GAMES AND ECONOMIC BEHAVIOR 5, 485–504 (1993)

Asset Markets as an Equilibrium Selection Mechanism: Coordination Failure, Game Form Auctions, and Tacit Communication*

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Received July 8, 1992

In this paper, we explore the possibility that asset markets provide a means of tacit communication, which may allow subjects to coordinate on the payoff-dominant equilibrium in an underlying coordination game. We find that the existence of a market price for the right to play does communicate information about the equilibrium selection problem. Specifically, behavior *never* converged to the efficient outcome when subjects were endowed with the right to participate, but *always* converged to the efficient outcome when subjects purchased the right to participate. *Journal of Economic Literature* Classification Numbers: C720, G120. © 1993 Academic Press, Inc.

In a large number of market and nonmarket situations, it is possible to identify multiple equilibrium outcomes that can be ranked by efficiency.[1] While theorists sometimes resort to the expedient of selecting the payoff-

* The National Science Foundation (SES-8911032; SES-9122565), the Texas Agriculture Extension Service, the Texas Engineering Extension Service, and the Texas A&M Center for Mineral and Energy Research provided financial support.

[1] Cooper and John (1988) demonstrate that many of these situations exhibit strategic complementarities and demand spillovers and, hence, have a similar strategic form representation. Milgrom and Roberts (1990) demonstrate that extant models of oligopoly competition, macroeconomic coordination failure, bank runs, technology adoption and diffusion, R&D competition, and manufacturing with nonconvexities exhibit strategic complementarities; see also Bulow *et al.* (1985).

0899-8256/93 $5.00

dominant equilibrium in such situations, we think it is important to discover how people cope with the strategic uncertainty inherent in situations with multiple Pareto ranked equilibria. In Van Huyck *et al.* (1990, 1991), we reported treatments in which subjects always coordinated on mutual best response outcomes that were strictly Pareto dominated by other symmetric strict equilibria; that is, subjects never selected the payoff-dominant equilibrium. The experiments provide striking examples in which strategic uncertainty leads to coordination failure in the absence of preplay communication.[2]

In this paper, we focus on one of the coordination games previously studied, which never resulted in an efficient mutual best response outcome, and investigate the possibility that selling the right to participate in the coordination game provides a means of tacit communication, which may allow subjects to coordinate on an efficient outcome of the underlying coordination game. When the right to participate in the coordination game is sold by auction, subjects can observe the price of the right to play. This price reflects an average forecast of the outcome in the coordination game that owners are likely to implement. Since the existence of multiple Pareto ranked equilibria confronts owners with a strategy coordination problem, they may use the price of the right to play to inform their own beliefs about the likely outcome and, consequently, implement the outcome implicit in the price of the right to play.

In this paper, the information about the strategy coordination problem communicated by the price of the right to play will be called "tacit communication." The price of the right to play, P, can reduce the subjects' strategic uncertainty by allowing them to eliminate from consideration outcomes in the coordination game that do not pay at least P. Common sense suggests that nobody would pay P to play unless they expected to earn at least P. This common sense inference underlies equilibrium refinements based on "forward induction" in that it involves making an inference about future play in the subgame based on information about play leading up to the subgame.[3]

We find that the price of the right to play does communicate information about the strategy coordination problem in the underlying coordination game. The outcome in the underlying coordination game when subjects purchase the right to participate is dramatically different from our previous

[2] Beckman (1989), Cooper *et al.* (1990), and Straub (1990) also report experiments exhibiting coordination failure. Cachon and Camerer (1991) replicate our baseline results with University of Pennsylvania undergraduates.

[3] Examples of refinements based on forward induction are strategic stability and the intuitive criterion. Gale and Hellwig (1989, p. 24) and van Damme (1989, p. 484) demonstrate that the logic of forward induction is not equivalent to the equilibrium refinement of strategic stability.

experiments in which subjects were endowed with the right to participate. Specifically, behavior *never* converged to the efficient outcome in the underlying coordination game when subjects were endowed with the right to participate, but behavior *always* converged to the efficient outcome when subjects purchased the right to participate.

1. Analytical Framework: A Two Stage Game

To focus the analysis consider the following two stage game consisting of an asset market and a coordination game. The asset sold at auction in the asset market is the right to participate in the coordination game and can be thought of as a one period lease on a production opportunity. In the first stage, m players bid to purchase the n assets, where $m > n$, in the asset market. In the second stage the n owners play the underlying coordination game, which has multiple Pareto ranked equilibria. This two stage game can be solved recursively: first solve the coordination game, then price the asset.

1.1. *The Asset: Participation in the Coordination Game*

Let $e_1, \ldots, e_n$ denote the actions taken by the n owners in the coordination game, let n be odd, and let M be the median of these actions. The coordination game Γ is defined by the payoff function $\pi(\cdot)$ and strategy space $\mathbf{E}$ for each of the n owners,

$$\pi(e_i, M) = aM - b[M - e_i]^2 + c, \qquad a > b > 0, \tag{1}$$

where $e_i \in \mathbf{E} = \{1, 2, \ldots, \bar{e}\}$ and $\bar{e}$ is the largest feasible integer. An owner's payoff is decreasing in the difference between the owner's choice e_i and the median M and, holding this difference constant, is increasing in the median M. The payoff function and strategy space are common knowledge.

If the owners could explicitly coordinate their actions, their decision problem would be trivial. Given $a > 0$, each owner should choose the action $\bar{e}$. Moreover, a pregame agreement to choose $\bar{e}$ would be self-enforcing. Hence, implementing the efficient outcome does not involve an incentive problem.

However, when the owners cannot engage in explicit pregame negotiation they face a nontrivial coordination problem: an average opinion problem.[4] In Γ, owner i's best response is to set e_i equal to i's forecast of the median action. The principle of mutually expected rationality implies that, when forecasting the median, owner i expects owner j to set e_j equal to j's forecast of the median action. Hence, owner i's best response becomes to set e_i equal to i's forecast of the median of the forecasts of the median. Again, the principle of mutually expected rationality applies and owner i confronts an infinite regress of forecasts of the median of the forecasts of the median of the forecasts. . . .

Suppose that the owners attempt to use the Nash equilibrium concept to inform their strategic behavior in Γ. Formally, a vector of feasible actions $(e_1', \ldots, e_n')$ constitutes a Nash equilibrium point, if the vector satisfies the mutual best response condition,

$$\pi(e_i, M') \leq \pi(e_i', M'), \tag{2}$$

for all $e_i \in \mathbf{E}$ and for all i.

The pure strategy e_i is a best response to the pure strategies $(e_1, \ldots, e_{i-1}, e_{i+1}, \ldots, e_n)$ if and only if e_i equals the median of $(e_1, \ldots, e_n)$; thus any symmetric combination of pure strategies $(e, \ldots, e)$, where $e \in \mathbf{E}$, is a strict Nash equilibrium, and such combinations are the only pure-strategy Nash equilibria. The Nash concept neither prescribes nor predicts the outcome of Γ. Since the equilibria are strict, equilibrium refinements, like perfection, do not reduce the multiplicity of equilibria; see van Damme (1987). All feasible actions can be rationalized as part of some Nash Equilibrium outcome.

1.2. *The Asset Market*

This section calculates a competitive price for the asset—the right to participate in Γ—given an equilibrium point $(e, \ldots, e)$. Let P be the price a player must pay to acquire the asset. If P were greater than $\pi(e, e)$, then no rational player would choose to enter the subgame. Conversely, if P were less than $\pi(e, e)$, then all rational players would prefer to enter the subgame. Equilibrium in a competitive asset market requires that players be indifferent between entering and not entering the coordination game Γ. Hence, the market clearing condition for the asset market, given an equilibrium $(e, \ldots, e)$ in Γ, is

$$P(e) = \pi(e, e). \tag{3}$$

[4] Keynes' (1964) chapter on expectations provides a lucid exposition of the average opinion problem in beauty contests and stock markets.

Condition (3) is a zero profit condition. It gives a different price for each of the $\bar{e}$ product market equilibrium points; that is, $P(1) < \cdots < P(e) < \cdots < P(\bar{e})$.

A vector $(e', \ldots, e')$ satisfying condition (2) and a price $P(e')$ satisfying condition (3) define a competitive equilibrium in the two stage game. The set of competitive equilibria in the two stage game contains $\bar{e}$ equilibrium points. Consequently, players confront an equilibrium selection problem in the two stage game. The deductive equilibrium analysis is incomplete, that is, it neither prescribes nor predicts behavior in the two stage game.

2. Equilibrium Selection Principles

The coordination game Γ confronts owners with two nontrivial strategy coordination problems. First, owners may fail to correctly forecast the median and, hence, regret their individual choice, that is, $e_i \neq M$. This results in disequilibrium: outcomes that do not satisfy the mutual best response condition, (2). Second, the existence of multiple equilibria that are Pareto ranked raises the possibility that owners, while giving a best response, may implement a Pareto dominated equilibrium. While not regretting their individual choice, they regret the equilibrium implemented by these choices, that is, $M \neq \bar{e}$. Hence, all owners may give a best response, but, nevertheless, the outcome may result in coordination failure.

An interesting conjecture–Schelling's 1960 (1980) conjecture—is that decision makers may focus on some selection principle to identify a specific equilibrium point in situations involving multiple equilibria. Hence, the outcome of situations involving strategic uncertainty may, nevertheless, satisfy the mutual best response condition, (2). A salient principle selects an equilibrium point based on its conspicuous uniqueness in some respect. The salience of an equilibrium selection principle is essentially an empirical question.

2.1. *Payoff-Dominance and Security*

When multiple equilibrium points can be Pareto ranked, it is possible to use concepts of efficiency to select a subset of self-enforcing equilibrium points: examples include Luce and Raiffa's (1957; p. 106) concept of joint-admissibility and Harsanyi and Selten's (1988; p. 81) concept of payoff-dominance. An equilibrium point is said to be payoff-dominant if it is not strictly Pareto dominated by any other equilibrium point. When unique, considerations of efficiency may induce players to expect and, hence, implement the payoff-dominant equilibrium point.

In game Γ, the equilibrium points are strictly Pareto ranked. Each owner prefers a larger median. Consequently, the payoff-dominant equilibrium point is the n-tuple $(\bar{e}, \ldots, \bar{e})$. Payoff-dominance and backwards induction then determine a price of $P(\bar{e})$ for Γ. However, a prescription to play $\bar{e}$ in Γ ignores the strategic uncertainty associated with multiple equilibria. Specifically, it requires that the owners believe payoff-dominance is a salient equilibrium selection principle.

Alternatively, selection principles based on the "riskiness" of an equilibrium point have been identified and formalized: examples include von Neumann and Morgenstern's 1944 (1972) concept of maximin and Harsanyi and Selten's (1988) concept of risk-dominance. A secure strategy is a pure strategy whose smallest payoff is at least as large as the smallest payoff of any other feasible strategy. Given existence and uniqueness, security selects the equilibrium point supported by players' secure strategy. Security, in contrast to payoff-dominance, may select very inefficient strategy combinations in nonconstant sum games.

2.2. *Asset Prices and Tacit Communication*

Voluntarily purchasing the right to participate in a game can communicate useful information about the equilibrium selection problem. Specifically, in the second stage of the two stage game, owners share common knowledge that they all voluntarily paid price P for the right to participate in the coordination game Γ. Presumably, all the owners expected to earn at least P by participating in the coordination game when they purchased the asset. Hence, common knowledge that all owners voluntarily paid P to participate in the coordination game could be interpreted as the following tacit communication:

> "Look, each of us had the opportunity not to participate, but nevertheless we decided to participate in Γ and we paid P for this right. As you can see from the description of Γ, none of us has an incentive to choose to participate and choose an action that pays off less than P under all possible outcomes, because we would have done better not to participate at all. Since we are intelligent people, you should conclude that we will choose an action with some possibility of a payoff at least as large as P."

This tacit communication, if credible, may rule out some equilibrium points in Γ and, hence, reduce the strategic uncertainty confronting players in Γ.

This argument can be formalized as follows. Rational players never use strategies that are strictly dominated in the two-stage game; it follows that the actions they choose are contained in the set of undominated actions, $U(P)$:

$$U(P) \equiv \{e \in \mathbf{E} : \pi(e, M) \geq P \text{ for at least one } M \in \mathbf{E}\}. \quad (4)$$

Further, given the form of $\pi(e, M)$, the median of their actions will also be in this set. A more restrictive condition is that owners will choose actions that pay at least P in *equilibrium*. Rational players who all expect the same outcome in the underlying game will choose FI-admissible actions, $FI(P)$:

$$FI(P) \equiv \{e \in \mathbf{E} : \pi(e, e) \geq P\}. \quad (5)$$

Restricting M equal to e implies that $FI(P)$ is a subset of $U(P)$; compare definition (5) with definition (4).[5]

The principle of individual rationality and the requirement of mutually consistent expectations imply that owners will select an FI-admissible action, $e \in FI(P)$, in Γ. If $e \in FI(P)$ for all owners, then the median will be contained in the set of FI-admissible actions. Hence, changing the asset price P not only changes the set of FI-admissible actions, $FI(P)$, but also changes the set of mutual best response outcomes that are consistent with FI admissibility.

An asset price that selects a unique equilibrium in Γ must select the payoff-dominant equilibrium. As long as $FI(P)$ is not empty, it contains $\bar{e}$, because $\bar{e}$ gives the largest payoff in equilibrium. From definition (5) and Eq. (1) it follows that the interval of prices such that $FI(P^*) = \{\bar{e}\}$ is $\pi(\bar{e}, \bar{e}) \geq P^* > \pi(\bar{e} - 1, \bar{e} - 1)$. An asset market price in this interval selects the payoff-dominant equilibrium of Γ, $(\bar{e}, \ldots, \bar{e})$. Tacit communication, because it reduces the set of candidate equilibria, may reinforce the salience of payoff-dominance.

The tacit communication hypotheses to be examined below are that $e_i \in U(P)$ and $e_i \in FI(P)$ for all i.

3. Experimental Design

The coordination game, represented by payoff table Γ, is derived from Eq. (1) when $a = \$.10$, $b = \$.05$, $c = \$.60$, and $\bar{e} = 7$; see Fig. 1. Nine subjects participate in the coordination game. Note that cells along the diagonal give the payoffs corresponding to the seven equilibria. Hence, equilibrium payoffs range from \$1.30 in the payoff dominant equilibrium, $(7, \ldots, 7)$, to \$0.70 in the most inefficient equilibrium, $(1, \ldots, 1)$. The

[5] $FI(P)$ differs from $U(P)$ despite the fact that i does best, all else equal, when $e_i = M$, because when $a > b$ raising M one unit above e_i always benefits i. (When $a = 2b$, raising M two units neither helps nor hurts, and three or more units actually hurts.)

	MEDIAN VALUE OF X CHOSEN							
		7	6	5	4	3	2	1
YOUR CHOICE OF X	7	1.30	1.15	.90	.55	.10	-.45	-1.10
	6	1.25	1.20	1.05	.80	.45	0	-.55
	5	1.10	1.15	1.10	.95	.70	.35	-.10
	4	.85	1.00	1.05	1.00	.85	.60	.25
	3	.50	.75	.90	.95	.90	.75	.50
	2	.05	.40	.65	.80	.85	.80	.65
	1	-.50	-.05	.30	.55	.70	.75	.70

FIG. 1. Payoff table Γ.

secure equilibrium is (3, . . . , 3), which pays \$0.90 in equilibrium and ensures a payoff of at least \$0.50.

Given these parameter values, the sets of undominated actions, $U(P)$, and the sets of FI-admissible actions, $FI(P)$, for a price $P \in [0, 1.30]$ are as follows:

$$\begin{array}{lll}
1.30 \geq P^7 > 1.25 & 1.30 \geq P^* > 1.20 & U(P^7) = FI(P^*) = \{7\}, \\
1.25 \geq P^6 > 1.15 & 1.20 \geq P^{f6} > 1.10 & U(P^6) = FI(P^{f6}) = \{7, 6\}, \\
1.15 \geq P^5 > 1.05 & 1.10 \geq P^{f5} > 1.00 & U(P^5) = FI(P^{f5}) = \{7, 6, 5\}, \\
1.05 \geq P^4 > 0.95 & 1.00 \geq P^{f4} > 0.90 & U(P^4) = FI(P^{f4}) = \{7, 6, 5, 4\}, \\
0.95 \geq P^3 > 0.85 & 0.90 \geq P^{f3} > 0.80 & U(P^3) = FI(P^{f3}) = \{7, 6, 5, 4, 3\}, \\
0.85 \geq P^2 > 0.75 & 0.80 \geq P^{f2} > 0.70 & U(P^2) = FI(P^{f2}) = \{7, 6, \ldots, 3, 2\}, \\
0.75 \geq P^1 \geq 0.00 & 0.70 \geq P^{f1} \geq 0.00 & U(P^1) = FI(P^{f1}) = \{7, 6, \ldots, 2, 1\}.
\end{array}$$

These then are the implications of the tacit communication hypotheses for payoff table Γ. Specifically, subject i's behavior conforms to the tacit communication hypotheses if $e_i \in U(P)$ and $e_i \in FI(P)$.

Because the tacit communication hypotheses are independent of the asset market institution that generates the price P, we are free to select a game form auction with desirable properties. In a game form auction, the value of the object being auctioned is determined by the strategic interaction of the owners and this strategic interaction can depend on the price generated in the auction. Consequently, the object has no exogenously determined private, affiliated, or common value.

However, desirable properties for the asset market are that it generates one price for all nine assets, that it induces nine subjects to participate, that it is easy to learn, that it is easy to administer, that the price paid is determined by the last rejected bidder, and that it gives competitive results with relatively small group sizes. After some experimentation with alternative institutions, we concluded that the multiple unit English Clock (EC) auction was the most suitable institution for the experiments.[6]

The EC auction works as follows: In the asset market, 18 subjects bid for the 9 rights to participate in Γ. Initially, all subjects hold up their bid card. The initial price is 65 cents, which is less than the payoff in the worst equilibrium. Every 5 sec the price ticks up an increment. When the price goes above the price a subject is willing to pay that subject lowers his or her bid card. Initially, price increments are 5 cents until only 11 subjects remain, at which time, price increments are 1 cent until only 9 subjects remain. The nine subjects with raised bid cards pay the price at which the 9th bid card was lowered. These 9 subjects then proceed to play Γ. (Ties are broken by randomly selecting however many subjects are needed from amongst those subjects lowering their bid card on the final price tick. The price paid equals the price preceding the price tick that resulted in a tie.)

An experimental treatment differs from the game described in Section 1 in that the period game, that is, the two stage game, was repeated a finite number of periods: either 10 or 15 periods. Repeated play allows the players to use selection principles based on the history of previous period games to inform their behavior after the initial play of the game. Hence, repeated play allows subjects to learn how to coordinate; see Crawford (1991) and Lucas (1987). For example, repeated interaction allows subjects to use precedent—past instances of the present coordination problem—to form mutually consistent beliefs and, hence, to implement a mutual best response outcome.

The instructions were read aloud to ensure that the description of the game was common information. No preplay negotiation was allowed. After each repetition of the asset market stage game, the market clearing price, P, was announced. After each repetition of the stage game Γ, the median action was announced and the subjects calculated their earnings

[6] We thank Vernon Smith for suggesting this institution to us. While the tacit communication hypothesis was supported in the alternative treatments, the EC auction produces prices higher than last period's payoff given a best response more frequently than the other auctions we tried and, hence, provides a stronger test of the tacit communication hypothesis.

TABLE I

EXPERIMENTAL DESIGN MATRIX

Experiment #	Subject pool	Treatment: No auction game $\Gamma(9)$	EC auction private value	EC auction game $\Gamma(9)$
1	TAMU*	1, 2, . . . , 10	—	—
2	TAMU*	1, 2, . . . , 10	—	—
3	TAMU*	1, 2, . . . , 10	—	—
4	TAMU*	1, 2, . . . , 10	—	—
5	TAMU*	1, 2, . . . , 10	—	—
6	TAMU*	1, 2, . . . , 10	—	—
7	Auburn	1, 2, . . . , 10	11, . . . , 15	16, . . . , 30
8	Auburn	1, 2, . . . , 10	11, . . . , 15	16, . . . , 30
9	Auburn	1, 2, . . . , 10	11, . . . , 15	16, . . . , 30
10	TAMU	—	1, . . . , 5	6, . . . , 15
11	TAMU	—	1, . . . , 5	6, . . . , 15
12	Auburn	—	1, . . . , 5	6, . . . , 20
13	Auburn	—	1, . . . , 5	6, . . . , 20
14	Auburn	—	1, . . . , 5	6, . . . , 20

Note. EC—multiple unit English Clock auction. *—Group size nine; see Van Huyck *et al.* (1991).

for that period. The only shared historical data available to the subjects was the price in the asset market and the median in Γ.

Table I outlines the design of the 14 experiments reported in this paper. (The actual instructions, questionnaire, extra instructions, and record sheets used in the experiments are available upon request.) In Experiments 1 to 6 and in the first treatment of Experiments 7 to 9, subjects are endowed with the asset and, hence, subjects are unable to use an asset price to inform their behavior in Γ. Experiments 7 to 14 introduce an asset market stage game and, hence, subjects could use asset prices to inform their behavior in Γ.

Before participating in the two stage game, subjects were trained in a private value EC auction. As McCabe *et al.* (1990) report, subjects quickly learned to bid their private resale value and the institution assigned the asset to those subjects with the highest resale value. These experimental results are not reported in this paper. Subjects were endowed with a \$12 balance when the auction began an experiment: Experiments 10 to 14.

The subjects were sophomore and junior economics students attending Texas A&M University and Auburn University. A total of 198 students participated in the 14 experiments. The experiments take about 2 hr to conduct and the average subject earns about \$17. After reading the instruc-

TABLE II

MEDIAN CHOICE FOR THE FIRST 10 PERIODS OF EXPERIMENTS 1 TO 6: NO ASSET MARKET AND REPEATED PLAY WITH NINE SUBJECTS

	Period									
Experiment	1	2	3	4	5	6	7	8	9	10
1	4	4	4	4	4	4	4*	4	4*	4*
2	5	5	5	5	5	5	5	5	5	5
3	5	5	5	5	5	5	5	5	5	5*
4	4	4	4	4	4	4*	4*	4*	4*	4*
5	4	4	4	4*	4*	4*	4*	4*	4*	4*
6	5	5	5	5	5	5	5	5*	5*	5*

Note. * indicates a mutual best response outcome.

tions, but before the treatment began, the students filled out a questionnaire to determine that they understood how to calculate the median of nine numbers and how to read the payoff table for the treatment—that is, how to map actions into money payoffs.

4. BASELINE EXPERIMENTAL RESULTS

The experimental results are reported in two sections. This section reports results for repeated play of game Γ when subjects are *endowed* with the right to participate. Section 5 reports results for repeated play of game Γ when subjects are endowed with money and must *buy* the right to participate.

The initial outcome of Experiments 1 to 6—the baseline experiments—was never the payoff-dominant equilibrium and was never the secure equilibrium; see Table II. Specifically, the median action was 4 in three experiments and 5 in three experiments. Consequently, the period 1 data for Γ exhibit coordination failure. Moreover, the subjects implement a disequilibrium outcome.

In period one, the payoff-dominant action, 7, was chosen by only 15%—8 out of 54—of the subjects. The secure action, 3, was also chosen by only 15% of the subjects. No subject chose an action less than 3. The modal response was action 4 chosen by 35%—19 out of 54—of the subjects. Rather than play either the payoff-dominant or the secure action, 70%—38 out of 54—of the subjects chose an action between the payoff-dominant action, 7, and the secure action, 3.

In the baseline experiments, the initial outcome is extremely stable in repeated play of the stage game Γ; see Table II. While the period 1 median differed across experiments, the median in subsequent periods was always equal to the period one median. In five out of six experiments, the period 10 outcome satisfied the mutual best response condition (2). Hence, repeated play helps individuals solve the coordination problem. However, since subjects coordinate on a median of 4 or 5, which are inefficient equilibria, the baseline experiments provide a striking example of coordination failure.[7]

In the baseline experiments, the historical accident of the initial outcome determines which equilibrium point obtains in every case. Repeated play of Γ in the baseline experiments differs from repeated play of Γ in the two stage game in that the asset market selects different subjects to participate in Γ. To determine if the results found in the baseline experiments are robust to changes in the identity of the subjects playing Γ, we ran three additional experiments: experiments 7 to 9. We also wanted to determine if experience with repeated play of the one stage game influenced subjects' behavior in repeated play of the two stage game; see Section 5.2.

In Experiments 7 to 9, the coordination game was played by 18 subjects. Each period the 18 subjects chose an action. A subject's payoff was determined by payoff table Γ, where the column was determined by the median of 9 actions randomly selected from the 18 actions made by the subjects.

The initial outcome in Experiments 7 to 9, as in the baseline experiments, was never the payoff-dominant equilibrium and was never the secure equilibrium; see Table III. Specifically, the median action was 4 in Experiment 9 and 5 in Experiments 7 and 8. As in the baseline experiments, subjects implement a disequilibrium outcome in period 1.

In period 1, the payoff-dominant action, 7, was chosen by only 17%—9 out of 54—of the subjects. The secure action, 3, was chosen by 7 %—4 out of 54—of the subjects. (One subject chose an action less than 3.) The modal response was action 5, chosen by 44%—24 out of 54—of the subjects. As in the baseline experiments, 76%—41 out of 54—of the subjects chose an action between the payoff-dominant action, 7, and the secure action, 3.

Experiments 7 to 9 are less stable than the baseline experiments; see Table III. In period 2, the median declined in Experiment 8 and increased in Experiments 7 and 9. However, after a few periods of instability the median settles down and, as in the baseline games, the period 10 median equaled the initial median in Experiments 7 and 8. Since subjects coordinate on medians of 5 or 6, which are inefficient outcomes, Experiments 7 to 9 provide additional examples of coordination failure.

[7] See Van Huyck *et al.* (1991) for a more extensive description and analysis of Experiments 1 to 6 and related average opinion games not reported here.

TABLE III

MEDIAN CHOICE FOR THE FIRST 10 PERIODS OF EXPERIMENTS 7 TO 9: NO ASSET MARKET AND 9 SUBJECTS RANDOMLY SELECTED FROM 18

	Period									
Experiment	1	2	3	4	5	6	7	8	9	10
7										
Reported	5	6	5	5	5	5	5	5*	5*	5*
Overall	5	6	5	5	5	5	5	5	5	5
8										
Reported	5*	4	5	5	5	5	5	5*	5	5*
Overall	5	4	5	5	5	5	5	5	5	5
9										
Reported	4	5	5	6	6	6	6	6	6	6*
Overall	5	5	5	5	5	6	6	6	6	6

Notes. Reported = the median for 9 randomly selected subjects, which was reported to the subjects. Overall = the median using all 18 subjects. * indicates a mutual best response outcome.

In Experiments 1 to 9, we *never* observed the payoff-dominant outcome. Intuitively, we believe this result is due to the perceived "riskiness" of selecting 7, an extreme value, in Period 1. Initially, subjects are uncertain about what value the median will take. Choosing action 7 exposes a subject to the largest potential out-of-equilibrium losses. Consequently, subjects respond to this strategic uncertainty by choosing middle values. Once an inefficient median is observed and becomes common information, it is even less likely that subjects will choose the payoff-dominant action, 7. The precedent set by the initial median determines the Period 10 median in eight of nine treatments without an asset market stage game.

5. EXPERIMENTAL RESULTS WITH AN ASSET MARKET

Experiments 10 to 14 and the continuation treatment of Experiments 7 to 9 provide evidence on the influence an asset market can have on the equilibrium selection problem in a coordination game. Because the baseline experiments reveal that the median in previous periods is a powerful selection mechanism, we report the results in two subsections: Section 5.1 reports results when subjects have no experience with average opinion games and Section 5.2 reports results when subjects are experienced.

TABLE IV

DISTRIBUTION OF ACTIONS IN FIRST PERIOD: BASELINE VS. EXPERIMENTS 11 TO 15

	Exp. 1 to 6 Baseline		Exp. 11 $p = \{1.24\}$		Exp. 14, 15 $p = \{1.05\}$		Exp. 12, 13 $p = \{1.00, .95\}$	
	#	Per.	#	Per.	#	Per.	#	Per.
# of 7s	8	(15)	7	(78)	2	(11)	5	(28)
# of 6s	4	(7)	2	(22)	8	(44)	1	(6)
# of 5s	15	(28)	0	(0)	4	(22)	8	(44)
# of 4s	19	(35)	0	(0)	3	(17)	3	(16)
# of 3s	8	(15)	0	(0)	1	(6)	1†	(6)
# of 2s	0	(0)	0	(0)	0	(0)	0	(0)
# of 1s	0	(0)	0	(0)	0	(0)	0	(0)
Total	54	(100)	9	(100)	18	(100)	18	(100)
χ^2				16.8*		4.2*		1.1
Prob.				.00		.04		.30

Note. .... partitions actions into undominated actions above the line and dominated actions below the line. ---- partitions actions into the set of FI-admissible actions above the line and the set of FI-inadmissible actions below the line. * statistically significant difference at the 5% level. † $U(1.00)$ does not include Action 3. However, the observed Action 3 occurs in exp. 13 and Action 3 is contained in $U(.95)$.

5.1. *Inexperienced Subjects: Experiments 10 to 14*

In Period 6—which is the first period after the private value auction trainer—the price of the asset varied from a high of \$1.24 in Experiment 10 to a low of \$0.95 in Experiment 12. Given Period 6 prices, 98%—44 out of 45—of the subjects chose an undominated action and 84%—38 out of 45—of the subjects chose an FI-admissible action; see Table IV. Hence, the Period 6 data are consistent with the hypothesis that most subjects play undominated actions and the more restrictive hypothesis that most subjects play FI-admissible actions.

In Period 6 of Experiment 10 the market price was \$1.24, which is a market price within the range of prices predicted to select the payoff-dominant equilibrium. The median was a 7 and 7 subjects gave a best response. (Only 2 subjects failed to choose an FI-admissible action, and all subjects chose an undominated action.) Experiment 10 is the only experiment in which a median of 7 was observed in the first period and it is also the only experiment with a first period price greater than \$1.20.

To distinguish between the tacit communication hypotheses and other hypotheses, like payoff-dominance or security, we partition the distribution of actions in Experiments 10 to 14 by asset price and partition the baseline data into similar sets. It is then possible to use nonparametric procedures to test the hypothesis that the distribution of actions in the first period of Γ are independent of the asset market treatment.

Chi-square statistics are reported in Table IV. In Experiment 10, $FI(1.24)$ equals $\{7\}$ and the data reject the hypothesis of equal distributions at the 1% level of statistical significance. In Experiments 13 and 14, $FI(1.05)$ equals $\{7, 6, 5\}$ and the data reject the hypothesis of equal distributions at the 5% level of statistical significance. The data cannot reject the hypothesis for Experiments 11 and 12 as $FI(.95)$ equals $\{7, 6, 5, 4\}$. When P restricts the set of FI-admissible actions, the observed distribution of actions in the two stage experiments differs from the observed distribution of actions in the baseline experiments. Hence, the data support the conclusion that the price from the asset market influences subjects' behavior in the coordination game.

In Period 7, the second period of the treatment, the price of the asset varied from a high of \$1.24 in Experiment 10 to a low of \$1.04 in Experiment 12. Given Period 7 prices, 98%—44 out of 45—of subjects chose an undominated action and 84%—38 out of 45—of subjects chose an FI-admissible action; see Table V. From Period 8 through the end of the treatment, 99%—491 out of 495—of the actions are contained in $U(P_t)$ and 98%—487 out of 495—of the actions are contained in $FI(P_t)$. Hence, the continuation data, like the initial period data, are consistent with the hypothesis that subjects play undominated actions or the more restrictive hypothesis that subjects play FI-admissible actions.

The dynamics in Experiment 13 illustrate the influence asset price has on subjects' behavior in Γ. The Period 7 price of \$1.14 restricts the set of FI-admissible actions to exclude the Period 6 median of 5. The Period 7 median is a 6, which is contained in $FI(1.14)$. The Period 8 price of \$1.18 does not restrict the set of FI-admissible actions further—that is, $FI(1.14) = FI(1.18)$—and the Period 8 median equals the Period 7 median: again, a 6. The Period 9 price of \$1.25 is within the range of prices predicted to select the payoff-dominant equilibrium and the median is a 7. From Period 10 on, the price is within the range of prices predicted to select the payoff-dominant equilibrium and the payoff-dominant equilibrium was observed.

The dynamics observed in repeated play of the two stage game are remarkably different from repeated play of the one stage game Γ; compare Table V and Table II. In the baseline experiments, actions are distributed about equally above and below the previous median. With repeated play the range on this fairly symmetric distribution collapses and, consequently, the equilibrium obtained in the final treatment period is equal to the initial median. However, in Experiments 10 to 14, because 99% of the

TABLE V

DISTRIBUTION OF ACTIONS FOR GAME Γ(9): EC AUCTION

	Period														
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Exp. 10															
Price	1.24	1.24	1.28	1.29	1.30	1.30	1.30	1.30	1.30	1.30	—	—	—	—	—
Undom. actions	≥6	≥6	7	7	7	7	7	7	7	7	—	—	—	—	—
# of 7s	7	8	9	8	9	9	9	9	9	9	—	—	—	—	—
# of 6s	2	1	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 5s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 4s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 3s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 2s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 1s	0	0	0	1	0	0	0	0	0	0	—	—	—	—	—
Median	7	7	7*	7	7*	7*	7*	7*	7*	7*	—	—	—	—	—
Exp. 11															
Price	1.00	1.20	1.29	1.30	1.29	1.30	1.29	1.29	1.30	1.30	—	—	—	—	—
Undom. actions	≥4	≥6	7	7	7	7	7	7	7	7	—	—	—	—	—
# of 7s	4	5	9	9	9	9	9	9	9	9	—	—	—	—	—
# of 6s	1	3	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 5s	2	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 4s	2	1	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 3s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 2s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
# of 1s	0	0	0	0	0	0	0	0	0	0	—	—	—	—	—
Median	6	7	7*	7*	7*	7*	7*	7*	7*	7*	—	—	—	—	—
Exp. 12															
Price	.95	1.04	1.08	1.10	1.15	1.20	1.25	1.25	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Undom. actions	≥3	≥4	≥5	≥5	≥5	≥6	≥6	≥6	7	7	7	7	7	7	7
# of 7s	1	0	1	3	2	5	8	9	9	9	9	9	9	9	9
# of 6s	0	3	5	6	7	4	0	0	0	0	0	0	0	0	0
# of 5s	6	2	2	0	0	0	0	0	0	0	0	0	0	0	0
# of 4s	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0
# of 3s	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
# of 2s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 1s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	5	5	6	6	6	7	7	7	7*	7*	7*	7*	7*	7*	7*
Exp. 13															
Price	1.05	1.14	1.18	1.25	1.29	1.25	1.25	1.30	1.25	1.30	1.30	1.30	1.30	1.30	1.30
Undom. actions	≥4	≥5	≥6	≥6	7	≥6	≥6	7	≥6	7	7	7	7	7	7
# of 7s	2	2	4	6	9	9	9	9	9	9	9	9	9	9	9
# of 6s	1	6	5	3	0	0	0	0	0	0	0	0	0	0	0
# of 5s	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 4s	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 3s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 2s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 1s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	5	6	6	7	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*
Exp. 14															
Price	1.05	1.15	1.27	1.25	1.25	1.30	1.30	1.25	1.30	1.30	1.25	1.30	1.30	1.30	1.30
Undom. actions	≥4	≥5	7	≥6	≥6	7	7	≥6	7	7	7	7	7	7	7
# of 7s	0	5	8	8	9	9	9	9	9	9	9	9	9	9	9
# of 6s	7	4	0	1	0	0	0	0	0	0	0	0	0	0	0
# of 5s	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
# of 4s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 3s	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 2s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 1s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	6	7	7	7	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*

Notes. * indicates mutual best response outcome. —— Partitions actions into $FI(P)$ and the complement of $FI(P)$.

subjects play undominated actions and because the increasing market price shrinks the set of undominated actions, the bottom of the distribution of actions is cut off. Consequently, the median increases until it reaches 7.

Experiments 10 to 14 all converge to an outcome that satisfies conditions (2) and (3) of a competitive equilibrium point in the two stage game. But the competitive equilibrium selected is *always* an asset price of \$1.30 and coordintion stage outcome (7, . . . , 7), which is the payoff-dominant equilibrium in Γ. In the competitive equilibrium of the two stage game, subjects are playing strategies that are weakly, but not strictly, dominated by not participating. Given that participating in Γ earns \$1.30 with probability 1, exiting the EC auction at \$1.30 does not strictly dominate not exiting. If everyone exits at \$1.30, then the price is \$1.25 and all participants earn \$0.05, but a subject that exits only has a chance of participating while a subject that does not exit is sure of participating. These data suggest that by the end of Experiments 10 through 14 subjects on the margin in the asset market expect the payoff-dominant equilibrium to obtain in Γ with probability 1, that is, they behave as if we were simply auctioning \$1.30. The bidding behavior reveals no evidence of any residual strategic uncertainty.

5.2. *Experienced Subjects: Experiments 7, 8, and 9*

Subjects in Experiments 7, 8, and 9 had 10 periods experience with the coordination game and 5 periods experience with the private value EC auction before starting the two stage treatment in Period 16. In Period 16, the price of an asset was \$1.15 in Experiment 9 and \$1.09 in Experiments 7 and 8; see Table VI. All three prices are one price tick below the payoff earned in Period 10 given a best response to the Period 10 median; see Table III. (Five periods of the EC auction trainer separate Period 10 and Period 16.) Moreover, Experiments 7 and 9 reproduce the Period 10 median in Period 16. Consequently, precedence does influence the initial outcome of the continuation treatment.

However, in Period 17, Experiments 8 and 9 both generate a price within the range of prices predicted to select the payoff-dominant equilibrium—\$1.25 and \$1.21 respectively—and the median was a 7 in both treatments. Given these two prices, 94%—17 out of 18—of the subjects chose an undominated action and 78%—14 out of 18—of the subjects chose an FI-admissible action; see Table VI. For the remainder of Experiments 9 and 10 the payoff-dominant equilibrium obtains in the stage game Γ.

Note that the median in Experiments 8 and 9 increases after the EC auction generates a price that is one price tick above the payoff obtained

TABLE VI

DISTRIBUTION OF ACTIONS FOR GAME Γ(9): EC AUCTION AND EXPERIENCED SUBJECTS

	Period														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Exp. 7 (M = 5)															
Price	1.09	1.09	1.10	1.19	1.29	1.29	1.30	1.29	1.30	1.30	1.30	1.29	1.30	1.25	1.29
Undom. actions	≥5	≥5	≥5	≥6	7	7	7	7	7	7	7	7	7	≥6	7
# of 7s	0	0	2	5	9	9	9	9	9	9	9	9	9	9	9
# of 6s	2	1	5	4	0	0	0	0	0	0	0	0	0	0	0
# of 5s	6	8	2	0	0	0	0	0	0	0	0	0	0	0	0
# of 4s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 3s	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 2s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 1s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	5	5	6	7	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*
Exp. 8 (M = 5)															
Price	1.09	1.25	1.28	1.29	1.30	1.29	1.30	1.30	1.29	1.30	1.29	1.30	1.29	1.30	1.30
Undom. actions	≥5	≥6	7	7	7	7	7	7	7	7	7	7	7	7	7
# of 7s	3	7	9	9	9	9	9	9	9	9	9	9	9	9	9
# of 6s	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 5s	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 4s	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 3s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 2s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 1s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	6	7	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*
Exp. 9 (M = 6)															
Price	1.15	1.21	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29
Undom. actions	≥5	≥6	7	7	7	7	7	7	7	7	7	7	7	7	7
# of 7s	0	7	9	9	9	9	9	9	9	9	9	9	9	9	9
# of 6s	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 5s	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 4s	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 3s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 2s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of 1s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	6	7	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*	7*

Notes. * indicates mutual best response outcome. ___ Partitions actions into $FI(P)$ and the complement of $FI(P)$.

in the previous period given a best response to the median. Given such positive price ticks, the tacit communication hypothesis implies that the median should increase and the median does increase. Like Experiments 10 to 14, Experiments 7, 8, and 9 all converge to the efficient outcome, (7, . . . , 7).[8]

[8] Abdalla *et al.* (1989), Brandts and Holt (1989), Cachon *et al.* (1990), and Schotter *et al.* (1990) report experimental results in pairwise random matching games that provide mixed support for "forward induction" hypotheses that involve tacit communication.

TABLE VII

CONTINGENCY TABLE FOR THE OUTCOME OF GAME Γ IN THE 10TH TREATMENT PERIOD

Asset market	Outcomes of Game Γ: Payoff-dominant equilibrium	Inefficient outcome	Total treatments
EC auction	8	0	8
None	0	9	9
Total treatments	8	9	17

6. SUMMARY

This paper has demonstrated that the existence of an asset market can influence the equilibrium selected in the underlying coordination game. When the coordination game exhibits multiple Pareto-ranked equlibria, owners are uncertain which equilibrium, if any, will be implemented. Common information that all owners voluntarily paid P informs an owner's reasoning about the equilibrium selection problem by ruling out equilibria supported by strategies that do not pay at least P in equilibrium.

Table VII summarizes the 10th treatment period results of Experiments 1 to 14. When endowed with the right to participate in the coordination game Γ, subjects never implement the payoff-dominant equilibrium. Without an asset market the precedent established by the historical accident of the initial median appears to select the mutual best response outcome coordinated on in repeated play. Yet the multiple unit English Clock (EC) auction always induced subjects—regardless of the initial median and after only a few periods of "learning"—to implement the efficient outcome in the underlying coordination game Γ. As reported in the contingency table, observations of the efficient outcome in Γ are perfectly correlated with the existence of the asset market institution.

Selling the right to participate in the coordination game, rather than endowing subjects with the right to participate, has a significant influence on the equilibrium selected in the coordination game. The asset price influences both initial behavior in the coordination game and the disequilibrium dynamics. Initially, subjects do not price the asset equal to its payoff in the payoff-dominant equilibrium nor do they implement the payoff-dominant equilibrium in the coordination game. We consistently observed subject behavior converging to the efficient competitive equilibrium in the repeated two stage game. In these experiments, the existence of an asset market promotes efficient behavior in the coordination game.

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