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Information Aggregation with Costly Information and Random Ordering: Experimental Evidence*

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Abstract

The cost of information is an often ignored factor in economic situations although the information acquisition behavior of the decision makers has a crucial influence on the outcome. In this experiment, we study an information aggregation process in which participants decide in a random sequence. Participants observe predecessors' decisions and can acquire additional private information at a fixed price. We analyze participants' information acquisition behavior and updating procedures. About one half of the individuals act rationally, whereas the other participants systematically overestimate the private signal value. This leads to excessive signal acquisitions and reduced conformity.

JEL C92, D8

Keywords: information aggregation, information acquisition, Bayes' rule, heuristics

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Sequential, non-revocable economic decisions must be made in a multitude of everyday situations. Before making the final decision it is often possible to gather additional costly private information. For example, an institutional or private investor is considering a new investment. Believing in efficient markets it is not always necessary to acquire additional information. However, existing or imagined inefficiencies may lead to spending money by acquiring information from someone or by searching to find new information. Obviously, this is only rational if the expected additional information value given the new private information is at least as high as the information cost.

Searching a new dean for a business school is another example in which additional information can be acquired. The search committee must decide in various stages of the search process whether they want to hire somebody whose application is already available. Alternatively, it is possible to ask (and pay) consultants to find other suitable candidates. Even some potentially low stake decisions such as choosing a restaurant for dinner may involve a decision whether to rely on others' decisions or to buy a restaurant guide.

In general, information acquisition is only rational if the price is less or equal the expected benefit. Bayes' law is used to calculate the benefit of the additional information.[1] Deviations from Bayes' law can lead to different acquisition behavior and may influence the aggregation process. For example, observable decisions by others may contain aggregation errors. As a result, acquisition behavior changes compared to Bayesian updating. On the one hand, private information will have a higher value and more information will be bought if public information is underweighted due to suspected errors. However, if others' error rates are overestimated, this

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[1] If the decision process is sequential and non-revocable, the information paradox as described by Sanford Grossman and Joseph Stiglitz (1980) will not arise.

“adjustment” is inappropriate and the decision looks like an overreaction. On the other hand, systematic aggregation errors can exist but they are not detected because of the belief that all decisions are fully rational. As a result, too few private information is bought. In both cases, errors can accumulate because they are not random. Thus, these errors do not cancel out and can lead to irrational herding. Therefore, it is necessary and useful to study information acquisition behavior.

It is almost impossible to study information acquisition behavior and information revelation based on real world data because the fundamental value of the information cannot be determined due to various sources of uncertainty with regard to public and private information. For example, timing of decisions can significantly change the aggregation process and thus the information value. Even in laboratory markets as in Copeland and Friedman (1991/1992) as well as in Sunder (1992), it is difficult to find explanations why specific individuals bought information. By simplifying the aggregation process to a sequential decision process with random ordering, we can extract and analyze individual errors concerning both, the acquisition behavior and the updating procedures.

In our experiment with costly private information, the acquisition behavior reveals the assumed relationship between private and public information. In addition, the decisions allow us to determine the actual updating errors. Even though our focus is not the investigation of the cascades phenomenon, we use the experimental framework introduced by Anderson and Holt (1997) because it provides a simple and sufficient aggregation process.

Anderson and Holt (1997) conducted the first experiment to analyze the development of information cascades based on Bikhchandani, Hirshleifer, and Welch (1992). In their experiment, six participants predicted sequentially, which of the two possible states, denoted by A and B, had occurred. Participants received information from two sources: publicly announced predictions of predecessors and private information *a* or *b*, which indicated the occurred state with probability $p(A|a) = p(B|b) = \frac{2}{3}$. The ordering of the subjects was determined randomly within each round. In this setting with free private information, cascades should occur whenever one state is predicted more often than the other. Cascades formed in 87 of 122 situations in which they were rational. Since some subjects seemed to rely more on their private information, some rational cascades collapsed.

Hung and Plott (1999) used the Anderson and Holt (1997) design to study the effect of different incentive schemes on conformity. They estimated the weights of public and private information and found that even in a simple setting in which a counting heuristic leads to the same decisions as using Bayes' law, participants put too much weight on their (free) private information. Nöth and Weber (1999) extended the Anderson and Holt (1997) design by introducing two signal qualities. As before, agents received private information without incurring any cost. Only 63.2% of all possible rational cascades developed due to subjects' overconfidence[2] and because of gambler's fallacy.[3] This behavior was not rational given the (unobservable) error rates of other participants. These results can be used as a benchmark in our experiment if a participant buys private information since we use the same information structure but with optional information acquisition.

2 Overconfident subjects put too much weight on their private information. Huck and Oechssler (1999) studied a modification of the Anderson and Holt (1997) design and found that the heuristic "follow your own signal", which is an extreme form of overconfidence, explains the observed behavior better than Bayes' law.

3 Gambler's fallacy is considered to be a prediction of the state, which is less likely based on either public, private or public and private information.

In our experiment with information acquisition, participants bought on average too many signals compared to a Bayesian rational individual. We identify two homogenous groups which have different signal acquisition behavior. About one half of the participants buy additional private information only if this is rational. The other participants are responsible almost exclusively for the excessive signal acquisitions after observing two identical and information based predictions of their immediate predecessors. Risk aversion, a simple position based heuristic and the consideration of updating and prediction errors cannot explain the observed behavior. Instead, we identify conservatism as the most likely reason, i.e. the decision to buy additional private information is based on an inadequate adjustment of priors given the public information. The resulting excessive information acquisition and the common overweighting of private information caused the collapse of rational cascades. In our experimental setting, the observed behavior had a negative effect on welfare but it avoided many reverse cascades in which all decisions are identical and ex post not correct.

The next section contains a description of the experimental design. In section II, the rational Bayesian strategy is presented. Section III presents the results as well as some explanations for the observed behavior. Section IV concludes.

I. Experimental Design and Procedures

As mentioned, the experimental design is an extension of the experimental design used in Nöth and Weber (1999). The main difference is that private information is not available free of charge. Instead participants have the choice to acquire private information at a fixed price. Participants shall predict sequentially which of the ex ante equally likely two possible events, denoted by A and B $(p_A = p_B = 0.5)$, occurred in each round.

At the beginning of each round the state is determined randomly. Then the computer draws the random ordering of all six subjects for that round. Finally, a private signal for each participant is generated randomly in a two step procedure depending on the realized state:

1. The signal's strength is either weak or strong with probability $p_W = p_S = 0.5$. Note that the signal's strength does not depend on the realized state.
2. If the signal should be strong, the information is drawn from an urn containing one wrong and four correct signals, i.e. $p(A|a_S) = p(B|b_S) = 0.8$. A weak signal is correct with probability $p(A|a_W) = p(B|b_W) = 0.6$.

Before a participant submits her prediction she observes the following information without incurring any costs:

- The design including all probabilities and payment procedures is public knowledge since it is explained as part of the instructions (see Appendix A).
- Predictions of predecessors can be publicly observed. In addition, it is known which predecessors bought additional information. However, this additional information, i.e. the acquired signal and its' accompanying strength, is not revealed. Moreover, predecessors' identities cannot be observed since predictions are submitted anonymously and the participants' ordering is determined randomly for each round.

Based on this public information she has to decide first whether she wants to acquire a private signal for 15 cu (currency units), or not. As described above, the private signal can be one out of four possible signals $s \in \{a_S, a_W, b_S, b_W\}$. Then the public and - if applicable - the private information can be used to predict the state. After all six participants submitted their predictions the true state is revealed and a new round begins. An ex post correct prediction yields 400 cu and a wrong prediction is accompanied by a reward of only 100 cu. The information structure is common knowledge since it is outlined in the instructions (see Appendix A).

Figure 1 illustrates the course of a round. Note that subjects face no time restrictions for their actions.

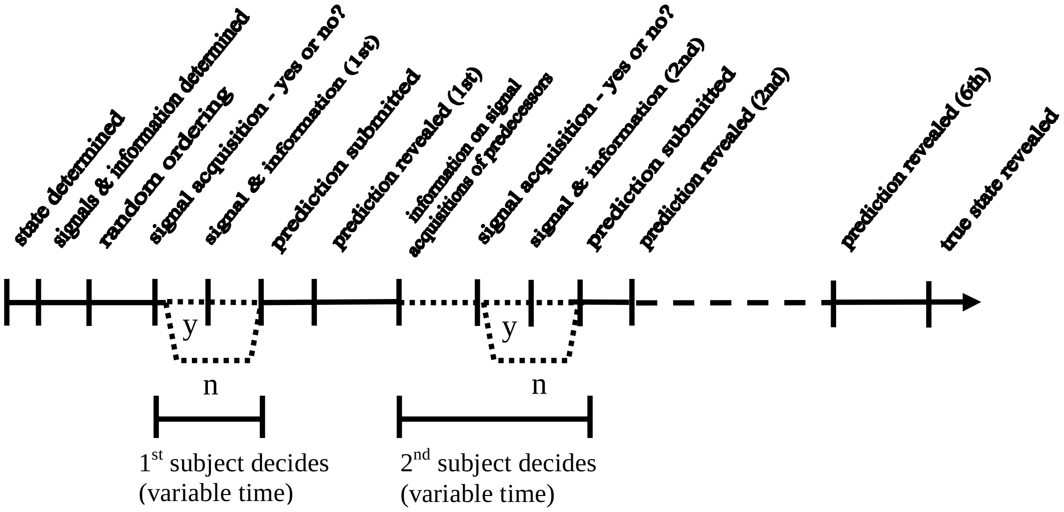

Figure 1: Course of a round

The decision sequence is illustrated in this figure. Each round begins with the determination of the state, the signals and the ordering of the six subjects. Except for the first acting subject each acting individual receives information regarding the signal acquisitions of her predecessors prior to her own signal acquisition decision. Then she either receives a private signal followed by her own state prediction or she has to submit her state prediction without additional information. There is no time limit for the actions of each participant.

The experiment was conducted in the SFB Computer Lab of the University of Mannheim in June 1999. Each session consisted of at least 48 and not more than 60 paid rounds and lasted about two hours. At the end of each experiment currency units were converted to Deutsche Mark (DM) such that on average subjects receive DM 16.00 per hour, which was about US$ 9.00 then. Participants earned on average DM 35.14 for two hours, varying between DM 23.00 and DM 44.00. The earned currency units V_{cu} were converted to Deutsche Mark (DM) using the following conversion formula:

$$V_{DM} = 32 + \frac{V_{cu} - (310 \cdot r)}{200} \quad \text{(r: number of rounds)} \qquad (1.1)$$

The conversion formula adjusts the average payment of DM 32.00 for two hours according to the individual's performance. 310 cu multiplied by the number of rounds is the amount of currency units needed in order to earn the average payoff of DM 32.00. For each 200 cu, subjects earned less or more than the average payoff, DM 1.00 was subtracted or added to the average payment, respectively. The calculated payments were rounded up to the next DM.

While we computed the subjects' final payments, they had to fill out a final questionnaire (see Appendix B). Participants' answers provide additional insights about individuals' updating procedures and information acquisition behavior. 66 subjects, studying business administration at the University of Mannheim, Germany, participated in this experiment (= 11 sessions). All participants had no previous experience with this experiment.

II. Rational Bayesian Strategy

The benchmark to analyze the observed behavior is Bayesian updating (BU). Under Bayesian updating an individual acts rationally if she uses Bayes' law to aggregate all available information. Furthermore the rational Bayesian strategy is based on the assumption that all predecessors acted rationally, too. We relax this assumption later while searching for possible explanations for the observed non-Bayesian behavior.

In the experimental setting presented here, a Bayesian subject would eliminate first all predictions, which are solely based on public information using the disclosed acquisition decisions of her predecessors. Predictions that are not preceded by an acquisition of private information do not convey any additional information and should therefore be excluded from the further processing. This procedure generates the reduced history (of predictions). This reduced history is the relevant basis to evaluate the probability of the two states based on public information, which then determines the signal value. A participant should buy a signal if the difference between the expected value of the payoff V_{signal} with private information and the expected value of the payoff $V_{no\text{-}signal}$ without private information equals or exceeds the cost of the private signal.[4]

The expected profit from buying private information based on the reduced history is calculated as follows. As already mentioned the probability for state A and B based on public information can be calculated using the reduced history. For example, if the reduced history is $h_1 = (A_1)$ then the

4 If the expected profit from buying private information is equal to the cost, we assume that a signal is bought since it is rational to buy private information if at least one predecessor acted non-Bayesian with an infinitely small probability.

probability that state A occurred is $p(A|\, A_1) = 0.7$, assuming that the first subject acted rationally. This is, because a rational subject at position 1 predicts state A, if she has a strong or weak signal indicating state A.[5] Because the two signal strengths are equally likely, the probability that state A occurred after observing one private informative prediction is 0.7.[6]

Without private information it is rational to predict the state X that has a probability greater or equal to 0.5 according to the reduced history h_n. Assuming risk neutrality, this leads to an expected value of the payoff $V_{no\text{-}signal}\,(h_n)$ without a private signal of:

$$EV(V_{no-signal}(h_n)) = p(X \mid h_n) \cdot 400 + (1 - p(X \mid h_n)) \cdot 100 \tag{2.1}$$

If the participant acquires a private signal, she receives one out of four possible signals $s \in \{a_W, a_S, b_W, b_S\}$ with probability

$$p(s \mid h_n) = p(S \mid h_n) \cdot \frac{1}{2} \cdot \frac{3}{5} + (1 - p(S \mid h_n)) \cdot \frac{1}{2} \cdot \frac{2}{5} \tag{2.2}$$

if it is a weak signal that indicates state S and

$$p(s \mid h_n) = p(S \mid h_n) \cdot \frac{1}{2} \cdot \frac{4}{5} + (1 - p(S \mid h_n)) \cdot \frac{1}{2} \cdot \frac{1}{5} \tag{2.3}$$

if it is a strong signal that indicates state S

Using Bayes' law the probability that state A or B occurred after observing signal s can be calculated. A rational subject will then predict the state X with the higher a posteriori probability,

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5 If nothing else is stated, "position" always refers to the decision position based on the reduced and not the complete history of predictions.

6 The probability calculations do not differ from Nöth and Weber (1999) for reduced histories.

which leads to an expected value of the payoff $V^{s}_{signal}(h_n)$ based on the public reduced history h_n and the private signal *s* of:

$$EV(V^{s}_{signal}(h_n)) = p(X \mid h_n, s) \cdot 400 + (1 - p(X \mid h_n, s)) \cdot 100 \qquad (2.4)$$

The probability weighted sum of the signal dependent expected payoffs $V^{s}_{signal}(h_n)$ yields the signal independent expected value of the payoff $V_{signal}(h_n)$ with private information of:

$$EV(V_{signal}(h_n)) = \sum_{s \in \{a_W, a_S, b_W, b_S\}} EV(V^{s}_{signal}(h_n)) \cdot p(s \mid h_n) \qquad (2.5)$$

The information value is then defined as

$$IV(h_n) = EV(V_{signal}(h_n)) - EV(V_{no\text{-}signal}(h_n)) \qquad (2.6)$$

As a result of the above calculations only 12 out of 64 histories can occur, if all participants act rationally. In all other cases, at least one subject diverged from rational Bayesian behavior. For example, the history AABBBB with information purchased by the first and second subject can only occur if the third subject irrationally predicts state B. This can be either due to a non-rational signal acquisition followed by a (possibly rational) prediction of state B or simply due to random errors.

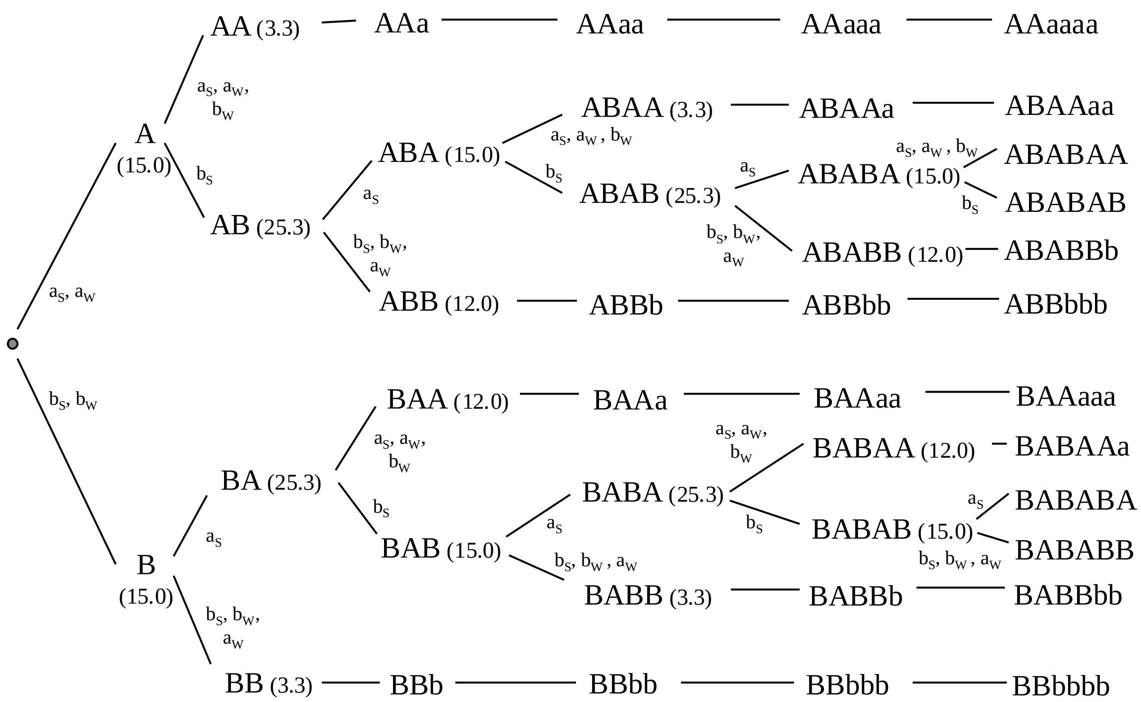

Figure 2: Rational histories

State predictions in capital letters are based on private as well as on public information. The numbers in brackets represent the signal value after observing a specific history. If the signal value is less than 15 cu, no additional private information is acquired. Note that observed histories might be different due to non-rational behavior.

Figure 2 shows that it is always rational to buy a private signal at positions 1 and 2. A subject at position 3 then faces two possible situations. If the two predecessors made contradicting predictions the signal value is 25.3 cu, i.e. a signal acquisition is rational. Otherwise the signal value is 3.3 cu. A Bayesian individual would therefore refuse to buy private information and would simply follow the preceding state predictions. All subsequent subjects face the same situation as the third one because the preceding prediction conveys no additional information and should therefore be eliminated. Again, they should refuse to acquire additional information and simply follow the first two informative predictions. An information cascade develops.

In general, a cascade occurs with costly signals when it is optimal for an individual, having observed the predictions and information acquisition behavior of her predecessors, not to buy a private signal and simply follow the preceding individuals' prediction. Figure 3 illustrates the signal value with an increasing number of conforming informative predictions, which eventually leads to an information cascade. In this setting a cascade always develops, when the two preceding informative predictions are identical.[7] We will focus on cases of identical predictions of predecessors, which lead to a cascade if at least two of them are informative.

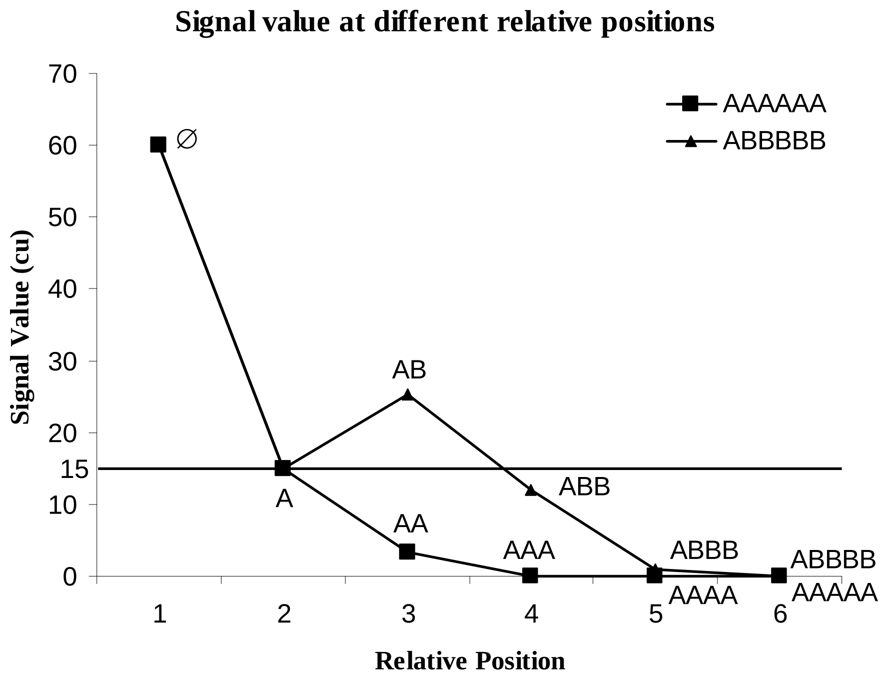

Figure 3: The decreasing expected signal value in currency units (cu) is shown in this figure if all participants acquire a private signal.

7 The only exception to this rule is the reduced history ABBAA. In this case a signal acquisition is rational even though the two preceding information based predictions (AA at positions 4 and 5) are identical.

III. Results

The following analysis is based on experimental data collected in 11 sessions with a total of 582 rounds. All in all, 3492 information acquisition decisions and state predictions were submitted.

We find that participants acquired on average too many signals compared to the rational Bayesian benchmark. Based on the available information, participants bought 28% (=459) more signals than the BU model predicts (=1639).[8] More specifically, subjects acquired private information in 551 cases with an information value of less than 15 cu and refused to buy a signal in 92 cases in spite of an information value of more than 15 cu. On the individual level, the deviation from rational behavior is measured by the subject-specific excessive signal acquisitions per round. The excessive acquisition is calculated as the difference of actually acquired signals minus the signals, which should have rationally been acquired, divided by the number of rounds in which this subject participated. For example, if a subject participated in 48 rounds and purchased 40 signals although she should have rationally purchased only 23 signals, then she averaged $\frac{40-23}{48}=0.354$ excessive signal acquisitions per round. The arithmetic mean of the individual's excessive signal acquisitions per round is 0.133, which is significantly positive with a t-statistic of -7.9 ($\alpha<0.001$).[9]

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[8] It is always rational to buy a signal at absolute positions 1 and 2 (=582+582 acquisitions). In addition, a total of 475 signals should be bought at absolute positions III to VI based on the non-uniform previous informative predictions.

[9] The normal distribution hypothesis could not be rejected according to a Kolmogorov-Smirnov Z of 1.019 ($\alpha=0.250$).

Since the decision whether to buy a signal, or not, should depend only on predictions that are based on new information, we will first analyze these “reduced” histories. Moreover, the individual behavior within identical histories may provide additional hints to find explanations for the excessive acquisitions. A cluster analysis to identify different types of participants is the next step. Based on this classification, we will analyze learning and other possible explanations for the observed buying behavior. Next, the position within a round, risk aversion and error rates influencing preceding decisions within the round will be studied. Finally, we will focus on overconfidence and updating conservatism as possible explanations. Before we conclude, we will analyze how the observed buying behavior and the resulting predictions influenced individual and group earnings.

As mentioned we start by analyzing the information acquisition behavior in specific situations. In the following analysis these decision scenarios are differentiated by the reduced rather than the complete history of predictions since we assume that subjects rationally eliminated the uninformative predictions prior to their own information acquisition decision. This assumption is supported by the fact that the signal acquisition behavior in cases where the reduced history equals the complete history compared to those cases where the two histories differ revealed no obvious influence of the uninformative predictions. For example, there was in general no difference whether subjects had to decide based on the complete history AB with private information purchased by both predecessors or based on the complete history AaB with private information acquired by the first and third subject.

Of special interest for the further analysis are reduced histories with identical preceding predictions. In this case the information value is monotonously decreasing, dropping from 60 cu to 15 cu to 3.33 cu after zero, one or two informative conforming predictions, respectively. After three, four and five identical predictions a signal acquisition does not increase the expected payoff at all. This monotonously decreasing signal value makes it possible to identify a critical information value which induces subjects not to purchase a signal. Figure 4 illustrates the mean individual signal acquisition ratios after observing identical reduced histories and the according signal values. The individual signal acquisition ratio for a given reduced history is the number of signals the subject purchased after observing a particular reduced history, divided by the total number of observations in this situation. For example, if a subject observed a reduced history AA ten times and acquired a signal on six of these occasions, then her signal acquisition ratio based on the reduced history AA is 60%. The following analysis assumes that these individual signal acquisition ratios are statistically independent.[10]

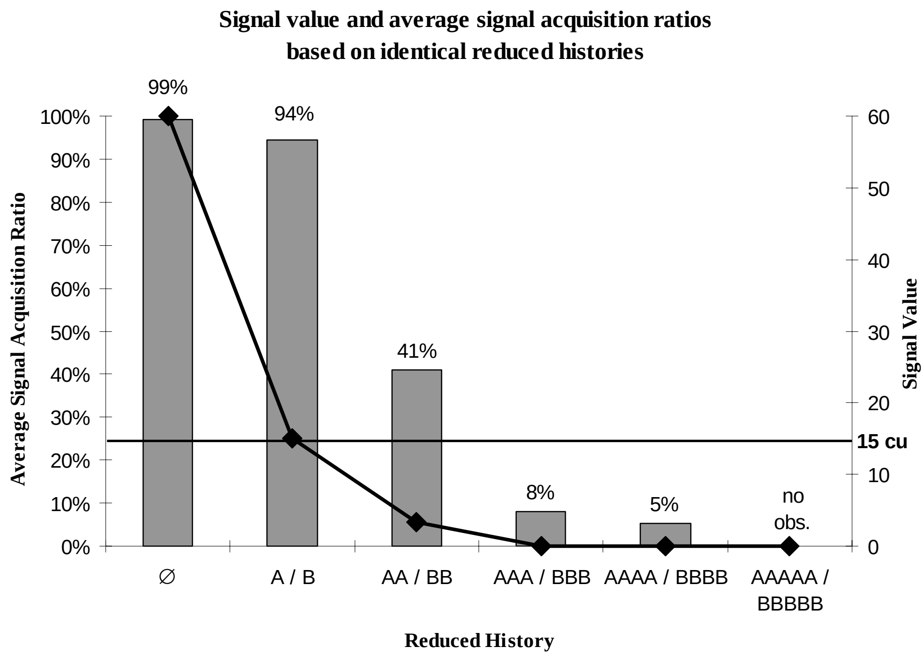

Figure 4: Mean individual signal acquisition ratios after observing identical reduced histories.

10 Both, Anderson and Holt (1997) and Hung and Plott (1999), treated all predictions as being independent. We will argue later that there is no reason to believe that the individual acquisition ratios are dependent based on the learning pattern.

If no informative prediction has been submitted, participants acquired on average a signal in 99.2% of the cases. A single informative prediction led to an average signal acquisition ratio of 94.3%. Both numbers indicate that the subjects acted mostly rational at positions 1 and 2. In cases in which the reduced history consisted of 3 or 4 informative identical predictions, subjects had an average signal acquisition ratio of 8.1% and 5.2%, respectively, which is close to the rational behavior. However, decisions after two informative identical predictions at position 3 exhibit a large fraction of non-rational behavior. The mean signal acquisition ratio is 40.9% although it should be 0%. Thus, the individual signal valuation is biased towards an overestimation of the private information value.

Taking a closer look at the behavior of certain individuals in the case of identical reduced histories reveals that the behavior is homogenous at positions 1 and 2 as well as at positions 4 and 5 but it is heterogeneous at position 3. With 53 of 66 acquisition ratios falling in the ranges 0%-30% and 70%-100% at position 3, it should be possible to separate participants according to their tendency to acquire signals based on the reduced histories AA and BB. In order to verify this assumption we performed a cluster analysis. The resulting classification provides an answer to the question whether the excessive signal acquisitions are caused by occasional deviations from rational behavior borne by all participants or by a systematic bias that can only be attributed to a fraction of the subjects. The cluster analysis classified subjects based on their signal acquisition ratios after observing the histories A/B, AA/BB and AAA/BBB.[11] Clusters were constructed to maximize the distance between groups measured by the squared Euclidean distance.

[11] Signal acquisitions with no preceding informative prediction were excluded because only three subjects refused once to buy a signal in this situation but still acquired signals in 75% of all cases. In addition, signal acquisition

With the exception of two individuals, the cluster analysis divided all subjects into two major groups. These two individuals (G_-) acquired a signal only if no preceding informative prediction had been submitted. As opposed to the behavior of the other participants, this indicates an underestimation of the signal value. Since only two subjects showed this valuation behavior, they will not be analyzed separately but added to the group of rational subjects instead. This group of rational subjects, labeled group G_0, consists of 34 subjects, who act mostly rational, i.e. they buy on average a signal after 0 or 1 informative prediction and they do not acquire private information after 2 or more informative identical predictions. The other large group, denoted by G_+, bought on average too many signals. In addition to the rational signal acquisitions at position 1 and 2, the 30 members acquired a private signal in most cases after 2 and sometimes even after 3 or 4 informative identical predictions were submitted. Figure 5 illustrates the different behavior of the G_+ group compared to the rest of the participants.

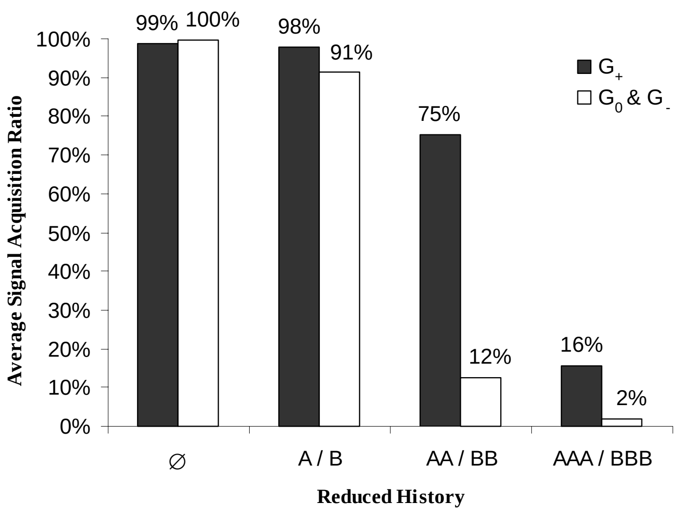

Figure 5: Average signal acquisition ratios based on identical reduced histories.

ratios based on identical reduced histories at position 5 and 6 cannot be used due to the small number of observations.

The cluster analysis revealed that a well defined group of people is mainly responsible for the divergence from rational behavior. The G_+ group averaged a signal acquisition ratio of 75.2% with histories AA or BB. The rest of the subjects purchased a signal in only 12.4% of these situations. The null hypothesis of equal means can be rejected (two-sided non-parametric Mann-Whitney test: $Z=-6.98$, $\alpha<0.001$). Based on the reduced histories AAA and BBB, the group G_+ bought on average signals in 15.6% cases compared to only 1.7% by the rest of the participants, which is also significantly higher (Mann-Whitney: $Z=-4.17$, $\alpha<0.001$).

Although the clustering was performed using acquisition ratios in the case of identical histories the classification of subjects concerning their tendency to err on the valuation of the private signal is also valid in general. The group G_+ was responsible for 420 of all 551 signals that were acquired despite the fact that the signal value was below its cost and for only 28 of all 92 irrational non-acquisitions. On average, each member of the G_+ group acquired 0.249 signals per round in excess of a rational trader compared to only 0.036 excessive signal acquisitions per round by the rest of the participants. The difference is statistically significant with a t-statistic of 9.82 ($\alpha<0.001$).[12] Based on these and the above mentioned numbers we can say that the members of the G_+ group are subject to a general overvaluation of the private signal.

A comparison of the first fifteen and the last fifteen rounds of each experiment revealed that the percentage of non-rational information acquisitions increased significantly in the G_+ group. The average acquisition ratio of the group's members after observing a reduced history AA (or BB) increased from 61% in the first fifteen rounds to 91% in the last fifteen rounds (Wilcoxon Signed

[12] The normal distribution hypotheses could not be rejected for the rest of the participants' and the G_+ group's distribution of excessive signal acquisitions per round using a Kolmogorov-Smirnov test ($Z=0.888$, $\alpha=0.409$; $Z=0.703$, $\alpha=0.706$; respectively).

Ranks Test: $Z=-3.306$, $\alpha=0.001$). Nevertheless, the behavior of the rest of the participants showed no signs of learning. Their percentage of information acquisitions based on the reduced history AA (or BB) dropped insignificantly from 17% in the first 15 rounds to 11% in the final 15 rounds (Wilcoxon: $Z=-1.232$, $\alpha=0.218$). Hence the increasing ratio of non-rational signal purchases within the G_+ group is most likely not caused by inter-personal learning but rather by an over time strengthening intra-personal bias. If there were influences of learning among participants, the difference of the average acquisition ratio of both groups (G_+ and $G_{0,-}$) should decrease. Since the opposite is true, we can assume that the individual signal acquisition ratios are statistically independent.

The state predictions based on public and private information are mostly in line with the results from the Nöth and Weber (1999) experiment and will therefore not be analyzed in detail. State predictions without private information based solely on the reduced history are mostly rational. In only 9 out of 1394 (0.65%) cases in which a subject did not acquire private information the following state prediction was non-rational. The rational predictions without private information may be a consequence of the following modified counting heuristic rather than an indication that participants used Bayes' law. This heuristic, which was derived from the final questionnaire, produces rational state prediction in 54 out of 64 possible histories:

> At position 1, with no private information, guess the state. In all other cases without private information, follow the majority. If there is no majority, follow the last informed predecessor.

Note that the given heuristic is based on the assumption, that the subject has already rationally or irrationally refused to buy a signal. Therefore, the heuristic only tries to explain the state predictions given the fact that the individual did not acquire private information. Unfortunately, it was impossible to verify if the observed behavior can be explained by the above heuristic or if subjects indeed acted rationally, since 8 of the 10 cases in which the heuristic leads to a non-rational prediction are at position 6, where we have only a small number of observations.

Explanations for the observed acquisition behavior

Now, we will analyze possible explanations for the observed non-rational information purchases following a reduced history AA (or BB). First, we investigate whether subject's behavior can be explained by a simple position based heuristic. Then, we focus on possible rational explanations like risk aversion and a consideration of other participants' non-rational behavior. Finally, we consider systematic biases like overconfidence and conservatism.

First, we want to investigate whether information acquisitions with reduced histories AA or BB are influenced by the absolute position of the participant, or not. The absolute position is defined as the decision position based on the complete history before elimination of uninformative predictions. Figure 6 illustrates the results.

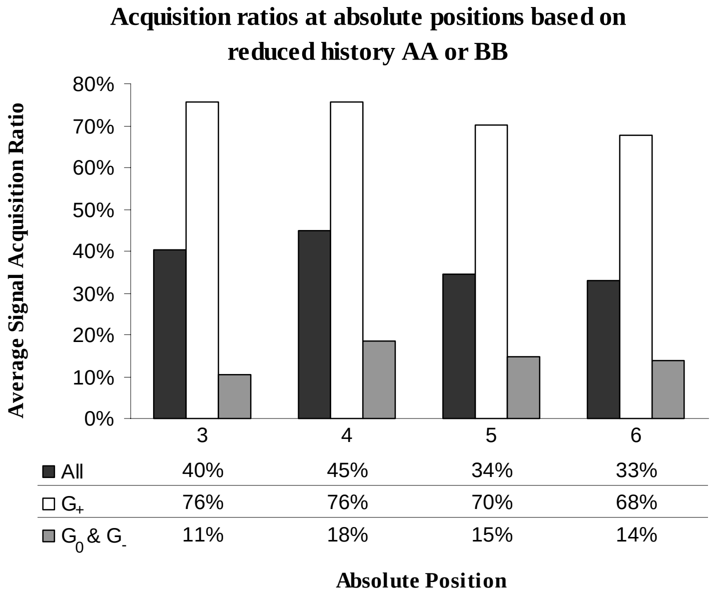

Figure 6: Influence of the absolute positions on the information acquisition decision based on the reduced history AA or BB.

There is no obvious influence of the absolute position on the acquisition decisions of the participants. The only observable effect is a tendency to acquire more signals at positions > 3 by the members of the G_0 and G_- groups. But the differences of the ratio at position 3 and the ratios at the other positions are not statistically significant based on a Wilcoxon test.[13] The same analysis for the signal acquisitions based on the reduced history AAA or BBB led to similar results.

The average signal acquisition ratios based on the reduced histories AA or BB of 75.2% and based on AB or BA of 99.45% indicate that subjects from the G_+ group followed the heuristic of always acquiring a signal after 0, 1 or 2 informative predictions and not buying otherwise. On the other hand, as mentioned above, the members of the G_+ group do not only commit excessive signal acquisitions after observing the reduced histories AA or BB but have a general tendency to overestimate the signal's value. This is supported by the significantly higher ratio of signal acquisitions based on the reduced histories AAA or BBB.[14] In addition, the average decision time regarding the signal purchase of the group G_+ at position 3 indicates a difference in the decision process depending on the underlying reduced history. In contrast to the overall average decision time of 4.58 sec. the average decision time based on the reduced history AB/BA was only 3.2 sec. Based on two identical preceding predictions (AA/BB), however, the average decision time was 4.6 sec. This difference is statistically significant (Wilcoxon: $Z=-3.655$, $\alpha<0.001$).[15] Since the use of the heuristic would imply a signal acquisition regardless of the reduced history at position 3, the decision time should not depend on the reduced history. Therefore, the significantly higher decision time contradicts the assumption that the above heuristic was used.

The calculation of the signal's value was based on the assumption that individuals are risk-neutral. One might argue that risk aversion could have led to the excessive signal acquisitions facing the reduced history AA or BB. But risk aversion cannot be an explanation for the observed behavior in our setting since the alternative of deciding solely based on public information stochastically dominates the alternative of acquiring additional information in second order (see Appendix C for a formal argument). This means that a risk averse trader with an increasing and concave utility function would always prefer not to buy a private signal regardless of the specific shape of his utility function.

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[13] The difference of the ratios at position 3 and 4, 3 and 5 and 3 and 6 have a Z-value of -1.010 ($\alpha=0.312$), -0.336 ($\alpha=0.737$) and -0.551 ($\alpha=0.581$) respectively.

[14] For the exact ratios and significance of the difference refer to the results of the cluster analysis.

An error model

The information value can also be influenced by a consideration of possible mistakes committed by predecessors. Since we try to explain the excessive information purchases based on the reduced history AA (or BB), we will only consider those errors in the following analysis, which lead to two conforming state predictions at positions 1 and 2. Thus, errors at position 2, which result in a state prediction that contradicts the prediction at position 1, are not considered, because they lead to a reduced history AB (or BA).

On the one hand, possible predictions errors at position 1 raise the information value because predictions are less informative if there is a possibility that a person at position 1 does not follow her signal, thus not conveying her private information. At position 2, there are one or two possible mistakes to be considered, depending on the second individual's consideration of errors committed by her predecessor. If the subject at position 2 assumes that the first individual acted rationally, then the only possible error leading to a reduced history AA or BB is a prediction against a strong signal, which contradicts the prediction at position 1. In case the second individual considered a possible mistake by her predecessor there is another possible error, which could have led to an identical reduced history at position 3. In that case, it is rational to follow even a weak private signal which contradicts the first prediction if one assumes an error rate at position 1 large enough to force $p(A \mid A_1) \leq \frac{3}{5}$. This means that if the second individual follows the first prediction even though she assumed an error rate large enough to justify a prediction

[15] Two subjects were excluded due to the lack of observations based on the reduced histories AB/BA. The average decision time of the remaining 28 subjects was significantly higher in the case of two identical preceding predictions.

according to her own weak signal, she commits a mistake which influences the information value at position 3.

In order to justify a signal acquisition after observing the reduced history AA or BB the assumed error rates have to be large enough so that $IV(AA/BB) \geq 15\ cu$. We consider errors at position 1 in the form of a rate ε of state predictions against a strong signal. Thus, an error rate $\varepsilon = 0$ implies that the subject at position 1 acted fully rational if she received a strong signal. Assuming that errors after observing a weak signal are at least as likely as those based on a strong signal, an error rate of $c_1 \cdot \varepsilon$ against a weak signal at position 1 is assumed. $c_1 > 1$ is a constant which was derived from the data generated in the experiments of Nöth and Weber (1999).[16]

At position 2 we assume that a subject, who receives a strong or weak signal conforming to the prediction of her predecessor, will always act rationally and follow the signal leading to a reduced history AA (or BB). The same is assumed if she receives a weak signal, which contradicts the first prediction. Both assumptions are necessary because non-rational behavior in these three cases would always lead to a reduced history AB or BA. If the second individual receives a strong signal, which contradicts the first informative prediction, then we assume that she rejects her signal in favor of the public information with rate θ, leading to a reduced history AA (or BB). For simplicity, it is assumed that the subject at position 2 does not consider possible

[16] The constant c_1 was derived from the Nöth and Weber (1999) experiments since in our experiment the error rate was $\varepsilon = 0$. Nevertheless, it seems reasonable to assume that with a larger number of observations the error rate based on a strong signal at position 1 is positive.

errors of her predecessor. According to the calculations outlined in section II, the above assumptions lead to a signal value after observing a reduced history AA (or BB) of:[17]

$$IV\,(AA) = 30 \cdot \frac{900 + 4100 \cdot \theta + 25509 \cdot \varepsilon + 13141 \cdot \varepsilon \cdot \theta}{8100 + 1900 \cdot \theta - 2319 \cdot \varepsilon + 2319 \cdot \varepsilon \cdot \theta} \tag{3.1}$$

The following figure illustrates the signal value depending on the assumed error rates ε and θ:[18]

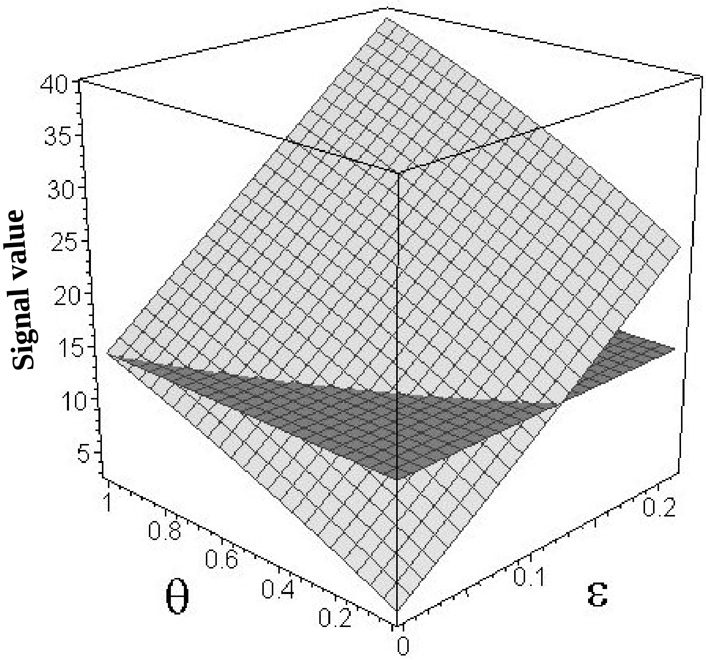


Figure 7: Influence of changes in the error rates on the signal value IV(AA/BB)

From figure 7 we can see that if the subject at position 3 assumes that the individual at position 1 acts rationally ($\varepsilon = 0$) no possible error rate θ at position 2 can lead to an information value over

17 $c_1 = 4.73$ is derived from the experiments by Nöth and Weber (1999). A more detailed calculation of the signal value is provided in Appendix D.

18 $\varepsilon \leq 0.2114$ is assumed since $\varepsilon = 0.2114$ leads to an error rate after observing a weak signal at position 1 of $c_1 \cdot \varepsilon = 1$.

15 cu. If irrationalities at position 2 are ruled out ($\theta = 0$), we have to assume a rather high error rate of $\varepsilon = 0.1181$, which is almost four times as high as in the Nöth and Weber (1999) experiments, to justify a signal acquisition based on a reduced history AA or BB. The actual error rates of $\varepsilon = 0$ and $\theta = 0.0115$ lead to a signal value of only 3.5 cu. If one takes into account the actual error rate of 0.0759 based on weak signal at position 1 instead of calculating the information value with an error rate of $c_1 \cdot \varepsilon = 4.73 \cdot 0 = 0$ the information value increases to 4.44 cu, which is still less than a third of the signal's cost. The error rates of $\varepsilon = 0.03$ and $\theta = 0.023$ observed in Nöth and Weber (1999) cannot explain the excessive signal acquisitions either, because they imply a signal value of 6.57 cu. The above mentioned numbers indicate that one has to assume rather high error rates to justify the excessive signal purchases based on the reduced histories AA or BB, making it quite unlikely that this is the reason for the observed behavior.

A model of non-rational information weighting

After we have ruled out a simple heuristic, risk aversion, and errors from predecessors as possible explanations for the excessive signal acquisitions, we will now turn to systematic biases like overconfidence and conservatism. These biases influence the weights that subjects put on the available information. At each position subjects possess public information, which is represented by the predictions of the predecessors. In addition, subjects have a private signal if they chose to purchase one after having observed the public information. If the updating procedures are biased, these two types of information can either be under- or overweighted. Since we have observed excessive signal acquisitions, we focus on those biases that lead to higher information values than rational Bayesian updating. The signal value is biased upward only if subjects either underweight the public information ($c < 1$) or overweight the private information ($d > 1$) or both.

Underweighting of the public information can be due to conservatism whereas overweighting of the private information can be caused by overconfidence. Following Edwards (1968), we use the following formula for the odds in favor of state A over state B after observing the reduced history AA (or BB) to express weighting biases in the updating process:

$$\frac{p(A|A_1A_2,s)}{p(B|A_1A_2,s)}=\left(\frac{p(A_1A_2|A)}{p(A_1A_2|B)}\right)^c\cdot\left(\frac{p(s|A)}{p(s|B)}\right)^d\cdot\frac{p(A)}{p(B)} \text{ with } s\in\{a_W, a_S, b_W, b_S\} \qquad (3.2)$$

Setting $c = 1$ and $d = 1$ leads to the rational Bayesian odds. Biases, which induce $c \le 1$ and $d \ge 1$ with $c \ne d$ lead to subjective signal values greater than the rational Bayesian signal value.

First, we analyze whether overconfidence ($d > 1$), or more generally overweighting of the private signal, influenced the participant's behavior. If overconfidence is the only reason for the excessive signal acquisitions, subjects who were mainly responsible for the non-rational signal acquisitions should also be more overconfident than others with regard to their state predictions. However, the two groups show no difference in their signal weighting behavior, i.e. the average ratio of rational state predictions by group G_+ does not differ from that of the remaining participants conditional on a signal acquisition. For example, in cases an individual observed the reduced history A (or B) and received a b_W (or a_W) signal, the G_+ group's average ratio of rational state predictions of 41% was only slightly smaller than that of the remaining subjects who averaged 44% rational state predictions (Mann-Whitney: $Z=-0.046$, $\alpha=0.963$). When subjects observed a reduced history AB (or BA) followed by an a_W (or b_W) signal, the group G_+ ignored on average their own signal more often than the rest of the participants with an average ratio of 20% compared to 8% by the remaining subjects (Mann-Whitney: $Z=-0.82$, $\alpha=0.412$). Thus, overweighting of the private information is not the decisive influence which ultimately resulted in the excessive signal acquisitions even though overweighting of the private information might have influenced the subjective signal value of all participants. In order to focus on the underweighting of the public information ($c < 1$), as this remains as the decisive reason for the excessive signal acquisitions, we set $d = 1$. This means that the homogenous weighting behavior concerning the private information of both groups is taken as the baseline to enable an isolated evaluation of the weighting behavior concerning the public information. Note that this does not rule out overconfidence in general since both groups can still be overconfident to the same extent.

Underweighting can be caused by conservatism. According to Edwards (1968) conservatism is an underweighting of the available information which leads to posterior odds that are closer to prior odds than those obtained through rational Bayesian updating. Since we assumed that $d = 1$, the general odds formula simplifies to:

$$\frac{p(A|A_1A_2,s)}{p(B|A_1A_2,s)} = \left(\frac{p(A_1A_2|A)}{p(A_1A_2|B)}\right)^c \cdot \frac{p(s|A)}{p(s|B)} \cdot \frac{p(A)}{p(B)} \quad \text{with } s \in \{a_W, a_S, b_W, b_S\} \tag{3.3}$$

Some algebra together with $p(A) = p(B) = \frac{1}{2}$ and $p(B|AA,s) = (1 - p(A|AA,s))$ leads to:

$$p(A|A_1A_2,s) = \frac{\left(\frac{p(A_1A_2|A)}{p(A_1A_2|B)}\right)^c \cdot \frac{p(s|A)}{p(s|B)}}{1 + \left(\frac{p(A_1A_2|A)}{p(A_1A_2|B)}\right)^c \cdot \frac{p(s|A)}{p(s|B)}} \tag{3.4}$$

The probability of state A based solely on public information is determined with this formula simply by setting $\frac{p(s|A)}{p(s|B)} = 1$. The following figure illustrates the relationship between c and the information value IV(AA/BB), which is calculated according to section II using the above modifications to account for conservative behavior.

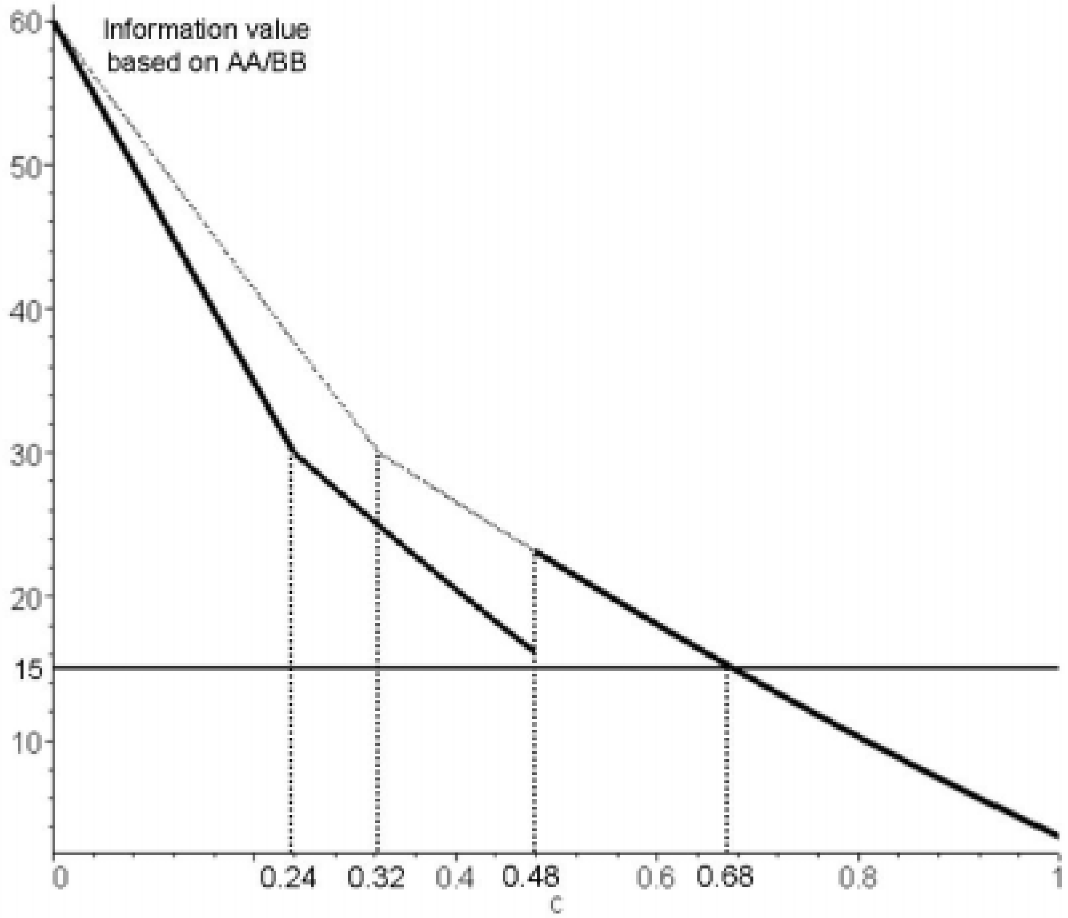


Figure 8: Relationship between the accuracy ratio *c* and the signal value IV(AA/BB)

The solid line in figure 8 represents the case in which all participants up to position 3 are conservative in the described manner. The dotted line shows the case in which only the subject at position 3 acts conservatively and both predecessors act rationally. At certain points, the conservative weighting of the public information leads to a shift in the rational behavior. This results in discontinuities or points of non-differentiability in the signal value function. In particular, if the underweighting of the public information is strong enough, a decision maker will follow her own signal even if it is only a weak signal, which contradicts the public opinion.[19] In

[19] In all other cases the decision maker will follow her own signal regardless of the degree of underweighting of the public information.

the case in which all participants act conservatively and $c \leq 0.48$ then the second subject's conservative assessment of the preceding state prediction's informativeness induces her to follow her own signal even if it is only a weak signal that contradicts the first prediction. As a consequence, the information value decreases instantly because the informativeness of the second prediction increases. If c decreases further, the third individual's conservative weighting of the public information (AA or BB) also induces her to follow her own signal independently of the strength of the signal, which in turn leads to a point of non-differentiability in the signal value function ($c = 0.24$ and $c = 0.32$, respectively).

Notice that the subjective information value exceeds 15 cu, which justifies a signal acquisition, if $c \leq 0.68$ in both cases. The shifts in rational behavior have no influence on this critical value since they never cause the information value to drop below 15 cu. Even though the two different ways to take into account conservative weighting of public information lead to different signal value functions, this has no influence on the decision at position 3 whether to acquire additional information or not.[20]

[20] A logit regression according to Hung and Plott (1999) in order to quantify the weights that subjects put on the public and private information if both predecessors predicted the same state does not seem useful in our design because in order to estimate the parameters *c* and *d*, we need observations where participants predicted based on both public and private information. But since the subjects from the G_+ group rationally refused to acquire a signal after observing a reduced history AA or BB, there are only very few observations for this group so that a regression is not possible due to the lack of data.

Welfare

The effect of the observed non-rational behavior on the aggregation process and on welfare is our next topic. We compare the histories of each round, which would have occurred if all participants had acted rationally, to the observed histories. Deviations from rational behavior will be analyzed further in order to identify the reason of non-rational behavior.

Actual / Rational	Correct cascades	Reverse cascades	Non-cascades	Sum
Correct cascades	283	2	109	394
Reverse cascades	3	40	53	96
Non-cascades	4	4	84	92
Sum	290	46	246	582

Table 1: Comparison of rational and actual histories.

From table 1 we can see that 167 (3+2+53+109) of 490 rational cascades collapsed.[21] In 5 (3+2) of these 167 cases even the opposite cascade developed. Taking a closer look at those cases in which the rational cascade collapsed reveals that in 60 of these 167 cases (35.93%) a non-rational information acquisition preceded a deviation from rational behavior, whereof 57 signal purchases are based on a reduced history AA or BB. In 56 cases the private signal was revealed through the following state prediction. Other reasons for a deviation from rational behavior include overweighting of the private signal[22] (41.92%) and random errors (17.96%). Overweighting is

[21] Correct cascades are cascades in which all individuals predict the state that actually occurred. Reverse cascades are cascades in which all participants predict the state that did not occur.

[22] Note that this is not inconsistent with the above stated assumption that $d = 1$, since our model only tries to explain the behavior of the group G_+ relative to that of the remaining subjects. Therefore subjects can still be overconfident on an absolute level.

referred to as a rational information acquisition with a subsequent non-Bayesian prediction that reveals the private signal, possibly due to overconfidence. Following these numbers and taking into account that state predictions without private information are mostly rational, we can say that the excessive signal acquisitions at position 3 based on identical reduced histories are a major reason for the collapse of rational cascades.

To expose the effect of the observed behavior on general welfare, we first have to mention that in 126 of 167 cases the non-rational behavior led to a disclosure of the private information and therefore increased the public information level. Nevertheless, the aggregated payoffs dropped from 1,146,270 cu if all participants were Bayesian to 1,137,030 cu actually paid.[23] If we divide the effect of deviations from rational cascades between correct and reverse rational cascades, deviations from correct rational cascades induce on average 1.81 following incorrect state predictions and 580.7 cu less aggregate payoff, whereas deviations from reverse rational cascades lead on average to 3.73 subsequent correct state predictions and 1082.4 cu more aggregate payoff. Both differences are highly significant according to a Mann-Whitney test with a Z-statistic of -6.7 ($\alpha<0.001$) and -4.57 ($\alpha<0.001$), respectively. Thus, the positive effect from avoiding a rational reverse cascade clearly outnumbers the negative effect from avoiding a rational correct cascade. But this positive relation did not lead to an increase in general welfare because rational cascades collapsed more often than reverse cascades due to our information structure, which induces a higher probability for the formation of a rational cascade. This means that the negative effect occurs more often offsetting the more intense positive effect in terms of aggregated payoffs.

[23] Note that 349,200 cu (582 rounds * 6 participants * 100 cu) were safe payments in both cases since even a wrong prediction yielded a payoff of 100 cu.

Taking into account that the non-rational behavior led to a disclosure of the private information in most cases and following the model of Bernardo and Welch (1999) an optimal fraction of non-rationally acting individuals combined with an increased number of participants may produce different results. First of all, an increased number of participants leads to an increased number of decision makers who can benefit from non-rational behavior, which reveals private information. Furthermore, it is reasonable to assume that deviations from rational correct cascades are only temporary. Because of the information structure, non-rational behavior leads to additional signal acquisitions, which in turn raise the public information level and lead to a convergence to the correct state. Under these assumption the positive effect from collapsed reverse cascades would increase with an increasing number of participants leaving the negative effect from collapsed correct cascades unchanged. Assuring an optimal fraction of non-rational participants this could lead to an increase in aggregate payoffs.

Individuals earned on average 5 cu per round less than if they would have acted rational based on their given information. Individuals from the G_+ group, who tend to overestimate the signal value, performed worst with an average of 6.7 cu per round less than a Bayesian trader. The rest earned 3.6 cu per round less than the BU-model predicts. This difference is not statistically significant (Mann-Whitney: $Z=-0.335$, $\alpha=0.738$).

Summing up we can say, that the observed behavior led to a decrease in general welfare because the negative effect thereof occurred more often although having less extend than the positive effect. An alternation in the setting may have produced different results.

IV. Conclusions

We investigated the information acquisition behavior in a simple aggregation process in this experiment. Almost half of the subjects tend to overestimate the signals‘ value leading to excessive signal acquisitions. These non-rational information purchases cannot be explained by neither risk aversion nor the use of a simple position based heuristic. A consideration of possible errors committed by predecessors also seems to be no reasonable explanation for the observed anomalies.

We developed a model, which explains the excessive signal acquisitions through conservative assessment of the weights that subjects put on preceding state prediction. Although overweighting of private information raises the subjective signal value too, the observed updating procedures do not support that this was the decisive reason for the non-rational signal acquisitions. Influences, which were not integrated in our model and which cannot be verified based on the given data, include regret aversion and locus of control.

Even though the observed behavior increased the public information level, it led to a decrease in aggregate payoffs. Nevertheless there might be other environments in which the observed behavior is favorable from a welfare perspective. The purpose of future research should be a better identification of the reasons which lead to excessive private information gathering as well as an investigation of the consequences of the observed behavior in market situations. Of high interest is the question whether excessive private information acquisition can prevent misaggregation of information in financial markets weakening the effects of herding.

References

ANDERSON, L. R. and HOLT, C. A. (1997), "Information Cascades in the Laboratory", *American Economic Review*, **87**, 847-862.

BANERJEE, A. (1992), "A Simple Model of Herd Behavior", *Quarterly Journal of Economics*, **107**, 797-818.

BERNARDO, A. and WELCH, I. (1999), "On the Evolution of Overconfidence and Entrepreneurs" (Mimeo, UCLA).

BIKHCHANDANI, S., HIRSHLEIFER, D. and WELCH, I. (1992), "A Theory of Fads, Fashion, Custom, and Cultural Change as Informational Cascades", *Journal of Political Economy*, **100**, 992-1026.

COPELAND, T. E. and FRIEDMAN, D. (1991), "Partial Revelation of Information in Experimental Asset Markets", *Journal of Finance*, **46**, 265-295.

COPELAND, T. E. and FRIEDMAN, D. (1992), "The Market Value of Information: Experimental Results", *Journal of Business*, **65**, 241-266.

EDWARDS, W. (1968), "Conservatism in Human Information Processing", in BENJAMIN KLEINMUNTZ, ed., *Formal Representation of Human Judgment* (New York: John Wiley), 17-52.

GROSSMAN, S. J. and STIGLITZ, J. E. (1980), "On the Impossibility of Informationally Efficient Markets", *American Economic Review*, **70**, 393-408.

HUCK, S. and OECHSSLER, J. (1999), “Informational Cascades in the Laboratory: Do They Occur for the Right Reasons?”, (Mimeo, University of Bonn).

HUNG, A. A. and PLOTT, C. R. (1999), “Information Cascades: Replication and an Extension to Majority Rule and Conformity Rewarding Institutions”, (Mimeo, forthcoming *American Economic Review*).

NÖTH, M. and WEBER, M. (1999), “Information Aggregation with Random Ordering: Cascades and Overconfidence”, (Mimeo, University of Mannheim).

SUNDER, S. (1992), “Market for Information: Experimental Evidence”, *Econometrica*, **60**, 667-695.

WELCH, I. (1992), “Sequential Sales, Learning, and Cascades”, *Journal of Finance*, **47**, 695-732.

Appendix A

Sequential Information Processing Experiment Instructions

Thank you for your participation in this experiment of economic decision making. The money for your payment has been provided by the Deutsche Forschungsgemeinschaft. This session will probably last about two hours. Please follow the instructions very carefully, in order to earn as much money as possible. You can always ask questions until the end of the test rounds.

Information structure and course of a round

In this experiment you shall predict the occurred state in each round based on your given information.

The course of the experiment is as follows. Two states, named A and B, can occur. Which one of the two states occurs is determined through a coin toss at the beginning of each round, i.e. both states are equally likely.

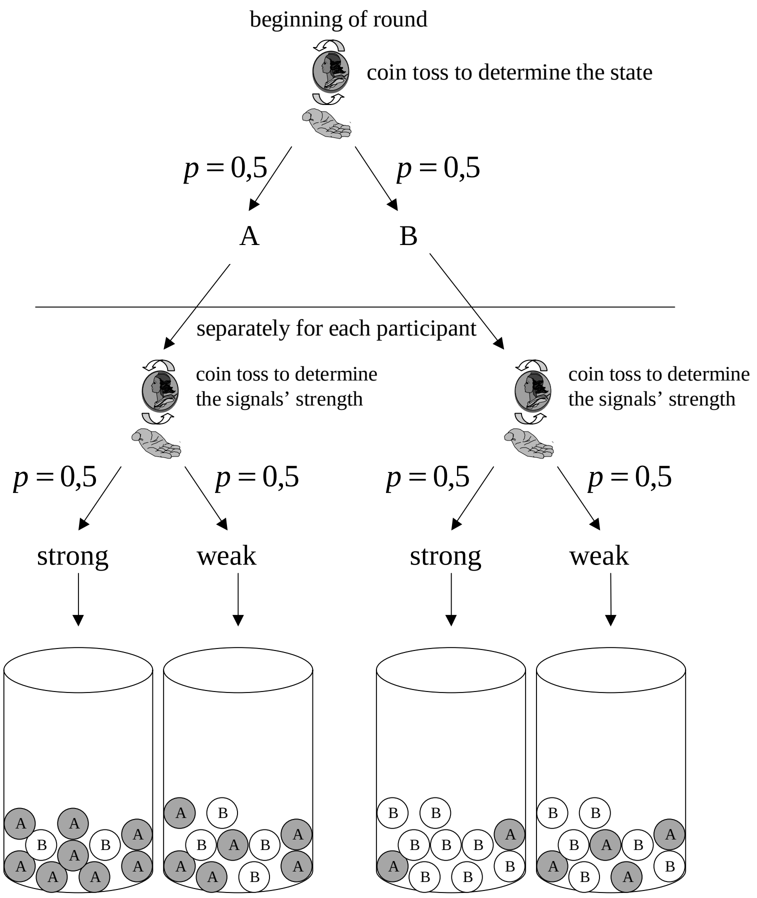
Your task is to predict the occurred state, which is not publicly observable. The ordering of the six participants is determined randomly in each round.

One source of information for your prediction are the publicly announced predictions of your predecessors. Along with the preceding state predictions the computer also displays if the predecessor bought a private signal or not, when it is your turn to predict the occurred state.

In addition to that public information you have the opportunity to acquire a private signal for 15 cu, which only you can see. This private signal gives you an indication which state could have occurred. The private signal will be determined depending on the true state as follows:

- First, a fair coin toss ($p = \frac{1}{2}$) determines if the signal is either strong or weak.
- The signal is now being determined, dependant on its strength, by a draw from an urn with 10 signals:
- The "strong" urn contains 8 signals indicating the occurred state and 2 signals indicating the opposite state. That means, the strong signal indicates the occurred state with a probability of $p = 0.8$ and the opposite state with a probability of $p = 0.2$.
- The "weak" urn contains 6 signals indicating the occurred state and 4 signals indicating the opposite state. That means, the weak signal indicates the occurred state with a probability of $p = 0.6$ and the opposite state with a probability of $p = 0.4$.

The following figure illustrates the determination of the signal.



If you have decided to acquire a signal the computer display the signal, as well as the accompanying strength of the signal. Afterwards you will be asked to submit your state prediction. If you refuse to buy a signal you have to submit your prediction immediately. Take into account that you have to spend 15 cu to buy a signal.

The rest of the participants can observe the predictions of their predecessors, which are made public after submission in the lower part of the program window. However, they cannot infer neither the underlying signal nor the accompanying signal's strength. The identification of the participant is not possible either. Your position within a round is displayed as a red number.

Attention: An additional information cannot be inferred from the reaction time of the acting participant since the computer enforces a random delay of at least 2 and not more than 5 seconds before asking for the state prediction even if the participant decides not to buy a signal.

As soon as all six participants have made their decisions, the occurred state will be announced and a further round (with new information) begins.

Test rounds

Before you can start earning money with your predictions, you will get to know the course of the experiment in three unpaid test rounds. During these test rounds you can always ask question about the information structure and the course of the experiment.

Payment

You will participate in at least 40 rounds, in which you will be paid according to the correctness of your predictions. For each correct predictions you will receive 400 cu and for each false prediction only 100 cu. A private signal costs 15 cu. At the end of the experiment your total payoff will be converted in Deutsche Mark (DM) according to the expected hourly earnings of 16 DM.

Appendix B

Final questionnaire

1. Which decision rule (or heuristic) have you used to decide whether to buy a private signal or not?

2. Which decision rule (or heuristic) have you used to make your state prediction? Did it make any difference to you, if you acted at the beginning, in the middle or at the end of a round?

3. Has your behavior changed during the experiment? If so, why?

4. In which way did you use the information concerning the signal acquisitions of your predecessors in your own decisions?

Appendix C

If the subject with the utility function *u(x)* refuses to acquire a private signal, the expected utility based on the reduced history AA is calculated as follows:

$$EU(V_{no-signal}(A_1 A_2)) = p(A \mid A_1 A_2) \cdot 400 + (1 - p(A \mid A_1 A_2)) \cdot 100$$

$$= \frac{7}{9} \cdot u(400) + \frac{2}{9} \cdot u(100)$$

The acquisition of a private signal yields an expected utility of:

$$EU(V_{signal}(A_1A_2)) = p(a_W \mid A_1A_2)\cdot\left[p(A\mid A_1A_2,a_W)\cdot u(385)+(1-p(A\mid A_1A_2,a_W))\cdot u(85)\right]$$

$$+\ p(a_S \mid A_1A_2)\cdot\left[p(A\mid A_1A_2,a_S)\cdot u(385)+(1-p(A\mid A_1A_2,a_S))\cdot u(85)\right]$$

$$+\ p(b_W \mid A_1A_2)\cdot\left[p(A\mid A_1A_2,b_W)\cdot u(385)+(1-p(A\mid A_1A_2,b_W))\cdot u(85)\right]$$

$$+\ p(b_S \mid A_1A_2)\cdot\left[p(B\mid A_1A_2,b_S)\cdot u(385)+(1-p(B\mid A_1A_2,b_S))\cdot u(85)\right]$$

$$=\frac{25}{90}\cdot\left[\frac{21}{25}\cdot u(385)+\frac{4}{25}\cdot u(85)\right]+\frac{30}{90}\left[\frac{14}{15}\cdot u(385)+\frac{1}{15}\cdot u(85)\right]$$

$$+\frac{20}{90}\cdot\left[\frac{7}{10}\cdot u(385)+\frac{3}{10}\cdot u(85)\right]+\frac{15}{90}\left[\frac{8}{15}\cdot u(385)+\frac{7}{15}\cdot u(85)\right]$$

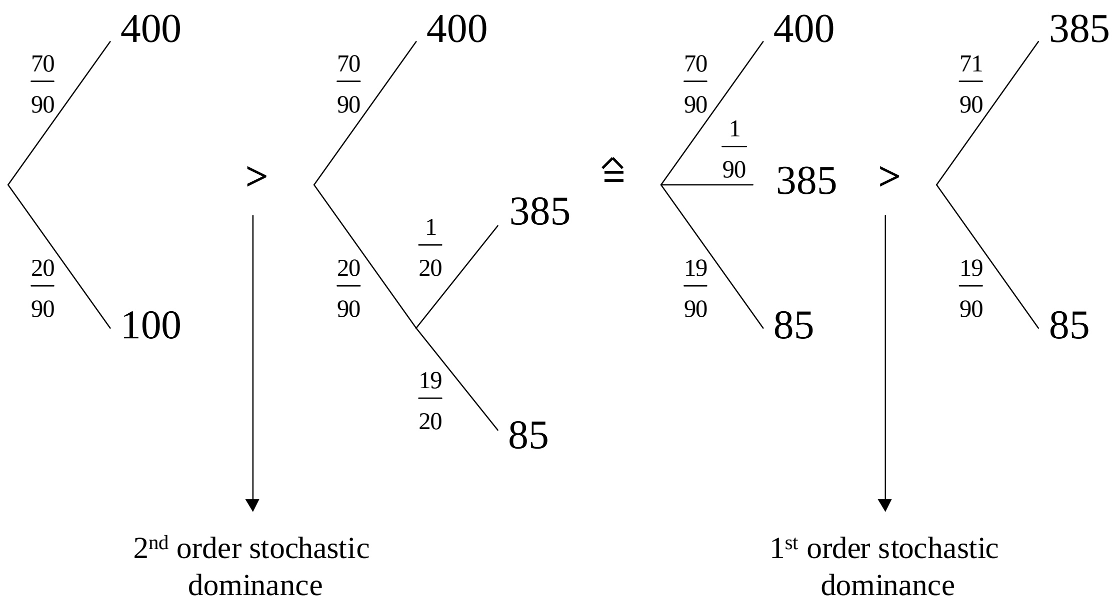
$$=\frac{71}{90}\cdot u(385)+\frac{19}{90}\cdot u(85)$$

A signal acquisition is rational if:

$$EU(V_{no-signal}(A_1A_2)) \leq EU(V_{signal}(A_1A_2))$$

$$\Leftrightarrow \qquad \frac{7}{9}\cdot u(400)+\frac{2}{9}\cdot u(100) \leq \frac{71}{90}\cdot u(385)+\frac{19}{90}\cdot u(85)$$

The following figure illustrates the relation between the two lotteries:



Because of the 2nd order stochastic dominance there exists no increasing and concave utility function, which satisfies the above condition.

Appendix D

Calculation of the information value based on the reduced histories AA or BB in consideration of possible errors of predecessors

Possible errors at position 1 are taken into account in the form of a rate ε of predictions against a strong signal at position 1 and a rate $c_1 \cdot \varepsilon$ of predictions against a weak signal. Due to the larger number of observations the constant c_1 was derived from Nöth and Weber (1999). This led to $c_1 = 4.73$ inducing a probability that the first subject predicts state A under the condition that state A occurred of:

$$p(A_1 \mid A) = \frac{1}{2} \cdot \frac{4}{5} \cdot (1-\varepsilon) + \frac{1}{2} \cdot \frac{3}{5} \cdot (1 - 4.73 \cdot \varepsilon) + \frac{1}{2} \cdot \frac{2}{5} \cdot 4.73 \cdot \varepsilon + \frac{1}{2} \cdot \frac{1}{5} \cdot \varepsilon$$

$$= \frac{7}{10} - 0.773 \cdot \varepsilon$$

If one assumes that subjects at position 2 predict against a strong signal, which contradicts the prediction at position 1, with rate θ, the probability of a prediction of state A at position 2 under the condition that state A occurred and the first subject predicted A is:

$$p(A_2 \mid A, A_1) = \frac{1}{2} \cdot \frac{4}{5} + \frac{1}{2} \cdot \frac{3}{5} + \frac{1}{2} \cdot \frac{2}{5} + \frac{1}{2} \cdot \frac{1}{5} \cdot \theta$$

$$= \frac{9}{10} + \frac{1}{10} \cdot \theta$$

This leads to a probability of state A based solely on the reduced history AA of:

$$p(A \mid A_1 A_2) = \frac{p(A_1 \mid A) \cdot p(A_2 \mid A, A_1) \cdot p(A)}{p(A_1 \mid A) \cdot p(A_2 \mid A, A_1) \cdot p(A) + p(A_1 \mid B) \cdot p(A_2 \mid B, A_1) \cdot p(B)}$$

The probability of state A after observing the private signal *s* is calculated as follows:

$$p(A \mid A_1 A_2 s) = \frac{p(A_1 \mid A) \cdot p(A_2 \mid A, A_1) \cdot p(s \mid A) \cdot p(A)}{p(A_1 \mid A) \cdot p(A_2 \mid A, A_1) \cdot p(s \mid A) \cdot p(A) + p(A_1 \mid B) \cdot p(A_2 \mid B, A_1) \cdot p(s \mid B) \cdot p(B)}$$

According to the calculations of the signal value in section II this ultimately leads to a signal value based on the reduced history AA of:

$$IV(AA) = 30 \cdot \frac{900 + 4100 \cdot \theta + 25509 \cdot \varepsilon + 13141 \cdot \varepsilon \cdot \theta}{8100 + 1900 \cdot \theta - 2319 \cdot \varepsilon + 2319 \cdot \varepsilon \cdot \theta}$$

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