Option Pricing by Students and Professional Traders: A Behavioural Investigation

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Abstract

We compare the behaviour of students and professional traders from an influential German bank in an experiment involving financial options. The arbitrage free option price is independent of the probability distribution of the underlying asset. The experimental data uncover a probability dependent option valuation of the students, however, they learn to exploit more arbitrage as they gain experience. The professional traders exhibit a less probability sensitive valuation, but their overall performance is lower than the students'. We offer the explanation that the professional traders choose a more intuitive and less analytic pattern of behaviour than the students, despite their superior knowledge in financial market theory and practice. At real financial markets, traders are typically not confronted with given and known exact probability distributions, but they must rather rely on their intuitive calibration of the prospects.

Keywords

Experiment, Option Pricing, Arbitrage, Bounded Rationality

JEL Classification Codes

C91, G12, G14

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1. Introduction

An option contract gives its holder the right to trade (either buy or sell) a certain object at a pre-specified price in a pre-specified time span, and thus enables the holder to hedge the risk of future price changes. Option contracts are widely observed. Next to options on financial assets, option features can also be found in all investment contracts that provide a unilateral right of cancellation prior to maturity. This right is an option that may be exercised if the market conditions meanwhile improve compared to the pre-specified contract conditions. A typical example is a mortgage contract with a fixed interest rate, which can be terminated before maturity. If the market interest rates fall, the mortgagee concludes a new mortgage contract with lower rates and pays back the remaining debt of the old one. If, however, the market rates rise, the mortgagee does not exercise the option and profits from the lower contract rates. [1]

The question of how an option contract should be priced cannot be answered without considering the strong relationship between the option and the underlying asset (e.g. the stock). Since the seminal paper by Black and Scholes (1973) a huge theoretical literature has emerged on option valuations. Because the payoff streams of the option and the underlying asset are strongly connected, it is – under some assumptions – possible to duplicate the payoff stream of the option by a combination of the underlying asset and some other financial contract (e.g. a bond). The requirement that every two objects which have the same payoff stream must have the same price, uniquely determines the price of the option contract for a rational investor. If the two assets – the option and the duplicating portfolio – were priced differently at the market, then this price gap would provide an opportunity for a risk free arbitrage profit. Rational traders would exploit this opportunity, such that market forces would immediately correct any mispricing of the assets. The strong rationale behind this no-arbitrage condition allows making rather weak assumptions on the underlying market structure.

Some of the necessary assumptions, however, may not be met in the real world. Financial markets are often, at least to some extent, imperfect. Transaction costs and information deficits may prevent competitors from exerting market pressure if a mortgagee does not make use of arbitrage opportunities. Markets for financial derivatives are often thin, characterised by few professional traders and many small private investors and amateur speculators. Even if there are smart traders identifying all possible arbitrage opportunities, they may be too few to exert competitive pressure: A coalition of few insiders would prefer to leave some persistent arbitrage opportunities and exploit rather than eliminate them. Therefore, an observed mispriced option may either be caused by inappropriate market conditions or by the pricing decisions of the individual investors, or by a mixture of both. In an analysis of the reasons for a potentially observed mispriced option it would be desirable to separate between these causes and to describe its potential interaction. In an

[1] A discussion of the option feature in mortgages is provided by Gerber and Carron (1990).

empirical analysis this separation is often impossible due to the lacking information and control of the market conditions.

The advantage of an experimental investigation lies in the possibility to control the market framework in such a way that the individual behaviour of investors can be isolated as the only endogenous variable. This allows studying the individual investment behaviour under the theoretically appropriate market conditions. Experimental research on behaviour in a financial market framework has created a fruitful stream of research, called behavioural finance. It incorporates psychological aspects of decision making into the analysis of financial markets. The present paper is a contribution to this research. An overview of the parts of this literature which are important for our study is given in section 2.

In this paper, we analyse option pricing decisions in a controlled laboratory experiment. We create an option-pricing scenario based on the binomial option-pricing model by Cox, Ross, and Rubinstein (1979), where we consider only one decision period. The model involves a stock which goes up with probability q and moves down with probability $1 - q$, and in addition, a call option on the stock. Furthermore, the investor can buy or sell a bond with a riskless interest rate. This model seems especially appropriate as a starting point for the behavioural analysis of option pricing for two reasons: first, the model is strikingly simple, and second, it involves a very clear theoretical prediction. The parameters of the stock, the bond, and the exercise price of the option uniquely determine the "correct" price of the call for a rational investor. It is independent of the probability q of the stock movement, and also independent of the investor's utility function, as long as he or she prefers more money to less.

Since our main interest is on studying the individual pricing behaviour we chose the simplest institutional framework. In a non-interactive situation a trader acts on a fictitious market in which he or she is confronted with a (randomly chosen) option price at which he or she may either buy or sell options. Moreover, the trader can buy or sell stocks and bonds at fixed prices. If a trader exploits arbitrage by trading mispriced calls, he or she does it "against the experimenter". Each trader is confronted with consecutive fictitious market situations, so that we are able to study a potential learning. Since the market conditions provide the necessary requirements to ensure arbitrage-free option pricing, potentially mispriced options can unambiguously be attributed to behavioural regularities in the trader behaviour.

The experimental data show that the option is valued by a price which depends on the probability of the stock movement. For probability values q for which the discounted expected value of the call is "close" to the arbitrage free price, the pricing of the call is close to its discounted expected value. However, for probability values q such that the discounted expected call value is drastically different from the arbitrage free price, we observe a sharp decrease in the call valuation. With increasing experience it moves away from a value close to call's discounted expected value in the direction of the arbitrage free price. In these treatments the traders experience with an increasing practice that the valuation by the expected payoff is not adequate.

Of course, a behavioural approach to option pricing must not ignore the fact that different option contracts may be traded by different people. Sophisticated financial options are often used by highly trained specialists, whereas mortgage loans are taken by people without a particular background in finance theory. Thus, experimental results might be biased by the selection of subjects. The present experiment has therefore also been conducted with high-level professional traders from an influential German bank. It can be expected that professional traders who daily evaluate and handle financial contracts perform much better than student subjects. In the framework of our experiment this would mean that they exploit the arbitrage possibilities to a greater extend and in addition construct portfolios with a better performance.

There are, however, also hints in the literature that a superior performance of the professional traders is not self-evident. Experimental studies that compare student behaviour to that of professionals in the investigated field (for an overview see section 2) exhibit a phenomenon which is coined the *curse of knowledge*. It describes the observation that professionals transfer routines of their every day work situation to the lab situation. The fact that these routines may have proven successful in their daily practice, but are not appropriate in the experimental situation then leads to a better performance of the students in comparison to the professionals. The advantage of the students is that they analyse the (to them completely unfamiliar) situation in a more analytic way as if it would be an exam question.

Our experimental data support the second hypothesis. The professional traders perform worse than the students with respect to the exploitation of arbitrage opportunities as well as with respect to the exploitation of expected payoffs. Professional traders seem to follow a more adaptive strategy, in which the exactly specified probabilities for the future states of the world are of secondary importance. This can be explained by the practical decision tasks the traders must solve in their working life, which can typically not be based on exactly specified probabilities. This conjecture is supported by additional data collected with students who have less formal training than those of our original sessions. Their advantage over the professional traders is only minimal (albeit still significant in one dimension) such that we suggest that the difference between the students and the professionals is mainly attributed to the familiarity the former have with solving abstract decision problems.

2. Review of the Literature

Experimental studies on option pricing are rare in the literature and the major interest of the existing studies is on information aggregation in option markets.[2] O'Brien and Srivastava (1990 and 1993) study whether the exploitation of arbitrage produces informational efficiency in an option market. They consider a two-period model with two stocks, one American call option and one American put option. A trader can be of two different types and distinguished by the

[2] Overviews over the experimental literature on markets for financial assets in general can be found in Sunder (1995) and Cadsby and Maynes (1998).

information on the stock dividend. Together these two types have full information. At the full information price no trader can perceive an arbitrage opportunity based on the private information. In both experimental studies O'Brien and Srivastava find, that in many cases where the information aggregation failed, arbitrage possibilities persisted over time.

Kluger and Wyatt (1995) study the information aggregation in option markets with asymmetrically informed agents. They compare the efficiency in two different markets: an asset market and the identical market with the possibility to trade options. Kluger and Wyatt find that options are not informationally redundant, but speed up the information aggregation process. They lead to a higher efficiency in the underlying security market.

Rietz (1991 and 1993) studies the exploitation of arbitrage in a market which may provide the possibility of a sure gain. In an experimental asset market, participants can trade green and blue certificates. At the end of the period a ball is drawn from an urn containing blue and green balls (with a known distribution). If the drawn ball is green (blue), the green (blue) certificates pay 1 and the blue (green) certificates are worthless. Therefore, a unit portfolio, containing one green and one blue certificate is worth 1. If a trader can buy such a portfolio for less than 1 or sell it for more than 1, the trader can make risk-free arbitrage. In his first paper, Rietz (1991) observes a large number of arbitrage possibilities, which persist over time. In his second study (Rietz, 1993) he extends the market by an arbitrageur (the experimenter), who's task it is to exploit arbitrage by buying a unit portfolio, whenever it's price is below 1 and selling it on the market, whenever it's price is above 1. The role of the experimenter is explicitly explained to the subjects. Nevertheless, the professional arbitrageur could reduce, but not eliminate arbitrage possibilities.

The main focus of our paper, however, is on the individual pricing decisions of subjects in option contracts. Shavit, Sonsino, and Benzion (2001) also compare subjects' trading behaviour of financial assets in an individual decision setting. They compare buying and selling lotteries with a situation in which subjects can buy and sell options on lotteries. The main finding is that subjects frequently violate no-arbitrage conditions, especially when they are very risk-averse. Fellner, Güth, and Maciejovsky (2004) and Dittrich, Güth, and Maciejovsky (2004) observe an overconfidence effect when subjects have the choice between actually equivalent alternatives. Rockenbach (2004) also considers individual option pricing decisions and identifies mental accounting as a major behavioural determinate of individual behaviour. The subjects act as if they associate the risky assets to the same mental account, while the bond is treated separately. This corresponds to the construction of a two-layer portfolio (of a risky and a safe layer) in the behavioural portfolio theory of Shefrin and Statman (2000).

In the literature, several experimental studies which oppose behaviour of student subjects to that of professionals are known. An excellent survey is provided by Ball and Cech (1996), who deal with subject pool differences in laboratory experiments more generally.

The majority of studies do not detect a substantial difference in the behaviour of students and practitioners. If a different behaviour of the two subject pools is found, it is the case in studies in which a concrete real situation is modelled in the experiment. The phenomenon named the "curse of experience" describes that practitioners apply certain patterns of behaviour, which are adequate for the real life situation but not optimal for the model, to the experimental situation. This leads to lower performance rates of the professionals, compared to the student subjects. Towards the end of this section, we will get into this issue more deeply.

One of the first studies that deal with the comparison of student and professional subjects is the one by Siegel and Harnett (1964). Like in the experiment by Banks, Camerer, and Porter (1994), who analyse signalling games, the experimental situation was not particularly related to the practitioners' professional background. Both studies find no significant difference in behaviour between the two types of subjects. A similar result is obtained in the studies by King, Smith, Williams, and Van Boening (1992), who observe over-the-counter traders in experimental stock exchange markets, and by DeJong, Forsythe, and Uecker (1988), who examine the behaviour of businessmen in a principal-agent model.

Three further studies should be considered more comprehensively. One of these studies, which has raised larger interest, is the one by Burns (1985). The experiment utilised a similar approximation to the Australian wool auction. The subjects were inexperienced students on the one hand, and professional Australian wool traders with a long time experience with the wool auction. The results of the experiment can be summarised in the finding that the professional traders suffered from the "curse of experience", and therefore achieved lower payoffs than the students. Burns hypothesises that the professional wool traders intuitively consider low prices as a signal of poor quality, and thus do not exploit them optimally. Second, they buy quantities even at too high prices, possibly because they are used to buy minimum quantities to maintain production.

Dyer, Kagel und Levin (1989) study common value auctions with students and managerial employees from the construction industry. The experiment discovers no significant difference between the subject pools with respect to the winner's curse phenomenon. However, students exhibit a stronger response to variations in the signal precision than the experts do. The authors conjecture that in their scope of work, practitioners are not familiar with stochastic cost situations and therefore do not take them into consideration very much.

Lo, Cooper, Kagel, and Gu (2001) study the *ratchet effect*, which can occur in centrally planned economies. If the central planner sets a target to each worker, adjusted according to the worker's capability, then it is the high capability workers' optimal strategy to imitate a low capability worker. Doing so, they will receive a low target which they can easily achieve without too much effort. The workers' understatement of their capabilities leads to the ratchet effect resulting in inefficient allocations observed in planned economies. In one treatment, the instructions were presented in a real-life context, the other treatment used neutral instructions. The results show that students are not influenced by the particular context, whereas managers behave differently in the two treatments.

3. The Model

In all experiments (the ones with students as well as the one with professionals), we use the binomial option-pricing model, introduced by Cox, Ross, and Rubinstein (1979). It was our goal to structure the model as simple as possible, but nevertheless capture all the relevant features of this model. Therefore, we restrict our attention to a binomial model with just one decision period.

Time is divided into two stages, called today (t=0) and tomorrow (t=1). Tomorrow, two states of the world are possible: state *up* will occur with probability q and state *down* occurs with the residual probability 1–q. There is a stock which has a value of S today. In tomorrow's state up the stock moves to uS and in state down it moves to dS. There is a call option on the stock with the strike price K. Tomorrow the holder of this option has the right to buy the stock at price K. In case the option is exercised, the difference between the stock value and the exercise price (i.e. uS−K in state up and dS−K in state down) is the profit of the holder of the call. If the call is not exercised it has a value of zero to its holder. Finally, there is a bond with a one plus riskless interest rate of r for borrowing as well as for lending. This means that every today's amount B of bonds, has a value of rB tomorrow. Assume that u>r>d and r>1.

Consider an investor with an increasing utility for money. At which prices should this investor be willing to buy the call option and at which prices should he/she rather sell it? Let $C_u=\max\{0,uS-K\}$ and $C_d=\max\{0,dS-K\}$ be the call value in state up and down, respectively. Cox, Ross, and Rubinstein (1979) show in their analysis of the binomial option pricing model that whenever the call price is different from $C_0 = \frac{1}{r}[pC_u + (1-p)C_d]$, [1] with p=(r–d)/(u–d), there is a possibility for (risk-free) arbitrage. In order to see this, construct a hedge portfolio, containing Δ stocks and B bonds, which exactly duplicates the payoff of the call option in each state of tomorrow. Choose $\Delta = \frac{C_u - C_d}{(u-d)\,S}$ and $B = \frac{u\,C_d - d\,C_u}{(u-d)\,r}$. Then it is straightforward to verify that the portfolio containing Δ stocks and B bonds pays C_u in tomorrow's state up and C_d in state down. Today's value of the hedge portfolio is C_0.

Two objects, the call option and the hedge portfolio, which have the same value in all states of the world tomorrow must have the same price today. Otherwise there is a possibility for arbitrage. Therefore, C_0 is the *arbitrage free price of the call option*. Whenever the investor faces a call price other than C_0 he/she can make a risk free gain by trading the option and the hedge portfolio. The investor should buy the call and sell the hedge portfolio in case the price is below C_0. And, if the call price is above C_0, the investor should sell the call and buy the hedge portfolio. In both cases the difference between the call price and C_0 can be invested into bonds, which generates a sure gain of r times the price difference.

The option pricing approach has several notable features and we shall focus on two of them. First, the option pricing formula does not contain the probability q of the stock movement. At first glance this seems counterintuitive. However, the intuition of this probability independence is actually quite simple. Since the hedge portfolio duplicates the payoff of the call in each of tomorrow's states, no matter how likely they are to occur, the probability q is not relevant for the valuation.[3] Thus, in order to derive the probability independence of the option valuation, the option has to be considered in the framework of the stock and the bond. A naive valuation approach, which considers the option isolated from the stock and the bond, would be to value the call with its discounted expected value $\frac{1}{r}[qC_u + (1-q)C_d]$.

The second notable feature is that we did not make any assumptions about the investor's utility function, apart from that more money is preferred to less money. This assumption is essential, because the investor has to have a positive utility from making the arbitrage gain. The risk attitude of the investor, however, does not affect this analysis, since the arbitrage gain is made riskless. Notice that for the risklessness of the arbitrage it is crucial that the stock and the bond prices are fixed and known at the stage of the option trading. Thus, the implications of the model are very strong: all investors with an increasing utility for money agree on the price C_0 of the call option.

In both experimental studies we considered the following example. The stock has a today's price of S=100 and moves up to 150 or down to 90, thus d=0.9, u=1.5. The strike price of the call option is K=88. This means that the option is always in the money and pays 62 if the stock goes up and 2 if the stock goes down. The interest rate of the bond was chosen as 10%, this means r=1.1. With these special parameters, it is possible to determine the arbitrage free call price in an intuitive way, which does not assume the knowledge of the special model. The intuition is as follows: in each state of the world tomorrow, the call pays 88 less than the stock; 88 in prices of tomorrow are worth 80 today; therefore a trader should be willing to pay 80 less for the call than for the stock, which means that the trader should price the call with 20 today, which is the arbitrage free call price.

The second advantage of a call that is always in the money is that the hedge ratio Δ equals 1 in this case. This means that it is very easy to hedge the risk of the call. A trader who buys (sells) calls has to sell (buy) equally many stocks to be perfectly hedged.

4. The Experimental Design

The terminology used in the experiment was chosen neutral without any links to the underlying financial model. We avoided the terms stock, option, bond or short sale. Instead we called the option the investment form X; the stock was called investment form Y and the bond was just called cash. The two possible future states up and down were labelled red and blue.

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[3] The value p which appears in the pricing formula is between 0 and 1 and can be interpreted as a probability. In a more general framework p is called the *equivalent martingale measure*, or it is called the *objective probability* while q is called the *subjective probability*. If the probability q for the stock movement equals p, then the expected return of the stock would be r and C_0 would simply be the discounted expected call value.

4.1. The Experimental Setup of the Experiment with Students

The experiment with students was conducted at the *Laboratorium für experimentelle Wirtschafts-forschung* at the University of Bonn, with experimental software which was developed using *RatImage* (Abbink and Sadrieh, 1995).[4] The subjects were students, mostly from the economics and the law department. They never participated in a financial market experiment before. The subjects were orally informed about the experimental procedure in a 15 minutes introductory session. An English translation of the basic sheet (original text in German) of the introduction is given in Appendix B.

The experiment examines the example analyzed in section II. It consists of six treatments, which are distinguished by the value for the probability of the stock movement. We studied the values q=0.1, 0.2, 0.33, 0.5, 0.7, and 0.9. This means that in one treatment the probability q approximately equals the equivalent martingale measure p=⅓. Then, the discounted expected call value equals the arbitrage free price 20. In two treatments the probability q is lower than p, and finally in three treatments it is higher than p. Moreover, the values for q cover a wide range of the 0-1-interval.

In each treatment we observed 18 subjects. Since the subjects did not interact, they are statistically independent. Hence, we observed 108 independent subjects. Each subject was confronted with 50 consecutive investment decisions (rounds). After a subject finished the 50 rounds he or she was paid according to the sum of his or her round payoffs. The subjects needed between one and two hours to fulfil the task.

In each of the 50 rounds a trader's task is to invest an initial endowment of 600 *Thalers* (the experimental currency). For this three investment forms are available, the two risky ones X and Y and cash as a riskless investment form. The payoff of a risky investment depends on the state of the world in the next period, which can be either red (with probability q) or blue (with probability 1–q).

Table 1. The investment possibilities

Cash flows of the investment forms							
when **Selling**				when **Buying**			
	today	red	blue		today	red	blue
X	+36	–62	–2	**X**	–36	+62	+2
Y	+100	–150	–90	**Y**	–100	+150	+90
The interest rate for cash is 10%							

The parameters of each round are identical, except for the today's price of X. At the beginning of the round the today's price of the investment form X is randomly drawn between the tomorrow's

[4] Appendix C shows the main screen displays the subjects faced.

payoff bounds 2 and 62. All values 2,...,62 are drawn equally likely. Let us assume that 36 was drawn as the random price of X. Then the trader faces investment possibilities as illustrated in table 1.

If a trader sells one unit of X he or she receives 36 Thalers today and has the obligation to pay 62 Thalers if tomorrow's state is red and has to pay 2 Thalers if tomorrow's state is blue. If, however, the trader buys one unit of X he or she has to pay 36 today, but receives 62 in state red and 2 if tomorrow's state is blue. Analogously, the cash flows for the investment form Y are constructed. All the money that is not invested in X or Y remains as cash with a riskless interest rate of 10%. Cash can be positive or negative.

At first the trader has to decide on the investment form X. He or she can either buy at most 9 units of X, sell at most 9 units of X, or refrain from investing in X. The traders know that the limit of 9 units is independent of X's price and that it is the same in each round.[5] After the investment decision in X was completed the trader sees the following overview over the personal portfolio, as it is chosen so far. Let us assume that the trader decided to sell 5 units of X.

Table 2. The portfolio after the X investment

			Payoffs	
	Action	#	red	blue
X	Sell	5	–310	–10
Y				
Cash			858	858
Sum			**548**	**848**

If the trader would do no further investment his or her payoff would be 548 Thalers in state red and 848 Thalers in state blue.

Following the X decision the trader is confronted with the investment form Y. He or she also has the possibility of buying Y, selling Y or refraining from trading in Y. The traders know that the unit limits in Y are calculated in a way that up to this limit the portfolio has a non-negative payoff in red as well as in blue (the *bankruptcy restriction*). In the example we follow a trader would be able to buy at most 42 units and to sell at most 13 units. Let us assume that the trader decides to buy 10 units of Y. This leads to the portfolio as in table 3.

Finally, the state (red or blue) is determined according to the probability q and the trader receives the corresponding payoff as the round payoff. In our example the trader receives 948 if state red is drawn and he or she receives 648 if state blue is drawn.

[5] It may be interpreted as the demand and supply of calls in the fictitious market.

Table 3. The portfolio after the Y investment

			Payoffs	
	Action	#	red	blue
X	Sell	5	–310	–10
Y	Buy	10	1500	900
Cash			–242	–242
Sum			**948**	**648**

The traders were informed that all random draws are independent of the random draws of previous rounds and the random draws for other traders. Each trader had access to a calculator and a history window showing the own investment decisions of previous rounds. Upon request each could be displayed on the screen.

4.2. The Experiment with Professional Traders

The experiment with professional traders was conducted in the building of an influential German Bank in Frankfurt/Main. The participants were 24 employees of the bank, coming from the departments of foreign exchange, security, futures, bonds, and money trade. All of them were decision makers in the areas mentioned. They were recruited by announcements in the bank. In a conference room of the bank, controlled conditions comparable to those in the laboratory could be implemented. Six portable personal computers were located sufficiently distant from one another, such that mutual influencing of the subjects was prevented.

Four hours time was available for the experiment, divided into four one-hour sessions with six participants each. The shorter time span available for the experiment required a restriction of the setup from 50 to 30 decision rounds. Therefore, it seemed reasonable to select the 30 option prices occurring in the experiment beforehand. By this, it was ensured that each participant would observe prices spread over the entire interval, despite the fewer number of rounds. The order in which the 30 prices occurred was drawn randomly, independently for each participant. We chose the 30 odd numbers in the interval between the two possible tomorrow's payoffs of X (2 to 62).

The course of the experimental sessions was analogous to that of the preceding experiment with the students. The exchange rate of the thalers earned in the experiment was chosen such that it was comparable to the one used in the corresponding students treatment.

The experiment was conducted in two treatments, where the probability for the state red was q=0.2 in one treatment, and q=0.7 in the other one. Two sessions were conducted in each treatment, such that 12 independent observations are available for each treatment.

5. Results

In this section, we analyse individual trader behaviour observed in the experiment with respect to two main features: the valuation of the option and the portfolio construction. The strong theoretical predictions of the model prescribe that the trader – independently of his or her utility function – sells the option when its price exceeds 20 and buys the option when its price is below 20. The further portfolio construction is subject to the trader's risk perception. In both analyses we will compare the behaviour of the student traders with the one of the professional traders.

5.1. The Valuation of the Option

An investor who follows *an option pricing strategy with the separating price P* buys the option, whenever the option price is lower than P and sells the option, whenever its price is higher than P. For price P, the investor is indifferent between buying and selling the option. A rational investor follows an option pricing strategy with separating price 20. In the experimental data, we cannot directly observe the separating price, we solely observe whether a subject buys or sells the option for a given price (i.e. trades at that price), or whether he/she refrains from trading at that price. From these observations, however, we can estimate - for each subject - the trading strategy with the separating price that best explains the option pricing decisions of that subject. Hence for each subject i we can estimate the price P_i that has the highest accordance with the rule 'buy the option if its price is lower than P_i and sell it if its price is higher than P_i'.

To be specific, we estimate trader i's separating price P_i by applying the following iterative procedure: we systematically vary the possible option prices P in the admissible range {2,...,62}. A fixed P is then confronted with each of the investment decisions of investor i. Denote with M_{ik} the option price that investor i faced in investment decision (round) k. For $P \neq M_{ik}$ we say that the investment decision of trader i is in accordance with a separating price P, if either investor i bought calls in his/her investment decision k and $M_{ik}<P$, or investor i sold calls and $M_{ik}>P$. For $P= M_{ik}$ we cannot achieve any information about the accordance with a trading strategy with separating price P, since all actions (buy, sell, no trade) are rational in that case. Let $AC_i(P)$ denote the number of rounds for which the investment decision of trader i is in accordance with the separating price P. Let $N_i(P)$ denote the number of rounds investor i traded options when facing an option price unequal P. Then the *accordance rate with price P* is defined as $AR_i(P)=AC_i(P)/N_i(P)$. The *price which separates between buying and selling* (shortly: the *separating price*), B_i for investor i is the price with the highest accordance rate, i.e. $B_i=\text{argmax}_{P\in\{1,\ldots,62\}} AR_i(P)$.

Table 4 provides the average over the separating prices of all subjects in each treatment. If the investors would be guided by the arbitrage-free option price, the separating price would be 20 in each treatment. Table 4, however, clearly shows that the average separating prices increase with the probability q. However, the probability dependence of the separating prices seems to be more pronounced for the student traders.

Table 4. The Separating Prices

average separating price	Treatment q=					
	10%	20%	33%	50%	70%	90%
students (all rounds)	11.88	19.47	19.61	27.19	35.73	42.19
professional traders		31.42			39.93	
students (rounds 1-30)		19.73			40.51	

Are Professional Traders less Probability Sensitive?

Table 4 indicates that professional traders also exhibit sensitivity to the probability of the stock movement, but that their probability sensitivity is less pronounced than the one of the students. A statistical analysis of the data supports these observations.[6]

Result 1. *In the students' population, the separating prices in the treatment q=20% are significantly lower than separating prices in the treatment q=70% (.001, one-tailed).*

Result 2. *In the professional traders' population, the separating prices in the treatment q=20% are statistically not distinguishable from the separating prices in the treatment q=70% (.15, one-tailed).*

Result 3. *For the treatment q=20% the students have significantly lower separating prices than the professional traders (.01, one-tailed).*

Result 4. *For the treatment q=70% the separating prices of the students and the professional traders are not statistically different (.15, one-tailed).*

The results suggest that the treatment differences might be less pronounced in the subject pool of the professionals, due to a weaker response by the traders to the different probabilities. To test whether the different responses to treatment variations are systematic we develop the *four-sample permutation test for partial treatment differences*, which tests the following hypotheses:

H_0 (Null hypothesis). *Both samples (students and professionals) are drawn from the same population. They effect of the treatment variation is the same for both samples. The observed larger treatment differences are due to sampling variation.*

H_1 (Alternative hypothesis). *The students' response to the treatment variation is stronger than the professional traders'.*

The null hypothesis postulates that a treatment difference exists, but that its different effect on the subject pools occurred by chance. Under the null hypothesis the present observations are two samples of size 30, drawn from the same population. They were divided randomly into two groups of size 18 and 12, the former labelled "students", and the latter labelled "professional traders". The two samples experienced the two different treatments and responded to them such

[6] The statistical analysis applies the Mann-Whitney u-test to the independent subjects (18 in the students' treatments and 12 in the professional traders' treatments). In the student population only round 1-30 are considered.

that we observe a treatment difference. However, the different response to the treatment difference in the two subject groups are, given H_0, caused solely by the random division of the samples into two groups each. Incidentally, the division into groups resulted in a combination which exhibited larger treatment differences between the groups randomly labelled “students” than between the groups labelled “professional traders”. If, however, the probability for that such an extreme value of the difference of treatment differences as observed occurs by sampling variation, does not exceed a given significance level α, we can reject H_0 in favour of H_1.

By a Monte-Carlo simulation with 500,000 draws we computed the approximate probability to obtain such a larger, or larger, difference by random division of the two samples into groups. Only 4.64% of the permutations exhibited a difference in treatment differences as large as or larger than the observed one. Thus, we reject the null hypothesis H_0 in favour of the alternative hypothesis H_1 at a significance level of $\alpha = 0.05$ (one-tailed).

Result 5. *The response of the students to the different probabilities is significantly more pronounced than that of the professional traders.*

Learning the Arbitrage-Free Price?

The analysis of the previous section shows that student subjects value the option depending on the stock movement probabilities, contrary to the theoretical prediction. However, if we look at the evolution of the separating price over time, we can also see that in most treatments the separating prices tend to move towards the arbitrage-free price. In order to study the development over time, we subdivide the 50 investment decisions into three *experience phases* of similar length, i.e. the rounds 1 to 15, 16 to 30, and the rounds 31 to 50 and compute separating prices for the single experience phases. Table 5 shows the results.

Table 5. The Separating Prices over Time

Experience phase	Students						Professionals	
	Treatment q =							
	10%	20%	33%	50%	70%	90%	20%	70%
All rounds	11.88	19.47	19.61	27.19	35.73	42.19	31.42	39.93
rounds 1-15	17.63	25.17	23.41	34.26	38.70	48.97	27.48	36.49
rounds 16-30	13.52	18.64	20.88	29.02	35.89	39.78	32.08	39.35
rounds 31-50	12.58	18.83	20.35	26.46	32.14	38.34	–	–

Except for the treatment q=20% the average separating prices in the students’ population monotonically decrease over the experience phases. The sharpest decreases, however, are observable in the treatments with the probability value that are “far away” from p=1/3. In the treatments q=70% and q=90% the average separating price moves towards the arbitrage-free price. For the treatment q=10%, in contrast, it moves away. In both treatments with professional traders the best separating price seems to move up, further away from the arbitrage-free price.

5.2. Do the portfolios of professional traders achieve a better performance than the ones of students?

At first glance one would expect that professional traders who daily evaluate and handle financial contracts perform much better than student subjects, i.e. they exploit the arbitrage possibilities to a greater extend and in addition construct portfolios with a better performance. There are, however, also hints in the literature that a superior performance of the professional traders is not self-evident. Hence, as discussed in section 2, the professional traders might be "victims" of the *curse of knowledge*. For the present experiment, we examine the question whether expert knowledge and practical experience in fact lead to better performances in option pricing tasks, or whether the "curse of experience" leads them to worse results. We measure performance with respect to two aspects: first, we look at the exploitation of the arbitrage possibilities, and second, we analyse the efficiency in maximising the expected payoff that can be gained mainly at the stock trading stage of the experiment.

Arbitrage Exploitation

Independent of the individual risk preferences a successful trader has to exploit all the arbitrage possibilities the option provides. The size of the riskless arbitrage gain depends on two factors: on the distance of the option price M_{ik} in round k from the arbitrage free price 20 and on the number of options traded. Denote with γ_{ik} the number of options subject i trades in round k and with the indicator variable τ_{ik} the nature of the trade ($\tau_{ik} = -1$ for an option purchase and $\tau_{ik} = 1$ for an option sale). Then the arbitrage gain realised by trader i in round k is $\tau_{ik} \cdot \gamma_{ik}(M_{ik} - 20)$.[7] The maximum possible arbitrage gain is realised if the maximum number of 9 units is bought at $M_{ik} < 20$ and sold at $M_{ik} > 20$, i.e. $9 \cdot |M_{ik} - 20|$. Aggregated over the 30 rounds of the experiment, we obtain for each subject i an arbitrage exploitation coefficient AEC_i as

$$AEC_i = \frac{\sum_{k=1}^{30} \tau_{ik}\gamma_{ik}(M_{ik} - 20)}{\sum_{k=1}^{30} 9 \cdot |M_{ik} - 20|}.$$

The AEC can have values in the interval from –1 to 1. A randomiser who is choosing his trading actions randomly, will achieve an arbitrage exploitation coefficient close to zero.

The median of the arbitrage exploitation coefficients in the group of students[8] is 0.803 (in the treatment q=0.2) and 0.625 (in the treatment q=0.7), respectively. In contrast, the professional traders achieved in the median coefficients of 0.580 (q=0.2) and 0.320 (q=0.7). The Mann-Whitney-U-Test rejects the null hypothesis of equal arbitrage exploitation coefficients in the two

[7] Obviously, the option trade may also result in a loss, namely when the subject sells at prices below 20 or buys at prices above 20.

[8] Considering the first 30 rounds only.

subject pools in favour of the alternative hypothesis of larger exploitation coefficients in the group of the students at one-tailed significance levels of α=0.05 (q=0.2) and α=0.1 (q=0.7).

Result 6. *The professional traders exhibit significantly lower arbitrage exploitation than the students.*

Expected Payoff Exploitation

Concerning the option trading the recommendations for a trader who strives to construct a successfully performing portfolio are unambiguously (see above). Concerning the stock, however, the trading strategy depends on the risk attitude of the trader. Since we cannot observe the risk attitudes of the traders we will benchmark their behaviour against that of an expected payoff maximising trader. For $q < p = 1/3$ an expected payoff maximising trader has to sell as many stocks as possible and for $q > p = 1/3$ he or she has to buy as many stocks as possible. For $q = p = 1/3$ all investment strategies lead to the same expected payoff. We study for each investor i how much of the maximally possible expected payoff he/she actually reached through his/her investment decisions. Let MEP_{ik} denote the *maximal expected payoff* that investor i can achieve in investment decision k, conditional on his/her call trade. Let AEP_{ik} denote investor i's *actual expected payoff* that he/she reached in investment decision k. Then

$$EPEC_i = \frac{\sum_{k=1}^{30} AEP_{ik}}{\sum_{k=1}^{30} MAP_{ik}}$$

is the *expected payoff exploitation coefficient* (EPEC) of investor i.

The students[9] exploit in the median 87.9% (in treatment q=0.2) and 82.8% (in treatment q=0.7) of the possible expected value, the professional traders achieve values of 79.6% (for q=0.2) and 67.6% (for q=0.7). The Mann-Whitney-U-test, applied to the individual expected payoff exploitation coefficients, rejects the null hypothesis of equal expected payoff exploitation in favour of the alternative hypothesis of larger expected payoff exploitation in the group of the students at a significance level of α=0.01 (one-tailed) for both treatments.

Result 7. *The professional traders realise significantly lower expected value exploitation than the students in both treatments.*

Figures 1 and 2 visualise the development of the exploitation of the expected payoff over time. In each treatment the median EPEC of all investors is calculated for each round. The figures depict a moving average over five rounds of these median EPECs. We find that the median EPEC increase with an increasing experience of the investors. Furthermore, the figures also show that the degree of expected payoff exploitation is much higher and grows much faster in the treatments with the low variance in the binomial distribution (q=10% and q=90%).

[9] Considering the first 30 rounds only.

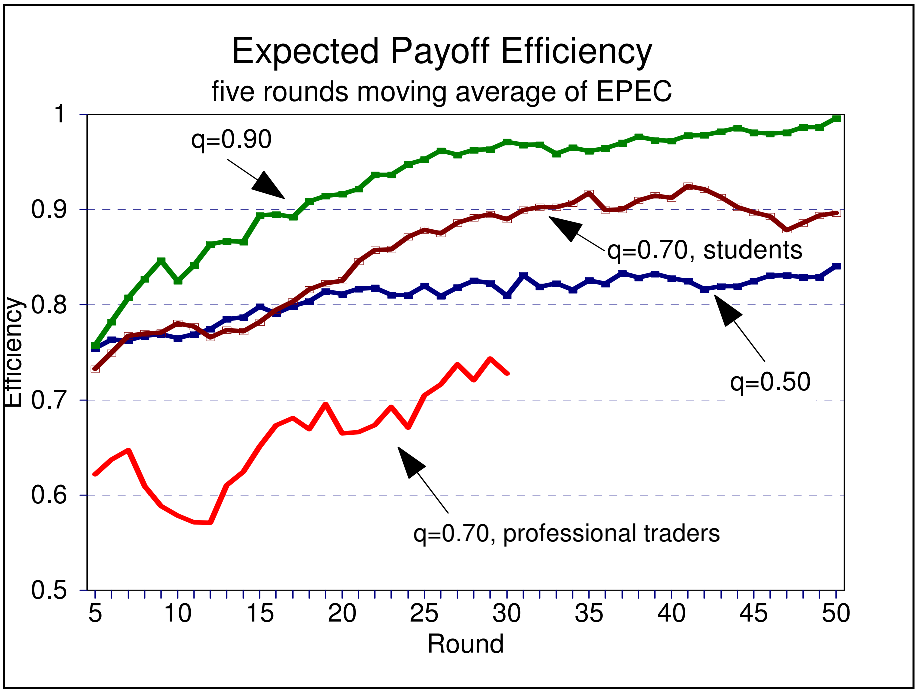

Figure 1

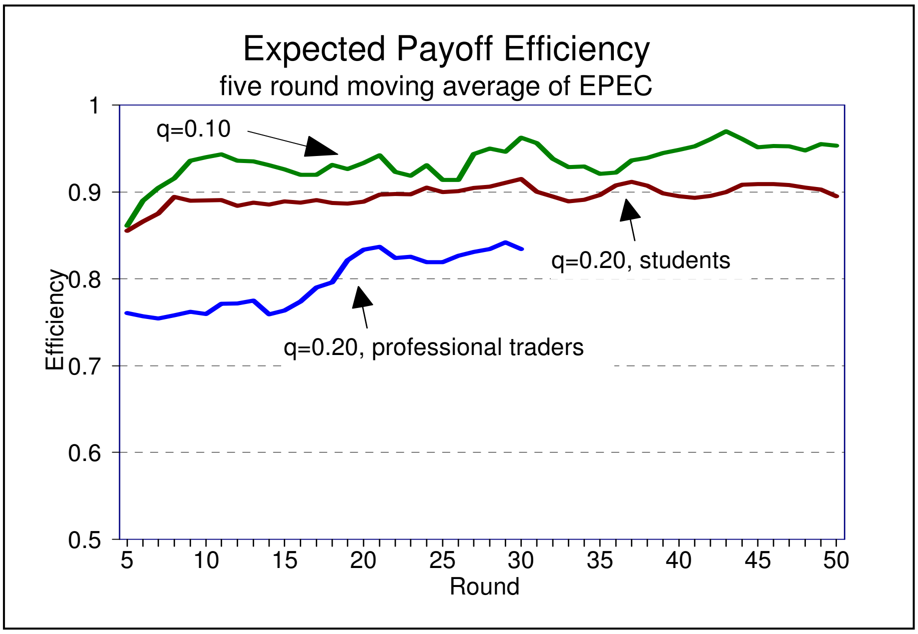

Figure 2

Surprisingly, professional traders from an influential German bank do not achieve higher performance levels in the experiment, neither with respect to arbitrage exploitation nor in their exploitation of expected payoff. The comparison with the students' data show that the professional traders respond to different probabilities of the stock movement much less than students. The hypothesis that the higher probability sensitivity of students is due to their lacking theoretical and practical education of the subjects, is in contrasts to their better performance in arbitrage exploitation. On the other hand, it seems well plausible to us that the experienced traders choose a more intuitive and less (formally) analytic pattern of behaviour than the students, despite their superior knowledge in financial market theory and practice. At real financial markets, traders are typically not confronted with given and known exact probability distributions, but they must rather rely on their intuitive calibration of the prospects. These cannot be made precisely, their nature is more qualitative. Chances and risks in the experiment are judged upon using the same qualitative reasoning, although exact information is actually available.

Students, however, are often confronted with abstract tasks, which require a specific solution for an exactly specified problem in a given, well-defined environment. In this sense, the tasks in the experiment are closer to a task in a student's exams, than to the real investment decision of a professional trader. This is especially true for our student subject pool at the university of Bonn which mostly had a strong formal and technical training.

5.3. Student subject pool effects

Our hypothesis leaves open the question whether the better performance of the student subjects might be peculiar to the choice of the student subject pool. The economics students at the university of Bonn take theory-oriented courses with a strong emphasis on formal mathematical methods. Further, option pricing is part of the curriculum of modules in finance, chosen by many economics students. If our hypothesis is true, then we might expect that students with a non-technical background fare worse than the students in Bonn, and might be more similar to the professional traders.

For this reason we conducted two more sessions of the experiment with a different subject pool. We used students from the University of Erfurt. This student population is similar to that in Bonn in that they have a comparable education level and, both universities being in Germany, also a similar cultural background. The difference is that the campus in Erfurt hosts mainly social science faculties with largely non-technical majors. Option pricing is not part of the curriculum in any of the courses offered in Erfurt.

For the new sessions we use the same protocol as in those with the professional traders, with probability values of q=0.2 and q=0.7. The following table 6 shows the average measures of arbitrage and efficiency exploitation in the three subject pools. The table shows that indeed the gap between the students' and the professional traders' performance has closed substantially when looking at Erfurt rather than Bonn students. [10] Only with respect to expected payoff exploitation

[10] We cannot completely rule out the alternative explanation that the minor differences in the experimental protocol caused the difference between Bonn students and professional traders (and consequently Erfurt students). Recall that the Bonn experiment lasted 50 rounds instead of 30, and that we restricted the random draws to all uneven number in the Erfurt and Frankfurt sessions. However, note that we consider only the first 30 rounds of the Bonn sessions for the comparison, and that subjects knew the option price when they made the decision. A substantial effect of these procedural variations is therefore rather implausible.

the Erfurt students have a significant advantage over the professionals, albeit only at the one-sided 10% level (Fisher's two-sample randomisation test).

Table 6. Arbitrage and expected payoff exploitation

Subject pool	Bonn students	Professional traders	Erfurt students
Arbitrage (AEC)			
q=0.2	0.80	0.58	0.70
q=0.7	0.63	0.32	0.20
Expected payoff (EPEC)			
q=0.2	0.88	0.80	0.90
q=0.7	0.83	0.68	0.64

6. Summary and Discussion: In Search of the Causes for the Difference in Student and Professional Trader Behaviour

The paper reports on a basic experiment which was conducted in order to study individual pricing behaviour of financial options. The theoretical implications of the model are very simple and strong: each trader who has an increasing utility from money is guided be the arbitrage free call price, and this price is independent of the probability of the stock movement.

The experimental data show that the traders learn to exploit more arbitrage as they gain experience, however, they value the option by a probability dependent price rather than by the arbitrage free price. This price can be described as the discounted expected payoff of the call option, damped for high probability values (q=70% and 90%). In these treatments the best separating price sharply decreases away from the expected call value in the direction of the arbitrage free option price.

Professional traders from an influential German bank do not perform better in the experiment. In both arbitrage and expected payoff exploitation their performance is below the students' in our first experiment. We conjecture that experienced traders follow a more intuitive approach to the decision task, taking exact probabilities —which they do not know in their every-day work— less into account. Students, however, are often confronted with abstract technical tasks, which require a specific solution for an exactly specified problem in a given, well-defined formal environment. In this sense, the tasks in the experiment are closer to a task in a student’s exams, than to the real investment decision of a professional trader. The task is thus more favourable to the abstract approach used by the students, than to the intuitive approach used by professional traders. This is corroborated in additional sessions we conducted with a subject pool also consisting of students from predominantly non-technical disciplines. These students show a performance similar to that of professional traders which supports the conjecture that the formal training that students receive mainly drives their high performance in the present decision task.

In our view this simple option experiment is a good starting point for the further analysis of the option valuation approach. We gained a basic understanding of the boundedly rational behaviour of traders in this simple fictitious market and can now proceed to extend the analysis to more complicated experimental models.

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Appendix A: Instructions and Screen Display

This is the English translation of the instruction sheet, which was the basis for the introductory session (original text in German).

Instructions for the Investment Experiment

Investment Forms

There are three different investment forms:

- Investment form **X**
- Investment form **Y**
- Cash

At the beginning of each round the **price of investment form X** is randomly determined between 2 and 62. This price is independent from the random prices of previous rounds.
The payoff of investment forms X and Y is state dependent (*red* or *blue*).

- **Sell X:** You **receive** the price and **pay** 62 in state *red* and 2 in state *blue*
- **Buy X:** You **pay** the price and **receive** 62 in state *red* and 2 in state *blue*
- **Sell Y:** You **receive** 100 and **pay** 150 in state *red* and 90 in state *blue*
- **Buy Y:** You **pay** 100 and **receive** 150 in state *red* and 90 in state *blue*

The interest rate for **cash** is 10%.

Portfolio

Construct a **portfolio** using these three investment forms. Your choices are:

- Sell X or Buy X or no investment in X
- Sell Y or Buy Y or no investment in Y

Unit limit in X: You can buy or sell up to 9 units.
Unit limit in Y: The unit limit is chosen such that neither in state *red* nor in state *blue* you incur a loss.
All Thalers which are not invested in X and Y are invested in **cash**.

The randomly drawn State red or blue

The state of the round is randomly drawn and is independent of the states of previous rounds. It is:

- **red** with probability **20%**
- **blue** with probability **80%**

Payoffs

The portfolio payoff of the drawn state (*red* or *blue*) is your round payoff. The sum of the round payoffs is your final payoff.

Rounds

You perform 50 investment decisions

History

The history window shows your investment decisions of previous rounds.

Endowment

At the beginning of each round you are endowed with **600 Thalers**
Point to cash rate
For each **12 Thalers** you receive 1 Pfennig

Individual decision experiment

The decisions of the other traders do not influence your result!

Questionnaire

After the 50 investment decisions the following questionnaire is handed out to you and you are asked to fill it out.

The Main Screen Display

This is the English translation of the main screen display (original in German).