The Effect of Monetary Feedback and Information Spillovers on Cognitive Errors: Evidence from Competitive Markets

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Abstract

A vast literature shows that individuals frequently violate normative principles in reasoning. In evaluating the relevance of these findings for psychology, economics, and related disciplines, it is natural to ask whether reasoning errors reflect random aberrations or systematic biases. One straightforward way to approach this question is to test their persistence at the aggregate level. In this paper, we report results of four studies designed to determine if information dissemination in competitive auctions can reduce, or even eliminate, logical errors in the Wason selection task. Our results show that payoff feedback and exposure to the information flow drive the aggregate behavior toward the normative solution. We also found evidence of spillover effects from informed to uninformed traders in one-sided combinatorial auctions as well as positive transfer effects from competitive to individual settings. We discuss the implication of our results for future research at the interface of psychology and economics.

Keywords: Deductive reasoning, Experimental markets, Wason selection task, Combinatorial auctions, Double auctions, Reasoning errors

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Introduction

Over the last decades, a vast literature has emerged indicating that individuals frequently violate basic normative principles of rational and logical behavior. These studies involve principles of judgment under uncertainty (Gilovich, Griffin and Kahneman, 2002), rational choice (Kahneman and Tversky, 2000), and logical reasoning (Oaksford and Chater, 1998).

The impact of this line of work goes well beyond cognitive psychology. Work on biases in judgment, bounded rationality in decisions, and imperfect cognitive reasoning can be found in many other disciplines. For example, political scientists are concerned with the effects of biases on voting behavior and performance of committees (Quattrone and Tversky, 1988), and legal scholars are interested in their consequences for jury deliberations (Hastie, 1995) and legal decision making (Sunstein, 2000). Similarly, research in finance, economics, and marketing is concerned with the effect of some of these biases in the context of asset pricing (Hirshleifer, 2001), labor supply (Camerer, Babcock, Loewenstein and Thaler, 1997), and online bidding (Ariely and Simonson, 2003).

An intriguing question is whether, and if yes to what degree, these individual-level shortcomings matter at the aggregate level. This question is especially relevant for economic decisions that are often made in institutional settings that by design are expected to elicit truthful judgments, and to induce and reinforce optimal rational decisions. Thus, it is important to ask whether individual biases in judgment and fallacies of reasoning prevail and survive in institutional settings.

The purpose of this paper is three-fold: We investigate whether reasoning errors that are a reliable feature of individual behavior also persist in competitive environments that offer direct financial incentives. Second, we explore the interface between individual behavior, which is the focus of the psychological work on judgment, reasoning, and decision making, and its aggregate counterpart, which is the focus of most economic research. In particular, we seek to understand which factors of competitive auctions may cause some of these errors to diminish or disappear. Finally, we look for spillover effects of auctions by studying whether they lead to positive transfer effects on individual behavior.

To this end, we embed the Wason selection task in the context of competitive markets and auctions. This task (to de described in detail later) was chosen because it has been studied extensively (Evans and Over, 1996, p.356 refer to it as "the single most investigated problem in the psychology of reasoning"), and because only a small minority of people answers it correctly, providing ample opportunity for potential improvement. We investigate how much, and what type of, information is necessary to improve reasoning at the aggregate and individual level. The experiments are designed to allow us to contrast the effect of providing participants with period-by-period payoff feedback and experiencing the information flow in the auction.

The paper proceeds with a discussion of previous empirical evidence on the persistence of violations of normative principles in markets and with an introduction to the Wason selection task. Section 2 covers the four experimental studies, and in section 3 we summarize and discuss our main findings.

Individual biases and the market

Markets allow participants to engage in exchange relations typically involving physical goods and property rights. More importantly for the purpose of the present work, they also provide an efficient mechanism for dissemination of information to traders, and information aggregation across traders. The strong form of the efficient market hypothesis, one of the cornerstones of standard finance theory, predicts that all information, public or private, is fully reflected in market prices (Fama, 1970).

Empirical evidence, indeed, shows that markets, especially those using double auctions, *can* be informationally efficient (Sunder, 1995). Plott and Sunder (1982) report an experiment involving a market with three types of traders, whereby each could obtain one of two possible dividends, depending on an exogenously determined state of the world. Although only half of the traders were informed about the realized state, the prices on the market approached the theoretical predictions of rational expectations over repeated trading periods, evincing that information dissemination is attainable.

Laboratory experiments also confirmed that information can be aggregated efficiently. In another study by Plott and Sunder (1988) dividends could take three discrete values contingent upon the state of nature (X, Y, or Z). Traders received diverse, but imperfect, information about the state of the world prior to market opening. For example, in state Z half of the subjects were informed that the current state of nature was not X, and the other half was informed that it was not Y. If information is aggregated efficiently, all the traders should realize that the true state is Z, and act accordingly. The results supported this prediction.

Because of their effectiveness in disseminating and aggregating information, markets have also been used as forecasting instruments. Forsythe, Nelson, Neumann, and Wright (1992) have shown that political stock markets perform reliably and accurately, and similar results were reported for sport events (Schmidt and Werwatz, 2001), winners of entertainment awards (Pennock, Lawrence, Giles and Nielsen, 2001), box office returns for movies (Spann and Skiera, 2003), potential sales (Chen and Plott, 2002), and market shares for prototypes (Chan, Dahan, Kim, Lo and Poggio, 2002).

Experimental markets have emerged as important tools in empirical studies at the interface of psychology and economics. One natural way to study the relevance of individual biases and errors is by testing their persistence at the aggregate in competitive markets. Most previous research has focused on subjective probability judgments. Plott and Wilde (1982), Duh and Sunder (1986), and Camerer (1987) investigated whether asset prices in competitive markets are in line with Bayesian updating or the

representativeness heuristic (Kahneman and Tversky, 1972). In Camerer's study (1987), for example, participants were informed that assets pay state-dependent dividends, and the probabilities were represented by bingo cages, with various compositions of red and black balls. Participants were publicly informed about the prior distributions, and were confronted with a sample of three balls, which was drawn (with replacement) from one of the bingo cages. Based on the priors and the sample, predictions for asset prices can be derived from a variety of competing hypotheses, e.g. Bayesian updating, representativeness, etc. The general conclusion from these studies is that prices approach the Bayesian prediction,[1] but the deviations from this norm are consistent with the representativeness heuristic (Camerer, 1995).

The convergence of market prices to (or close to) the theoretically predicted level can be ascribed to two, presumably distinct but not independent, processes: learning based on payoff feedback and, auxiliary, based on the information flow in the market. These two sources of information are typically confounded in most market environments where information flow compliments and amplifies the direct effect of payoff feedback. A recent survey of regular eBay bidders indicates that the information flow itself may be pivotal in interactive settings, since bidders seem to place their bids strategically to keep prices down and to avoid sharing valuable information with others (Roth and Ockenfels, 2002). Market participants try to control the information flow, for example, by informing only a subset of traders on the market about trading offers (Kirchsteiger, Niederle and Potters, forthcoming).

The Wason selection task

The task was designed to test whether individuals employ the normatively correct strategy of formal logic in testing conditional rules. In the original setting (Wason, 1966), participants are shown cards, each with a letter (vowel or consonant) on one side and a number (even or odd) on the other side. The participants' task is it to verify a conditional rule of the form "if p, then q," more precisely "if there is a vowel (p) on one side of the card, then there is an even number (q) on the other side," by selecting the minimal number of cards that must be turned over to decide whether the rule is true or false. Four cards are presented to the participants who can only see one side of each card: one showing E (p-card), one K (not p-card), one 2 (q-card), and one 7 (not q-card). The correct solution involves (a) verifying the truthful implication of the rule by turning over E (p-card), and (b) examining possible violations of the rule by turning over 7 (not q-card). However, only a small fraction (typically around 10%) of the participants selects the two required cards (Griggs and Cox, 1983; for a recent review on much of the literature on the Wason selection task see Nickerson, 1996). Most people select the p-card, but fail to select the not q-card (failure to apply modus tollens), and frequently select the q-card (affirming the consequent) instead.

The present studies

The failures to apply the modus tollens and the spurious affirmation of the consequent have been replicated in numerous studies, but very little is known about the impact of institutional settings on reasoning. We address this question by studying the Wason selection task in competitive auctions.

We focus on two factors that might affect the market's performance: the provision of individual payoff feedback and the information flow generated by the traders. The two variables are varied systematically in a series of four studies. Study I examines the impact of different kinds of payoff feedback on trading behavior. Participants obtain individual payoff feedback at the end of each trading period. In study II, we do not provide payoff feedback. This allows us to study whether behavior is affected by mere exposure to the information flow of the market. Finally, in studies III and IV participants are not presented with individual payoff feedback, but a fraction of them is explicitly informed about the correct solution to the task.[2] This manipulation allows us to study possible informational spillovers between differently informed participants. In each of these studies, we compare the individual behavior in the selection task with various summary measures of the trading activity in the competitive auction, such as the transaction prices of the various cards.

Method

2. General Method

Each of the four studies comprises two stages. In the first stage, participants are asked to solve the selection task individually, whereas in the second stage they participate in competitive auctions. Next we will describe the common features of the experimental design, which was implemented in all four studies. The specific details of each of the studies will be explained in the corresponding sections later.

In the first stage, we used an abstract representation in all four studies, and an additional deontic version in study II.[3] For the abstract representation we used the standard target rule: "If there is a vowel on one side of the card, then there is an even number on the other side." Participants were confronted with four cards, but only one side of the cards (A, K, 2, 7) was shown. In study II, we also used the deontic version: "If a salesperson gets a bonus, he/she must have sold more than 125 units." The four cards displayed showed "bonus," "no bonus," "more than 125 units sold," and "less than 125 units sold." Participants were asked to select the minimal number of card(s), which must be turned over to test the target rule. Only if participants picked the correct cards, a payoff of €4 was granted and paid out at the end of the experiment. After subjects completed this short task individually, they participated in the competitive auction, the second stage of the experiment.

2.1 Results: Individual behavior in the Wason selection task

Table 1 displays the correct solution rates based on the 392 subjects who participated in all the studies (see details about the participants in subsequent sections). They ranged from 6.90% in study IV to 16.67%

in study I. The overall solution rate across studies was 12.50%, which closely corresponds to the percentage of 10% reported by Griggs and Cox (1983). Contrary to previous studies, the deontic representation of the Wason selection task did not improve the quality of solutions.

<div align="center">Insert Table 1 about here</div>

We do not observe significant differences in solution rates across the four studies and the two representations of the task ($\chi^2(4)=5.37$, $p>.05$), the frequency of choices of each of the four cards ($\chi^2(9)=7.49$, $p>.05$), and the frequency of individual card choices for the three most popular patterns (i.e., cards I and III; card I; cards I and IV) and the remaining cards in the abstract representation ($\chi^2(9)=10.54$, $p>.05$). Therefore, we can compare the results of the different market designs unambiguously: If we find differences between the auctions, they can be attributed to our experimental manipulation.

2.2 Study I

2.2.1 Experimental design and procedure

Ninety-six undergraduate students participated in 12 experimental markets, which were conducted at the Max Planck Research Lab in Jena, Germany. Fifty-one females and 45 males, aged 20 to 53 (M=24.31, SD=4.11), participated in the study.

After participants completed the individual Wason task, they were explained the functioning of the market in great detail. Understanding of the trading mechanism was tested using a short quiz. The experiment started only after all the participants answered correctly all the items of the quiz. Subjects participated in two training markets that lasted four minutes each. Afterwards the actual experimental market that included 16 trading periods with eight traders was opened. In the market participants could trade the four cards of the Wason selection task simultaneously in a continuous anonymous double auction, implemented with the software z-Tree (Fischbacher, 1999).

At the beginning of each period, subjects were endowed with 120 Experimental Currency Units (ECU),[4] and with four cards of the same type (i.e. card I, II, III, or IV). Two subjects in each market were endowed with the same type of card. Thus, in each trading period there were a total of eight cards of each type available for trade. Card endowments were counterbalanced across periods, so that each subject was endowed with each card type four times over the course of the experiment in a pre-specified balanced order.

The subjects' task was to select the minimal number of card(s) to be turned over to test whether the target rule is true or false. Participants were told that if they believe certain cards are part of the correct solution, they should strive to acquire them in the market. Correct cards paid out dividends of 40 ECU. Assume, for example, that at the end of a trading period a hypothetical subject holds three cards of type I, two cards of type III, and five cards of type IV. In this case, the subject held three complete sets of the correct cards (I and IV). Thus, the payoff would have been 3 (sets) * 2 (cards) * 40 ECU. The total

earnings of this hypothetical subject in this particular trading period would therefore have been 240 ECU plus her cash holdings.

Trading periods lasted 180 seconds. Participants could either submit bids and asks or accept standing bids and asks by other market participants. Only improving offers, i.e. higher bids and lower asks, were allowed. Participants were neither granted credit nor allowed to sell cards short. After each new entry by one of the participants, the bids and asks were ranked, and the best offer for potential buyers and sellers was constantly highlighted. Participants were also provided with a chronological list of all the trades concluded, and were informed about the remaining trading time. Figure 1 displays the schematic screen-shot of the auction. At the end of each trading period, participants were informed about their cash and card holdings.

<u>Insert Figure 1 about here</u>

In six markets (n=48), traders were informed about the dividends associated with each card they possessed (strong-feedback condition), whereas in the other six markets (n=48), they were only informed about the total sum of their dividends across all their cards (weak-feedback condition). After the last market period, participants were asked to solve again the standard Wason task (abstract form) individually.[5] Correct choices were rewarded with €4. At the conclusion of the study, participants received their earnings from stages I and III together with their dividend payments and cash holdings from one (randomly selected) period of stage II. Experimental sessions lasted about two hours and participants earned on average €22.51 (SD=8.19).

2.2.2 Results

We analyze three variables that represent market behavior:

(1) Trading prices --- the amount (in ECU) at which successful trades were completed.

(2) Trading volume --- the number of successful trades.

(3) Total demand --- the sum of bids (in ECU) submitted to the market.

Since all these market variables depend on the behavior of all eight participants in any given market, the unit of statistical analysis is the market, rather than the individual participant. Figure 2 plots the trading prices of the four cards under the two conditions.[6] It appears that the divergence of trading prices for correct cards from incorrect cards across periods is more pronounced in the strong-feedback treatment as compared to the weak-feedback treatment. However, results of preliminary analyses failed to detect any systematic changes across the 16 periods so, for the purpose of the primary analyses, the values of the dependent variables were averaged across all the periods of the market. The results of a 2-way mixed ANOVA with the between-subjects factor "feedback" (strong versus weak feedback) and the within-subjects factor "card" (I, II, III, and IV) reveal a significant main effect for card ($F(3; 30)=22.65$, $p<.05$, $?^2=.90$), but neither a main effect for feedback nor an interaction effect. Tukey's HSD post-hoc

tests (at the .05 level) show that trading prices for card I exceeded the prices for cards II, III, and IV. Also, cards II and III were traded at significantly lower prices than card IV.

<div align="center">Insert Figure 2 about here</div>

A 2-way ANOVA of the trading volume found a significant main effect for card ($F(3; 30)=78.53$, $p<.05$, $?^2=.97$), but neither a main effect for the feedback condition nor an interaction effect. The post-hoc tests indicate that trading volume for card I exceeded the trading volume for cards II and III, and cards II and III were traded at significantly lower volumes than card IV (all tests $p<.05$).

Next we study the total demand for the specific cards. Given that participants could not withdraw bids, this is probably the most direct measure of the participants' perception of the correct solution. The results of an ANOVA indicate a significant main effect for card ($F(3; 30)=47.93$, $p<.05$, $?^2=.95$) as well as a 2-way interaction between card and feedback ($F(3; 30)=14.50$, $p<.05$, $?^2=.85$). In general, the demand for cards I and IV, which make up the correct solution to the problem, was higher than the bids for the incorrect cards, but the differences are not uniform in the two experimental conditions. They were more pronounced in the strong-feedback ($M_I=892.75$ and $M_{IV}=694.75$ vs. $M_{II}=132.25$ and $M_{III}=155.50$) than in the weak-feedback condition ($M_I=637.67$ and $M_{IV}=475.08$ vs. $M_{II}=102.08$ and $M_{III}=200.25$).

Post-market individual task: To examine the effects of the market and its feedback, we compared the rate of correct solutions before and after the market. Originally, only 16 of the 96 subjects (17%) solved the problem correctly but, eventually, 67 participants (70%) selected the correct cards after being exposed to information flow and feedback of the market (McNemar-test: $?^2(1)=46.02$, $p<.05$).

To establish whether this striking difference between pre- and post-market performance is related to the auction stage, we performed a 2-way ANOVA of the dividends accumulated by the participants across all periods with feedback and post-market solution (correct vs. incorrect) as independent variables. We found a significant main effect for solution ($F(1; 92)=31.58$, $p<.05$, $?^2=.26$), indicating that participants who eventually solved the task correctly earned much higher dividends on the market ($M=73.12$ with $SE=4.89$) than those participants who did not identify the correct solution ($M=20.78$ with $SE=7.93$).

2.2.3 Discussion

This experiment shows unequivocally that individual biases and limitations can be rectified, at least in part, by a market institution that provides swift individual payoff feedback. Although only one-sixth of the participants solve the problem correctly and card III is selected (by itself or in combination with card I) much more often than card IV, all the market variables paint a different picture. People are bidding more, and more often, for card IV than for card III and, consequently, this card is traded at higher prices. In other words, the cards that make up the right solution are valued by the market more than those that are

not part of the solution, even though a vast majority of the participants failed to make this distinction initially!

This illustrates the operation of Adam Smith's "invisible hand": Individuals who operate with the sole purpose of maximizing, or at least increasing, their profits (dividends) caused the right solution to emerge at the aggregate level without communicating directly and without invoking any explicit coordination mechanism. An external observer of the market would, undoubtedly, infer that cards I and IV are the desirable commodities that pay dividends and make up the correct solution to the puzzle.

Furthermore, the post-market task documents an impressive level of transfer from the market to individual performance: A good majority of the subjects who failed to solve the task individually, managed to learn the correct solution based on their experience on the market. This powerful effect is due to the feedback provided by the market to the traders. Evidently, presenting traders with immediate feedback (even in the weaker form) was sufficient to shape their behavior and cause them to focus on the cards that make up the correct solution.

The feedback consists of two components: the payoffs associated with, and reported at the conclusion of, every period of trade, and the revelation of the other participants' preferences and values that can be extracted from observing their bids and asks, and the trades that take place. The first study shows that when both mechanisms operate the market can identify the correct solution. In the next study, we withhold the period-by-period monetary feedback in order to test whether mere exposure to the information flow on the market is sufficient to induce a similar pattern of trading behavior.

2.3. Study II

2.3.1 Experimental design and procedure

One hundred twenty-eight undergraduate students participated in 16 experimental markets, which were also conducted at the Max Planck Research Lab in Jena, Germany. Seventy-five females and 53 males, aged 19 to 35 (M=22.8, SD=2.45), participated in the study. Experimental sessions lasted about two hours and participants earned on average €12.31 (SD=5.37).

The basic market set-up employed in study II is identical with the one of study I. This time, however, we use a 2 x 2 design varying (a) the context of the individual Wason selection task (abstract versus deontic representation) and (b) the sequence of types of cards traded in the first (and second) half of the trading periods: In sequence *AD*, participants traded abstract cards in the first half of the markets and deontic cards in the second half. In sequence *DA*, the order was reversed. Also, in the pre-market stage half the individuals solved the abstract version of the task and the other half faced the deontic version. Each experimental condition consisted of four markets with a total of 32 participants. Participants were not given payoff feedback at the conclusion of trading periods.

2.3.2 Results

We analyzed the market variables in 4-way mixed ANOVAs with the two within-subjects factors "context" (abstract, deontic) and "card" (I, II, III, and IV), and the two between-subjects factors "context of the individual task prior to the market" (abstract, deontic) and "sequence of markets" (abstract-deontic=*AD*, deontic-abstract=*DA*). In the analysis of the trading prices, we found no significant effects for the two between-subjects factors, and no significant interactions involving these factors. The average trading prices in the various within-subject conditions are depicted in Figure 3. There was a significant main effect for context ($F(1; 12)=5.55$, $p<.05$, $?^2=.32$), suggesting that the average prices for deontic cards exceeded the prices for abstract cards. There was also a significant difference between the four cards ($F(3; 36)=6.84$, $p<.05$, $?^2=.67$). Tukey's HSD post-hoc tests (at the .05 level) indicate that trading prices for card I were higher than for cards II and IV.

Insert Figure 3 about here

A similar 4-way ANOVA of the average trading volume yielded identical results. In the ANOVA of the total demand we found a significant main effect for card ($F(3; 36)=19.94$, $p<.05$, $?^2=.86$) as well as a 3-way interaction between context, card, and trading sequence ($F(3; 36)=4.33$, $p<.05$, $?^2=.57$). A follow-up analysis suggests that this interaction is due to the differential trading sequence between conditions.

2.3.3 Discussion

This study was designed to test whether mere exposure to the behavior of market participants, in the absence of monetary feedback, is sufficient to rectify individual reasoning errors at the aggregate. The empirical results are crystal clear: When the period-by-period payoff feedback is eliminated, most market variables reflect quite closely the misperceptions and biases that characterize the behavior of the individuals who populate the market. In sharp contrast to the results of study I, the traders are bidding less, and more rarely, for card IV than for card III suggesting that the market fails to identify the critical importance of the non q-card to the solution of the problem. The obvious interpretation of these results is that immediate payoff feedback is necessary, whereas the information flow generated by those traders who know the correct solution is not sufficient to cause the market to mirror the correct cards.

Before endorsing this conclusion, we need to acknowledge two caveats. The first relates to our experimental design. In this study, we manipulated the context of the problem (abstract vs. deontic) within groups. On average, the deontic cards traded for more, possibly indicating that people may have been more comfortable with this format of the problem. We also uncovered a 3-way interaction involving the context in the analysis of total demand. We do not have a simple explanation for this interaction, nor for the fact that it was observed only for *one* market variable, but its presence suggests that conclusions about the effects of the information flow must be carefully qualified.

The second, and more important, reservation concerns the nature of the information available to the traders. The efficiency of markets likely depends on the existence of a (possibly small) core of rational traders whose behavior can affect the rest of the market directly through their trading behavior, and/or indirectly through imitation by others. However, in five of the 16 markets there was not even one person who solved the problem correctly in stage I, and in eight markets only one person solved it correctly.

We designed a third study in which we address these problems. We focus again (as in study I) on the abstract representation of the task. More importantly, we manipulate directly the amount of information available to the traders by informing a subset of them about the correct solution. We refer to this subset as the "informed" traders or "insiders." Thus, the goal of study III is to test whether the effect of the information flow on the market's behavior depends on the size of the rational core of traders.

2.4 Study III

2.4.1 Experimental design and procedure

Ninety-six undergraduate students participated in 12 experimental markets, which were also conducted at the Max Planck Research Lab in Jena, Germany. Sixty-two females and 34 males, aged 19 to 52 (M=23.31, SD=4.12), participated in the study. The experimental sessions lasted about two hours and participants earned, on average, €15.04 (SD=6.92).

Study III was identical to study II in most respects. However, there were two major changes in the design: (a) In this study, we only used the abstract representation of the task. Thus, each market consists of 16 periods. (b) We introduced and manipulated the number of informed market insiders (0, 1, 2, and 4). Each experimental condition consisted of three markets of 24 participants each.

It was ensured that those participants who solved the task correctly in stage I were assigned the role of insiders. The remaining insider roles were filled randomly with other participants. Insiders were informed about the correct solution to the Wason selection task at the beginning of each trading period. Naturally, they maintained their informed status throughout the experiment. Participants were also informed that not all subjects might have received identical information, so they did not know if, and how many, informed participants were on the market.

2.4.2 Results

We analyzed the trading prices in a 2-way mixed ANOVA with the within-subjects factor "card" (I, II, III, and IV) and the between-subjects factor "number of insiders" (0, 1, 2, and 4). Figure 4 displays the average trading prices of the four cards in the various groups. We found a significant main effect for card ($F(3; 24)=10.00$, $p<.05$, $?^2=.83$), but neither a main effect for the number of insiders nor an interaction effect. Tukey's HSD post-hoc tests (at the $p=.05$ level) show that trading prices for card I were higher than for all other cards and prices for card IV exceeded those of card II. We applied similar 2-way ANOVAs to the trading volume and demand and found identical results.

Insert Figure 4 about here

Although the interaction of card and condition was not significant, in the presence of two or four insiders, the non q-card (card IV) was traded at higher prices and at higher volume than the q-card (card III). This observation is supported by the results of an additional 2-way ANOVA on trading prices. For this analysis, we aggregated the prices of the cards that are part of the correct solution (card I and IV) and those that are not (card II and III) by computing the weighted averages with respect to the number of trades for either category. In addition, we combined the groups with zero and one insider(s), and compared them to the groups with two and four insiders. The results show an interaction effect between (correct and incorrect) cards and the number of insiders ($F(1; 10)$=5.38, $p<.05$, $?^2$=.35). As expected, we find that average trading prices for correct cards are higher (M_C=44.79, SE=2.29), and prices for incorrect cards are lower (M_I=27.08, SE=3.59), when at least two insiders are present in the market than in the group with fewer insiders (M_C=37.27, SE=2.29 and M_I=30.69, SE=3.54 respectively).

Comparison of insiders to outsiders: The impact of insiders on market behavior becomes most evident if one analyzes the nature and frequency of the transactions. Table 2 summarizes the frequency of trades involving cards that are part of the solution (I and IV), as a function of the information status of the seller and of the buyer. The table presents the ratio of observed to expected number of trades[7] for those cards that are part of the correct solution. Ratios above (below) 1 indicate more (less) trades than expected by purely random matching. The last column of the table presents a likelihood ratio G^2-test of the hypothesis that the observed frequencies match the expected ones. All the tests are significant (compared to a $?^2$ distribution with three degrees of freedom), but these values should be interpreted with caution, since the assumption of independence is not met.

Insert Table 2 about here

First, note that insiders trade correct cards among themselves (I-I) more frequently than expected, while outsiders trade these cards among themselves (O-O) less frequently than expected. This behavior on part of the insiders makes perfect sense since subjects were initially endowed with cards of one type, and they knew that dividends were paid only when the correct cards are held in equal proportions. Thus, even if a participant holds part of the correct set she nevertheless had to engage in trading to acquire the missing card. Second, in those transactions involving the two types of participants, insiders tend to buy correct cards from outsiders at rates exceeding expectation, but the opposite pattern is very rare. Both trends hold for all experimental conditions.

The results show that insiders benefit from their informational advantage: Informed participants accumulated average dividends of 1,123.81 ECU (SE=133.45), whereas the corresponding average dividends for uninformed subjects were only 419.20 ECU (SE=70.61). This difference is statistically significant ($F(1; 94)$=21.78, $p<.05$, $?^2$=.53), and can be attributed directly to the informational advantage,

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rather than to superior trading skills. There was no significant difference between informed and uninformed participants with respect to trading profits, i.e., market insiders did not profit more from selling their cards than uninformed participants.

Do outsiders learn from the actions of the insiders? To examine possible effects of information dissemination on the market, we compared the trading behavior (bids and asks), and the outcomes (dividends earned) of the informed and the uninformed participants in the first half (periods 1-8) and the second half (periods 9-16) of the market. It is extremely difficult to conduct complete and proper statistical analyses since not all participants in the various markets engaged in relevant transactions in the different periods. Therefore, there are many instances of missing data and highly unbalanced numbers in the various sessions. An examination of the number of bids submitted for cards that are part of the solution and those that are not in the solution shows no systematic change in the second half of the market in the behavior of the uninformed participants following their exposure to the behavior of the informed subjects. In fact, the trading behavior of the uninformed participants is undistinguishable from the one observed in the baseline treatment (with zero insiders).

2.4.3 Discussion

The main result of this study is the differential pattern of trading prices in the two panels of Figure 4. The left panel that summarizes the results of markets with 0 or 1 informed subject(s) replicates the results of study II and suggests that the market values the q-card (card III) more than the non q-card (card IV). This result is, of course, consistent with the faulty individual solutions of the Wason task. On the other hand, the right panel of the figure shows that when a sufficiently large fraction (in this case at least 2/8=25%) of traders identifies the correct solution, the pattern is reversed and the normatively correct solution (non q-card) is valued more. This panel replicates the results of study I. Thus the payoff feedback, although sufficient, is not necessary to push the market towards the normative solution. Similar results can be obtained even in the absence of such feedback, as long as there is a "sufficiently large" rational core of traders. In study I, this core was formed spontaneously through the effect of the immediate monetary feedback, whereas in the present experiment, it was created by our direct manipulation of the amount of inside information.

The other important result of this study follows from the analysis of the trades of the informed subjects (insiders) and the uninformed subjects (outsiders). It is obvious that the market's optimal behavior did not reflect the behavior of all its participants. On average, outsiders were not able to infer the correct solutions from the information flow on the market and did not alter their trading behavior.

Before concluding that there is no effective information spillover, we need to consider the possibility that a number of features in our market design may have made such spillovers extremely difficult. Participants traded the four cards in a continuous double auction that required them to engage in

selling and buying activities simultaneously with seven others. This is quite a complicated mechanism and it is possible that some participants were so busy trying to keep track of all these transactions that they could not follow and analyze properly the market behavior. Also, some participants may have acquired cards that are not part of the solution with the intention of selling them for a profit to others. Indeed, it pays to trade incorrect cards if one can sell them for higher prices than their initial acquisition price had been. Such behavior, of course, would make it harder for uninformed subjects to infer the correct solution.[8]

The fourth study is a refined replication of study III, in which we replaced the double auction with a combinatorial continuous auction. In this set-up, participants can bid for each of the 15 possible card combinations, rendering a much clearer picture of their preferences for cards and facilitating information discovery by outsiders. We reduced the number of auction participants to four, and increased the number of periods to 30, in the belief that this would allow subjects to track and process the information about the other traders' behavior more efficiently and accurately. Finally, we "individualized" the market by linking the various bids to specific traders. This allowed participants another way of tracking the information flow, by focusing their attention on certain traders. We expect to replicate the results regarding the improved aggregate performance as a function of the number of informed traders. In addition, we hypothesize that this simpler and more transparent procedure also facilitates information spillovers and improves the individual performance of the uninformed traders.

2.5 Study IV

2.5.1 Experimental design and procedure

Seventy-two undergraduate students participated in 18 combinatorial auctions, which were conducted at the Max Planck Research Lab in Jena, Germany. Forty-nine females and 23 males, aged 19 to 32 (M=22.32, SD=2.92), participated in the study. Experimental sessions lasted about one-and-half hours and participants earned on average €13.76 (SD=5.34).

We introduced and manipulated the number of informed bidders. Out of the four market participants, we either allowed for zero, one or two insiders. Experimental conditions therefore consisted of six auctions with 24 subjects each. Insider selection and information available to participants were identical to study III.

A combinatorial continuous auction was implemented: Participants could submit bids for each of the 15 possible combinations of the four cards in the Wason task. They were told that only four cards of each type were available for allocation, and that the seller's objective is to maximize profits.[9] Overall, 30 auctions with four traders that lasted for 60 seconds were performed. At the beginning of each auction, participants were endowed with 500 ECU.[10] The endowment was only granted as a credit to participants, and had to be paid back at end of the experiment. Subjects were informed about the average bids and

quantities of bids of their fellow participants, identified by labels (A, B, C, D). Figure 5 displays the schematic screen-shot of the auction.

<center>Insert Figure 5 about here</center>

The participants' task was to identify the correct card(s) that make up the solution to the Wason problem. Correct card holdings were rewarded with dividends of 200 ECU for each set of cards. As in the previous three studies, participants were not punished for acquiring incorrect cards. Their return, however, was zero.

After the last auction period, participants were asked to solve again the standard Wason selection task (abstract form) individually. Correct choices were rewarded with € 4. At the conclusion of the session, participants received their earnings from stages I and III as well as their dividend payments from three randomly selected auctions in each of the three blocks (auctions 1-10; 11-20; 21-30) of stage II.

2.5.2 Results

We analyzed the average bids submitted in a 2-way mixed ANOVA with the within-subjects factor "card" (I, II, III, IV) and the between-subjects factor "number of insiders" (0, 1, 2). For this analysis, we computed the average bids for each card by (a) multiplying the bids with the corresponding quantity, and (b) dividing the bids equally among all the cards in a given combination. For example, if a participant submitted two bids of 100 ECU for the card combination I, II, and IV, we assigned each of the three cards in this combination the value $2*100/3=66.67$.

The ANOVA yielded a 2-way interaction effect for card and the number of insiders ($F(6; 28)=3.39$, $p<.05$, $?^2=.42$). Average bids for card III decrease, whereas bids for card IV increase, in the number of informed bidders (see Figure 6).

The design of this study allows us to separate the influence of the informed and the uninformed subjects' behaviors on aggregate bids. We repeated the ANOVA using only the bids of the outsiders. We found a significant main effect for card ($F(3; 13)=38.61$, $p<.05$, $?^2=.90$), but no interaction effect (see Figure 7). Tukey's HSD post-hoc tests (at the .05 level) show that average bids for card I exceeded those for cards II, III, and IV. Finally, bids for card II were lower than the corresponding bids for cards III and IV.

<center>Insert Figure 6 and 7 about here</center>

Average bids for cards I and II in the various insider-conditions appear almost constant, whereas the bids for the crucial cards III and IV decline and increase, respectively, with the number of insiders. To test this hypothesis, we compared the bids on cards III and IV. Indeed, the differences of the average bids for cards III and IV decrease monotonically from the zero-insider condition (M=74.81, SE=22.92) to the one-insider (M=38.35, SE=22.92) and the two-insider condition (M=5.98, SE=22.92). A Cochran-Armitage test for trends, based on the number of subjects who bid more for card III than for card IV,

<center>15</center>

confirms that the increase in the number of informed participants caused the uninformed subjects to bid more for card IV than for card III ($\chi^2(1)=4.25$, p<.05).

   Post-market individual task: To examine the effects of exposure to the behavior of the informed participants, we calculated the rate of correct solutions of those subjects who did not solve the task correctly prior to the auction stage and who were not explicitly told the solution (n=54). Interestingly, we observe a monotonic increase in correct choices across experimental conditions: In the condition with no informed traders, one out of 24 participants solved the task correctly (4.16%); in the condition with one insider, two out of 18 participants solved the task (11.11%); and in the condition with two insiders, two out of 12 solved the task correctly (16.67%).

2.5.3 Discussion

The results replicate, in part, our findings of study III. Aggregated across the participants (informed and uninformed), the auction values the correct cards higher than the incorrect cards. If two (50%) of the bidders knew the correct cards, the auction reflected the normative solution to the Wason task. However, unlike study III, we also found evidence that an increase in the number of informed subjects in the auction shifted the bidding behavior of the uninformed participants towards the correct solution.

   Finally, we observe a positive transfer effect from the auction setting to the individual task. Some participants who failed to identify the correct solution prior to the interactive setting correctly solved the task after being exposed to the behavior of the informed bidders. Moreover, we find a positive and monotonic relation of the percentages of correct choices: The higher the number of informed bidders in the auction, the higher the solution rates of the uninformed participants.

3. General discussion

The purpose of this paper was to investigate whether reasoning errors that are a reliable feature of individual behavior prevail in competitive auctions. To this end, we focused on the effects of monetary feedback on various aggregate market measures, and informational spillovers between traders with different degrees and types of information. We also studied whether competitive environments provide learning opportunities that allow for positive transfer effects from the auction setting to individual behavior.

   A series of four studies, involving almost 400 subjects who traded the cards of the Wason selection task in a variety of competitive auctions, shows that providing individual period-by-period payoff feedback (even in a relatively opaque format that did not link directly payments with specific cards) is sufficient to drive the market towards the correct solution, in the sense that prices, trading volume, and overall demand reflect the correct solution unambiguously. A similar effect at the aggregate level was observed in the presence of a sufficiently large core of rational traders, even without payoff feedback. At the individual level, mere exposure to the information flow did not cause the uninformed

subjects to change their bidding behavior in a fashion consistent with the normative solution in double auctions. This effect was observed, to some degree, only in a one-sided combinatorial auction that allowed participants to track the individual bidding behavior of others.

The study of individual errors and biases in the context of competitive environments has frequently been motivated by the desire to contrast the viewpoints of economists and psychologists on this matter. A belief shared by many economists is that markets, and other competitive institutions, would wipe out individual biases just as averaging cancels out random noise. The trading patterns obserevd in our studies seem to support this view. Cognitive psychology does not have specific predictions about the effects of aggregation, but it tends to stress that fallacies and biases that plague individuals are robust and systematic. One posssible corrolary of this view is that these biases would survive and affect behavior at the aggregate level. The fact that, at least in the cognitively more demanding double auction, most of our uninformed traders failed to learn from the market lends credence to this view. Thus our results seem to reinforce simultaneously two contradictory positions! The solution to this apparent paradox is the realization that the aggregate behavior of the market is disproportionally affected, and driven to a large degree, by a minority of active, intelligent, and informed traders (see also comments by Forsythe et al., 1992, on this very point in the context of the Iowa political market).

Perhaps most importantly, our results demonstrate that expecting biases to disappear completely or, alternatively to always persist are naïve and simplistic positions. The question whether individual-level errors prevail or disappear in competitive environments does not have a simple categorical answer that can be readily accepted by scientific disciplines that focus on different levels of analysis - the individual and the aggregate. Our findings highlight the need to develop new and more sensitive research paradigms at the interface of psychology and economics that would, eventually, yield results that would benefit both. The manipulation of the number of informed traders (insiders) that we used in studies III an IV, is an example of such an approach. It allowed us to analyze elegantly the nature of the various trades among informed and uninformed traders in study III, and to track changes in the pattern of individual bids of the uninformed subjects in study IV.

With this in mind, we turn now to the question of learning from the market. We uncovered differential levels of spillover in the two types of auctions -- we found no trace of such transfer in the double auctions, but there was considerable evidence of changes in the bids of the uninformed subjects who were matched with informed ones in the one-sided combinatorial auction. It is impossible to identify the key feature(s) of this auction that made it more succesful in our study, but it highlights the relevance of designing appropriate markets for various purposes.

Finally, consider the transfer effects from the auction setting to individual beahvior. In two of our studies, we followed up the auctions by a repeated test of the participants' ability to solve the Wason task

individually. The results of the first study are not surprising, but nevertheless impressive. Feedback (even weak and indirect) allowed a majority of participants to learn the optimal strategies to test conditional rules. In fact, one can argue that the reason individuals do better when this problem is presented in familiar context and content, as in the deontic representation, is that they have encountered it in similar forms numerous times before and have experienced appropriate feedback from their natural environment. Study I demonstrates that similar effects can be achieved even in the abstract representation of the task with swift monetary feedback.

The results of the last study are more intriguing: five of the 54 (9.3%) uninformed traders learned to solve the problem without receiving any monetary feedback. This may not be a very high number in absolute terms, but recall that only five participants in this study (6.9%) solved the problem correctly in the initial presentation. In other words, the rate of correct solutions was almost doubled through exposure to the information flow on the auction. How can we explain this learning? It is widely recognized that groups solve intellective problems with demonstrable solutions better than their individual members (e.g., Laughlin and Ellis, 1986). Our results seem to indicate that a similar effect can even be obtained in competitive markets although, unlike the interactive groups, they do not allow for direct communication among members, nor for obvious ways to "demonstrate" the correct solution. Nevertheless, a subset of traders was able to distinguish between the relevant and irrelevant cues of the market (i.e., the behavior of the informed and the other uninformed subjects, respectively), allowing them to infer the correct solution eventually. Future work on this topic should focus on the analogy between markets and interactive groups and attempt to identify the critical features for successful learning in both institutions.

Endnotes

[1] Similar results were also reported for the Monty Hall dilemma (e.g., Friedman, 1998, Slembeck and Tyran, 2004).

[2] Study IV is part of a larger project with other experimental conditions that will be reported elsewhere.

[3] Empirical evidence indicates that deontic contexts, such as social obligations and rights, facilitate performance in the Wason selection task (e.g., Pollard and Evans, 1987).

[4] Ten Experimental Currency Units equal €1.

[5] This post-market individual stage was only included in studies I and IV.

[6] Some of the trading prices in the figure are higher than the dividends the cards pay and, as such, appear to be irrationally high. We calculated in each period in each market the rate of irrational trades. We considered all possible combinations of anticipated solutions and actual endowments and tested whether the net cost of the desired combination (i.e., the average price of purchasing the necessary cards minus the profit of selling one's endowment, if it is not part of the solution) is, indeed, higher than the expected

dividends. Such instances occurred in about 5% of the cases, and many of them were associated with rare anticipated solutions (e.g., if the trader believes the solution is to be I, III, and IV, and is endowed with card II). Thus, we concluded that this is not a serious concern.

[7] The expected number of trades is a function of the number of insiders, N_i, and outsiders, N_o, and varies across conditions. For example, if $N_i = 2$ (and $N_o = 6$), and if all pairings are equally likely, we expect 30/56 of the trades to involve only outsiders, 2/56 of the trades to take place among insiders, 12/56 to involve insiders selling cards to outsiders, and 12/56 to involve insiders buying cards from outsiders.

[8] This conclusion also follows from current research on the "combined value problem" (e.g., Bossaerts, Fine and Ledyard, 2002).

[9] Winner determination in a combinatorial auction can be thought of as an integer programming problem (see, for instance, Pekec and Rothkopf, 2003), where one seeks an allocation that maximizes the auctioneer's (experimenter's) revenue subject to card availability. We solved the winner determination problem by enumeration of exhaustive partitions of items (see Sandholm, 2002, for an introduction).

[10] One hundred ECU equal €5.

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Table 1: Solution rates for the Wason selection task across the four studies

Study	Representation	% Correct	Subjects
I	Abstract	16.67	96
II	Abstract	7.81	64
	Deontic	14.06	64
III	Abstract	14.58	96
IV	Abstract	6.90	72
Total		12.50	392

Table 2: Ratio of observed to expected trades of cards corresponding to the correct solution for the various groups (study III)

Number of insiders	Number of outsiders	Number of trades	I - I	O - O	I - O	O - I	G^2
1	7	783	-	0.86	0.54	2.30	83.20
2	6	732	2.06	0.78	0.88	1.49	78.90
4	4	892	1.33	0.59	0.77	1.31	56.95

Note: "I" denotes insider and "O" denotes outsider. G^2 values should be considered with caution, since the assumption of independence is not met.

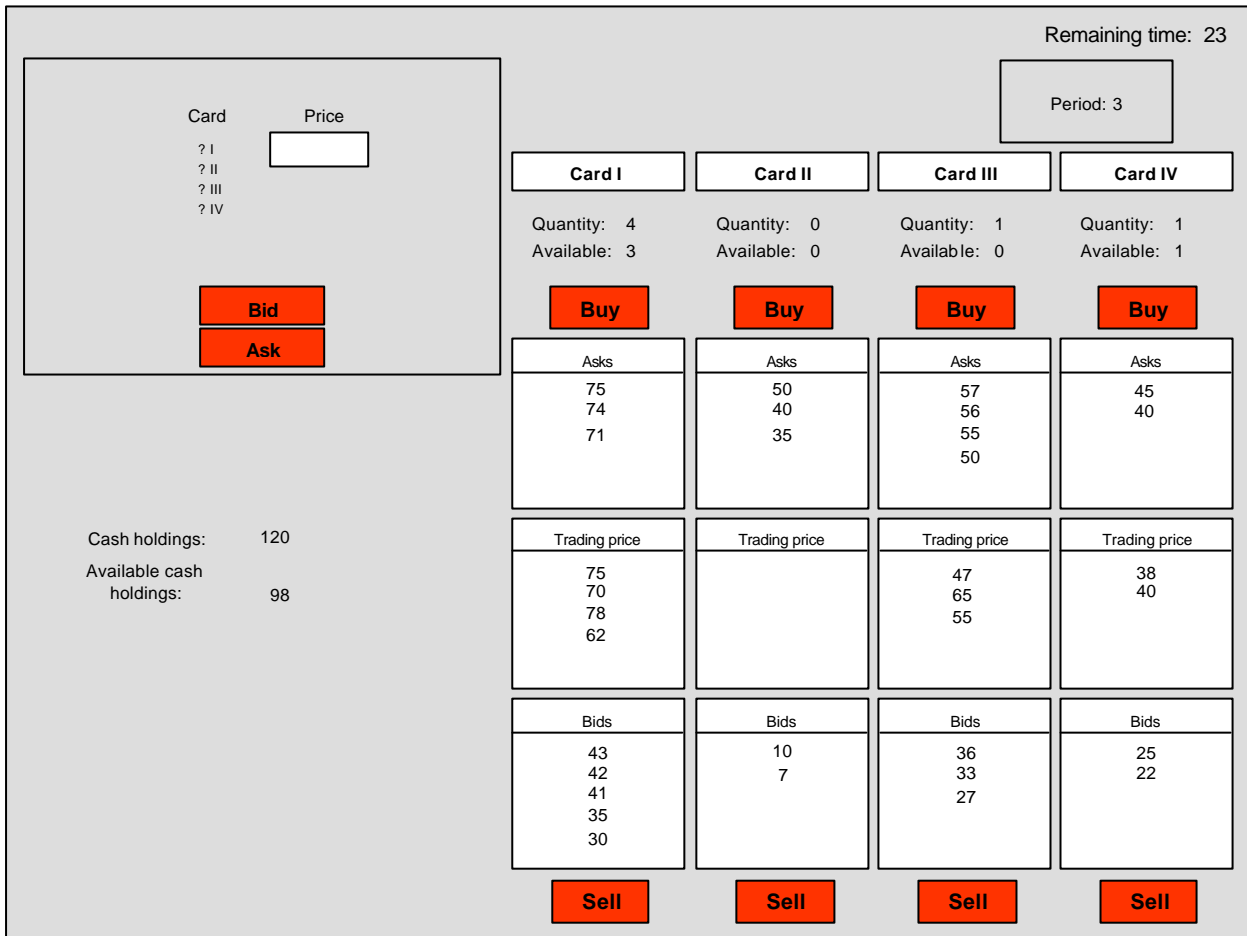Figure 1: Schematic screen-shot of the auction (studies I, II, and III)

Figure 2: Average trading prices in the strong- and weak-feedback condition (study I)

Average prices

Strong-feedback condition

Weak-feedback condition

Periods
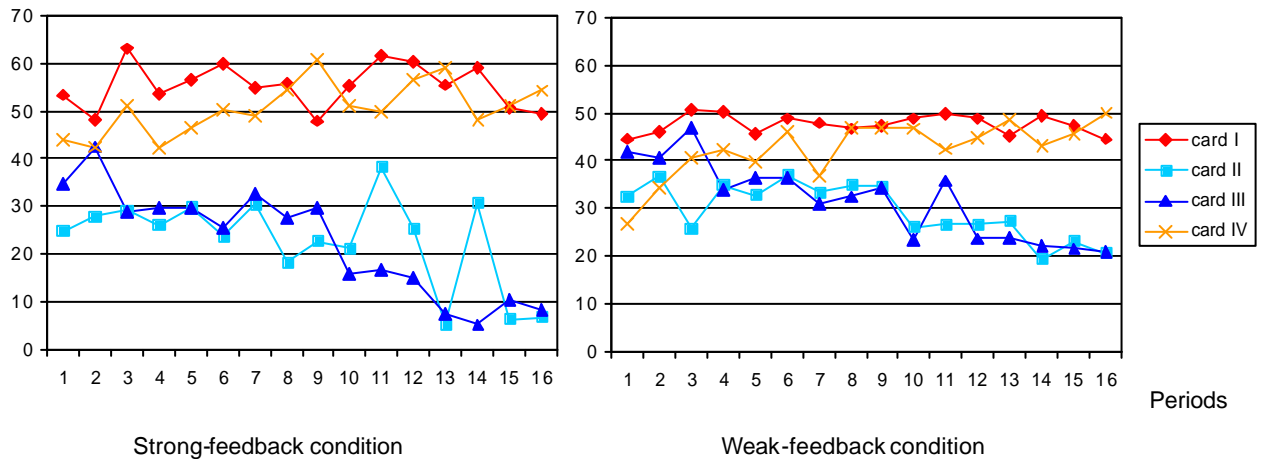
Figure 3: Average trading prices in the abstract and deontic markets (study II)

Average prices

Abstract market   Deontic market
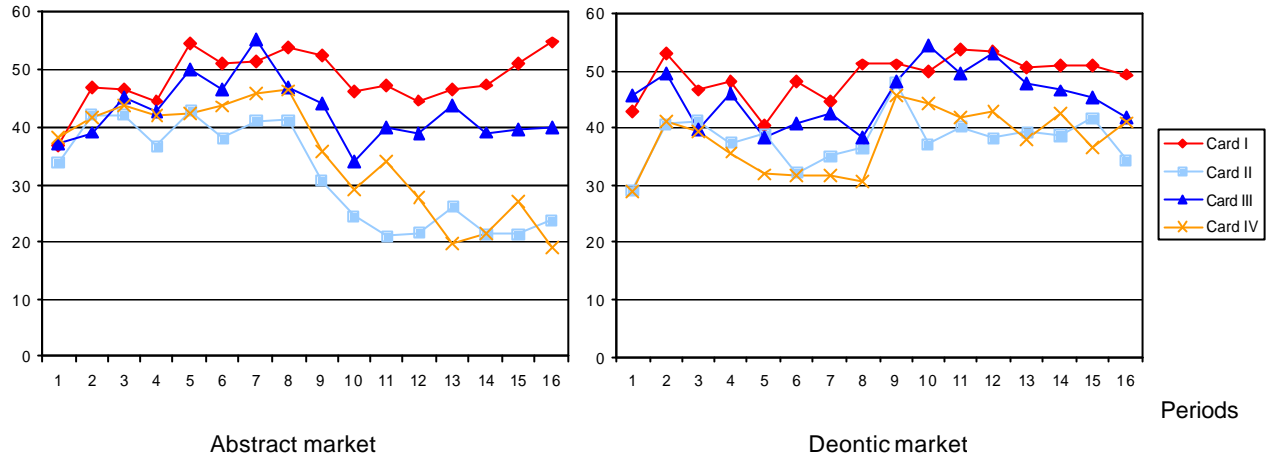
Figure 4: Average trading prices for markets with 0 and 1 insider(s) and for markets with 2 and 4 insiders (study III)

Average prices

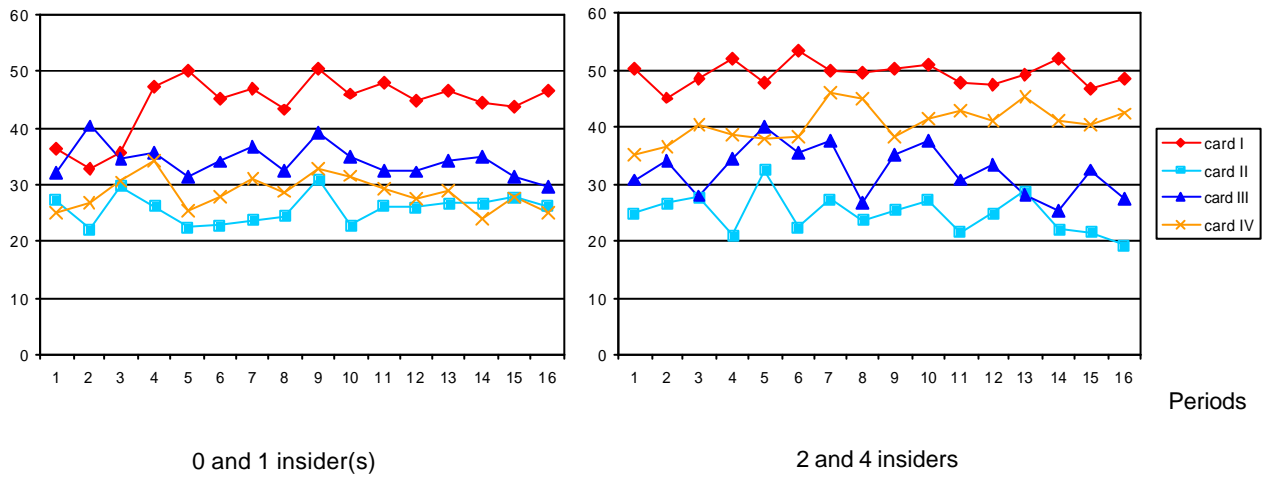0 and 1 insider(s)   2 and 4 insiders

Figure 5: Schematic screen-shot of the auction (study IV)

You are PARTICIPANT C   Period 5   Seconds 9

Participant A

Mean Bid (Quantity) in Period

Combination	2	3	4	current
I	-	13 (1)	25 (1)	-
II	-	-	-	-
III	-	13 (1)	25 (1)	-
IV	-	-	-	-
I, II	-	-	-	-
I, III	37 (3)	-	-	-
I, IV	-	-	-	-
II. III	-	-	-	-
II. IV	-	-	-	-
III, IV	-	-	-	-
I, II, III	-	-	-	-
I, II, IV	-	-	-	-
I. III. IV	-	-	-	-
II. III. IV	-	-	-	-
I, II, III, IV	-	50 (1)	40 (2)	-

Participant B

Mean Bid (Quantity) in Period

Combination	2	3	4	current
I	15 (1)	20 (1)	-	-
II	-	-	-	-
III	15 (1)	20 (1)	-	-
IV	-	-	-	-
I, II	-	-	-	-
I, III	-	-	100 (2)	-
I, IV	-	-	-	-
II. III	-	-	-	-
II. IV	-	-	-	-
III, IV	-	-	-	-
I, II, III	-	45 (1)	-	-
I, II, IV	-	-	-	-
I. III. IV	-	-	-	-
II. III. IV	-	-	-	-
I, II, III, IV	-	-	-	-

Combination	Price	Quantity
I		
II		
III		
IV		
I. II		
I, III		
I, IV		
II. III		
II. IV		
III. IV		
I, II, III		
I, II, IV		
I. III. IV		
II. III. IV		
I. II. III. IV		

Participant C

Mean Bid (Quantity) in Period

Combination	2	3	4	current
I	-	-	-	25 (1)
II	10 (1)	15 (1)	30 (1)	-
III	-	-	-	-
IV	-	-	-	-
I, II	-	-	-	-
I, III	-	-	-	-
I, IV	-	-	-	-
II. III	-	-	-	-
II. IV	-	-	-	-
III, IV	-	-	-	-
I, II, III	-	-	-	-
I, II, IV	-	-	-	-
I. III. IV	-	-	-	-
II. III. IV	-	-	-	-
I, II, III, IV	-	-	-	-

Participant D

Mean Bid (Quantity) in Period

Combination	2	3	4	current
I	30 (1)	30 (1)	20 (1)	-
II	-	-	20 (1)	-
III	-	-	20 (1)	-
IV	-	-	20 (1)	-
I. II	-	45 (2)	-	-
I, III	-	-	-	-
I, IV	-	-	-	-
II. III	-	-	-	-
II. IV	-	-	-	-
III. IV	-	-	-	-
I, II, III	-	-	70 (1)	-
I, II, IV	-	-	-	-
I. III. IV	-	-	-	-
II. III. IV	-	-	-	-
I. II. III. IV	-	-	-	-

Your cash holdings: 475

SUBMIT

Figure 6: Average bids in the various insider conditions including insiders and outsiders (study IV)
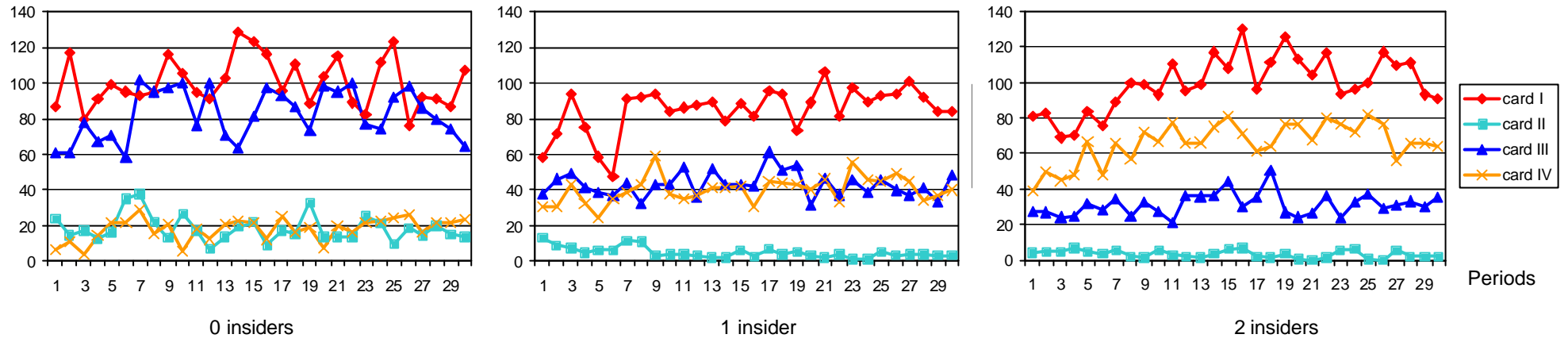
Average bids

0 insiders

1 insider

2 insiders

Figure 7: Average bids in the various insider conditions including only outsiders (study IV)

Average bids

1 insider

2 insiders