrium obtains. In this regard, our work is similar to theoretical work demonstrating potentially harmful effects of public information in coordinating beliefs and behavior (Morris and Shin 2002), highlighting potentially harmful effects of communication in situations where coordination is both critical and difficult.

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6 Tables

Table 1: **Minimum-Input Game Payoff Table (Exp 1)**

		Minimum input (output) 4	3	2	1
	4	2.00	1.60	1.20	0.80
Player's	3		1.80	1.40	1.00
input	2			1.60	1.20
	1				1.40

Table 2: **Average Group Output by Condition (Exp 1)**

	Periods 1-8		Periods 5-8	
	Small Groups	Large Groups	Small Groups	Large Groups
Control	3.66	2.44	3.75	2.28
Market H (Insiders)	1.33	1.02	1.21	1.00
Market L (Insiders)	2.59	1.22	2.81	1.19
Market H (Outsiders)	1.73	1.29	1.71	1.04
Market L (Outsiders)	1.56	1.44	1.63	1.50

Table 3: **Group Output by Condition Relative to Control (Exp 1)**

	(1)	(2)	(3)	(4)	(5)	(6)
	Group Output: Insiders (vs. Control)			Group Output: Outsiders (vs. Control)		
Market	-3.936***	-8.450***	-3.667***	-4.269***	-8.237***	-18.890***
	[0.485]	[0.993]	[0.714]	[0.661]	[0.938]	[1.949]
Market-H			-4.337***			10.916***
			[1.173]			[1.326]
Large Group		-1.260***	-1.284***		-1.528***	-1.509***
		[0.146]	[0.164]		[0.182]	[0.177]
Market x		0.734***	-0.087		0.945***	2.765***
Large Group		[0.145]	[0.108]		[0.149]	[0.293]
Market-H x			0.455**			-1.899***
Large Group			[0.200]			[0.239]
Period	-0.02	-0.019	-0.02	-0.079	-0.077	-0.08
	[0.059]	[0.063]	[0.064]	[0.060]	[0.061]	[0.062]
Observations	288	288	288	288	288	288
Log likelihood	-176.79	-166.54	-160.54	-194.82	-184.30	-184.93

Ordered probit regression with group random effects; Huber-White standard errors. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 4: **Individual Portfolio Holdings and Input Choices (Exp 1, Insiders)**

Holdings	(1) Input = 1	(2) Input =2	(3) Input = 3	(4) Input = 4
Security 1	0.043***	-0.015***	-0.031*	-0.014**
	[0.009]	[0.005]	[0.017]	[0.006]
Security 2	-0.017	0.034***	-0.007	-0.014***
	[0.012]	[0.009]	[0.007]	[0.004]
Security 3	-0.012	-0.024***	0.043***	-0.004
	[0.010]	[0.007]	[0.015]	[0.005]
Security 4	-0.012	-0.001	-0.018	0.025**
	[0.011]	[0.008]	[0.011]	[0.011]
Constant	-0.282	-1.003***	-1.529***	-0.730***
	[0.194]	[0.177]	[0.358]	[0.115]
Observations	720	720	720	720
Fraction	0.453	0.186	0.142	0.219
Log likelihood	-365.13	-275.11	-191.72	-280.92

Probit regression with market random effects; Huber-White standard errors. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 5: **Portfolio Holdings and Equilibrium Selection (Exp 1)**

	Panel A: Small Groups					
	{1}	{1,2}	{1,2,3}	{1,2,3,4}	Overall	Control
Output = 4	0.03	0.00	0.00	0.29	0.13	0.72
Output = 3	0.09	0.11	0.33	0.26	0.16	0.23
Output = 2	0.06	0.11	0.00	0.26	0.14	0.03
Output = 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
Output = 4	0.00	0.00	0.00	0.00	0.00	0.23
Output = 3	0.00	0.00	0.00	0.00	0.00	0.30
Output = 2	0.02	0.00	0.00	0.30	0.10	0.14
Output= 1	0.98	1.00	0.00	0.70	0.90	0.33
Observations	46	2	0	23	80	64

Table 6: **Security Prices and Group Output (Exp 1, Insiders)**

	(1)	(3)	(3)	(4)
	Group Output			
Expected Output	1.411***	1.385***	1.657***	1.342***
	[0.299]	[0.240]	[0.287]	[0.401]
Market-H		-1.632		-2.987
		[1.089]		[1.838]
Large Group			1.37	0.179
			[1.077]	[1.297]
Expected Output		0.25		0.784
x Market-H		[0.620]		[0.955]
Expected Output			-0.881*	-0.486
x Large Group			[0.511]	[0.546]
Last Period	1.329***	1.252***	1.224***	1.111***
Output	[0.286]	[0.241]	[0.280]	[0.217]
Period	0.233***	0.187**	0.197**	0.142
	[0.086]	[0.089]	[0.099]	[0.092]
Observations	88	88	88	88
Log likelihood	-39.87	-36.38	-39.00	-34.86

Ordered probit regressions; standard errors are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 7: **Second-Order-Statistic-Input Game Payoff Table (Exp 2)**

		Second lowest input (output)			
		4	3	2	1
	4	2.00	1.60	1.20	0.80
Player's input	3	1.60	1.80	1.40	1.00
	2	1.20	1.40	1.60	1.20
	1	0.80	1.00	1.20	1.40

Table 8: **Average Group Output by Condition (Exp 2)**

	Periods 1-8		Periods 5-8	
	Small Groups	Large Groups	Small Groups	Large Groups
Control	3.92	3.38	4.00	3.50
Market (Insiders)	3.25	3.00	3.25	2.94
Market (Outsiders)	3.38	2.66	3.44	2.69

Table 9: **Group Output by Condition Relative to Control (Exp 2)**

	(1)	(2)	(3)	(4)
	Group Output: Insiders (vs. Control)		Group Output: Outsiders (vs. Control)	
Market	-2.739***	-4.692***	-3.063***	-2.306**
	[0.651]	[1.519]	[0.629]	[1.065]
Large Group		-0.812***		-1.111***
		[0.224]		[0.271]
Market x		0.666***		0.375
Large Group		[0.253]		[0.39]
Period	0.129**	0.130**	0.177**	0.187***
	[0.063]	[0.064]	[0.071]	[0.063]
Observations	160	160	160	160
Log likelihood	-88.57	-85.47	-78.55	-74.40

Ordered probit regression with group random effects; Huber-White standard errors. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.

Table 10: **Security Prices and Group Output (Exp 2, Insiders)**

	(1)	(2)
	Group Output	
Expected Output	1.398**	1.514*
	[0.639]	[0.844]
Large Group		-1.718
		[3.313]
Expected Output		0.407
x Large Group		[1.206]
Last Period	0.604**	0.481
Output	[0.303]	[0.340]
Period	-0.157*	-0.170*
	[0.088]	[0.091]
Observations	54	54
Log likelihood	-45.36	-43.48

Ordered probit regressions; standard errors are clustered by group. *** denotes $p < 0.01$, ** denotes $p < 0.05$, and * denotes $p < 0.10$.