Perfect versus imperfect observability—An experimental test of Bagwell's result*

Steffen Huck and Wieland Müller
Humboldt–University†

April 17, 1998

Abstract

In a seminal paper Bagwell (1995) claims that the first mover advantage, i.e. the strategic benefit of committing oneself to an action before others can do, vanishes completely if this action is only imperfectly observed by second movers. In our paper we report on an experimental test of this prediction. We implement three versions of a game similar to an example given by Bagwell, each time varying the quality of the signal which informs the second mover. For experienced players we do not find empirical support for Bagwell's result. Instead, we find some support for the noisy Stackelberg equilibrium emphasised by van Damme and Hurkens (1997).

1. Introduction

The existence of a first mover advantage, i.e. of the strategic benefit of committing oneself to an action before others can do, is a celebrated insight of game theory. It was first demonstrated by von Stackelberg (1934) in the context of a quantity setting duopoly. Schelling (1960) has deepened our understanding of the first mover advantage in at least two respects. First, he described other settings in which commitment to a certain action is beneficial and second, he pointed out necessary conditions for a commitment to be strategically advantageous: the

---

*We wish to thank Werner Güth, Jörg Oechssler and seminar participants at Queen Mary & Westfield College for helpful discussions and Tobias Händel for assistance in conducting one of the experiments. Financial support from the TMR project "Savings and Pensions" of the European Commission is gratefully acknowledged. Furthermore, the first author acknowledges financial support from the German Science Foundation, DFG.

†Institute for Economic Theory III, Spandauer Strasse 1, 10178 Berlin, Germany, Fax +49 30 20935704, email *huck...* and *wmueller@wiwi.hu-berlin.de*.

commitment has to be irreversible and it has to be reliably communicated to the rival.

In a recent paper Bagwell (1995) shows that the reliability of the communication device is indeed crucial for the commitment to be valuable. For that purpose he first considers a two–person simultaneous–move game in which no player has the possibility of committing himself. From this game he then constructs a so–called noisy–leader game in which player 1 chooses an action before player 2 does. The action taken by player 1, however, is only imperfectly observed by player 2 who receives a stochastic signal which informs her about 1's decision in so far as signals and decisions are assumed to be correlated. The signal technology might be almost perfect in the sense that the correlation between signal and actual decision is close to 1. The surprising result derived by Bagwell is that the set of pure–strategy Nash equilibria of the noisy–leader game coincides exactly with the set of pure–strategy Nash equilibria of the simultaneous–move game.[1] This implies that whereas the first mover can select his favorite outcome (henceforth called the Stackelberg outcome) if his actions are perfectly observable this is not true in the presence of the slightest imperfection associated with the observation of the leader's choice: The strategic benefit of commitment is lost.

Bagwell (1995) emphasises the use of pure Nash equilibria (although he also derives the mixed strategy equilibria of an illustrating example he discusses). This leads him to summarize his results by claiming that "the first–mover advantage is eliminated when there is even a *slight* amount of noise associated with the observation of the first mover's selection" (p.271).

This neglect of mixed equilibria is criticised by van Damme and Hurkens (1997). They argue that "the restriction to pure strategy equilibria is not compelling and the game theoretic literature has offered no justification for this restriction so far" (p. 284). In their study they show that under certain regularity assumptions each noisy–leader game has an equilibrium in mixed strategies with an associated outcome that converges to the Stackelberg outcome when the noise goes to zero. (Adopting the terminology of van Damme and Hurkens we shall refer to this equilibrium in mixed strategies as the noisy Stackelberg equilibrium.) Furthermore, they propose a new equilibrium selection theory by combining elements from the theory of Harsanyi and Selten (1988) with elements from the theory of Harsanyi (1995). This approach selects exactly the noisy Stackelberg equilibrium. In addition, they provide a number of arguments for why this equilibrium should be viewed as a unique focal point by perfectly rational players.

There are a number of other authors who subsequently generalised and/or extended the result obtained by Bagwell (1995) and van Damme and Hurkens

[1] This holds whenever the second mover's best–response correspondence is single–valued.

(1997). Güth, Kirchsteiger, and Ritzberger (1998), for example, consider general n–player (noisy) Stackelberg games with m ($\leq n$) "leaders" and $n - m$ "followers". Most notably they show that equilibrium outcomes of the simultaneous move game in which leaders play pure strategies remain equilibrium outcomes in sequential games with imperfectly observable commitments but that the converse is not necessarily true. Adolph (1996) adds "trembles" in players' execution of actions to the model of Bagwell. She shows that the unique equilibrium in pure strategies of this double distorted game converges to the unique equilibrium of the unperturbed simultaneous-move game as long as the probability of the noise is small relative to the probability of trembles.

In our study we test experimentally the behavioral relevance of Bagwell's result. In particular, we are interested whether his claim that the first–mover advantage is *eliminated* in the presence of noise holds true in a laboratory. Therefore, we construct a simple 2–person game similar to the example provided by Bagwell. Relying on a between–subjects design we study three treatments—one with perfect observability of the leader's action and two with noisy signals. In all treatments we provide sufficient opportunities for learning. What we find is somewhat devastating for Bagwell's claim and rather supporting the view of van Damme and Hurkens: In both noisy–leader games play converges close to the Stackelberg outcome.

The remainder of the paper is organised as follows: Section 2 introduces the experimental design and presents a game theoretic analysis of the implemented games. In Section 3 we describe the experimental methods and procedures. The results of the experiments are presented in Section 4. Finally, we discuss our findings in Section 5.

2. Experimental design and theoretical predictions

We study a 2–player game which is very similar to the example provided by Bagwell (1995, p. 272). The first mover (or Stackelberg leader) has a binary choice between S and C. Afterwards the second mover (or follower) receives a signal about the decision the leader has taken. The signal is either s or c. For each signal the follower has two choices called S_s and C_s if the signal was s and S_c and C_c if the signal was c. Figure 2 shows the extensive form game for the case of a perfect signal.

The payoffs resemble the payoffs of an asymmetric homogenous market with quantity competition on which the two firms are restricted to choice sets with two quantities only—one pair of quantities being those of the Cournot equilibrium in the unrestricted game where firms can choose from a continuous action space, the

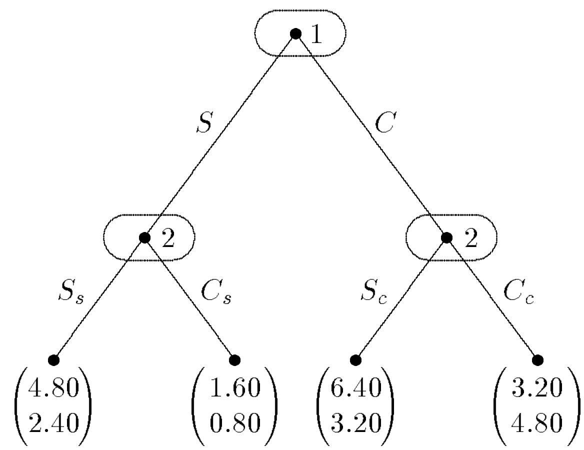

Figure 2.1: The game in case of a perfect signal

other pair of quantities being those of the according Stackelberg equilibrium.

It is worthy to note that the payoffs were chosen such that fairness issues cannot play a leading role: There is no path implying equal payoffs, and both pure equilibrium outcomes are associated with similar degrees of inequality.

We implement three versions of this game each time varying the quality of signals. In treatment No Noise the signal was perfect, i.e. $\text{prob}(s \mid S) = \text{prob}(c \mid C) = 1$. In treatment Low Noise the according probabilities were .99, and in treatment High Noise they were .9. In all treatments the game was played five rounds with full anonymity between subjects and a random matching procedure ensuring that nobody would meet the same opponent twice. For reasons explained below we conducted an additional High Noise session with ten rounds.

The game with zero noise has two pure equilibria, the Stackelberg equilibrium $(S, (S_s, C_c))$ and the Cournot equilibrium $(C, (C_s, C_c))$. Furthermore, there are two continua of mixed equilibria. Of these equilibria only the Stackelberg equilibrium is subgame perfect and therefore selected as the solution of the game. The opportunity of moving first exhibits its full advantage: Provided players are rational and have mutual knowledge of rationality the Stackelberg leader can always achieve his preferred equilibrium.

As Bagwell shows things change dramatically as soon as noise is introduced—even if it is arbitrarily small. If the probability of receiving the correct signal is smaller than 1, only one equilibrium in pure strategies survives, namely the

Cournot equilibrium in which the follower simply ignores his signals and the leader chooses C. The reason for this result is that the follower, if he believes that the leader has taken a certain pure action, can never increase his expected payoff by adapting to the signal. If he believes that the leader has chosen S, he also prefers playing S and if he believes in C, he prefers playing C—in both cases regardless of his signal. In other words adapting to the signal, i.e. playing (S_s, C_c) is no longer a dominant strategy for the second mover.

The pure Cournot equilibrium in the games with noise is accompanied by two mixed equilibria:

$$\text{prob}(S) = 1 - \varepsilon, \quad \text{prob}(S_s) = 1 \quad \text{and} \quad \text{prob}(S_c) = \frac{1 - 4\varepsilon}{2 - 4\varepsilon} \tag{2.1}$$

and

$$\text{prob}(S) = \varepsilon, \quad \text{prob}(S_s) = \frac{1}{2 - 4\varepsilon} \quad \text{and} \quad \text{prob}(S_c) = 0. \tag{2.2}$$

Note that the mixed strategy equilibrium (2.1) converges to the Stackelberg and the mixed strategy equilibrium (2.2) converges to the Cournot outcome as the noise, ε, goes to zero. (In the remainder of this paper the mixed equilibrium (2.2) will be referred to as the noisy Cournot equilibrium.)

In our setup all these theoretical results hold for all rounds: Since interaction is anonymous and one–shot the five rounds are repetitions of static games and not a repeated (or dynamic) game giving rise to further equilibria.

Summarizing the theoretical predictions one should expect

Prediction A Subjects will play the subgame perfect equilibrium in treatment No Noise.

Prediction B1 Most of the outcomes in treatments Low Noise and High Noise will coincide with the Cournot outcome.

Prediction B2 Most of the outcomes in treatments Low Noise and High Noise will coincide with the Stackelberg outcome.

The conflicting predictions B1 and B2 are the core issue of the study at hand. If Bagwell's claim that first movers lose their advantage in the presence of noise is of any behavioral relevance B1 must hold true. If van Damme and Hurkens' result has descriptive power B2 should hold.

3. Method and procedure

The experiments reported in this study were conducted at Humboldt University on January, 21st and 23rd, 1998 and on February, 18th, 1998. One hundred and twenty subjects participated in the first three sessions. Forty subjects were allocated to each of the three treatments. Another twenty–two subjects participated in an additional High Noise session over ten rounds. All subjects of the first three sessions were undergraduates in economics participating in an intermediate micro course. This ensured some familiarity with the notions of backward induction and Nash equilibrium which seemed helpful for making a good comparison between the three treatments.[2]

The experiments were run with pen & paper. Subjects were sitting in large lecture rooms with enough space between seats to rule out any attempts of communication. After receiving the instructions (see Appendix) questions could be asked and were answered privately. Anonymity was assured. Roles were assigned randomly. It was announced that there would be five rounds of the experiment with full feedback between the rounds, that the matching would be random, but that nobody would meet the same opponent twice. The assigned roles were kept fix through the whole experiment.

Sessions lasted between 50 and 75 minutes. Subjects' average earnings were DM 24.97.[3]

The frame of all treatments was identical and as neutral as possible. The game was illustrated by a graph, players were labelled A (first mover) and B (second mover), and choices were simply labelled l(eft) and r(ight) for the first and L and R for the second mover. In treatment No Noise first movers received in each round decision sheets on which they had to note their code numbers and their decisions by entering the appropriate letter into a box. These sheets were then passed on to the followers[4] who had to insert their code numbers and decisions on the same sheet. Thus, they had immediately full information about what happened in the course of their game. Afterwards we collected the sheets again and passed them back to the first movers to inform them about the outcome of the play. Then we collected the sheets again and the next round was started.

In treatments Low Noise and High Noise first movers received a small white sticker and an envelope instead of a decision sheet. They had to write down their decision on the sticker. Then they stuck it on the inside of the envelope and wrote

[2] At least it ensured maximum homogeneity of the three subgroups facing the different noise levels.

[3] Note that subjects in the treatments with noise received an additional flat payment of DM 5 to compensate them for the longer time they had to spent.

[4] It was not observable in which way we allocated the first mover decisions to the followers.

their codenumber on the envelope. After that we proceeded with the chance moves. All subjects carried them out themselves by grabbing numbered chips out of an urn containing 100 chips. Depending on the chosen chip the experimenters wrote the signals on the envelopes which were sealed and collected afterwards.[5] The sealed envelopes were then handed out to the followers who had to write code numbers and decisions on them. When all subjects acting as a follower had made their decisions they were allowed to open the envelopes to learn about the actual decisions of their partners. After collecting the envelopes they were passed back to the leaders in order to inform them about the reaction of the followers. This completed a round.[6]

4. Results

Table 4.1 summarizes the results of the first three treatments. For each round the table shows the total absolute frequencies of first and second movers' decisions. In the following we will first analyse each of the three treatments separately discussing only some comparisons across them. After that, we will focus on Predictions B1 and B2 by comparing the experimental data with both, Bagwell's pure equilibrium prediction and van Damme and Hurkens' mixed equilibrium prediction.

4.1. No Noise

In treatment No Noise all first round decisions are in line with equilibrium play. Seventy five percent of all observations coincide with the subgame perfect Stackelberg outcome, 25% with the Cournot outcome. All followers play best replies. The deviations from the strong prediction of the subgame perfect equilibrium seem to be entirely caused by the five Stackelberg leaders who do not make use of

[5] In treatment Low Noise the second mover got the wrong signal if the chip showed the number 100 otherwise she got the right signal. In treatment High Noise the second mover got the wrong signal if the chip showed the numbers from 91 to 100 otherwise she got the right signal.

[6] The obvious reason for this sticker–envelope procedure was that we wanted to have one physical device containing all information about a particular play. However, this device had to be constructed in a way to ensure that the followers had absolutely no chance to infer the decisions of the leaders by inspecting this device. Hence, the stickers and the envolpe. For the sake of common procedures we could have chosen the same method for No Noise. However, we refrained from doing so because without noise the procedure would have made absolutely no sense in the eyes of any reasonable subject. Therefore, the procedure might have caused suspicions of all kind and biased the behavior in some unreasonable direction.

	No Noise				Low Noise				High Noise			
	S		C		S		C		S		C	
Round	S_s	C_s	S_c	C_c	S_s	C_s	S_c	C_c	S_s	C_s	S_c	C_c
1st	15		5		13		7		7		13	
	15	–	–	5	12	1	1	6	6	1	3	10
2nd	17		3		16		4		10		10	
	15	2	–	3	15	1	1	3	10	–	1	9
3rd	17		3		18		2		9		11	
	15	2	–	3	16	2	–	2	10	1	2	7
4th	14		6		17		3		11		9	
	12	2	1	5	13	3	2	2	11	–	1	8
5th	14		6		19		1		14		6	
	12	2	–	6	18	1	–	1	12	1	–	7

Table 4.1: Summary of experimental results in Sessions 1 to 3.
In the 4th round of session Low Noise one S–decision led to a c–signal. In the 2nd round of High Noise one S and one C produced the opposite signals, in the 3rd round two C's led to s and in the 5th round one S led to c.

their power and choose C. In the second round the number of first movers committing themselves to move S increases by two. In fact, there were three players who had previously chosen C and switched to S, and of the 15 subjects playing S in the first round 14 repeated this choice in the second. Of the followers 18 maximized their monetary payoff, while two preferred to punish leaders who had gone for their preferred equilibrium. One of these two followers continued to do this in all following rounds—he never was matched with a first mover playing C. On the aggregate level third round behavior is the same as in round 2. However, the 17 first movers playing according to the subgame perfect solution in round 3 were not identical with the 17 of round 2. What started to happen in round 3 of this session was—and this is more than a conjecture—that subjects got bored. From observing participants during the experiment it seems fair to say that they perfectly understood the situation after the second round and that they could not quite understand why they were forced to repeat a situation as simple as the one at hand for three further rounds. So some subjects started to do something different than before for the pure sake of doing it which also explains the decreasing number of first movers choosing S after the third round.[7] This is stressed when one looks at individual data over time: Of all 23 C–decisions only three can be justified by bad experiences with move S, i.e. with encounters in which a follower played C_s. In fact, only 9 first movers played S all the time, many of the others switched in later rounds from S to C without any obvious reason besides the one to go for something different. Having some change seemed worth the sacrifice of money.

In all, we see only weak support for Prediction A. Subgame perfect play surely has appeal to the subjects but other motivational forces, let it be boredom or a vague concern for fairness, lead them sometimes to deviate from it as the game is repeated too often.

4.2. Low Noise

Comparing behavior in treatments No Noise and Low Noise we see that the introduction of 1% noise does not have a significant influence on first round behavior. But while there is no convergence of behavior in treatment No Noise (and no convergence to expect if the number of rounds is increased), behavior in treatment Low Noise exhibits not only a clear trend but nearly perfect convergence to uniform behavior. Furthermore, fifth' round behavior of first movers in this

[7] An alternative explanation for Stackelberg leaders switching from S to C could be that they followed some general fairness concern trying to balance their own payoff with the average payoff of their opponents.

treatment is significantly different ($p = .07$, $\chi^2 = 3.12$ (McNemar, two-tailed)) from behavior in the first round. However, in contrast to Bagwell's theoretical prediction play in treatment Low Noise does not converge to the Cournot equilibrium but rather to Stackelberg behavior—a non–pure equilibrium outcome.[8] So the main difference between No Noise and Low Noise is that the introduction of noise keeps subjects more interested: First movers do not get bored by exploiting their advantage—even those playing S in round one continue to do so in all further rounds. Since the structure of the game is cognitively far more demanding than in the absence of noise there is ample room for learning and the envelope procedure ensures a certain kind of thrill keeping subjects attentive: Play converges to the Stackelberg outcome.

4.3. High Noise

While the introduction of 1% noise does only slightly change first round behavior, with 10% noise play starts significantly different from where it started in treatment No Noise ($p = .01$, $\chi^2 = 6.46$ (with regard to first mover behavior)). Note also that the relative frequency of playing Cournot in the first round increases monotonically with the level of noise (25%, 30%, 50%). In fact, the first round data would suggest that Bagwell's result is of empirical relevance provided the noise level is clearly perceptible. However, as soon as subjects gain more experience a markedly different picture emerges: More and more first movers decide to commit themselves to the Stackelberg move S such that in round five the data are no longer distinguishable from the data of treatment No Noise.

The behavior in treatment High Noise exhibits a clear tendency towards the Stackelberg outcome[9] which suggests that—as in treatment Low Noise—play would move closer or even converge to the Stackelberg outcome if subjects were given the opportunity to play more rounds. We therefore decided to run an additional High Noise session, this time over ten rounds. The 22 subjects who participated in this session were also paid every round according to the payoffs given in Figure 2 and choices were again elicited using the above described envelope procedure.

Table 4.3 summarizes the results of the additional 10–round session with noise level $\varepsilon = 0.1$. For each round the table shows the total absolute frequencies of first and second movers' decisions.

[8] Note, however, that the last round data is not too far away from the prediction of mixed equilibrium (2.1).

[9] Behavior in the fifth round of treatment High Noise is significantly different from behavior in the first round of this treatment ($p = .039$, $\chi^2 = 4$ (McNemar, two-tailed)).

High Noise (10 Rounds)									
	S		C			S		C	
Round	S_s	C_s	S_c	C_c	Round	S_s	C_s	S_c	C_c
1st	3		8		6th	8		3	
	5	1	2	3		7	–	–	4
2nd	10		1		7th	8		3	
	8	1	–	2		7	1	–	3
3rd	6		5		8th	9		2	
	4	1	–	6		9	–	–	2
4th	7		4		9th	9		2	
	6	1	–	4		9	–	–	2
5th	9		2		10th	9		2	
	7	–	–	4		7	–	1	3

Table 4.2: Summary of experimental results in Session 4.
In the 1st round three C–decision led to a s–signal. In the 2nd, 3rd and 6th round one S–decision led to a c–signal. In the 5th and the 10th round two S's led to c.

Again most of the first movers choose the Cournot move C in round one.[10] But whereas in the according 5–round session more than one half of the second movers chose action C in this session only 4 out of 11 do so. Hence, not even first round behavior in this session is supportive for pure Cournot–Nash equilibrium play. In the second round the picture changes drastically. Suddenly, all but one first mover choose the Stackelberg action and about three quarter of the second movers react by also choosing the Stackelberg strategy. Interestingly, all of the eight first movers who chose action C in round one switched to action S in round two. This happened although four of the first movers earned the highest possible payoff (6.40 DM) in round one and one could have understood if they had tried it again. However, this is not the end of the learning process. In the third round play moves back into the direction of the Cournot outcome. Now a process similar to the one in Low Noise begins and from the 8th round on play settles down close to the Stackelberg outcome: Only 2 out of 11 first movers choose the Cournot action in the last three rounds. It turned out that these C–decisions in the last rounds stemmed from the same two subjects.[11] Thus, we observe convergence in two respects: not only aggregated play but also individual play has stabilised at the end of this session.

4.4. Bagwell's claim

With regard to Prediction B1 (the hypothesis relying on Bagwell's claim of loss of commitment) we make the following observations:

1. *First round behavior* supports B1, i.e. Bagwell's result seems to be of empirical relevance with regard to inexperienced play in the first round provided the noise level is clearly perceptible (see Tables 4.1 and 4.2).

2. The support for Prediction B1 regarding *aggregated behavior* is rather tenuous (see Table 4.3). First of all the introduction of 1% noise drives the results even closer to the Stackelberg outcome. The relative frequency of the Stackelberg outcome increases from 69% in treatment No Noise to 74% in treatment Low Noise whereas the relative frequency of the Cournot outcome decreases from 22% in treatment No Noise to only 13% in treatment Low Noise. These figures suggest that subjects simply ignore this low

[10] Note that first mover behavior in round one of this session is again significantly different from first mover behavior in round one of the No Noise treatment ($p = .01$, $\chi^2 = 6.46$).

[11] With one exception (round two) these two subjects always chose action C. These subjects' debriefing revealed that they found the action C less risky than action S. In particular by almost always choosing C they avoided to get the worst payoff of 1.60 DM.

No Noise				Low Noise			
S		C		S		C	
S_s	C_s	S_c	C_c	S_s	C_s	S_c	C_c
.77		.23		.83		.17	
.69	.08	.01	.22	.74	.09	.04	.13

High Noise (5)				High Noise (10)			
.51		.49		.71		.29	
.47	.04	.09	.40	.61	.10	.05	.24

Table 4.3: Comparison of outcomes (average proportions across rounds)

level of noise while the envelope procedure keeps them attentive. Without observing convergence in the 5–round session of treatment High Noise the relative frequency of the Cournot outcome in this treatment is higher than in the No Noise treatment. But as soon as subjects have the opportunity to gain more experience, i.e. to play 10 rounds the relative frequency of the Cournot outcome is essentially the *same* as in the No Noise treatment (see Table 4.3).

3. Finally and most importantly, *last round behavior* clearly contradicts the predictions of Bagwell's result: When subjects have enough time to gain experience we observe in both noise treatments, Low Noise and High Noise, clear convergence to the Stackelberg outcome.

It is important to observe that both, first and second movers, violate Bagwell's pure equilibrium prediction. With regard to first mover behavior this is already clear to the naked eye. Moreover, the pure equilibrium predicts that second movers (learn to) ignore their signal and always play the action C. But in all noisy–leader games only in 16 out of 212 cases (7.5%) the action C was chosen by second movers who observed the signal s. After observing action S in the No Noise treatment second movers chose action C in 10.4% of all cases—suggesting that it makes no difference for the subjects whether they observe the *action* S or the *signal* s.

How can we explain these results? The data indicate that subjects do not follow the logic that drives Bagwell's result. Second movers tend to adapt to the signal. This, in turn, is learned by the first movers and encourages them to choose the Stackelberg action. Before we discuss in the next subsection the alternative Prediction B2, i.e. the relevance of the noisy Stackelberg equilibrium, we summarise our findings so far. Most importantly we find

Observation 1. *If first movers' actions are only imperfectly observable the unique equilibrium in pure strategies, i.e. the Cournot equilibrium (as well as the noisy Cournot equilibrium (see (2.2)), is of no relevance in predicting actual play of experienced subjects. Therefore, Prediction B1 is falsified.*

This is the core result of the study at hand. But we find also the following (minor) observations worthwhile to denote:

Observation 2. *Comparing first and last round behavior in each session we find significant differences in the treatments in which first movers actions are only imperfectly observable indicating that subjects go through a learning process while playing the games.*

Observation 3. *Only when the level of noise is high (10%) noise has a significant impact on first round behavior as compared to behavior in the absence of noise.*

4.5. Van Damme and Hurkens's claim

In this subsection we will focus our attention on (2.1) the noisy Stackelberg equilibrium that is selected by van Damme and Hurkens (1997). However, testing the relevance of this equilibrium statistically is difficult within our setup. Whereas we have enough observation of first movers, the number of observations of second movers deciding after the signal c is usually very low.[12]

Nevertheless, with the justified assumption that play has converged in the fifth round of Low Noise and the tenth round of High Noise, we test for last round behavior the hypothesis

$$H_0 : \text{prob}(S) = 1 - \varepsilon$$

[12] One might object that for this purpose we should have used the so–called strategy method by simultaneously asking all players to decide for *every* possible information set. But first of all our experiment was mainly designed to test Bagwell's strong pure equilibrium prediction. Secondly, a recent experimental study by Güth, Huck, and Müller (1998) has cast serious doubt on the validity of results obtained by eliciting choices in a sequential game with the strategy method.

against the alternative hypothesis

$$H_1 : \text{prob}(S) \neq 1 - \varepsilon$$

with ($\varepsilon \in \{.01, .1\}$). These hypotheses concern first mover behavior in the noisy–leader games and are tested by using a two–tailed Binomial test: For both games we cannot reject H_0 in favor of H_1 on a reasonable significance level. Thus, our first–mover data give tentative support to the hypothesis that experienced subjects play the noisy Stackelberg equilibrium.[13] With respect to the second–mover data the support is weaker since we can reject the hypothesis that followers play S_s (after signal s) with probability 1. However, allowing for slight "trembles" in second movers' decisions the hypothesis that they follow signal s by playing S_s with a probability *close to* 1 cannot be rejected. Furthermore, it is not possible to reject the hypothesis that the data stems from subjects using the equilibrium probability $1 - \frac{1-4\varepsilon}{2-4\varepsilon}$ for move C_c after signal c though this is partly due to the rather small number of observations after signal c. We summarize by

Observation 4. *Prediction B2 cannot be falsified for experienced players; subjects might indeed have converged to play the noisy Stackelberg equilibrium in the last round.*

5. Discussion

Models in which agents can commit themselves to an action before others do and, therefore, may have a strategic advantage are widespread in economic theory. It was already pointed out by Schelling (1960) that one of the requirements of such commitments to be of any value is that they can be reliable communicated to players who move on later stages in the game. Bagwell (1995) impressively demonstrated how important the reliability of the communication channel is if these games are played by rational players. Concentrating on the use of pure strategies he showed that the first mover advantage is lost if actions made at the first stage of the game are only imperfectly observed by a player moving at the second stage. Even more surprisingly, this result holds if there is only the slightest amount of noise associated with the observation of actions taken by the first mover.

In order to test the behavioral relevance of this result experimentally we implement three versions of a simple two–person sequential–move game that can be viewed as a mini–Stackelberg game with quantity competition on an asymmetric

[13] Alternatively, one could say that the shares of individuals playing one of the two pure strategies may be viewed as resembling the shares predicted by the noisy Stackelberg equilibrium.

homogeneous market. These versions varied in the quality of the signal that the second mover received about the action taken by the first mover. Moreover, subjects played these games often enough to have ample opportunities for learning. Our main results are: (1) Subjects who act as first movers do not always make use of their power when actions are perfectly observable. (2) When the quality of signals is nearly perfect (99 %) play almost completely converges to the Stackelberg outcome. (3) When the quality of signals is low (90 %) play starts far away from the Cournot outcome and clearly moves in the direction of the Stackelberg outcome in a five–round session and settles down close to the Stackelberg outcome in another ten–round session.

The explanation for results (2) and (3) is straightforward. Second movers tend to identify the signal they receive with the action taken by first movers' and mostly play a best response against the assumed action. This is most easily seen if one looks at second movers' decisions after receiving the signal that indicates the Stackelberg action: The bulk of second movers replies with the Stackelberg action and not, as the pure strategy equilibrium predicts, with the Cournot choice. First movers, in turn, learn or anticipate this behavior of second movers and are thus encouraged to commit themselves to the Stackelberg action. Since most of the time the signal coincides with the action taken by first movers play is driven closer and closer to the Stackelberg outcome.

Our main conclusion is that first movers in experimental games do not lose their commitment power in the presence of noise. Rather subjects seem (to learn) to play the noisy Stackelberg equilibrium as predicted by van Damme and Hurkens—the equilibrium which is preferred by the first mover. This finding seems to be related with the observation that the physical timing of decisions may serve as an equilibrium selection device enabling the party who comes first to score best.[14] However, to test this hypothesis rigorously one will need a larger data set with more decisions in both possible information sets of second movers. As mentioned above such a data set might be extremely difficult to obtain since simply increasing sufficiently the number of subjects may well be beyond every obtainable budget and relying on the so–called strategy method which economizes on subjects may significantly alter the behavior in a sequential game like this.[15]

Of course, investigating the mixed equilibrium hypothesis is not the only option for future experimental research in this area. With respect to markets it would also be worthwhile to compare simultaneous games and sequential games with and without noise in settings with larger action spaces, e.g. by relying on

[14] For studies dealing with behavioral effects of (game theoretically irrelevant) physical timing see e.g. Rapoport (1997).

[15] Compare Güth, Huck, and Müller (1998).

standard Cournot, respectively Stackelberg oligopolies.[16] While in our setup first movers gain–after a phase of learning–nearly full commitment power in the presence of noise, it might well be that when strategy spaces are larger play converges to outcomes somewhere in between the Stackelberg and Cournot predictions. However, that commitment power is totally lost on markets like that seems in the light of our result very unlikely.

References

[1] Adolph, B. (1996): Commitment, Trembling Hand Perfection and Observability in Games, *Discussion paper No. 84*, Sonderforschungsbereich 373, Humboldt–University Berlin.

[2] Bagwell, K. (1995): Commitment and Observability in Games, *Games and Economic Behavior,* **8**, 271-280.

[3] Güth, W., Huck, S., and Müller, W. (1998): The Relevance of Equal Splits: On a Behavioral Discontinuity in Ultimatum Games, *Discussion paper No. 7*, Sonderforschungsbereich 373, Humboldt–University Berlin.

[4] Güth, W., Kirchsteiger, G., and Ritzberger, K. (1998): Imperfectly Observable Commitments in n–Player Games, *Games and Economic Behavior,* forthcoming.

[5] Harsanyi, J. C. (1995): A New Look at Strategic Rationality: At Equilibrium Selection, Risk Dominance and Payoff Dominance, *Games and Economic Behavior,* **8**, 91-122.

[6] Harsanyi, J. C., and Selten, R. (1988): *A General Theory of Equilibrium Selection in Games*, Cambridge, MA: MIT Press.

[7] Levine, D. K., and Martinelli, C. (1998): Reputation with Noisy Precommitment, *Journal of Economic Theory,* **78**, 55 - 75.

[8] Rapoport, A. (1997): Order of play in strategically equivalent games in extensive form, *International Journal of Game Theory* 26, 113 - 136.

[9] Schelling, T. (1960): *The Strategy of Conflict*, Cambridge, MA: Harvard University Press.

[16] See for example Levine and Martinelli (1998) who study the noisy-signal technology in a richer environment theoretically.

[10] van Damme, E., and Hurkens, S. (1997): Games with Imperfectly Observable Commitment, *Games and Economic Behavior,* **21**, 282-308.

[11] von Stackelberg, H. (1934): *Marktform und Gleichgewicht*, Springer Verlag, Vienna and Berlin.

Appendix

Translated Instructions

Read this sheet carefully. In case of questions, give notice! We will then come to you and answer them privately.

Welcome to our experiment, in which you can earn some money—depending on your decisions and the ones of randomly chosen other participants. The rules are quite simple. Look at the following decision tree:

[Figure of decision tree, similar to Figure 2 with the exceptions that players are labeled "A" and "B", resp., and that player 1's actions are labeled "l" and "r" and player 2's "L" and "R".]

First, A decides between "l" and "r". Then, before making his own choice, B is informed about the decision of A.

This ¶ only in noise treatments.

This information is only partially reliable. This is because it is determined by chance whether B receives the correct information or the or a wrong one. This works as follows: After A has made his decision, we take a random draw out of 100 chips. These chips are numbered from 1 to 100. If A draws one of the first 99 [90] chips, B will receive the correct information about A's decision. This means that if A has chosen "l" (respectively "r"), we will tell B that A has chosen "l" (respectively "r"). If A draws the chip with the number 100 [a chip with a number from 91 to 100], B receives an incorrect information. This means that if A has chosen "l" (respectively "r"), we will tell B that A has chosen "r" (respectively "l"). After B has received the information about A's choice, he has to make his decision. This means that B has to decide between "L" and "R". The real decision of A (which, as explained above, need not necessarily be identical with the one transmitted to B) and the decision of B determine the payoffs.

There are four possible cases:

A chooses "l", B chooses "L": In this case A receives 4,80 DM and B receives 2,40 DM.

A chooses "l", B chooses "R": In this case A receives 1,60 DM and B receives 0,80 DM.

A chooses "r", B chooses "L": In this case A receives 6,40 DM and B receives 3,20 DM.

A chooses "r", B chooses "R": In this case A receives 3,20 DM and B receives 4,80 DM.

This ¶ only in noise treatments.

The procedure is as follows: A writes his decision whether to choose "l" or "r" on a little sticker. Then he sticks the sticker on the inside of an envelope, without closing it. After the random draw has decided about the information to be transmitted to B, we write the according information on the envelope and close it. Then each envelope is given to a randomly chosen B. B receives the envelope and writes his decision on it, without opening it. Finally, all envelopes are collected by the experimenters.

This is the end of the first round of the experiment. After this there will be four [nine] further rounds, in each of which you will be randomly matched with a different participant. We will ensure that you will be matched with five [ten] different participants during the five [ten] rounds.

This ¶ only in the treatment without noise.

The decisions are marked on a separate decision sheet, which we are going to hand out to all participants with the role A in a moment. A indicates on the sheet the alternative he chooses. After this the experimenters hand the sheet to a randomly selected B. Knowing the decision of A, B makes his decision.

After each of the five [ten] rounds all participants are informed about the outcome of their round.

To guarantee anonymity you receive a code number. Please keep your code card carefully, because you will only obtain your payoff, when showing this card. In addition to this, the code number ensures your anonymity towards us and the participant you are matched with.

Your total payoff is the sum of the single payoffs of the five rounds. In addition to this you will receive DM 5 [DM 10] independent of the outcome of the rounds.

You have the role A [B].