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Bubbles and Crashes in Experimental Asset Markets

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Chapter 2
Literature Review

It takes a great piece of history to produce a little literature.
Henry James, 1843–1916

2.1 Literature on Market Efficiency[1]

The role of bubbles in financial markets is intricately connected to the question of informational efficiency. The reason is both that bubbles above and below fundamental values are a violation of market efficiency, and that the fundamental value itself and deviations from it can only be defined with reference to a framework of informational efficiency in a market (cp. Roll's critique in Roll (1977)). Because of this observation, this section starts with a short introduction to the topic of market efficiency (Sect. 2.1.1 below), briefly reviews evidence of market inefficiency (Sect. 2.1.2), and finally spends some time on the specific anomaly of price bubbles (Sect. 2.1.3).

2.1.1 Literature in Favor of the Efficient Market Hypothesis

If there is to be one "father" of the efficient market hypothesis, this man is Eugene Fama, who remains an outspoken proponent of the hypothesis to this day. In Fama (1970, 1991, 1998), he gave comprehensive overviews of the literature on the topic

[1] As one of the best-researched topics in modern finance, the efficient market hypothesis has been the subject of countless papers and it would exceed the scope of this text to give a more comprehensive overview than the brief introduction in this section. The interested reader is referred to Palan (2004) for a more extensive discussion of the literature on market efficiency.

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and documented its evolution over the three decades spanned by these papers. Fama defined an efficient market as "A market in which prices always 'fully reflect' available information,"[2] and proposed the classifications of weak-form, semistrong-form, and strong-form market efficiency to concretize the "available information." These three categories have by now become the standard in descriptions of market efficiency.

Nonetheless, the history of the efficient market hypothesis had begun earlier. Bachelier (1900)[3] laid the theoretical groundwork for the efficient market hypothesis, which was postulated half a century later by Maurice Kendall. Kendall (1953) found that stock prices evolved randomly and that his data offered no way to predict future price movements. The explanation for this phenomenon, the efficient market hypothesis, initially seemed counterintuitive to the academic community. However, after the first shock had passed, scholars quickly embraced the theory and began to document its validity in real-world markets by studying empirical data.

To do so, they developed different frameworks to model the characteristics of market prices. The first type of framework – based on expected return efficient markets – includes such well-known models as the fair game model, the random walk and the submartingale models, as well as the market model and the famous capital asset pricing model (CAPM) of Sharpe (1964); Lintner (1965); Mossin (1996).

In the years from the 1950s to the 1970s, most studies based on the CAPM and fair game models found evidence consistent with the efficient market hypothesis. Despite some evidence to the contrary from the variance-based literature (which will be introduced below), by the early 1970s markets had therefore largely come to be considered to be efficient in the semistrong form, as defined by Fama (1970). As a case in point, Malkiel noted with regard to market efficiency:[4]

> "I don't know of any idea in economics that I've studied and been associated with over this period of time [since the first publication of 'A Random Walk Down Wall Street' in 1973] that has held up as well."

A second class of models used to test market efficiency focuses on variance as the key characteristic. Among them are the model of Shiller (1981), who reported that stock prices were too volatile to be efficient when compared to subsequent dividend payouts, and the model of Marsh and Merton (1986), which showed that Shiller's results could be reversed by a change in assumptions regarding the dividend model. The reply of Schwartz (1970) to the seminal paper of Fama (1970) could also be considered to fall into the category of variance efficient market models, as it propagated the use of models that tested for variance-based strategies to generate excess returns in capital markets.

The first variance efficient market models in the early 1980s coincided with the advent of behavioral finance and behavioral market models, which soon started to

[2]Fama (1970), p. 383.

[3]As quoted in Ziemba (1994), p. 200.

[4]Malkiel et al. (2005), p. 124.

erode the solid standing the efficient market hypothesis had (until that time) enjoyed in academic circles.[5] A number of anomalies were discovered in empirical data, suggesting that the universal belief in the applicability of the efficient market theory had been overly optimistic. Today, evidence of widespread efficiency in developed markets coexists with well-recognized anomalies, both in these highly developed markets in industrialized countries and – much more frequently – in less developed market economies. These anomalies can be subsumed under a few broad categories, which are summarized in the following section.

2.1.2 Literature on Market Inefficiencies and Anomalies

Over the years, a substantial number of market inefficiencies or "anomalies" has been documented. Among them are the serial correlation of returns and variances, return seasonality, the neglected-firm and liquidity effect, and excess returns earned by insiders. The following paragraphs give a brief overview of this literature, which is reviewed in more detail in Palan (2004). Due to its prominent relevance for the present study, the literature on asset price bubbles is discussed separately in the next section.

In certain instances, securities have been found to display autocorrelation of returns and of return variability – a topic that has received considerable attention since the 1990s. Such a property of time series of returns indicates a lack of market efficiency, since the inequality of conditional and unconditional expectations violates the fair game model of financial market returns. The search for serial correlation in these variables is probably the most straightforward test for market efficiency, although shortcomings of the measurement techniques often cast doubts on the validity of results. The anomaly of serial correlation is in the literature frequently referred to as a "short-term momentum, long-term reversal" effect.[6] The reason for this moniker is that early studies detected evidence of positive serial correlation (i.e., momentum) over periods of up to 12 months, while finding negative serial correlation (i.e., reversal) for periods ranging from 13 to 60 months. Conrad and Kaul (1988) for example reported positive serial autocorrelations for stocks listed at the New York Stock Exchange (NYSE). Jegadeesh and Titman (1993) found both short-term momentum and long-term reversal for stocks from the database maintained at the Center for Research in Securities Prices at the University of Chicago (CRSP), and De Bondt and Thaler (1985) documented negative serial correlation for the same underlyings. Negative serial correlation over longer time periods is also a result of the studies by Fama and French (1988), and Poterba and Summers (1988). Rouwenhorst (1998) extended the analysis to twelve European countries, finding a similar momentum-and-reversal effect for his 1978–1995

[5] Some selected papers of this strand of the literature are Black (1986); Shleifer and Summers (1990) and – for a more critical view – Fama (1998).

[6] Cp. e.g., Jegadeesh and Titman (1993).

sample. Later studies, however, provided evidence that this effect might be decreasing or disappearing over time (e.g., Jegadeesh and Titman (2001)), or disputed its presence altogether (Fama (1998)).

Anomalies subsumed under the heading of return seasonality are characterized by patterns in financial asset prices or in their variability that recur regularly at specific calendar dates and times. Seasonality has been documented in intraday, weekly, monthly and annual return data. A famous example of such a pattern is the day-of-the-week effect or weekend effect – the observation that returns at the beginning of a week are more likely than not to be below average, while returns at the end of the week are frequently higher than the average. Studies documenting this phenomenon are e.g., Cross (1973); French (1980); Gibbons and Hess (1981); Keim and Stambaugh (1984). Similarly well-known is the turn-of-the-year effect, January effect, or the small-firms-in-January effect, which refers to the pattern that returns tend to be higher in January than over the rest of the year, particularly for small firms. (Cp. e.g., Keim (1983); Rogalski (1984); Ziemba (1988); Ritter and Chopra (1989).)

The neglected-firm effect and the effect of stock prices' reaction to the inclusion of a stock into an equity index can be subsumed under the heading of liquidity effects. The former was coined by studies which showed that, compared to larger firms, small and less-reported-on firms offer a liquidity premium, because investors purchasing them are subject to liquidity risk (cp e.g., Amihud and Mendelson (1986, 1991); Pratt (1989); Chordia et al. (2000); Ross et al. (2005)).The second term refers to a finding by Shleifer (1986), who studied the price reaction stocks exhibited upon being included into a market index. A stock's index inclusion is an event that arguably does not reveal new information about the stock, but does cause purchases by mutual funds, which are in many cases accompanied by a liquidity crunch with a concurrent effect on prices.

Finally, the evidence on the question of whether individuals privy to inside information can earn excess returns (i.e., markets not immediately adjusting to inside information) is relatively unequivocal. It was confirmed in studies like Pratt and DeVere (1968); Jaffe (1974); Lorie and Niederhoffer (1968); Seyhun (1986). In a rare conflicting result, Hawawini (1984) found evidence consistent with strong-form market efficiency for French, Spanish and U.K. mutual funds.[7]

2.1.3 Price Bubbles

Bubbles in financial market prices have already been briefly discussed in Sect. 1.2. They are a sign of inefficient markets, because they lead to an inefficient allocation of capital to productive uses. Bubbles are a phenomenon that has received relatively

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[7] However, Hawawini relied on the assumption that mutual fund managers possess insider information. If they do not, his evidence lends support only to semistrong-form efficiency.

widespread attention compared to other signs of market inefficiencies, which might be due to an issue of magnitude: Most findings of inefficiencies in market prices are small; so small in fact that they are often only statistically – but not economically – significant. The same does not apply to bubbles, which in the form of stock (or, more recently, real estate) market crashes received attention not only in the financial but also in the mainstream press.[8] Naturally, science also took up the topic both in theoretical and empirical work, some of which is summarized below. Note that bubbles seem to be a research subject with a particularly bright future, since scientists cannot only not agree on what exactly causes bubbles, but rather hold differing opinions even on the question of whether stock market prices in the late 1990s and early 2000's, or in the great depression, could actually be considered bubbles. The reason for this lack of agreement lies both in problems of measurement and statistical technique and in the different definitions used by different scholars. To shed some light on this literature, the following paragraphs list a number of bubble definitions, discuss their differences and present the literature dealing with this phenomenon.

As one of the early papers dealing with bubbles in a theoretical model, Diba and Grossman (1988) defined a *rational bubble* as follows:[9]

> "A rational bubble reflects a self-confirming belief that an asset's price depends on a variable (or a combination of variables) that is intrinsically irrelevant–that is, not part of market fundamentals–or on truly relevant variables in a way that involves parameters that are not part of market fundamentals."

This argument is reminiscent of the *sunspot* literature, which is captured well in the seminal article by Cass and Shell (1983). A sunspot is – in the words from above – a variable that is intrinsically irrelevant, yet influences prices nonetheless.[10]

Camerer (1989) found that what he calls *rational bubbles* can occur if rational traders expect to profit from participating in the bubble. He points out that under *common knowledge of rational expectations*, each trader should expect to on average make a loss by purchasing at excessive prices, because the *average* trader cannot expect to resell the asset at an even higher price, and each trader is equally likely to be in the losing group. This is because common knowledge of rational expectations implies an infinite conditioning on others' information, in that each trader knows that each trader knows that each trader knows ... that all traders in the market are rational, which is a sufficient condition to ensure that prices follow fundamental values and do not exhibit even rational bubbles.

Assuming rational traders but no common knowledge of this fact, the ingredient missing for a bubble in Camerer (1989) is a departure from rationality, for which he

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[8] See e.g., Independent (2001), International Herald Tribune (2007); New York Times (2008). A prescient article regarding today's housing crisis was for example Los Angeles Times (2005).

[9] Diba and Grossman (1988), p. 520.

[10] Kraus and Smith (1998) define a *pseudo-bubble* as a bubble based on sunspots, with prices which stay above or below fundamental value over all trading dates. Since this type of bubble is of no particular relevance for this book, however, it will not be discussed here in more detail.

suggested overconfidence as a natural candidate. Overly optimistic expectations are a well-documented trait of the human species,[11] which Camerer argued is rational if it has biological (i.e., evolutionary advantage for optimistic individuals) or psychological (i.e., preference for optimistic belief) value. Furthermore, what Camerer called *near-rational bubbles* are possible if traders are unsure about others' beliefs and perceive a positive (subjective) probability that other traders will expect a given bubble to burst at a later point in time than the time at which they themselves expect it to burst. This argument is reminiscent of the *winner's curse* phenomenon[12] in that the individuals with the largest positive error term in the estimation of the time until the bubble bursts are the most likely to end up holding the overvalued asset when the bubble does indeed burst. As in the case of the winner's curse, individuals in such a situation should adjust their expectations to take account of this fact but – just like there – often fail to do so. A complicating factor in this dilemma are the dynamics of the problem: In the winner's curse, an individual is "cursed" if she ends up purchasing an asset at a price above its (ex ante unknown) fundamental value. Yet, in that setting, the individual could evade this problem by adjusting her value expectations downward. In the bubble example, this is only possible ceteris paribus, but not if all other market participants likewise adjust their expectations. If they do so in a rational way, their backward iterative reasoning will step-by-step lead them to (cognitively) reduce the length of the bubble period, until it finally disappears entirely, causing the inflated market prices to drop immediately. Even if investors are only partially rational, it is hard to see by which amount one should revise one's expectation of the bubble's length, when that very number depends on the expectations and revisions of all other agents.[13]

Allen and Gorton (1993) proposed a theoretical model to similarly show that settings can exist where rational behavior is consistent with stock price bubbles. The novelty of their approach was to populate the model with – among others – portfolio managers, who pick stocks for investors, but have only limited liability. Their position is that of a call option, which makes them willing to buy stocks which are overvalued, if there is a positive probability that prices will increase further

[11] See e.g., Svenson (1981) for evidence of overconfidence among automobile drivers, Roll (1986) for displays of overconfidence among managers, and Camerer (1987) for overconfidence among experimental subjects.

[12] See e.g., Wilson (1977) and Milgrom and Weber (1982).

[13] This observation might remind the reader of another famous example from the economic literature – that of the p-beauty contest of Moulin (1986), which in turn derives from Keynes' (1936) famous beauty contest. In Moulin's example, the task was to pick, out of the interval from 0 to 100, a number that comes as close as possible to 2/3 of the average of all numbers submitted. Naturally, like in the bubble problem above, this leads to an infinite conditioning, where one tries to pick the number that is 2/3 of the number the average person thinks is 2/3 of the number the average person thinks is 2/3 the number the average person thinks . . . the average person will pick. In both the bubble and in Moulin's example, zero is the rational solution for the length of the bubble period and the number to pick, respectively. However, in both examples, the evidence suggests that the average individual does not act rationally and expects (picks) a bubble of positive length (a positive number).

before they need to sell. While otherwise plausible, the model unfortunately relies on exogenously determined, monotonously increasing security prices – a feature that renders the model rather unrealistic and limits the conclusions which can be drawn from its outcomes.

A different bubble definition is used in the theoretical model of Allen et al. (1993), where an *expected bubble* occurs whenever the price strictly exceeds each agent's expected value of the asset. A *strong bubble*, in turn, is defined as a price where every agent knows that it strictly exceeds the possible future dividends.[14] Figure 3 on p. 7 illustrates these concepts. An expected bubble as defined by Allen et al. (1993) would be characterized by prices lying above the solid line, while in a strong bubble prices would exceed even the broken line. Allen et al. (1993) found that – in their rational expectations model – necessary conditions for the existence of expected bubbles are ex ante inefficient endowments, and a short-sales constraint for every agent in some state of nature at a time later than that at which the bubble occurs. Furthermore, for strong bubbles, all agents must also have some private information that is not revealed in equilibrium prices, and their actions must not be common knowledge.

De Long et al. (1990) probed the role of rational speculators in markets characterized by positive feedback traders. In their model, rational speculators buy stock following price increases. Once feedback traders catch on to the trend of increasing prices and start buying themselves, the rational speculators sell their holdings and reap capital gains. By mimicking the actions of positive feedback traders, rational speculators in their model destabilize prices and increase overvaluations.[15] This behavior of the two heterogeneous groups of traders leads to positive autocorrelation of returns in the short run and negative autocorrelation in the long run, a pattern that conforms well to the short-run momentum and long-run reversal effect reviewed in Sect. 2.1.2 above. Furthermore – as De Long et al. (1990) pointed out in their motivation – their findings are consistent with accounts of the investment strategies of investors like George Soros and others, as well as with the intent behind market newsletters and some investment pools.

Moving away from theoretical models and toward empirical work, Guenster et al. (2007) analyzed bubbles in the context of US industries, using the CAPM, the Fama and French (1993) model, and the Carhart (1997) model to derive fundamental values. Defining bubbles as price patterns where the price's growth rate exceeds that of fundamental value and where the growth rate of price experiences a sudden acceleration, they found a significantly positive relation between the occurrences of bubbles and subsequent abnormal returns of between 0.41% and 0.64%. On the other

[14] Actually, theirs is a three-period model with a single liquidating dividend, so they formulate their definition as follows: "We will say a 'strong bubble' exists if there is a state of the world such that, in that state, every agent knows (assigns probability 1 to the event) that the price of the asset is strictly above the liquidating dividend." (Allen et al. (1993), p. 211) For the sake of this book, their definition is generalized to the case where there is more than one future dividend – as stated in the text above. Note that this definition is silent on the role of discounting.

[15] Note that this mechanism describes closely observations made during the course of the experiments conducted for this book, which are discussed below in Sect. 4.2.3.

hand, bubbles were accompanied by a doubling of the probability of a crash (defined as a return below 1.65 times the standard deviation of abnormal returns) in subsequent months. Nonetheless, their results indicated that the additional risk upon detection of a bubble was more than outweighed by the prospect of superior returns in their sample. Finally, they reported that, conditional on a crash having occurred in the preceding 12 months, another crash became more likely during the following months.

A counterpoint to the majority view of bubbles being present in the world's stock markets is formed by articles like Donaldson and Kamstra (1996), and Pástor and Veronesi (2006). The former showed that dividend forecasts in the 1920s justified the stock prices prior to the market crash in 1929, while the latter demonstrated that the high expectations with regard to the riskiness of NASDAQ stocks in the 1990s suggest that the observed prices prior to the sharp decline in the early years of the twenty first century had been justified. On another note, Barlevy (2007) raised an interesting point with regard to the connection between bubbles and efficiency. He argued that, once one departs from the idealized world of perfectly functioning markets, where bubbles are detrimental to the well-functioning and efficiency of financial markets, bubbles may actually serve a beneficial purpose. He insisted that in some cases where the market is already biased due to structural imperfections like transaction costs, asymmetric information, etc., bubbles may be a device that helps to mitigate the market's structural problems. Nonetheless, despite these occasional reports of bubbles that are not undesirable, the present argument will continue on the much more common premise that most bubbles in market prices indicate an informational inefficiency which is potentially accompanied by negative repercussions for allocational and production efficiency.

2.2 Literature on Information and Derivative Markets

In Grossmann (1976), Grossman provided some of the most influential insights into the role of information in markets. He constructed a simple model of a market with a single risky asset and traders who can be either uninformed or become informed by incurring some cost. He reasoned that, in a perfect market with costly information, there must be noise so that agents can earn a return on their investment in information gathering. Otherwise the market will break down because it lacks both an equilibrium where agents earn a return on their information and one where agents do not gather information.

In reality, markets are not characterized by perfect information and noise is an ever-present fact in real-world financial exchanges. Recognizing this, in the 1970s finance research began asking the question of which markets are the first choice of traders who are in the possession of new or superior information. The results pointed away from spot, and toward derivatives exchanges. Several studies documented the propensity of information traders not to trade on their information in traditional stock markets. They are rather shown to take their business to options and futures markets, since these markets offer larger absolute returns with lower capital investment than the markets for the respective underlying. The major findings from these studies are summarized in the following paragraphs.

Manaster and Rendleman (1982) argued that in the long run, the instrument providing the greatest liquidity paired with the lowest trading costs and restrictions would be likely to play the predominant role in the market's determination of equilibrium stock prices. To support their conjecture that options are such an instrument, they argued that options entail relatively low trading costs compared to the underlying stocks. They are furthermore not subject to an uptick rule for the purpose of short-selling, may enable investors to reinvest the proceeds from such transactions, and come with lower margin requirements due to the higher leverage for a given investment amount.

In their empirical analysis, they calculated Black/Scholes-implied stock prices from option prices, using option price data from the CRSP tapes from April 26, 1973, to June 30, 1976, and weekly interest rate data from 91-day Treasury Bills. If options were priced according to the Black/Scholes model, these implied stock prices would be the option market's assessment of equilibrium stock values. They found that the difference between the implied and the observed stock prices (on day t) was positively related to returns on the stock on the following day ($t + 1$). Furthermore, they could reject the hypothesis that the previous day's ($t - 1$) implied stock prices contained no information concerning the following day's ($t + 1$) return at the 1%-level. In their own words, "[. . .] there did appear to be evidence that closing option prices contained information that was not reflected in stock prices for a period of up to 24 h."[16]

Chern et al. (2008) used an event study approach of stock split announcements to compare stocks that were the underlying of an option (optioned stocks) to stocks that had no such accompanying option. They found a significantly greater anticipation of stock split announcements for optioned than for non-optioned stocks at the NYSE, AMEX and NASDAQ exchanges, conditional on there having been significant evidence of an anticipation of a particular stock split. They also reported a significantly smaller price reaction on the announcement day and on the following day for optioned NYSE and AMEX stocks. Taken together, this evidence supported their hypothesis that the announcement of a stock split conveys less new information in the case of optioned stocks than for non-optioned stocks, and that the former adjust more quickly to this information than the latter.

Figlewski and Webb (1993) echoed the arguments of Manaster and Rendleman (1982) in reasoning that option markets give traders who cannot or will not engage in short sales (e.g., due to transaction costs) an opportunity to sell short indirectly. They argued that the option market maker who is the counterparty of such a transaction will usually hedge by performing a short sale herself, subject to lower transaction costs and fewer constraints. Starting from this assumed mechanism, the authors conjectured that the existence of options should be positively related to the

[16] Manaster/Rendleman (1982), p. 1056.

average level of short interest.[17] They tested this hypothesis empirically using a sample of 342 stocks with uninterrupted data from 1969 to 1985 from the Standard & Poor's 500 index (S&P 500), taken from the CRSP tapes. The results show that relative short interest was significantly higher for stocks that had traded options than for those without, in each year of the sample.

Jennings and Starks (1986) examined quarterly earnings announcements from NYSE-listed stocks of the S&P 500 from June 15 to August 21, 1981, and from October 4 to December 31, 1982, to find what effect the trading of options on a stock had on the price impact of earnings announcements. They found that the prices of non-option companies took longer to adjust following earnings announcements than that of companies which were the underlying of option trading, supporting the notion that the latter were more efficient. Skinner (1990) arrived at similar results when he found that optioned stocks at the Chicago Board Options Exchange (CBOE) and the American Stock Exchange (AMEX) were being followed by a larger number of analysts than stocks without options written on them. He took that as an explanation for his second finding, namely that the stock price reaction upon the release of accounting earnings information for newly optioned stocks, as compared to levels prior to options being written on their shares, declined both in absolute terms and conditional on unexpected earnings, with significance at the 1%-level. Easley et al. (1998) showed that option volumes led stock price changes and carried information about future stock price changes, an interdependence that was later complemented by the results of Jayaraman et al. (2001). The latter reported that, for their sample period of 1986–1996, the CBOE led equity markets in terms of volume. Pan and Poteshman (2003) came to the same conclusion and reported that the effect was particularly evident for small stocks (which can generally be assumed to be less informationally efficient) and remained consistent at the annual level over a period of 12 years.

Lee and Yi (2001) found that informed traders preferred trading on the CBOE to trading on the NYSE, but not for all volumes. They calculated that large-volume informed trades were more frequent at the NYSE and argued that the reason for this observation may have been that large trades at the CBOE tended not to be anonymous, while they were more so at the NYSE. They argued that, since market makers at the CBOE could distinguish between informed and uninformed traders for larger orders, they increased the spread for informed traders, thus making the CBOE less attractive for such large informed orders. Furthermore, their results suggested that informed investors were attracted to options with lower option deltas, i.e., larger leverage.

Chakravarty et al. (2004) focused on a slightly different aspect of the topic and argued that informed insiders sometimes trade in option markets, a conjecture that they arrived at after reviewing insider trading convictions in option markets. They employed an approach first applied by Hasbrouck (1995), which allowed them to

[17] As a mechanism working in the opposite direction, they mention that the introduction of options may cause prior short sellers to switch their shorting activity to option markets, thus reducing short interest in the underlying. However, they believe this effect to be of inferior relevance, since short selling in stocks is relatively limited and because the hedging activities of the option counterparties would cancel out this effect to some degree.

measure directly the share of price discovery across 60 stocks listed at the NYSE that possessed options exclusively at the CBOE over a period from 1988 to 1992. With this method, they calculated implied stock prices from call option prices and compared them to actual prices in the stock market. The results showed that an average of between 17% and 18% of the price discovery occurred in the option market, with estimates for individual stocks ranging from close to 12–23% – numbers that they found to be significantly different from zero at the 1%-level. They also observed that the information share of out-of-the-money options seemed to be higher than for in- or at-the-money options, and that option market price discovery appeared to be an increasing function of volume – evidence that is consistent with informed traders who value both leverage and liquidity.

Schlag and Stoll (2005) broadened the research focus by analyzing both options and futures, again finding that (signed) options and futures volumes had a contemporaneous effect on the DAX price index in 1998. They investigated the source of price discovery in this market and found that futures traders possessed information about the index that was not reflected in the quotes, while the price effect of signed options volumes was largely temporary, which points to a liquidity (as opposed to an information-based) explanation. Interestingly, they also reported that signed futures volume led signed options volume. In an earlier article that focused only on futures markets, Cox (1976) developed a model to relate the effect of organized futures trading on spot market prices. Applying it to data from six different commodities over the years 1928–1971, he found evidence for more informed traders and a disappearance of spot price autocorrelation during periods of futures trading. Cao (1999) proposed a model which implied that the introduction of options caused an increase in the prices of the underlying asset and the market index, decreased the price response of the asset upon new public information, and increased the number of analysts following the underlying asset (consistent with Skinner (1990)). His empirical evidence backed up the predictions of the model, supporting his hypothesis that the installation of an options market induced investors to acquire more precise information, because it gave them additional opportunities to profit from trading on it.

Taken together, the evidence suggests relatively strongly that the presence of derivatives markets in general and option markets in particular tend to increase the efficiency and market quality in the market for the underlying stock. It were these results that formed part of the motivation for the experiments described in the following chapters.

2.3 Literature on Prediction Markets, Market Structure, and the Double Auction Mechanism

The phenomenon of prediction markets is a relatively new one, and even more so is the analysis of such markets by the economic literature. Nonetheless, the two decades since the introduction of prediction markets in 1990[18] have seen a

[18] Cp. Tziralis and Tatsiopoulos (2007), p. 75.

number of publications reporting on political stock markets, prediction markets used by companies to forecast future sales or project termination dates, and online betting sites. The steadily increasing number of studies dealing with this topic and the creation of the *Journal of Prediction Markets* by the University of Buckingham Press in 2007 indicate that the monotonicity of this increasing trend will not soon end. Because of their centrality to the research questions investigated in this book, the literature on prediction markets is reviewed below. The following paragraphs explore the reasons for individuals' participation in prediction markets, mention a study on a novel information aggregation procedure, and provide evidence on the performance of prediction markets with abstract underlyings. They furthermore briefly discuss markets in the fields of finance, sports and politics.

In the first formal theoretical study of prediction markets, Forsythe et al. (1992) explored why individuals would spend time trading in such a market. Specifically, they listed five motivations for traders to participate in a political stock market experiment, which were (1) entertainment, (2) expected differences in information (confidence in their knowledge about the political event relative to other traders), (3) expected differences in information-processing ability (confidence in their ability to interpret news relative to other traders), (4) expected differences in their talents as traders, and (5) risk-seeking behavior. Forsythe et al. expected these differences to attract a diverse group of experimental subjects and were able to confirm this belief when analyzing actual political stock market participants' demographic characteristics, political and ideological preferences, investments, and earnings.

In the context of prediction markets, another issue of considerable practical importance (originally identified by Manski (2004)) is under which conditions prediction market prices reflect the true aggregate beliefs of the individual traders. To explore this issue, Wolfers and Zitzewitz (2006) proposed two simple models based on a log utility function, which lead to an equilibrium price in the market that is equal to the mean belief of traders. They then went on to relax some of the simplifying assumptions, showing that the dual symmetry assumptions of (1) demand being a function of the difference between beliefs and market prices which is symmetric around zero, and (2) a symmetric distribution of beliefs, lead to the same result (i.e., equilibrium prices being equal to the mean belief) without the need for log utility. They also found that if wealth and beliefs are not orthogonal, the equilibrium price turns out to be a wealth-weighted average of individual beliefs. Once the dual symmetry assumptions were also dropped, the possibility was raised that prices deviate from mean beliefs, but the authors argued that these deviations remain small under most reasonable specifications of utility and distributions of beliefs.

In a third theoretical inquiry into the properties of markets as information gathering tools, Plott (2000) set out by questioning whether it is at all possible that a market aggregates and processes the immense number of simultaneous equations and inequations expressing investors' beliefs, preferences, and differential information. In answer to this question, he then reasoned that this process is simplified by investors themselves, since each investor reaches his opinion of the "correct" price not only by considering the information she herself is privy to, but also forms expectations of the information others possess and of the beliefs others will form. Switching from theoretical to empirical argumentation, Plott then described a laboratory experiment in which he showed that an experimental market was indeed capable of extracting a larger set of information from the transactions of experimental subjects, each of whom had gotten only a small bit of the full information set regarding the value of an abstract underlying asset. In a similar vein, Wolfers and Zitzewitz (2004) also provided encouraging testimony of the ability of prediction markets to forecast uncertain future events. They found that "[...] simple market designs can elicit expected means or probabilities, more complex markets can elicit variances, and contingent markets can be used to elicit the market's expectations of covariances and correlations [. . .]"[19]

Berg et al. (2003) used the Iowa Electronic Market's prediction of the outcomes of the 1988, 1992, 1996 and 2000 U.S. presidential elections to provide the first study of the long-run predictive power of forecasting markets, finding that their markets gave accurate forecasts at both short and long horizons (single day vs. weeks and months). They then compared the predictions of the Iowa Electronic Market to the forecasts of various polling organizations, reporting that the latter were being outperformed by the former.[20] In another study on the predictive power of prediction markets, Tetlock (2004) used data from tradesports.com, an online market which at that time allowed wagers on both sports events and financial market data. He showed that financial prediction markets can be surprisingly efficient with relatively low numbers of market participants. His study also documented that results from sports wagering markets may not be replicable in economic prediction markets, since inefficiencies in the former segment of his sample did not reappear in the latter.

In contrast to the studies discussed so far, Ortner (1996) reported results from prediction markets run on election outcomes in Austria, where markets showed clear signs of manipulation and did not reliably provide forecasts of higher quality than polling organizations. Rather, the market's results in his experiment had been deliberately and successfully manipulated by a minority of traders to deviate from the market's earlier consensus opinion, at the same time influencing the prices of related markets. Chen et al. (2003a) also deviated from the bulk of the prediction market literature, albeit in an entirely different way. While most studies reported on markets employing standard double auctions, in their experiment they performed a nonlinear aggregation of individuals' predictions based on said individuals' skills and risk attitudes, as determined in previous prediction rounds in the same market.

[19] Wolfers and Zitzewitz (2004), p. 124.

[20] In section I of their paper, they also gave a good overview of online prediction markets in existence at the time of their publication (see Berg et al. (2003), pp. 2–3).

The results from such a "weighted" prediction outperformed both the simple market and the best of the individuals.

Overall, the diverse topics of studies on prediction markets and their heterogeneous findings underline the novelty of the field. While not specifically focusing on prediction markets, this study nonetheless offers new evidence on markets' ability to process information and harmonize expectations.

2.4 Literature on Experiments in Economics[21]

Economists began analyzing the special properties and functioning principles of market-based exchange in the eighteenth and beginning nineteenth century, starting with the work of Adam Smith[22] and Antoine Augustine Cournot. While the use of laboratory experiments in economics dates back to about the same timeframe (cp. Bernoulli (1738), as argued in Roth (1995)), the beginning of its widespread adoption by a sizable number of economists took place no earlier than in the twentieth century.

Generally, experimentation in economics can be segregated into three different research directions – those of game theoretic experiments, individual decision-making experiments, and market experiments.[23] The latter, which is the line of research the present study fits into, had its origin in the work of Chamberlin (1948). Chamberlin performed a laboratory market experiment by assigning reservation prices to a number of student subjects and allowing them to roam around the classroom with the goal of finding partners to trade with. He reported finding transaction volume in excess of the equilibrium quantity in 42 out of 46 markets and mean prices below the equilibrium price in 39 cases. Due to the substantial deviation of these results from theoretical predictions, Chamberlin dismissed them after one publication and discontinued his experimental research. While Chamberlin had thus laid the groundwork with his initial experiments, it was his student Vernon Smith (1962, 1964) who made experimentation the center of his life's research effort. It is a sign of the importance experimentation has since gained in economics, that in 2002 the Royal Swedish Academy of Sciences awarded him with the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, "for having established laboratory experiments as a tool in empirical economic analysis, especially in the study of alternative market mechanisms."[24] Before that, the award of the prize to Maurice Allais in 1988 and to Reinhard

[21] Cp. Davis and Holt (1993) and Roth (1995).

[22] Cp. Smith (1843).

[23] There are also experiments like those of Williams and Walker (1993), which serve no research question but are conducted in university classes to introduce student subjects to topics from the field of microeconomics.

[24] Royal Swedish Academy of Sciences (2002).

Selten in 1994 could be considered indirect signs of recognition of the importance of experimentation, which had featured in a prominent role in Allais' tests of game theoretic concepts and in Selten's work on individual behavior.[25]

Compared to traditional empirical studies, experimentation under controlled conditions has the advantage that single parameters may be varied while keeping all other conditions constant, thereby allowing for the isolation of the effect of variations in single variables. In natural data, tests of market propositions are always tests of the joint hypotheses of the primary hypotheses to be tested and the auxiliary hypotheses regarding the general market situation, equilibrium, agents, and a plethora of other circumstances. Any result, be it supportive or contradictory, may under these circumstances be caused either by mechanics implied in the primary hypotheses, or be due to erroneous auxiliary hypotheses. Conducting controlled experiments alleviates this problem by allowing the experimenter to reduce the number of auxiliary hypotheses. Experimentation also enables the researcher to obtain repeat observations under identical conditions, an important prerequisite for the analysis of the robustness of results. This advantage is all the more important since empirical data – if available – is usually expensive, while at the same time often lacking in accuracy.

Nonetheless, experimental economics has been subject to strong criticism over the years. One point of criticism is that a majority of economic experiments employs student subjects, raising the concern that this group is not representative of agents in real economic contexts. The results of studies testing this proposition somewhat invalidate this argument; they are reported in Sect. 2.4.4.6. Another concern is that the simplification of markets, the environment and the sets of possible actions in laboratories yield results that are not meaningful when applied to real-world markets. This is a valid point which must, however, also be applied to theoretical research and model building; just as in experimental research, simplification is a necessary component of this strand of research. Besides, experimental studies hold the possibility to probe the impact of these simplifications, by varying individual parameters and measuring their impact on the results. Laboratory markets have also been criticized as not being "real," an argument that Plott (1982) countered by pointing out that, in the context of experimental markets, the same principles of economics apply as elsewhere. As he put it, "Real people pursue real profits within the context of real rules."[26] He noted that the simplicity of laboratory markets should not be confused with the question about their reality as markets.

Smith (1994) listed a number of reasons from the literature as to why economists conduct experiments, among them the wish to test a theory or explore the reason for its failure, the observation of empirical regularities as a basis for a new theory, the comparison of environments and institutions, and the evaluation of policy proposals and test of institutional design. The present book set out to do the last, i.e., test the

[25] Cp. Haase (2006), p. 166–167.

[26] Plott (1982), p. 1520.

impact of digital option trading on spot market efficiency. As mentioned in the introduction, the observation of empirical regularities then led to the formulation of a new hypothesis. This work thus is a good illustration of one of the points Smith (1994) made, namely that experimentation has many dimensions and can shed light on topics of scientific research in a variety of ways.

In their book surveying the whole discipline of experimental economics, Davis and Holt finally drew the following conclusion regarding the value of experimentation as a research methodology in economics:[27]

> "Overall, the advantages of experimentation are decisive. Experimental methods, however, complement rather than substitute for other empirical techniques. Moreover, in some contexts we can hope to learn relatively little from experimentation."

One can summarize the above deliberations by noting that the experimental method is one of a number of instruments in the economist's toolbox. Its value depends on the research question under examination, yet it is able to address issues that are hard – if not impossible – to tackle with alternative approaches. In the case of the research question addressed by this study, its advantages by far outweighed its shortcomings, a point that will become clearer in the discussion of the results in Chap. 4.

2.4.1 Expectations and Equilibrium Models in Experimental Asset Markets

Models are to be used, not believed.
Henri Theil (1971)

The question of efficiency and inefficiency in any market, both inside and outside of the laboratory, is intricately intertwined with that of the formation of expectations by the market participants. The topic of expectation formation has been a staple of economics research for a number of decades, but received additional momentum with the advent of behavioral finance and the increasing influx of results from psychology and biology into the economic sciences. For this reason, this literature is reviewed in this section. As will become clearer during the discussion of the results in Chap. 4, the process and mechanics of expectation formation are of central importance for this work.

2.4.1.1 Prior Information Equilibrium

Plott and Sunder (1988) defined a *prior information equilibrium* (also referred to as a naive price equilibrium in Forsythe et al. (1982)), as an equilibrium following from the actions of agents which consider only their private information

[27] Davis and Holt (1993), p. 18.

in investment decisions. In other words, in such an equilibrium, individuals evaluate prices based solely on their own information – ignoring the possibility that market prices, by aggregating information from other traders, also contain information. They are assumed to apply Bayes' law to determine the likelihood of a state of nature given their private (prior) information. After having done so, they maximize their utility dependent on that likelihood, but do not take into account market prices and possible speculation potential depending on the actions of other market participants.

The prior information equilibrium does not play a major role in the experimental literature, but is sometimes used as a somewhat extreme bound on subjects' behavior. By benchmarking experimental results against the expectation formation mechanism implied in this equilibrium model, strong deviations from the predictions of rational expectations theory can sometimes be better illustrated, or statements can be made regarding the (lack of) plausibility of results (for an example, see e.g., Plott and Sunder (1982)).

2.4.1.2 Rational Expectations Equilibrium

Our fundamental view is that the experimentalist has as much to learn from experimental subjects about subjective rationality, as human decision makers have to learn from the models that we call "rational."

Vernon L. Smith and James M. Walker (1993b)

Smith et al. (1988) distinguished between two definitions of rational expectations. They quoted the more common Muth (1961) definition that rational expectations for the same information set tend to be distributed about the prediction of the theory,[28] as well as the earlier and less restrictive Nash (1950) definition, that for expectations to be rational, they should be realizable.[29] They interpreted the difference to be that rational expectations according to Nash (1950) need to be sustained or reinforced by outcomes, while rational expectations as defined by Muth (1961) are implied to be sustained by outcomes that in turn support theoretical predictions. Specifically, Muth wrote that "the expectations of firms (or, more generally, the subjective probability distribution of outcomes) tend to be distributed, for the same information set, about the prediction of the theory (or the 'objective' probability distributions of outcomes)." In short, the rational expectations hypothesis states that the expected price is an unbiased predictor of the actual price. Muth qualified this statement by saying that it holds true only in the aggregate.[30]

A theory of rational choice that is considerably more realistic, albeit much harder to operationalize than the above concepts, is that described by Simon

[28] Cp. Smith et al. (1988), pp. 1136–1137, and Muth (1961), p. 316.

[29] Cp. Smith et al. (1988), p. 1137 and Nash (1950), p. 158.

[30] Cp. Muth (1961), p. 333.

(1955). He drew a picture of individual behavior that is characterized by bounded rationality and a variety of coping strategies. Agents in this model curtail the set of all possible actions to derive a subset of actions they take into consideration in their decision-making process. Furthermore, they do not optimize the expected outcome over the available alternative space of actions, but employ a strategy of satisficing, i.e., choosing an action that leads to expected outcomes which satisfy some subjectively set minimum acceptable level, as opposed to providing the maximum possible benefits.

Despite its better fit with reality (and with a large portion of experimental results), Simon's (1955) notion of rational choice has not been widely adopted in the experimental literature.[31] This is possibly due to the difficulty of operationalizing its predictions in real applications. Muth's (1961) definition, which is the concept most often employed in the literature, often fails in describing the actual behavior of subjects encountered in experimental and empirical studies. Yet the beauty of its predictions is that they constitute a natural upper bound on the possible extent to which individuals *can* adhere to models based on the assumption of homines oeconomici. One of the stated objectives of many economists is the discovery of a market structure that does the best possible job of processing information, so that asset prices correctly and completely reflect the available information set. Testing the performance of any given market system by comparing its outcomes to the predictions of the theory of rational choice as formulated by Simon (1955) might yield a broad congruence between prediction and outcomes, yet it would not further the objective of finding a market structure that optimizes information processing and price efficiency in line with economic theory. This is something that a comparison with the predictions of a model of behavior following Muth (1961) and a program of minimizing the deviations of actual outcomes from the results predicted by his concept of rationality would accomplish.

Note that it is somewhat dangerous to use the word "rational" in the context of such discussions. While it is tempting (and common practice) to refer to individuals resembling the theoretical concept of the homo oeconomicus as being rational, this is correct only when abstracting from e.g., the cost of thinking. When Smith (1985) talked about the modification of standard theories by introducing elements of the subjective cost of transacting, he (correctly) referred to this as "imbedding standard theories in larger (and more '*rational*') frameworks" [italics added for emphasis]. In reality, individuals who take into consideration the cost of finding an optimal solution (in terms of cognitive effort, time dedicated to search, etc.) should be referred to as more rational than their compatriot homines oeconomici, who pursue optimality regardless of the cost of this pursuit. Nonetheless, unless otherwise noted, this study will follow the conventional practice of equating rationality in economic decision-making with adherence to the theoretical model of the homo oeconomicus, which coincides with Muth's (1961) definition of rational expectations.

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[31] It has found more adherents in the literature on behavioral finance and decision-making.

Another important observation regarding this topic is the difference between the meaning of rational expectations in the market efficiency literature and in the experimental literature. While in the former, market efficiency is a characteristic of a given platform of exchange, in the latter it is the result of a process. Plott and Sunder (1988) summarized this when they wrote:[32] "Rational expectations can be seen either as a static theory of markets (e.g., in the efficient market literature in finance) or as an end-point of a dynamic path of adjustment." Most experimental evidence indicates that expectations are adaptive and that rationality may take some time to settle in (if it does at all). A study that nicely illustrates the importance of the adaptation of expectations (and its speed) was Arthur et al. (1996). The authors proposed a model of rational, heterogeneous agents who endogenously form expectations about market prices, which are subject to influence from their own decisions. In doing so, these agents assign a positive probability to the existence of irrational agents – in other words, the rationality of all agents is not common knowledge. With this setup, the authors wished to explore the question of whether such a market leads to an evolution toward homogeneous (rational expectations) beliefs or whether it exhibits more varied behavioral patterns which could explain some of the seemingly irrationality-motivated phenomena in real-world markets. Simulating markets with the characteristics described above, they found that both outcomes were possible and robust over certain subsets of the parameter space. If they parameterized their agents in a way that had them adapting their forecasts unrealistically slowly, the market converged to a rational expectations equilibrium. In parameterizations where forecasts were adapted at a more realistic rate, behaviors in the market did not converge and pseudo-psychological effects like bubbles and profitability of technical trading rules could be observed. In this latter design, they also found persistence in volatility and trading volume, as well as GARCH effects. Williams (1987) arrived at a similar verdict after showing experimentally that subjects are not Muthian rational when forecasting experimental double auction market prices. Forecasts in his study turned out to be biased with regard to the mean price, and to display significant first-order serial correlation. He concluded that an adaptive expectations model describes the experimental regularities better, a finding that was arrived at also in a large number of other experimental studies, including Smith et al. (1988) and this present study.

An interesting twist on the topic of expectation formation and rationality was discovered by Frédéric Koessler, Charles Noussair and Anthony Ziegelmeyer. In Koessler et al. (2005) they documented that the elicitation of beliefs from experimental subjects moved their choices in a parimutuel betting market closer to those predicted by a rational expectations model.[33] It also increased the amount of information aggregated in prices. They found that – without requiring subjects to state their expectations – public information was being overweighted relative to each subject's private information. Once subjects were asked to submit their beliefs

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[32] Plott and Sunder (1988), p. 1104, footnote 6.

[33] In a parimutuel betting system, all bets are pooled and later shared among the winning tickets.

regarding future outcomes, they started placing more weight on their private information relative to public information, leading to a more efficient aggregation of the existing information into prices.[34] Furthermore, in cases where subjects had erroneous private information, it also induced them to more often follow public information that was (correctly) in conflict with their private information. Such a phenomenon is called an *information cascade* in the literature. Alevy et al. (2007) described it as follows:[35]

> "Information cascades arise when individuals rationally choose identical actions despite having different private information."

In the same article, Alevy et al. also pointed out that this is a phenomenon that is distinct from herding, as the latter does not necessarily involve rational individuals, but can be caused by preferences for conformity, social sanctions or lower necessary cognitive effort.

2.4.1.3 Perfect Foresight Equilibrium

As the final theoretical model in their article, Forsythe et al. (1982) listed the perfect foresight equilibrium (which in the case of their experiments equaled the rational expectations equilibrium), also referred to as a fully revealing rational expectations equilibrium in Plott and Sunder (1988). In this theoretical model, agents behave as if they had the perfectly forecasted theoretical equilibrium price at their disposal. In other words this is the rational price a homo oeconomicus-type investor would arrive at were he in possession of full information. In their experimental work, Forsythe et al. (1982) then found that the rational expectations equilibrium (i.e., the perfect foresight equilibrium) was an excellent predictor of the performance of their simple markets and that replication was both a necessary and sufficient condition for the applicability of the perfect foresight model. They reported that none of their five experimental markets converged in the first period, while all of them converged after replication.[36] Forsythe et al. (1984) similarly showed that the perfect foresight model was a good predictor of the last several years in experiments with spot- and futures markets, whereas in their sequential markets it was a good predictor only of the final year.

In the latter article, Forsythe et al. also analytically compared whether final-year allocations were more accurately predicted by the perfect foresight model than by the prior information model. They found that the perfect foresight equilibrium model was a good predictor of allocations in late years (always better in years six and seven), while the prior information model did better in the early years (nearly

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[34] Cp. Koessler et al. (2005), p. 14.

[35] Alevy et al. (2007), p. 151.

[36] Cp. Forsythe et al. (1982), p. 560: "The appropriate model may have the markets converging to a temporary (naive) equilibrium *first* and then adjusting to the perfect foresight equilibrium after "sufficient" information has accumulated [. . .]"

always better in years one and two) of their experimental markets. This again matched the observations reported in their earlier study. Camerer and Weigelt (1991) reported similar results in their article on the occurrence of information mirages, which is briefly discussed in Sect. 2.4.2.2. Both observations support the view of rationality as the result of a learning process within subjects.

2.4.1.4 Maximin Equilibrium

In addition to the Forsythe et al. (1982) models, Plott and Sunder (1988) described the maximin model, which is characterized by agents who act only on certain payoffs. In the maximin framework, the investors with the maximum (across all traders) of minimum (across all states) dividends will purchase the security at a price equaling their minimum dividend. Note that this equilibrium does not apply to experiments like Smith et al. (1988), where all investors face the same reservation cost and value for one unit of the experimental asset.

2.4.1.5 No-Trade Equilibrium

2.4.1.5.1 No-Trade Equilibrium in a Stock Market

A final possible equilibrium in many experimental markets is one where no trade takes place. This equilibrium is of particular interest for the discussion of the experimental results reported in later chapters, because it is frequently conjectured to be the "rational" equilibrium for Smith et al. (1988)-type asset markets. However, such an equilibrium requires the following five relatively restrictive conditions to hold:[37]

Condition 1: The initial cash and asset allocation is Pareto optimal.
Condition 2: All subjects are rational maximizers of expected utility.
Condition 3: Condition 2 is common knowledge.
Condition 4: Subjects derive utility only from final payoffs, not from the process of trading itself.
Condition 5: There are no cognitive or transaction costs to trading.

If the first condition is violated, trade is nonetheless limited to Pareto-improving transactions and will not display patterns where a subject for example first buys an asset and then sells it again, or vice versa. Once a Pareto optimal situation has been reached in such a market, trading once again ceases.[38] A violation of condition

[37] The author wishes to thank Erik Theissen for suggesting conditions one to three.

[38] The argument assumes that over the time of the laboratory experiment, subjects' preferences are constant and that changes in subjects' wealth due to the receipt of dividends over the experimental periods are insufficient to change their optimal portfolio sufficiently to induce subjects to develop the wish to rebalance their portfolios.

three has in turn been proposed as an explanation for many of the inefficiencies (in particular price bubbles) observed in experimental asset markets. As Lei et al. (2001) showed and as this book will also suggest, this explanation is not sufficient to explain the observations. The reason behind this is that in some designs common knowledge is irrelevant for market efficiency, yet inefficiencies are still observed. However, a violation of condition two can explain the results found by Lei et al. (2001) and is also consistent with the literature on bounded rationality. In a market with less than perfectly rational subjects, trade is possible even if the initial allocation is Pareto efficient.

Furthermore, trade is also possible in any market where subjects derive utility directly from the act of trading. Such a mechanism is suggested by the Active Participation Hypothesis proposed by Lei et al. (2001). It implies that subjects in experimental markets trade because they feel that they are supposed to trade, even if it does not increase their expected utility from the final future payoff. It is also consistent with Williams' observation that subjects in his experiment were so fascinated by the electronic trading mechanism that they traded significantly more than expected.[39] Finally, the fifth condition ensures that no considerations other than those of final payoffs bias subjects' actions.

Note that, if the five conditions above hold, there will be no trade, but there may be quotes (i.e., limit orders). If the initial allocation is Pareto optimal, but this is not common knowledge, even rational individuals (who do not know that they are in a situation of pareto optimality) may try to improve their situation by offering trades. However, due to Condition 1, no other individual will want to take the opposite side of any such quote. On the other hand, consider what happens in a market where the following condition is introduced:

Condition 6: Condition 1 is common knowledge.

In the case where Conditions 1 through 6 hold, the market will not only exhibit a no-trade equilibrium, but there will not even be any quotes, since every trader knows that no other trader will transact with her.

2.4.1.5.2 No-Trade Equilibrium in a Digital Option Market

Digital options are characterized by a trinary payoff structure that makes them unsuitable for hedging purposes.[40] To be suitable for hedging, an instrument needs to have a payoff structure in which the marginal payoff – at least over some parameter interval – runs opposite (or parallel) to that of the asset to be hedged.

[39] Williams (1980), p. 245.

[40] The payoff structure of the digital options employed in the empirical part of this study will be described in detail in Sect. 3.3. In short, a digital option pays a fixed amount to the winning party, pays nothing to the losing party, and splits the payoff equally in the case where the price of the underlying equals the option strike price at maturity (i.e., when the option is at the money at maturity).

This is not the case for digital options, which makes them primarily a vehicle for speculation. Because of this reason, it cannot be argued that subjects use digital options to improve their risk exposure, but only to improve their cash position. It must be assumed that they contract for digital options only if their subjectively perceived expected value from the digital option investment is positive.[41] Following this argument, a no-trade equilibrium in the digital option market relies on the following conditions:[42]

Condition 1: All subjects have homogeneous expectations.
Condition 2: All subjects are rational maximizers of expected utility.
Condition 3: Subjects derive utility only from final payoffs, not from the process of trading itself.
Condition 4: There are no cognitive or transaction costs to trading.

The interpretation of violations of Conditions 2 through 4 is analogous to the section above. Condition 1 is new in that the allocation of cash and assets is irrelevant when regarding digital options, yet the form of expectations about the future price of the underlying is critical. If Condition 1 is violated, investors will trade on their asymmetric information or on their heterogeneous interpretation of symmetric information (i.e., their heterogeneous expectations based on symmetric information, due to heterogeneous beliefs). Furthermore, consider the following condition:

Condition 5: Conditions 1 and 2 are common knowledge.

Condition 5 can be employed to make a similar argument as Condition 6 in the section on the stock market above. If it holds, then – in addition to there being no trade in such a market – no market participant will even post digital option offers (i.e., limit orders in the digital option market), since everybody is aware that no other trader would enter into an option contract that the first trader would consider favorable.

2.4.2 The Role of Experience in Experimental Asset Markets

The twin issues of learning and experience play a prominent role in any science investigating the actions and behavior of humans, regardless of the context. For the discipline of economics, Friedman et al. (1983) distinguished between

[41] This argument assumes that subjects are not risk-loving and is developed in more detail in Sect. 3.3.

[42] This analysis assumes that subjects cannot influence the future price of the underlying. If, as in the experimental market described later in this text, the same individuals trade both in the digital option market and in the market for the underlying, then a no-trade equilibrium in the option market also requires Condition 3 from the analysis of the stock market above – the condition that rationality be common knowledge.

three types of experience relevant in experimental asset markets, which would also lend themselves to generalization to other sciences employing systematic experimentation:[43]

> "In a real-time trading process such as that of our experiments, equilibrium can be achieved only as agents learn about their opportunities for gain through trade. In our experiments this learning can take place within each period as traders observe bids, offers and transactions (intra-period learning) – across periods and market years as traders observe trends in prices and the outcomes of their activities (inter-period learning), and across experiments as traders gain a better idea of what information is relevant and refine their strategies (experience)."

These three terms – intra-period learning, inter-period learning and experience – will be adopted for the purposes of this text. However, since no study reviewed for this book analyzed intra-period learning, the first category will be disregarded in the following literature overview.

2.4.2.1 Inter-Period Learning

The article of Forsythe et al. (1982) was already mentioned in Sect. 2.4.1 on equilibria, but shall be mentioned here again because of the relevance of its results for the topic of inter-period learning. Forsythe et al. (1982) found for their design that replication (i.e., the repetition of experimental runs with the same treatment, or "intra-treatment" experience) is both a necessary and sufficient condition for convergence to the price predicted by the perfect foresight model. Friedman et al. (1983) reported that in each of their four experiments (with the exception of a single period in one experiment) profits were generally higher in later market years. Friedman et al. (1984) also reported that their markets converged over time toward informationally efficient equilibria. In their experiments, this finding was robust to the presence or absence of futures markets and to that of uncertainty regarding the future state of nature.

Smith et al. (1988) reported on three of their experiments which in the first three periods seemed to converge to, and from then on closely followed the path of expected dividend value. Even in these experiments they found support for the conclusion that the rational expectations model of asset pricing can be confirmed only as an equilibrium concept underlying an adaptive price adjustment process. This is in conflict with Fama's concept of efficient capital markets, which requires that "security prices *at any time* 'fully reflect' all available information"[44] [italics added for emphasis].

In an experiment which forms a connection to Sect. 2.2 on the role of information in experimental markets, Camerer and Weigelt (1991) ran an experimental asset market where the subjects faced uncertainty about the presence of informed

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[43] Friedman et al. (1983), p. 130.

[44] Fama (1970), p. 383.

traders. Their treatments ran for between 15 and 21 periods and in the majority of their experiments the probability of insiders being present was 0.5 in each period. Their findings suggested that subjects sometimes wrongly interpreted price patterns as stemming from insider trades, which then caused them to trade on noise as if it were information. They dubbed this phenomenon an "information mirage." Analyzing their time series data, they found that no mirages occurred in later periods and concluded that traders learned to distinguish between insider and non-insider periods using non-price information (i.e., the speed at which trading took place).

Providing some more detailed evidence on the equilibrating process or the process of expectations formation, Peterson (1993) reported that inexperienced subjects submitted forecasts which were frequently biased and inconsistent with the rational expectations hypothesis. However, these subjects altered their learning model more often than experienced subjects, and usually in the direction of rational expectations. This suggests an asymptotic learning process with a steep learning curve for inexperienced individuals, which flattens as they gain experience and approach the forecasting model implied by the rational expectations hypothesis.

2.4.2.2 Experience

The literature knows mixed results regarding the question of which impact experience has on the results of experimental studies. Most articles report that experience increases efficiency and rationality, reduces the variance of subjects' actions and – in experiments where this is possible – increases subjects' profits. Nevertheless, expert subjects (which are frequently assumed to be experienced) do not consistently outperform inexperienced students in terms of rational behavior. As in the above sections, the below paragraphs will review the relevant literature on this topic.

In an early computerized experiment, reported in Williams (1980), inexperienced subjects failed to achieve as rapid a convergence to efficient prices as documented in earlier, oral double auction studies. While this result is not particularly spectacular in itself, the reason that Arlington Williams believed to have been the cause for it may seem amusing from today's point of view. As his following statement suggests, the result may not only have been due to the complexity of the economic task, but may rather have been caused to a considerable degree by his subjects' unfamiliarity with the computer interface:[45]

> "In conducting the first series of [computerized double auction] experiments it became apparent that the ocular-motor skills required to function well in [computerized double auction] markets generally developed after a few periods of trading but seemed to totally elude some people."[46]

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[45] Williams (1980), pp. 251–252.

[46] This example nicely illustrates the role experimental institutions play for the results and should serve as a cautionary tale for inexperienced experimenters. Note that the computer interface used for the experiments reported in later chapters was tested and adapted extensively prior to its first use in a live experimental session.

Nonetheless, when repeating the experiments with experienced subjects (who had shown themselves adept at grasping the computerized double auction mechanism) Williams found that the price convergence was faster and the market generally more efficient than in experiments with inexperienced subjects.

Similar findings – at least with regard to efficiency – were provided by Friedman et al. (1983), an article reporting on four markets: Two with inexperienced subjects, the other two with experienced subjects, and each with three periods per market year.[47] Friedman and his co-authors found that the dispersion of the transaction prices of inexperienced traders was consistently larger than that for experienced traders in their experiments, and that the latter had consistently smaller coefficients of variation. The authors interpreted this to mean that the experienced traders held probability beliefs with greater precision than the inexperienced subjects and would not accept bids or offers too far removed from the expected equilibrium price. They could also solidly reject the hypothesis that the mean transacted period B spot price converged to the perfect foresight equilibrium price for inexperienced traders, while equally firmly accepting the hypothesis for the experienced traders. Furthermore, aggregate profits in the experiments with experienced traders were all higher than those of the inexperienced traders.

In their seminal 1988 article, Smith, Suchanek, and Williams also dedicated considerable attention to the role of subject experience. Prior to their actual experimental sessions, they ran pilot experiments of their asset markets and found that subjects with no previous double auction experience of any kind (provided with relatively little information) produced prices deviating widely from the expected future dividend values. Thus, for their non-pilot experiments they used only once-experienced subjects and provided them with more information. After repeatedly observing price bubbles in markets with experienced subjects, they then conjectured that the bubbles with first-time traders were due to their inexperience, while experienced traders produced bubbles because they had gained their prior experience in a market that had similarly exhibited a bubble. To control for this possibility, they let inexperienced traders gain their first double auction experience in a market that was reinitialized after each period, so that no capital gains or losses were possible across trading periods.[48] However, these newly experienced traders, who had no prior experience of a market that had exhibited the bubble phenomenon, nonetheless produced bubbles when allowed to trade in Smith et al.'s (1988) baseline markets without reinitialization. The three authors also conducted a market experiment populated only with twice experienced subjects who had been among the top earning traders in previous rounds. The resulting bubble was similar to those observed in earlier experiments. Finally, they found that if a group of experienced

[47] A slightly more detailed account of the period design can be found in Sect. 2.4.4.2 on futures markets.

[48] They reported that the single period markets did also not exhibit any within-period price bubbles.

traders participated in two (additional) rounds, they no longer produced bubbles in the second.

Van Boening et al. (1993) similarly reported on a connection between experience and efficiency. They let subjects participate in a series of three markets, in order to collect data from one market design with the same group of subjects having first no experience in experimental asset markets, then being once-experienced and finally being twice-experienced. This design had already been used by Smith et al. (1988) and was also employed for this study.[49,50] Despite alterations in the trading institution (they used a closed-book call auction) and the dividend distribution (described in Sect. 2.4.4.1) they found that the only parameter that led to a decrease in price deviations from intrinsic value was an increase in subject experience. In a slightly later article, Porter and Smith (1995) also reported on the importance of experience, stating that their empirical evidence showed that inexperienced subjects tended to produce bubbles and crashes relative to a declining expected dividend value, while once-experienced subjects produced a less pronounced pattern of the same form that then practically disappeared for twice-experienced subjects.[51]

Oechssler et al. (2007) ran experiments of a somewhat different design and discovered a rare counterexample to the pattern of experience increasing price efficiency. Their subjects could trade five different assets, and in each session, one of these assets paid an extra dividend. The authors found that in treatments where the asset that carried this extra dividend changed from session to session, experience (up to two replications) did not lead to a reduction in the frequency of bubbles.

Dufwenberg et al. (2005) departed from the norm of having either only inexperienced or only experienced subjects in an experiment. They populated their markets with one third (two thirds) inexperienced traders and two thirds (one third) traders thrice experienced in a market similar to that employed in Smith et al. (1988). They found that in both treatments (one and two thirds experienced subjects) bubble-and-crash patterns were greatly reduced compared to the baseline case. Regarding a similar question, Ackert and Church (2001) reported no significant difference in price deviations from fundamental values between markets populated solely by experienced business or arts and sciences students and markets

[49] The only difference in this regard between Van Boening et al. (1993) and Smith et al. (1988) vs. this study is that, for procedural reasons, repetitions were conducted on the same day for this work, while the earlier articles invited subjects for experimental runs on different days. This topic will be elaborated upon in Sect. 3.1.

[50] Such a design is referred to as a within-subjects design in experimentation, pointing to the fact that differences in results from one round to the next – barring any changes in the experimental environment – must be due to changes within subjects, whereas in a between-subjects design, different results may be caused by different experimental subjects. Where possible, experimenters tend to prefer within-subjects designs, because they offer less possibility for noise to influence results.

[51] Cp. Porter and Smith (1995), p. 509.

made up of 43–50% inexperienced subjects and 50–57% (mostly twice) experienced subjects. They concluded that in the mixed markets, the subset of experienced traders was largely responsible for price-setting.[52]

Using a different modification in the subjects variable, Leitner and Schmidt (2006) wrote that, in forecasting tasks, expert subjects generally perform well in domains with static stimuli (e.g., weather forecasts), whereas they perform poorly in environments of dynamic stimuli and human behavior, such as financial markets. In their empirical study, they compared expert subject forecasts of the EUR/USD exchange rate from January 1999 to March 2003 with the forecasts of inexperienced students. To further enrich their tests, the students were provided with no other information than the realizations of the time series; they were not even told what kind of time series it was they were seeing and forecasting. The comparison of the two forecasts was based on three measures of efficiency: unbiasedness, absence of serial correlation in the forecast errors and efficient use of information. The results showed that all forecasts (from students and experts) of the horizons of 3 and 6 months exhibited significant correlation of forecast errors and made inefficient use of information at time lags of 1 and 2. The only efficient forecast (according to all three criteria named above) was that of the student subjects for 1 month ahead. More generally, the experts in their study seemed to expect trend reversals, while the students predicted short-term continuation of trends, with reversals in the long run, which corresponds to the short-term momentum and long-term reversal results for stock markets in the efficient markets literature, as mentioned in Sect. 2.1.2. Furthermore, the experts exhibited a bias toward fundamentals (i.e., purchasing power parity) in their forecasts, whereas the students' predictors did not. Overall they concluded that the experts' forecasts were significantly worse than the naïve student forecasts, a result which they could not attribute to a common failure in human decision-making.

2.4.3 The Baseline Experimental Market and its Extensions

Chamberlin (1948), and later Smith in his early work on double auctions, induced differing values of the experimental asset by assigning differing reservation costs and values to subjects. Later work, starting with Smith et al. (1988), assigned the same value to each unit of the asset, regardless of which trader ended up owning it at the end of the experiment. To the surprise of the experimenters, subjects generated trading volumes that far exceeded all bounds that could have been explained by differences in endowments or risk attitudes. The reason their article sparked a large number of additional studies, however, was the observation of price bubbles and crashes in their setting. The following sections present the original Smith et al.

[52] Cp. Ackert and Church (2001), p. 19.

(1988) study as well as two extensions thereof, both of which are of high relevance for the presentation of this study's design and results in Chaps. 3 and 4.

2.4.3.1 The Smith, Suchanek and Williams (1988) Baseline Market

The Smith et al. (1988) experimental asset market experiment has already been briefly introduced in Sect. 1.4 of the introduction. Due to its central importance for the experiment presented in Chap. 3, it is nonetheless summarized in more depth in the present section.

Smith et al. (1988) conducted experimental market experiments with between nine to twelve traders. The subjects participated in one to three repetitions of a market in which they could exchange assets for cash (and vice versa) in a double auction framework. The maximum length of one period was 240 s, but by pressing a button on their screens subjects could vote to end a period early. In such a case, trading continued either until the last subject had voted to end the period, or until the remaining time in the period had expired without a premature ending. At the end of each period, subjects received a random dividend payout for each unit of the asset they owned. Said dividend was discretely distributed over four equiprobable, non-negative values. The fundamental value process of a unit of the asset has already been graphically illustrated in Fig. 3 in Sect. 1.4 above. Expressed in terms of the number of periods T, the dividend in period t of d_t, and using $E[\cdot]$ as the expected value operator, the fundamental value started out at $T \cdot E[d_t]$ in their experiments and declined by $E[d_t]$ after each period. Since the asset did not bestow any lump-sum terminal payoff, its fundamental value in the last period was just its expected dividend payment for a single period, $E[d_t]$. This fundamental value path was both deterministic and known to all subjects.

One novelty in their design was that all units of the asset (stock) had the same value to every participant, and that all participants could both buy and sell the asset. Prior to their work, experimenters had routinely induced supply and demand schedules characterized by different costs (values) to different designated sellers (buyers) for different units of the asset.[53] The second new design feature in their treatments was that assets did not have single-period lives, but expired only at the end of the experimental session (in their case after 15 or 30 periods).

As noted, Smith et al. (1988)-type experiments almost invariably produce large deviations of transaction prices from the fundamental value, forming bubbles which in some cases even exceed the maximum possible value the asset could ever return in dividends (in the case where only the highest dividend would be drawn in each future period). This is true despite the common knowledge attribute of the

[53] In other words, it cost seller A a different amount to produce a unit of the asset than it cost seller B, and seller A was also subject to different costs for her first and for her second unit. The terminus technicus is that agents faced *heterogeneous reservation prices*. Furthermore, a designated seller (buyer) could not purchase (sell) any unit of the asset in the experiment. See Smith (1976a) for a discussion of induced value theory.

fundamental value process. It seems that some quirk in the process of how subjects form expectations obstructs the market from trading at prices consistent with the underlying fundamental value. As Miller (2002) later put it:[54]

> "At the same time that subjects are learning about the asset's intrinsic value, the market teaches them two things that can undermine that knowledge. First, as the asset price moves toward equilibrium in the early periods, subjects see that prices tend to increase over time. Second, because this increase occurs as the intrinsic value is decreasing, subjects learn that the market price does not need to track the intrinsic value, at least over the short run. Until the markets [sic!] crashes as the experiment nears its conclusion, subjects who learn to ignore the asset's intrinsic value are rewarded by speculative profits, while those who follow it are quickly priced out of the market. Indeed, in experiments that allow selling short, subjects who sell the asset short may not only lose money, should they liquidate their short positions too soon, their purchases can help sustain the bubble."

This and other conjectures regarding the learning process subjects undergo are at the core of the results presented in Chap. 4.

Note that although a number of variations from the original treatment and virtually hundreds of sessions were conducted over the years, the only treatment variation found to reliably and strongly reduce the bubble phenomenon is increased subject experience.[55] The robustness of the phenomenon of market inefficiency in this setting thus provides an exceedingly strong test of the capability of any change in market structure to lead to more efficient information processing. However, once subjects *have* gained experience by participating in repeat rounds, they tend to converge on rational, common, intrinsic dividend value expectations.

As a final observation it should be noted that – despite being often referred to as a stock – the Smith et al. (1988) asset does not bear a high resemblance to the common stocks of most companies. Nonetheless, there are industries where payoffs follow similar patterns as those modeled in the experimental asset markets with declining fundamental value. Good examples could be drawn from investments into the extraction of non-renewable natural resources, such as gold, oil, etc. Depending on the market price for steel for example, an iron ore mine will exhibit random payoffs each period, but will have a fundamental value that declines as the deposit is being used up and approaches zero.

[54] Miller (2002), p. 48.

[55] For complete accuracy, this statement needs to be qualified somewhat. First, Noussair and Tucker (2006) demonstrated the complete disappearance of bubbles in an experiment with a complicated structure of futures markets, a setting which unfortunately was rather artificial, thus possessing limited practical relevance (see Sect. 2.4.4.2 of this text). Second, there is mixed evidence with regard to short selling as a means to reduce asset price bubbles, with e.g. Ackert et al. (2001); Haruvy and Noussair (2006) having found evidence for such an effect, King et al. (1993) and Sunder (1995) having reported no such evidence, and Ackert et al. (2006a) having painted a mixed picture (Sect. 2.4.4.5). Third, Davies (2006) found that in a market similar to the Smith et al. (1988) design but with increasing asset values, the experimental asset tended to be undervalued (Sect. 2.4.4.8).

2.4.3.2 The Porter and Smith (1995) Futures Market

Porter and Smith (1995) tested a market design where, in addition to the spot market for an unspecified, dividend-paying good, they enabled the trading of futures contracts on that good in the eighth trading period – the midhorizon point. At the end of period eight, if a trader had a positive net futures position, these accumulated units were transferred to her trading account. If a trader had a negative net futures position, she had to cover the shortfall from her spot inventory.[56] Contrary to previous experiments by the same authors, a period lasted for 300 s, as subjects had to trade in two markets simultaneously. They conjectured that the possibility to trade on the asset's price in the future would facilitate a mechanism of backward induction, leading subjects to refrain from trading the experimental asset at inflated prices.

Porter and Smith (1995) reported that the futures market reduced the bubble amplitude and had no significant effect on duration (defined as the number of consecutive periods in which the difference between mean spot price and fundamental value increased – see Sect. 4.1.2.1) and turnover of the bubble with inexperienced traders in the futures market, but exhibited significantly reduced turnover with experienced futures traders. They interpreted their findings as signifying "that an important function of a futures market is to reduce each individual's uncertainty about other peoples' [sic!] expectations."[57]

Note that the Porter and Smith (1995) futures market was technically a forward market, since the contracts traded in their experiment were not settled daily, but only once at the maturity date.[58]

2.4.3.3 The Lei, Noussair and Plott (2001) No Speculation Treatment

One explanation for the bubble phenomenon in Smith et al. (1988)-type experimental markets is that all subjects are rational, but unsure about the rationality of their fellow subjects. If they assume that at least some other subjects are not rational, even rational subjects might buy the asset at inflated prices in the expectation of being able to resell it again at a later point in time. In so doing, they can earn capital gains and/or dividend income. Conversely, a competing explanation is that subjects simply *are not* rational.

Lei et al. (2001) set out to investigate the distinction between these two propositions. They assigned fixed roles of either buyer or seller to their subjects. A designated buyer could thus only buy assets, but never resell them, while a seller

[56] In the event that a trader had insufficient stock in her spot inventory, she was required to pay a penalty of $4.00, a figure that approximately equals the value of the stock assuming it paid the highest possible dividend ($0.60) in each of the remaining seven periods.

[57] Porter and Smith (1995), p. 525.

[58] Cp. Miller (2002), footnote 11, p. 16.

could never purchase an asset. A rational, risk-neutral or only slightly risk-averse subject being assigned the role of a seller in this design would therefore never sell her assets for a price below their fundamental value. More importantly, no rational buyer would ever purchase shares above their maximum possible dividend value, irrespective of her beliefs with regard to other subjects' rationality. This limits the extent of a bubble to the area between the two stepwise decreasing functions plotted in Fig. 3 (except for the case of clearly risk-loving subjects, a proposition that is itself unrealistic). To investigate also the opposite end of the potential price scale, Lei et al. (2001) employed positive minimum dividend values, such that there was also an absolute lower bound for rational asset sales.

The results Lei et al. (2001) reported were surprisingly clear in rejecting the hypothesis that the observed price patterns could be explained by rational agents who do not possess common knowledge of each other's rationality. They found that between 1 and 16.1% of all transactions (depending on the treatment) in their experiment took place at prices below the minimum, and an impressive 37.6–46.2% took place above the maximum possible dividend value of the asset. The only explanation for this result is the acceptance of the second hypothesis – irrational traders were present in the market. (Table 7 in Sect. 4.1.2.2 reports the relevant analytical bubble measures "Overpriced transactions" and "Underpriced transactions" for Lei et al. (2001) and other studies).

2.4.4 Alternative Treatment Designs

2.4.4.1 Dividends and Liquidity

Smith et al. (1988) were the first to depart from the then accepted norm of giving different traders different private dividend values, and found that such different dividend values are not a necessary condition for trade (as many had believed until then). They concluded that there is sufficient intrinsic diversity in subjects' price expectations or risk attitudes (or both) to induce subjective gains from trade. As reported in Sect. 2.4.3.1, their experimental assets paid dividends at the end of each market period, which could take one of four possible and equiprobable values, all of which were non-negative and originated from independent random draws. In some of their experiments they also deviated from their baseline design by paying a final buyout amount for each share to prevent the share price from going to the expected value of a single dividend draw in the last period. This buyout value equaled the sum of the dividend draws over all 15 periods plus or minus a constant (each with probability 0.5). The aim of this institutional detail was to enhance the possibility of a bubble; a measure that proved unnecessary and was subsequently dropped.

Smith et al. (2000) examined markets modeled after the example of the Smith et al. (1988) markets, but with three different dividend treatments. In the first institution, the asset paid a single dividend at the end of the trading horizon. In the second, dividends were paid at the end of each trading period (as in the classic

Smith et al. (1988) design). In the third setup, the asset paid some dividends at the end of the trading horizon and some at the end of intermediate periods. They found that the second setup produced the strongest bubble phenomenon. While the third design also reliably generated bubbles, they were less pronounced. The first treatment, finally, yielded a bubble in only one of ten sessions, suggesting that frequent dividend payments were conducive to the formation of bubbles. This result underlines the important role dividends play for the formation of bubbles in experimental asset markets – a role that will also be discussed before the background of the results in Chap. 4.

Noussair et al. (2001) conducted another experiment probing the role of dividend payment frequency and fundamental value structure for the observed market prices. They employed a dividend pattern of four discrete dividends with an expected value of zero, complemented by a lump-sum terminal payoff.[59] In contrast to the declining values of assets in earlier experiments, in this new structure the expected value of one unit of the asset remained constant and equal to the value of the terminal payoff throughout the experiment. With this setup, they found that bubbles occurred in only four out of eight sessions and exhibited smaller magnitudes, a marked improvement in market efficiency over the baseline markets. Nonetheless, the fact that the market exhibited a bubble pattern in 50% of all rounds proves that the frequently changing (and monotonically declining) fundamental value of earlier designs is not a necessary condition for bubble formation. In a related experiment, Davies (2006) modified the dividend structure so that the expected dividend became negative, and introduced a terminal payoff for each share of stock. This led to an asset exhibiting increasing fundamental value, which he found to cause trading at prices considerably below the fundamental value. He conjectured that the reason for this inversion of the observed price deviation may have been due to both failure of the agents to upwardly revise their perceptions of value over time and to decreasing liquidity relative to fundamental value as the experimental round progressed.

Porter and Smith (1995) investigated the role of risk in experimental markets. In their setting, the traded good paid future dividends which were certain, thereby eliminating from the experiment both risk and the influence of varying degrees of risk aversion among subjects. They found that the elimination of dividend risk had no significant effect with inexperienced traders. They also tried to confront subjects twice experienced in the certain dividend environment with a risky dividend structure, but failed to rekindle a price bubble. More specifically, they reported that their results were indistinguishable from experiments with traders twice experienced in a risky dividend environment. Finally, the certain dividend structure did not significantly reduce the bubbles observable in similar markets with risky dividends.

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[59] The four equally likely dividend values in their experiment were -24, -16, 4, and 36 units of experimental currency, while the terminal payoff consisted of 360 units. They referred to the two low values as *holding costs* to explain their negativity.

Van Boening et al. (1993) wanted to focus subjects' attention on the asset's expected value in an experimental double auction market, hoping that this would lead to less prominent deviations of market prices from fundamental values. To test this hypothesis, they departed from the common design of a discrete dividend distribution with four asymmetric and equally likely points (e.g., 0, 4, 8 or 20 cents, all with equal probability of 0.25, as in design 1 of Smith et al. (1988)) and used a discrete distribution with five symmetric points with unequal probabilities (5, 15, 25, 35, and 45 cents with probabilities 1/9, 2/9, 3/9, 2/9, and 1/9, respectively). Unfortunately, their results did not show a decline in the propensity of experimental markets to produce asset price bubbles under this new dividend regime. Caginalp et al. (1998) similarly modified the dividend structure in their experiment, where subjects traded a stock with a single dividend payment, payable in the last of 15 periods. The participants knew that the dividend had a 25% chance of being either \$2.60 or \$4.60 and a probability of 50% of being \$3.60, implying an expected value of \$3.60. Unfortunately, Caginalp et al. (1998) focused on the role different ratios of cash versus share value played in the price process, but did not report on how their experiments compared to standard Smith et al. (1988)-type markets.

Oechssler et al. (2007) ran experimental markets where the subjects could trade five different assets simultaneously, all of which paid a single dividend at the end of the experimental session. In order to find whether subjects were aware of overpricing but speculated on even higher prices, or whether they were unaware of deviations from fundamental values, the experimenters asked them to predict both the period end price and the final dividend of an asset. Their findings were consistent with subjects who were aware of overpricing, since they provided final dividend estimates in line with fundamental values. At the same time, they forecast prices significantly exceeding fundamental values in periods with bubbles. The authors also found that bubbles can occur without intermittent dividend payments if – as was the case in their experiment – inside information is present in the market, while finding no evidence for bubbles in a similar setting without insiders or with traders who were provided with the means to communicate. In fact, they found that the number of messages sent in sessions with a chat function was negatively related to the frequency of bubbles. They conjectured that an explanation for this could be that communication provided the means for more sophisticated traders to "educate" their less sophisticated colleagues, and to accelerate the synchronization of expectations. Furthermore, they also pointed out that the possibility to communicate might have given subjects something other to do than trading – a hypothesis that is consistent with the Active Participation Hypothesis suggested by Lei et al. (2001). The Active Participation Hypothesis implies that irrational actions in laboratory experiments may be due to the fact that subjects are required to participate in an experiment until the end and have no other activity available to them than that of acting in the experimental market. Colloquially speaking, subjects may "act out of boredom," instead of out of a desire to improve their payoff from the experiment.

Ackert et al. (2006c) employed two different assets, each of which, at the end of a period, offered a zero payoff with a probability of 0.98 and a payoff of \$20 with a probability of 0.02. The only difference between them was that – within one experiment – the first could pay out the dividend of $20 an unlimited number of times, while the second only paid out $20 if there had been fewer than three dividend payouts of $20 in earlier draws. The authors referred to the second kind of asset as "truncated." Due to the low probability of a payout, the expected values of these two assets were virtually identical. Aiming to prove that traders are subject to probability judgment error and irrationality, Ackert et al. (2006c) used these assets in three types of markets: One with ten periods and dividend draws after each period and a second (third) with a single period and eight (five) dividend draws, all of them after the single market period. They found that the difference in prices of the untruncated asset and the truncated asset was generally positive and declined as the experiment progressed. They also reported a positive correlation between the magnitude of the difference in prices of the untruncated asset and the truncated asset and the occurrence of bubbles. Furthermore, median asset prices in multi-period markets were higher than corresponding prices in single period markets in all cases. Similarly, the difference between prices in multi-period markets and single period markets was larger when there were eight dividend draws than when there were only five, which indicates that subjects engaged in speculation. Finally, they showed that the magnitude of the difference between asset prices in multi-period markets and single period markets was considerably greater in bubble markets than it was in non-bubble markets, another indication for speculation activity.

In a twist on the experiments just described, Ackert et al. (2006a) investigated the effects of margin buying and short selling on experimental asset markets with two assets – one with standard and one with lottery characteristics. They found that in markets with margin buying but without short selling, bubbles could be observed for both assets, with the lottery asset exhibiting the larger bubble. Restricting margin buying dampened the bubbles and caused the difference in bubble size between the two assets to disappear. When they restricted margin buying and allowed short selling, they did not observe bubble-and-crash patterns. Finally, consistent with Haruvy and Noussair (2006), they found that in some markets the lottery asset traded at prices considerably below its fundamental value.

Ackert et al.'s (2006a) results hinted at a connection between subjects' ability to buy on margin and the bubble extent. More generally, bubble extent seems to increase with increasing liquidity (i.e., the ratio of cash to stock value) in experimental asset markets. An article that provides evidence of this nature is Caginalp et al. (2001). They reported that each dollar per share of additional cash in their experimental markets (with periodic dividend payments) was associated with a $ 1 increase in the maximum share price, a $ 0.45 increase in the average transaction price and a $ 1.11 increase in the maximum price deviation from fundamental value. These effects were considerably reduced when subjects received information on all outstanding bid and ask quotes, i.e., when there was an open order book (the corresponding figures were: $ 0.36 increase in maximum share price, $ 0.28 higher average transaction price and $ 0.32 larger maximum deviation).[60]

[60] Cp. Caginalp et al. (2001), p. 87.

Note that the connection between the treatments with margin buying and those with dividend payments lies in the fact that both increase the amount of cash subjects can spend on stock purchases – an observation that is made in Huber et al. (2008).

Summarizing the findings of the studies discussed above, the verdict on the role of liquidity, and specifically dividends, in experimental asset markets is one of far-reaching importance. Apart from subject experience, dividends are the parameter with the most visible impact on the formation of bubbles. Due to their importance, they are also accorded some space in the discussion of the results in Chap. 4.

2.4.4.2 Futures Market

Early in the 1980s, experimental economists started investigating the influence of futures markets on spot market prices. These first experiments separated spot and futures trading periods and varied the asset's fundamental value. After the publication of Smith et al. (1988), experimentation turned to operating spot and futures market simultaneously, a design that more closely resembles real-world markets. Since this branch of experimental research constitutes the first experimental evidence on the effect of derivative markets on spot markets – the first option market experiments were conducted later – this literature is briefly reviewed in the following paragraphs.

Forsythe et al. (1982) conducted five oral double auction asset market experiments, where trading was structured into six to eight years, with two periods (A and B) each. All period A's of a given market were identical with respect to the underlying distribution of asset returns and all period B's were also identical (although different from the period A's of each year). In one of their five markets, a futures market of period B assets operated in period A and replaced the spot market of period B's assets. The results led the authors to conjecture that the existence of a futures market may increase the speed of information dispersal as well as the convergence to equilibrium, might remove the necessity of replication, and could increase market efficiency. Due to the small sample size of a single experiment, however, their results can only be interpreted as weak support of these conjectures. The same authors reported on nine additional experimental asset markets in Forsythe et al. (1984), four of which followed the original spot-only structure, with the remaining five featuring spot-and-futures trading. Their new results were less ambiguous and strongly confirmed the conjectures from the paragraph above. While the hypothesis that prices were transacted in the range predicted by a rational expectations equilibrium could not be rejected at the 5% significance level in 17 out of 35 years for the markets with futures trading, in the spot-only markets it was rejected 27 out of 28 times. They found that futures markets did accelerate convergence and that in the absence of futures markets, even experienced traders had problems overcoming the existing coordination problems. Interestingly, Forsythe et al. (1984) noticed that spot prices exhibited considerably increased variability in the early market years if there was a futures market present.

They explained this finding by stating that, since futures prices play a role in publicizing private information, the higher variance was a sign of the higher speed of convergence toward the rational expectations equilibrium. Testing this intuition analytically, they found that in the first 3 years, where the group of experiments with a futures market converged rapidly to rational expectations equilibrium prices, the group of experiments with futures markets always had significantly more price variation than those with sequential markets. Performing pair-wise comparisons between experiments with futures markets and those with sequential markets, but with otherwise identical parameters, they found that the hypothesis that the variance in the first case is larger than that in the second could be rejected at the 5% significance level in only six out of 70 cases.

Friedman et al. (1983) conducted four experimental asset markets, each with three trading periods per market year, referred to as periods A, B and C, with identical certificate returns across market years. Two of the four markets permitted only spot trading; the other two markets featured trading of spot contracts and futures contracts for period C-delivery in the two periods A and B, with no trading (but delivery of the futures contracts' underlying certificates) in period C. In all experiments, traders received a trading commission of one cent per transaction. Their results showed that the first (second) periods of experiments with futures trading converged slightly (considerably) faster than the spot-only markets. The evidence also suggested that the standard deviation of transacted prices was smaller in markets with futures trading than in those without. The authors interpreted these findings as supporting the conclusion that futures markets were associated with informationally more efficient spot market prices. In Friedman et al. (1984), the same authors reported that the hypothesis of a lower coefficient of spot price variation for a spot-and-futures treatment than for a spot-only treatment received a significance level of only 34.7 (29.8) percent in period A (B) in an environment of certainty. In the case of uncertainty regarding the future state of nature, the results were considerably stronger, with a significance level of 5.4%. Pooling the final year data across all their six experiments (and all periods) run with experienced subjects, they obtained a 19.7% significance level for a reduction of the coefficient of variation in the presence of a futures market. They criticized the results of Forsythe et al. (1984) on the grounds that the latter employed a joint treatment variable mixing the effects of the addition of a futures market to the spot market with those of trader experience. This led them to conclude that the results of Forsythe et al. (1984), which had suggested a higher coefficient of spot price variation in the presence of a futures market, also supported the results of Friedman et al. (1984), reporting a lower coefficient of variation. Friedman et al. (1984) also reported that insiders in their markets earned higher profits than non-insiders in every market year, yet this effect was reduced (with a significance level of 27.4% in a Mann-Whitney test) by the presence of a futures market, which they interpreted as evidence that the futures market caused "leakage" of insider information. Finally, they reported that futures markets tended to speed up the evolution of prices to more informationally efficient equilibria in the case of uncertainty regarding the future state of nature.

These experiments, which were conducted prior to the work of Smith et al. (1988), formed a blueprint for applying a similar analysis to their new design. In other words, they suggested the question of how adding a futures market would change the results in a Smith et al. (1988)-type environment. The first to address this question were Porter and Smith (1995). As reported in Sect. 2.4.3.2, they found that a futures market reduced the amplitude of the price bubble in the spot market and had a similar effect on the turnover measure for rounds played with experienced subjects, yet did not succeed in eliminating bubbles altogether. This accolade went to a treatment ran at the University of Canterbury, NZ, and at Purdue University, USA, in late 2002 and early 2003. Using an ingenious experimental market structure, Noussair and Tucker (2006) forced their subjects to form expectations about future prices by backward induction. In addition to a normal 15-period stock market, they operated 15 futures markets, each maturing at the end of one of the 15 trading periods. To prevent their subjects from being distracted from the backward induction task, they first opened only the period 15 futures market for trading. After a fixed pre-announced time interval, the period 14 futures market opened, and so on. Only when all 15 futures markets were open did the spot market start operating. At the end of the first period of spot trading, the period 1 futures market (i.e., the last futures market that had been opened) matured and was closed. They found that futures market prices deviated considerably from those suggested by rational expectations, but converged to levels close to the latter as they approached their respective maturity dates. More importantly, spot market prices closely tracked the stock's fundamental value. Unfortunately, this remarkable success in completely eliminating the bubble phenomenon came at the expense of an inherently artificial market structure, which does not lend itself to application in real-world markets.

2.4.4.3 Option Market

Experimental research findings from studies on the impact of option markets on spot market prices are the closest analog available for comparison to the work presented in this text. The largest discrepancy between earlier designs and this study's treatments is that prior work used conventional (usually European) options, while this study employs the digital option contract used in some online prediction markets. The literature on asset market experiments offering the possibility of option trading is briefly reviewed below.

Biais and Hillion (1994) analyzed the impact of the introduction of a non-redundant option into a double auction market populated with noise traders and an information trader (in their model called liquidity traders and insider, respectively). They found that option trading sometimes reduced the profits of the insider, yet did not do so reliably (i.e., for all parameterizations). Furthermore, they wrote that the introduction of the option seemed to mitigate the problem of market breakdown. Such a breakdown occurred when noise traders perceived the transaction costs due to asymmetric information (i.e., the risk of being exploited by better-informed insiders) to outweigh the possible benefits they could attain from trading to improve their asset-to-cash ratio. They conjectured that – by making the market more complete – the option reduced the risk from asymmetric information and thereby also reduced the frequency of market breakdowns.

Kluger and Wyatt (1995) conducted oral double auction asset market experiments and designed treatments somewhat similar to those used here. They ran one treatment only with an asset market and one where the asset market was complemented by an option market operating sequentially, with trading alternating between the two markets. Their findings in this setting showed that options dramatically accelerated the information aggregation process, making the asset market informationally more efficient. They also stated their impression that the efficiency gain was due to the options enriching the message space and speeding up the discovery of the correspondence between signals (about fundamental value) and prices.

De Jong et al. (2006) ran an experimental asset market and an option market, wishing to determine whether the presence of an option market would improve the market quality of the underlying asset by leading to price discovery across both markets. In their experiment, three competing dealers in each market were the counterparties to both the single existing insider – who knew the intrinsic value of the asset – and to two liquidity traders. The authors did not impose borrowing or short-sales constraints, so that leverage effects, which might have made options attractive to informed traders in real markets, were absent in their experimental treatments. All trades were constrained to a lot size of a single unit. The liquidity traders were faced with exogenous liquidity shocks by being required to meet uncorrelated end-of-period positions in both the option and the underlying.[61] They found that price efficiency in the asset market was higher and the asset's price volatility lower when the intrinsic value of the option was positive and that the presence of an option generally improved market efficiency (i.e., even if its intrinsic value was zero). They also reported that the insider, who could choose between trading in the market of the underling or in that of the option, chose the more profitable market to trade in 86.3% of all cases. Price discovery thus took place in both markets, and market markers in the asset (option) market revised their quotes in the direction suggested by the situation in the option (asset) market.

2.4.4.4 Monetary Incentives

Utility theory does not predict that people will make the "correct" decision when it is not in their interest to do so.

Vernon L. Smith (1973)

Over the set of all economics experiments in the literature, a large number of compensation mechanisms has been employed. Some experiments used hypothetical

[61] In addition to posting bid and ask quotes, all market makers could also initiate transactions with other market makers in either market. They neither received information regarding the end-of-period value of the asset, nor were they told the required end-of-period positions of the liquidity traders.

payoffs, some real payoffs, some converted the currency used in the experiment into real money, while others used real money in the experiments. There were experimenters who paid the full earnings for all decisions to their subjects, while others chose individual decisions or rounds at random and rewarded only those. This section gives an overview of the differing monetary incentive schemes employed in the literature. In the process, it also attempts to summarize findings on the impact these different incentive schemes had on experimental results.

Smith (1962) first made his observations regarding the behavior of double auction markets in a setting using hypothetical payoffs, and only later confirmed his results in real money markets. In Smith (1965), he again took up this line of research and investigated the differential impact of full payoffs (every subject received the payoff she had earned over the course of the experimental session) versus random payoffs (only a randomly chosen subset of all subjects received the payoff they had earned). He reported that in the random payoff treatment, actual equilibria deviated significantly more strongly from the theoretical equilibria than in the treatment of full payoffs.

Smith and Walker (1993a) investigated the bidding behavior in first price auctions with varying payoff levels. They reported that increases in real payoffs led to higher bids and fewer decision errors. Following up on their first article, Smith and Walker (1993b) conducted a survey on experimental articles that reported on the comparative effects of subject monetary rewards. They found that the error variance of observations around the predicted values tended to decline with increasing monetary rewards. From their observations they derived a theory of decision making that is a function of the effort dedicated to the decision-making process, an approach that is in line with earlier observations by Smith regarding the subjective cost of transacting.[62] The higher cognitive and response effort that is necessary for decisions closer to the optimum entails a disutility that can be compensated by higher monetary incentives. Nonetheless, for a given decision problem, higher monetary rewards might remain ineffective if – due to the complexity of the decision task – the agent's maximum possible effort has already been reached. The authors refer to this conjecture as a "labor theory of decision making."

A comprehensive survey of articles on the effect of financial incentives in economic experiments is Camerer and Hogarth (1999). In their deliberations, they distinguished "declarative knowledge," i.e., knowledge about facts, from "procedural knowledge," i.e., skills and strategies for using declarative knowledge in problem solving. Based on a literature overview of 74 experimental studies they concluded that subjects learnt from observation and "by doing," as opposed to "by thinking." However, they observed that effortful thinking can substitute for a lack of cognitive capital (i.e., declarative knowledge) in some tasks. As an example they quoted the stagecoach problem, which involves finding the least-cost series of nodes connecting two nodes in a network. Subjects with cognitive capital in the form of knowledge about the dynamic programming

[62] Cp. Smith (1985), p. 268, and as quoted therein, Smith (1982), p. 934.

principle were found to be able to backward induct and solve the problem with little effort. Subjects without such knowledge solved the problem with much larger effort by brute-force trial-and-error.

Relating this to monetary incentives, they found that incentives were ineffective in situations where the marginal return to increased effort was low, which was the case whenever it was either very easy or very hard to do well. In the first case, the monetary incentives did not matter because they were unnecessary to induce good performance; subjects did well even without incentives (or because they had sufficient intrinsic motivation). In the second scenario, even though subjects were incentivized to do their best, their effort failed to achieve significant improvements in their performance because the task was too hard or too complex for the experimental agents. However, in intermediate situations, the argument from the last paragraph seemed to become relevant – where increased cognitive effort was able to improve performance, monetary incentives sometimes caused better outcomes. This was also recognized by Hertwig and Ortman (2001), who wrote that:[63]

> "[. . .] economists think of 'cognitive effort' as a scarce resource that people have to allocate strategically. If participants are not paid contingent on their performance, economists argue, then they will not invest cognitive effort to avoid making judgment errors, whereas if payoffs are provided that satisfy saliency and dominance requirements [. . .], then 'subject decisions will move closer to the theorist's optimum and result in a reduction in the variance of decision error' [. . .]"

As a case in point, the authors quoted earlier studies which had found positive incentive effects in settings requiring little skill, such as pain endurance, vigilance or clerical or production tasks, while reporting weaker effects in memory, judgment, and choice tasks and no positive (and sometimes negative) effects in experiments involving problem solving. Nonetheless, even in situations where incentives had failed to improve performance, they had frequently decreased the variance in subjects' performance. If aggregate behavior is sensitive to outliers, which in turn are sensitive to monetary incentives, this induces a causal link between incentivization and aggregate results.

Moving away from the theory of cognitive effort, Forsythe et al. (1982) were among the first to use an artificial currency in experimental markets. They argued that using dollars (i.e., real currency) would have been prohibitively expensive in their experiments, where they distributed initial cash positions of between 10,000 and 20,000 currency units. They converted their artificial currency "francs" into dollars by calculating the payoffs for a given year as $a + bx$, where x was the quantity of francs held by a subject at the end of a trading year, $b > 0$ was a factor for the conversion of francs to dollars[64] and $a < 0$ were fixed costs which approximately equaled the initial cash endowment. In response to this, Friedman et al. (1983) somewhat disparagingly referred to the Forsythe et al. (1982) franc as an "arbitrary

[63] Hertwig and Ortman (2001), pp. 25–26.

[64] Conceptually, b is the exchange rate of dollars for francs, which in their experiments was set to \$0.002 per franc.

unit of account," writing that in their own article they "avoided what seems to us the needless complication (for traders) of converting francs to dollars."[65]

Ang et al. (1992) offered significant additional bonus payments to those of their subjects earning the highest profits in the first periods of a two-period-asset experiment, with the aim to shorten their investment horizons along the lines of portfolio managers in the investment community. They found that this modification caused a large bubble in the first periods of their market, with prices in the second periods remaining close to the risk neutral equilibrium. Since this bubble was only partially reduced when traders had to invest $20 of their own (real) money, they conjectured that its reason lay in the imbalance between the buying and selling powers of subjects in experimental markets, which in real markets are reflected in short-sale restrictions and high costs, as well as in the possibility to leverage long positions. Modifying this design by increasing the asset endowment and decreasing the cash endowment to approximately the market value of assets led to a disappearance of the bubbles and caused trading to take place at a discount from the risk neutral equilibrium in the first periods.

In another experiment employing a compensation scheme non-linear in terminal wealth, James and Isaac (2000) tested whether tournament incentives (i.e., compensation that is strongly dependent on an individual's outperformance of the average market participant, a common attribute of mutual fund managers' payoff functions) changes the common bubble-and-crash pattern in markets following the structure of Smith et al. (1988). They found that even for subjects who had previously participated in (at least) two markets without tournament contracts (and who were therefore expected not to produce any more bubbles), the repeated imposition of tournament contracts led to increasing deviations from fundamental value pricing, thus underlining the impact even comparatively small changes in the compensation scheme can have on experimental results. Williams (2008) also employed a rank-order tournament incentive scheme, awarding extra credits to student subjects who ranked best in final experimental cash holdings in their asset markets, but did not report on the effect of this institutional detail on the experimental outcomes.

Luckner and Weinhardt (2007) ran a prediction market for the FIFA World Cup 2006 with three different payment schemes to test a similar proposition as the two articles discussed in the previous paragraph. A first group of 20 students was paid a fixed amount, the three best-performing traders of a second group of 20 subjects received a payoff related to their rank within the group (with the remaining 17 players receiving nothing), and a final group of 20 players received a payoff that depended linearly on their terminal wealth. The average payment per agent was held constant (at € 50) over all three groups. They found that the third group (which was being rewarded according to what they termed a "performance compatible payment" scheme) actually yielded market prices that corresponded to predictions which were worse than randomly drawing one of the three events the prediction

[65] Friedman et al. (1983), p. 130.

market was meant to forecast. Conversely, the rank-order treatment outperformed the other two payment schemes and even the fixed payment group did better than the third group of subjects. The authors conjectured that their subjects were motivated by factors extrinsic to the experiment as opposed to the monetary incentives, but did not conduct any control experiments to alleviate the problem of their small sample size.

Ackert et al. (2006b) did not focus on the level of actual or expected payoffs, but instead analyzed the path dependence of subject actions conditional on the development of their wealth. In their investigation of the house money effect, they found that not only the expected payoff, but also payoffs received earlier in the experiment influence behavior in asset markets – the phenomenon that individuals tend to become less risk-averse after having recently received a gain. Their results from nine experimental sessions, with eight subjects each, showed that they could indeed observe the house money effect in their laboratory experiment. It is specifically this last experiment that shows that the word is not yet in on how compensation affects behavior in and results of asset market experiments, and that more sophisticated models and tests are needed to analyze this topic.

2.4.4.5 Short Selling

Experimental asset market bubbles are caused by subjects willing to pay exaggerated prices for the experimental good. Several studies reported that seemingly irrational traders kept trading at exaggerated prices long after more rational subjects had run out of assets. Due to this lack of liquidity, the latter were rendered unable to contribute to bringing prices back into line with fundamental values. Theorists thus conjectured that if subjects were permitted to sell short, more rational traders could profit from the asset's overvaluation by selling it. Such sales would at the same time keep prices at lower levels, because the irrational subjects would not have to trade only among themselves, but could instead enter into transactions with (rational) traders offering units of the asset for a lower price. This is a simple supply-and-demand equilibrium argument where increasing supply leads to lower prices. In an early experimental study contradicting this conjecture, Sunder (1995) reported that short selling in their experiment did not reduce the number of periods experimental asset market bubbles lasted, nor did it decrease their size. While this result was not encouraging for proponents of the efficient market theory, a much more alarming result was published in Haruvy and Noussair (2006). Ernan Haruvy and Charles Noussair employed a market similar to that of Smith et al. (1988) to study the effect of the relaxation of short-sales constraints on the bubble phenomenon typical for this market structure. They motivated their research with the observation that "In the absence of short selling, the asset price will simply be the price offered by the most optimistic trader with sufficient funds."[66] Contrary to King et al. (1993) and in line with Ackert et al. (2001) they found that decreasing obstacles to short-selling was

[66] Haruvy and Noussair (1993), p. 1155.

associated with lower security prices. Yet while Ackert et al. concluded that increased short-selling capacity led to more efficient markets, Haruvy and Noussair increased the extent of possible short sales in further experiments and found that facilitating short-selling seemed to simply decrease prices. When they permitted traders large leeway in their short transactions, prices followed a negative bubble pattern, consistently remaining below the fundamental value over the course of the experiment. They conjectured that the increased availability of units of the asset (i.e., a higher supply) paired with constant demand led to a decrease in the observed price.

Haruvy and Noussair (2006) also confirmed for their own setting a result from Caginalp et al. (2000b), who had reported that increasing the cash available for asset purchases increased transaction prices in settings without short-selling. Despite their modifications aimed at making the market more efficient, the markets in the Haruvy and Noussair (2006) experiments exhibited very high transaction volumes, large price swings relative to fundamental values and long periods of trading away from the asset's fundamental value.

2.4.4.6 Variations in the Subjects Variable

An important question in the experimental economic science is whether experiments with student subjects yield the same results as ones using business professionals. To investigate this issue, Dyer et al. (1989) compared the performance of upper-level students majoring in economics ("naive agents") with that of experienced business executives from the construction contract industry ("experts") in a laboratory experiment where participants were bidding for contracts, subject to an uncertain cost structure. They found that both subject populations exhibited irrational behavior and were subject to the winner's curse, with no significant differences at the 10% level or better in any of the following performance measures: the proportion of times the low bid was submitted by the agent with the lowest cost signal, average actual profits, the proportion of times the low bid was less than the rational minimum amount, and the proportion of times the low bid was less than the rational minimum amount at the individual level. (Conversely, Alevy et al. (2007) documented that in their information cascade experiments, market professionals emphasized their private information more strongly than did student subjects and were also impervious to which domain of earnings – gains or losses – they were operating in.) While there was no evidence for behavioral differences attributable to the subject pool, Dyer et al. (1989) did find some differences in behavior that they attributed to heterogeneity in risk aversion. They wrote: "The different pattern of profits/losses [. . .] and the differences in estimated bid functions, lead us to reject the maintained hypothesis that there are *no* differences between the two subject pools; however, we feel that the similarities are much more striking than the differences."[67] Güth et al. (1997) also specifically analyzed the impact of subjects'

[67] Dyer et al. (1989), p. 112.

risk aversion. They found that risk aversion – as determined in a pre-test to their experiment – had no explanatory power for the subsequent portfolio choice in a multi-period capital market experiment. In a purely descriptive article regarding the risk appetite of different types of subjects, Faff et al. (2008) surveyed a number of studies on this topic. They found that risk tolerance increased with education, income and wealth, decreased with age and was lower for females than for males and for married than for unmarried investors.

Ackert and Church (2001) compared results from experiments run using only senior business students as subjects with experiments conducted with only freshman arts and sciences students who had their majors outside of the fields of business and economics, and with a third type of subject pool formed from mixtures of the two groups. They found that bubbles were reduced when business students gained experience, while the same was not true for the non-business students.[68] Furthermore, experienced business subjects were able to make profits at the expense of inexperienced subjects from both subject pools. They also let their subjects forecast prices at the beginning of each period and found that in markets with business students, superior forecasters outperformed other traders in terms of profits. Ackert and Church (2001) summarized their results by stressing the importance of considering agent type in the development of models characterizing economic behavior.

In his experiments conducted at Indiana University, Williams (2008) modified not the subject pool but the size of the sample he drew from it. He reported on three asset market experiments, run over 8 weeks, and using between 244 and 310 traders. In these experiments, all agents were endowed with the same number of shares of stock and with the same amount of experimental currency, and they could access the market software at any time over fifteen periods, the majority of which lasted for 3.5 days. At the end of each round, owners of a share of stock received a common dividend stemming from a rectangular distribution. Extra credits were then awarded to the best subjects using a rank-order tournament design. Students participating in these markets were encouraged to discuss it with one another. In addition, the interim results of the markets were discussed in class during their operation. Surprisingly, the experiment yielded results very similar to those of comparable markets conducted with much fewer traders, a monetary reward structure, and in the laboratory.

2.4.4.7 Institutions of Exchange

> *The striking competitive tendency of the double auction institution, which has been confirmed by at least a thousand market sessions in a variety of designs, indicates that neither complete information nor large numbers of traders is a necessary condition for convergence to competitive equilibrium outcomes.*
>
> Charles A. Holt (1995)

[68] Ackert and Church (2001), p. 18.

The basic institution of exchange in many markets in all kinds of settings is the auction, a transaction medium that has been employed by mankind for millenia. Herodotus, in the fifth century B.C., described how women were auctioned off to be wives in Babylonia; in the Roman Empire, booty was transferred via auctions; and the possessions of deceased Buddhist monks in seventh century China were allocated to new owners using the auction institution.[69] Naturally, the technology of auctions has evolved since their first application in early human history, and today encompasses a variety of forms. Since the specific form of the auction mechanism is an important determinant of trader behavior and allocational efficiency in a market, some evidence on different transaction mechanisms is presented in the following paragraphs.

Smith (1976b) presented five institutions of exchange: the double auction, the bid auction, the offer auction, posted pricing, and the discriminative and competitive sealed-bid auctions. In a double auction, buyers and sellers submit bids and asks, which are tabulated and compared. When a buyer (seller) submits a bid (ask) which equals or exceeds (equals or is smaller than) the lowest ask (highest bid) in the market, a transaction takes place. In a continuous double auction, an order book is maintained and auctioning continues after transactions take place. The bid (offer) auction is similar to the double auction, with the difference that only the buyers (sellers) may post price quotes, while sellers' (buyers') single possible action is to accept a bid (offer). In a posted pricing market, sellers (buyers) independently select reservation price levels, which are then communicated to the market. Next, a buyer (seller) is chosen at random and matched with a seller (buyer), whom she can then make an offer at that seller's (buyer's) posted price. This procedure is repeated until the initial buyer (seller) does not demand any additional units, at which point a new buyer (seller) is chosen at random. Finally, in the discriminative (competitive) sealed-bid auction, the seller offers a specified quantity of the good and buyers submit bids. These are sorted highest to lowest and the highest bids are accepted, such that the seller's quantity can be fully allocated. The transaction price is the full price bid by the buyers (the price of the lowest accepted bid) in the case of the discriminative (competitive) sealed-bid auction.

Smith (1976b) reported that, in the double auction, "prices converge to 'near' the theoretical (Supply = Demand) equilibrium level usually within the first twenty to thirty transactions."[70] He furthermore wrote that the quantities exchanged were usually within one unit of the theoretical equilibrium, that an order improvement rule – requiring that new bids (offers) improve on the currently outstanding best bid (offer) – did not significantly accelerate convergence, and that convergence tended to be from below (above) when the producer surplus was larger (smaller) than the consumer surplus. Considering the variations of the bid and offer auctions, Smith (1976b) found that the side having the pricing initiative was usually disadvantaged with regard to eventual transaction prices, while in a posted-bid environment, the

[69] Cp. Milgrom and Weber (1982), p. 1089.
[70] Smith (1976b), p. 48.

opposite tended to be the case. Finally, accepted bids in competitive sealed-bid auctions stochastically dominated (i.e., were higher than) bids in discriminative sealed-bid auctions. Smith et al. (1982) built on this earlier work and also compared five market exchange institutions: the double auction (DA), a sealed bid-offer auction mechanism (PQ), a variable quantity sealed bid-offer auction mechanism (P(Q)), and tâtonnement versions of PQ and P(Q), referred to as PQυ and P(Q)υ. In the PQ mechanism, buyers (sellers) submitted a maximum bid (minimum ask) price and quantity, and an algorithm then determined a single market clearing price. In the P(Q) treatment, each buyer (seller) submitted one bid (ask) price for each unit of the asset she was assigned a valuation for, and the same algorithm as in PQ was used to determine a single market-clearing price. In the tâtonnement treatments PQυ and P(Q)υ, each trader had to give her consent to a proposed price and allocation offer. If there was a consent before the maximum number of trials *T* was reached, *T* times the proposed bid and offer quantities were exchanged. If there was no consent, no trade took place. Smith et al. (1982) found that the DA treatment yielded higher overall efficiencies than the PQ mechanism, even though experience seemed to ameliorate this difference. PQ in turn did not turn out to be inferior to PQυ, which yielded prices that were as erratic as under the non-tâtonnement institution. The P(Q) mechanism outperformed PQ, but underperformed DA. However, its tâtonnement version, P(Q)υ, performed at least as good as the double auction. Similarly, Pouget (2007) compared the performance of a call market and a Walrasian tâtonnement, making sure that both market institutions had similar equilibrium outcomes in both prices and allocations. He found that the gains from trade were higher in the Walrasian tâtonnement institution than in the call market, despite the fact that prices were fully revealing in both markets. Uninformed traders did not participate in the call market to the extent predicted by theory, a fact that Pouget (2007) traced to bounded rationality and strategic uncertainty. He wrote:[71]

> "Overall, this paper shows that limitations on human cognition can create transaction costs. Yet, adequate design of the market structure can overcome the impact of cognitive limits. In this experiment, compared to a Call Market, a Walrasian Tatonnement provides a way to economize on cognitive transaction costs. I explain the greater performance of the WT in terms of more tractable mental representations and robustness to strategic uncertainty, both features which foster learning. Hence, this paper suggests that even when it does not influence strategic outcomes, market design may still be an important source of efficiency gains through its effect on traders' ability to discover equilibrium."

Cason and Friedman (1996) conducted 14 laboratory experiments on double auctions, finding them to be a very efficient market structure and noting that initial inefficiencies (i.e., arbitrage opportunities) disappeared with increasing experience of market participants. Van Boening et al. (1993) compared a conventional double auction market setting with one that used call auctions, and expected a reduction of the bubble phenomenon that is well-documented for the former setting. Their results did not confirm their expectations, but showed that the change in trading

[71] Pouget (2007), pp. 303–304.

institution did not eliminate the bubble phenomenon. Haruvy et al. (2007) also documented bubbles in a call market setting. Liu (1992) found that in her experiments, continuous double auctions outperformed call auctions in terms of efficiency when all traders were endowed with diverse information, while the opposite was true when uninformed traders traded alongside diversely informed traders.

Easley and Ledyard (1993) were the first to work on a positive theory of how prices are formed and of the trading process in an oral double auction market. They derived their model from some ad hoc assumptions not flowing from an optimizing model but rather based on observations of empirical behavior of market participants, and reasonable interpretation of their actions. In a next step, they applied their theory to a number of empirical experiments both from oral and from computerized laboratory double auctions. Their predictions were largely borne out by the evidence, even though there were a small number of deviations in every experiment. In an even more universally applicable account, Jackson and Swinkels (2005) provided a general proof of the existence of at least one equilibrium involving positive volume of trade for double private value auctions.

Crowley and Sade (2004) investigated what effect the option to cancel orders has on trading volume and prices in a double auction environment. In their design, subjects could post one bid and one ask at a time in a continuous double auction market operating over 12 periods, lasting 3 min each. They conducted experiments using two different treatments – one in which traders could cancel their bids and asks, and one in which they could not. In the former, they found that the mean portion of orders that were being canceled was 4.2%, and that the mean number of standing orders was 46.52 versus 29.3 in the treatment without cancelation. On the other hand, they also reported that the ratio of transactions to standing orders declined (significantly) from 23% in the cancelation treatment to 19% without cancelations. They detected no statistically significant relationship between the two treatments with regard to the limits submitted or regarding the price variance.

2.4.4.8 Other Modifications of Experimental Design

This section contains a number of additional modifications that were explored compared to the original Smith et al. (1988) baseline market. While these treatments do not fit into one of the previous sections in this chapter, they nonetheless offer some interesting glimpses of the factors influencing outcomes in experimental asset markets and were important in the design of the institution chosen for the experimental work.

Williams (1980) reported "on the first series of computer-automated double auction experiments"[72] that aimed to mimic oral double auctions of the type reported in Smith (1962). The computer system he employed (PLATO) "handles all aspects of the experiment except the recruiting of subjects and their payment of

[72] Williams (1980), p. 236.

earnings in cash at the market's conclusion." It accepted inputs via touch screen and seems to have offered similar functionality as current experimental software packages (e.g., z-Tree) for double auction markets. Over the course of his experiments, Williams tested three different rules regarding the acceptance of quotes. The rule still employed in most experiments today (rule 3b in Williams' paper) was that price quotations had to progress so as to reduce the bid-ask spread. Any new bid (offer) had to be higher (lower) than the currently standing best bid (offer). Interestingly, as a second possible institution (3a), Williams (1980) named the rule that whenever a new quote enters the market, it should remain open to acceptance for a number of seconds before it can be replaced by another offer. He wrote:[73]

> "The necessity of having some minimum standing time for each price quote is easily seen if one considers the consequences of a dominant "bumping" strategy where subjects try to rapidly displace the current standing bid or offer with their own. In the absence of a human auctioneer-experimenter to slow things down and maintain order in the market, such behavior would render the act of accepting a particular price quote very difficult. Contract prices might tend to have a high degree of variation as haphazard and panic acceptance occurred."[74]

Finally, Williams' third rule (3c) stipulated that each price quote would be displayed to the market for a minimum number of seconds (as under 3a), but new quotes entered within that minimum display time were queued according to their time of entry and displayed in that order. All participants received continuously updated queue-length information. While an offer was in the queue, its creator could not accept any price quote - he or she was thus blocked from taking any action until the time during which his or her own offer was displayed had expired. Williams expected these opportunity costs to induce participants to refrain from entering new quotations when the queue was long. When reviewing the results of this regime however, he noted that the queues were considerably longer than expected, which he interpreted as a sign of his subjects' fascination with the technology of registering quotes, further documenting the novelty of the computerized trading mechanism at the time of Williams' experiments:[75]

> "It appeared that subjects were deriving sufficient utility from the mechanism itself (using the touch panel to enter price quotes) to offset the costs of queuing. In relation to this it is interesting to note that the number of bids and offers per period in experiment 1 ran about three times the number entered in the oral double auction (approximately 90:30). To the extent that such nonmonetary utility considerations affect individuals' behavior in the market, the experimenter's control on the underlying supply and demand conditions is lessened."

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[73] Williams (1980), p. 238.

[74] Note that such behavior was not prevalent in the experiment conducted for this book, even though there were cases where subjects reported that a quote was accepted just moments before they themselves clicked the "Accept" button, such that they accepted a quote different from the one they had wanted to accept. Nonetheless, this was a rare occurrence and there was no evidence for any impact on the experimental results.

[75] Williams (1980), p. 245.

A novelty introduced already in Smith et al. (1988) was that they solicited forecasts of next period's mean contract price from their subjects, rewarding the subject with the smallest cumulative absolute forecasting error with a bonus payment of $1. They found that subjects succeed in forecasting prices if they remained approximately constant, exhibited a small trend or followed intrinsic values, while they failed to predict turning points. Experience increased the quality of forecasts.

Ang et al. (1992) used psychological tests to sort subjects according to their respective risk appetites. They reported that in the baseline experiments, their less risk-averse subjects traded at a smaller discount from the more risk-averse subjects. Furthermore they showed that the introduction of a bonus payment in line with the experiments described in Sect. 2.4.4.4 led to a first-period bubble in the market of less risk-averse subjects, but not in the market of more risk-averse subjects. Based on these results, they suggested that excess volatility would be reduced by modifying the regulatory environment so that buyers and sellers face similar costs. King et al. (1993) tried the opposite tack when they introduced significant transaction costs to discourage trading and possibly reduce the occurrence of bubbles. They found that, while mean turnover increased (decreased) for inexperienced (experienced) subjects, mean amplitude and price variance declined.

Gode and Sunder (1993) explored the role of the double auction transaction form by comparing conventional laboratory markets with the results of computer simulated market experiments. They induced supply and demand curves for the single traded good and observed quick convergence to the rational expectations equilibrium in the human subject market. They then ran the same experiment with two types of "zero-intelligence" machine traders, which posted bid and ask quotes randomly. The simulated traders of the first group could only post bids which exceeded their redemption value or ask quotes that were below their cost (zero-intelligence with constraint), while the second group could post any quote within a range of 1–200 currency units, even if they caused them to lose money on the transaction (zero-intelligence unconstrained). This market design permitted the identification of systematic characteristics of human traders by comparing the results from the human subject market with that of the constrained zero-intelligence traders. By comparing the outcome of the constrained zero-intelligence traders with their unconstrained brethren, it also permitted the identification of the effects that ensued from the imposition of budget constraints on a market's traders. The results showed that a progressive narrowing of the opportunity set of the constrained computer traders led them to converge on the rational expectations equilibrium and made their efficiency hardly distinguishable from that of the human agents. While human subjects learned quickly and then stayed at virtually 100% efficiency, the constrained simulations – only through the enforcement of market discipline among unintelligent computer agents quoting random prices – similarly attained an average efficiency rating of 98.7%

Stanley (1994) conducted a market experiment modeled after the Smith et al. (1988) design, modifying the dividend structure, but more importantly, altering the termination rule by introducing uncertainty about the number of periods in the experiment. In his institution, trading lasted for between seven and fifteen periods, with an equal probability of the experiment terminating at the end of any of the periods after the seventh. He found that prices did not converge to fundamental values, but developed much like in previous experiments (i.e., they started out below the fundamental value and increased above it). An exception was that at the end they failed to crash back to the fundamental level, yielding a strongly negative correlation between actual prices and fundamental values. This disconnect between actual and fundamental prices caused Stanley to term this phenomenon a "silly bubble." In Stanley (1997), the author employed the same market structure, but ran three repetitions (rounds) with the same subjects. He reported that – contrary to the usual pattern – bubbles continued to be observed even after the subjects had gained experience and participated in one or two previous rounds. Caution is advised in interpreting these findings, however, since in each article, Stanley only had the financial support to conduct a single session with eight subjects, which is hardly encouraging for the robustness that can be expected of his findings.

Fisher and Kelly (2000) let subjects buy and sell two different assets, trying to gain insights into the relative prices, i.e., the exchange rate between these two assets. Despite observing clear bubbles in the individual asset prices, they reported that the exchange rate converged quickly and then stayed close to its theoretical value. Using forecasts made by their experimental subjects, the authors also found that 22 out of 24 agents acted rationally with regard to the exchange rate, while at the same time participating in markets with significant asset price deviations from their fundamental values. Caginalp et al. (2002) similarly let their traders transact in two different stocks. In ten of their experiments, both stocks were parameterized as value stocks (i.e., with relatively low variance of returns), while in four experiments one stock was a value stock and the other was a growth stock (i.e., had a higher variance). They reported that for their design, the presence of a speculative asset lowered the mean price of the less volatile asset by around 20%, while increasing its variance. This underlines the danger speculative bubbles in some goods pose for the remaining assets in an economy. In a second experiment, they employed a design of two markets in identical assets, where each trader could trade only in one of the two markets, but all traders could observe both markets. Using this institution, they found that increases in the cash endowments of traders in one market lead to increases in the prices in this market, but not in the other.

Smith and Williams (1981) ran 16 experiments with experienced subjects to test the impact on markets of price controls in the form of trading halts triggered by large price movements. They reported that markets with nonbinding price ceilings (floors) near the competitive equilibrium price caused markets to converge to this equilibrium from below (above). They provided evidence that the cause lay in a restriction of the bargaining strategies, predominantly of sellers (buyers). Ackert et al. (2001) also investigated the effect of trading halts on experimental markets. They ran three markets each with a treatment where the market was in continuous operation, with one where large price movements triggered a temporary stop in trading, and with a final set of rules where large price movements triggered a permanent halt of trading for the period. The main difference between their study and Smith and Williams (1981) was that each subject in Ackert et al. (2001) could both buy and sell the asset and that in their design, price limits changed dynamically with the level of the asset price instead of remaining constant as in Smith and Williams (1981). Their results suggested that the market structure employed had not influenced the dissemination of information or the generation of profits, but that trading activity by both informed and uninformed subjects surged prior to a trading halt. They controlled for subjects' current holdings and found that trade was motivated by differing expectations regarding the value of the asset, not by differences in current holdings. Evaluating responses to a questionnaire, Ackert et al. (2001) observed that traders used temporary trading halts to reassess their expectations and strategies. Finally, they documented significantly higher trading volume in the permanent halt regime than in the two other designs. On the one hand they concluded that the so-called circuit breaker rules came with no negative side-effects, but on the other hand they could not document any benefits from this kind of trading halts.

Corgnet et al. (2008) explored the impact of informative and uninformative announcements on bubble characteristics in a Smith et al. (1988)-type market. In the treatment with a message preset by the experimenter, they informed their subjects that a message would be displayed on their screens in periods 3, 7 and 12. This message would say either "THE PRICE IS TOO HIGH" or "THE PRICE IS TOO LOW," and subjects were told that the choice between these two messages would be made by the experimenter before the session started. They conjectured that this design would lend medium credibility to the message, since subjects would assume that the experimenter's choice would be informed. To provide additional insights, they also had a treatment where this message was selected randomly prior to the start of the period (low credibility of the announcement), and one in which it was chosen to correctly reflect the relative difference in prices to fundamental value in the previous period (high credibility of the message). Corgnet et al. (2008) found that – compared to the baseline design without an announcement – the random message design did not significantly affect any of the bubble measures they employed (see Table 7 to 11). They attributed this result to their subjects requiring a necessary minimum level of reliability for a message to have any effect. In the design with messages preset by the experimenter, the "high" ("low") message significantly reduced (did not affect) amplitude and duration of the bubble, as well as the price deviation from fundamental value, for inexperienced subjects (for any subjects). Finally, the message based on actual prices in the market succeeded in significantly reducing the bubble amplitude and a measure of normalized average price deviation.

Noussair and Powell (2008) compare the transaction price process in a market where the fundamental value declines and then increases again (valley treatment) to a market in which the fundamental value of the traded good first increases and then declines (peak treatment). They find evidence for a path-dependency of the bubble phenomenon, in that peak market prices tend to more quickly converge toward fundamental value. This result may be of interest considering that in real markets, investors constantly enter and exit the market. This results in different subjective price histories between investors and could possibly impact market efficiency, particularly if groups of investors (professional investors, naïve investors, etc.) share systematic differences in the timing of their market entry (i.e., the phases of the market cycle in which they are more and less likely to enter and exit the market).

Hussam et al. (2008) combined a baseline treatment of a Smith et al. (1988)-type market with a treatment where – after having run two consecutive baseline rounds with the same cohort – they modified the initial endowment and the dividend structure to see whether this would rekindle a bubble. Their results confirmed that experience significantly reduces bubble amplitude and turnover, but discovered that in the rekindle treatment, the resulting bubble amplitude and turnover (in the rekindle round with twice experienced subjects) are not significantly different from that produced by inexperienced subjects. They concluded that experience is a sufficient condition to eliminate bubbles in static replications of the baseline environment, but not for the changing environment of the rekindle treatment. Conversely, the bubble duration was reduced both in the baseline and in the rekindle treatment. In a more far-reaching result they also reported that in a third treatment that employed the parameterization of the rekindle treatment already in the first period, the bubble amplitude is not reduced even in the third round, while the duration and turnover do decline.

2.4.5 Efficiency in Experimental Asset Markets

The ubiquitous tendency for laboratory assets with a well-defined declining fundamental value to trade at prices below this value, then rise above it, and crash near the end of the horizon, has launched experimental inquiries designed to investigate why this is so. [. . .] Since the participants themselves are mystified by this pattern, interrogating them has not been a source of great insight beyond establishing that they are indeed baffled, much as stock market investors in the economy.

Porter and Smith (1995)

The most commonly reported dimension of a market's functioning in economics is its informational and allocational efficiency. Naturally, measurements of and reports on market efficiency were provided by a number of experimental studies and also play a prominent role in the presentation of the results in Chap. 4. The following paragraphs review studies from the prior literature which provide evidence on the efficiency of experimental asset markets.

Plot and Sunders (1988) investigated the efficiency of experimental asset markets and showed that, while their experimental markets were fair games and filter rules did not outperform a simple buy-and-hold strategy, they were not efficient in a rational expectations sense.[76] Moreover, even a strategy of trading on the rational expectations equilibrium price would have failed to beat the buy-and-hold strategy,

[76] Cp. Fama (1970) for more on the role of fair games and filter rules in studies on informational market efficiency.

since the markets consistently failed to converge to this price. They concluded that markets that are fair games need not necessarily be efficient. More generally, Sunders (1995) quoted studies showing that the absence of arbitrage opportunities does not imply informational market efficiency. In Gode and Sunder (1994), he and Dhananjay Gode also showed that with regard to the percentage of the available surplus exploited in a double auction market institution, zero-intelligence computer traders were not inferior to human and artificial intelligence traders, as was already mentioned in Sect. 2.4.4.8. In a similar approach (which at that time departed from much of the previous literature) Haruvy and Noussair (2006) showed that a simulated market populated with speculators, feedback traders and passive (fundamentalist) traders generated similar patterns as those they had observed in their experimental markets.

In a more theoretical account, Friedman (1984b) wrote that a generic trader in an experimental double auction market can immediately increase her utility using one of four actions. She can accept the market bid or ask if they – respectively – exceed or fall short of her own valuation, or place a more competitive bid or ask quote if she does not already hold the best quote and the current quotes do not – respectively – exceed or fall short of her valuation. The first two options lead to an immediate increase in utility, while the second two options lead to an increase in the expected value of the trader's position, as long as there is a positive probability that the new bid or ask will be accepted by another trader (which also induces an immediate increase in *utility*, though not necessarily in experimental wealth). Friedman called a trader limiting herself to one of these four actions *myopic*, since the maximization of the expected utility of *final* holdings might also entail accepting an ask (bid) price above (below) her valuation. He also suggested that especially (but not only) inexperienced traders face a tradeoff when faced with favorable market prices. Such a trader may either transact immediately, locking in an expected profit, or hold back in the hope of finding more favorable prices later in the period. Naturally, the option of holding back and waiting declines in attractiveness with the passage of time and the nearing of the end of the period. Friedman (1984b) reported that he occasionally observed a flurry of transactions late in a trading round, which were presumably caused by traders who had waited too long and were then trying to still complete profitable trades in the time remaining before the end of the trading period. Still, according to his findings, experienced subjects seldom missed out on attempted transactions because they had waited too long.

In this context, Friedman coined the term of a no-congestion equilibrium, which he characterized as follows:[77]

> "Roughly speaking, I ask: if the market were unexpectedly held open an extra instant, would anyone definitely wish to change his bid or ask prices, or accept the market bid or ask after all? If not, we have a no-congestion equilibrium."

[77] Friedman (1984b), p. 65.

He then went on to use a simple arbitrage argument to show that in his model three agents are sufficient to yield Pareto optimal final allocations in which the closing market bid and ask prices coincide. He argued that, with only two traders, there exists the possibility of a bilateral monopoly impasse in which both traders look to their counterparty to make price concessions, even in the extra instant. Once a third agent is added to the mix, competition forces prices to the Pareto optimum. In his conclusion, Friedman noted that three main features contribute to the remarkable efficiency of experimental double auction markets. The first is the double auction structure with strictly improving quotes, as it limits a trader's potential impact on prices and conveys high quality information to market participants. This is a marked contrast to the example of a tâtonnement institution, where price quotes are collected by an auctioneer who then announces a market-clearing price. In such a setup, very little information about the distribution of agents' reservation prices is conveyed to the market and there exist extensive possibilities to convey misleading information to the market (e.g., false excess demand). The second characteristic of experimental double auction markets leading to efficient outcomes is the fixed ending time of the trading period, which forces agents to become more myopic if they wish to realize remaining gains from trading. Together with the informational and competitive aspects of the double auction institution, he found that this alone may be sufficient to bring about an efficient final allocation even with agents who initially possess little information about what to expect. Finally, as a third feature that causes allocational efficiency, Friedman named stationary replication, the beneficial effects of which have already been discussed in Sect. 2.4.2 of the present text.

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