An Experimental Study of Bubble Formation in Asset Markets Using the Tâtonnement Trading Institution

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Abstract

We report the results of an experiment designed to study the role of institutional structure in the formation of bubbles and crashes in laboratory asset markets. In a setting employing double auctions and call markets as trading institutions, bubbles and crashes are a quite robust phenomenon. The only factor appearing to reduce bubbles is experience across markets. In this study, we employ the tâtonnement trading institution, whose role **in the formation of bubbles** has not been previously explored in laboratory asset markets, despite its historical and contemporary relevance. The results show that bubbles are significantly reduced, suggesting that the trading institution plays a crucial role in the formation of bubbles.

Keywords: Experimental Asset Markets, Price Bubbles, Trading Institutions, Tâtonnement

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1. **Introduction**

Price bubbles are not a rare phenomenon. Indeed, there are many historical examples of commodity or financial asset markets that have experienced a period of sharp rising prices followed by an abrupt crash. One of the earliest recorded and most famous examples is the Tulip mania (Holland, 1637) in which prices reached a peak of over ten times greater than a skilled craftsman's annual income and then suddenly crashed to a fraction of its value. More recently, the real estate bubble of 2007 plagued many of the major economies of the world from which most are still reeling today (Akerlof and Shiller, 2009).

As price bubbles represent a phenomenon with substantive economic implications, they are widely studied in finance and economics. Smith, Suchanek, and Williams (1988) were the first to observe price bubbles in long-lived finite horizon experimental asset markets. Many studies have followed the pioneering work of Smith et al. in order to test the robustness of the price bubble phenomenon. To date, the only treatment variable that appears to consistently eliminate the existence of price bubbles is experience of all or some of the markets participants via participation in previous asset market sessions with identical environments (Smith et al., 1988; Van Boening, Williams, and LaMaster, 1993; Dufwenberg, Lindqvist, and Moore, 2005; Haruvy, Lahav, and Noussair, 2007).[1]

[1] Hussam, Porter and Smith (2008) show that if the environment is subject to changes in liquidity and uncertainty, then even experience is not sufficient to eliminate bubbles. Noussair and Tucker (2006) seem to eliminate the spot market bubble via a stylized experimental design of a futures market for every spot market period. Crockett and Duffy (2009) show that intertemporal consumption smoothing inhibits the formation of bubbles.

Asset market experience addresses what we believe to be two leading explanations for the existence of price bubbles. The first is the lack of common expectations due to the rationality of subjects not being common knowledge (Smith et al., 1988; Smith, 1994). Even though the experimenter can make every effort to explain the dividend process to all subjects, they may still be skeptical about the rationality of other traders. That is, some subjects may believe that other traders may be willing to make a purchase at a price greater than the fundamental value, and thus provide opportunities for capital gains via speculation. This speculative demand can build upon itself, and thus endogenously push the prices higher and higher above the fundamental value creating a price bubble. Note that with the lack of common knowledge of rationality, speculative bubbles may exist even if all subjects understand the dividend process perfectly. The second explanation, as argued by Lei, Noussair, and Plott (2002) and Lei and Vesely (2009), is that the difficulty in assessing the dynamic asset valuation may generate confusion and decision errors leading to bubble formation. More specifically, subjects may struggle with backward induction in order to correctly calculate the fundamental value, and thus a rational price, in a given period. Accumulating experience by participating in multiple asset markets allows subjects to gain confidence in the rationality of other traders as well as to learn the dynamic asset valuation process, and thus eliminate confusion and decision errors.

The main innovation of our paper is that we consider a tâtonnement trading institution, as opposed to double auctions or call markets, typically used in experimental asset markets. We are interested in the tâtonnement trading institution for two reasons. Firstly, we believe that the tâtonnement addresses both of the driving forces for bubble formation described above, and thus conjecture that price bubbles will be significantly reduced by the implementation of a tâtonnement trading institution instead of the standard call market or double auction institutions. Furthermore, tâtonnement is a trading institution of historical and contemporary relevance. Indeed, the tâtonnement is one of the earliest classical theories which is explicit about market price dynamics and adjustment to equilibrium (see Duffie and Sonnenschein, 1989). Also, the tâtonnement trading institution is not just an abstract theoretical construct as it is employed in some actual markets, e.g., the Tokyo grain exchange (Eaves and Williams, 2007).

A characteristic of the double auction market mechanism is that buyers and sellers tender bids/asks publicly. Typically the highest bid to buy and the lowest ask to sell are displayed and open to acceptance, and price quotes progress to reduce the bid\ask spread. Trading is open for a limited period of time and occurs bilaterally and sequentially at different prices within a period. In the call market, on the other hand, bids and asks are accumulated and the maximum possible number of transactions are simultaneously cleared at a single price per period.

How does the tâtonnement differ from these institutions? In our implementation of tâtonnement institution, the initial price is selected randomly in every period. Subjects submit quantities to buy or sell at the given price. If aggregate demand is equal to aggregate supply, the market clears. Otherwise, the market proceeds with price adjustment iterations. More specifically, the provisional price moves upward if there is excess demand and downward if there is excess supply (the actual workings of the price adjustment mechanism are explained in Section 3). Subjects submit their desired quantity to buy or sell at the new provisional price, and the process continues until the market clears.[2] Thus, there may be several non-binding iterations *within* each period that are publicly observable and reflect the formation of aggregate demand, aggregate supply, and equilibrium price.

We believe that these non-binding price adjustment iterations in each period take into account both leading conjectures of bubble formation that are addressed by experience, and thus the tâtonnement market institution may significantly reduce price bubbles even with inexperienced subjects. That is, the tâtonnement market institution may allow subjects to learn from each other in each period thereby establishing common expectations and reducing decision errors and confusion. Indeed, subjects now have the ability to learn demand, supply, and equilibrium price without actual trading. This is in contrast with the double auction institution where trades occur in continuous time, and thus extreme behavior associated with confusion or decision errors may more easily influence the market into a price bubble scenario.[3] In other words, in order for trade to occur under the tâtonnement market institution, subjects need to come to a collective agreement (as market clears only if excess demand/supply is equal to zero) while in double auctions or call markets that is not the case.[4] Under tâtonnement, the sequence of non-binding price adjustment within a period itself reveals information, allowing subjects to have a more accurate belief about equilibrium, and gain experience within a period

[2] Note that the price adjustment process could result in an infinite number of oscillations. If the price changed by only one franc and remained in a region of three francs for four periods in a row, then the period was concluded manually (see Section 3 for more details).

[3] In a sense, the tâtonnement price adjustment process protects the market from extreme bids that (particularly in early periods) may lead to speculative bubbles under a double auction institution.

[4] Under the tâtonnement trading institution, the magnitude of excess supply/excess demand within the price adjustment process signals to subjects the general consensus regarding the equilibrium price and where their decision lies in relation to that consensus. Informally, suppose that the total number of shares is 120 units. If the excess supply is only 5 shares and I am a buyer, I should not be that concerned about doing something wrong. However, if excess supply is 100, and I am trying to buy, I might start thinking about why the vast majority of subjects have very different beliefs about the equilibrium price than me.

rather than across periods as is the case under other trading institutions. Thus, there is a strong learning tool for inexperienced subjects embodied in the trading institution.

We find that under the tâtonnement trading institution, price bubbles are indeed mitigated according to all bubble measures employed in the literature.[5] Furthermore, the performance of the tâtonnement in relation to these bubble measures is similar to those reported in double auctions and call markets from previous studies with once and twice experienced subjects (King et al., 1993), which have been the gold standard in the literature for eliminating price bubbles. This result is especially surprising when you take into account that it occurred in an environment that is very supportive to bubble creation, i.e., our experimental design has a much greater initial cash/asset ratio than most of the comparable studies (Caginalp et al., 1998).

Section 2 provides a short literature review of related studies, and Section 3 describes the experimental design and procedures. We discuss the results in Section 4 and conclude with Section 5.

2. Related Literature

The existence of price bubbles is one of the most interesting and robust results from the multi-period asset market studies in the experimental literature. Smith et al. (1988) were the first to observe price bubbles in long-lived finite horizon asset markets. Their design implements a continuous double auction market trading institution with a finite time horizon of 15 trading periods. It is common knowledge that (1) each unit of the asset pays a dividend to its holder at the end of each period, (2) the dividend value is

[5] In order to compare different treatments, we modified existing measures to take into account different dividend processes, experiment duration etc. (See also Section 3.)

drawn each period from an independent equi-probable 4-point distribution, and (3) assets are worthless after the final dividend draw in the terminal period. Therefore, subjects are able to calculate the fundamental value of the asset at any time during the experiment. The time series of the fundamental value declines over time, i.e., the fundamental value decreases each period by the value of the expected dividend payment. Smith et al. find that, with inexperienced subjects, the typical time series of prices in these markets exhibits a bubble and crash pattern. That is, prices initially start below the fundamental value and then climb over time to prices that are significantly greater than the fundamental accompanied by excess market activity, and ending with a crash in the last periods of the experiment to the fundamental value.

In the last twenty plus years, numerous studies have followed the seminal work of Smith et al. to try to explain the bubble phenomenon and test mechanisms that may mitigate their existence. Interestingly, only few studies have analyzed the effect of the trading institution. The majority of studies have employed the continuous double auction market trading institution in replication of the original study of Smith et al. The only other trading institution employed, that we know of, is the uniform-price sealed-bid-offer call market.

Van Boening, Williams and LaMaster (1993) were the first to implement the call market as a trading institution and the only to test it as a treatment variable against the double auction one. Their motivation was that the limited bid/ask information within a call market would reduce the triggers of speculative trading, and thus eliminate price bubbles. They conducted two series of sessions under each institution in order to collect data at three levels of experience. Each series consisted of the exact same cohort of subjects and the sessions were conducted on different days. They find that call markets do not eliminate price bubbles and in fact provide very similar asset price patterns and bubble measures as the double auction.[6]

Since the call market had been shown to produce similar price patterns as the double auction, it has been used as trading institution in other studies (e.g., Caginalp, Porter, and Smith, 2000; Haruvy, Lahav, and Noussair, 2007; Hussam, Porter, and Smith, 2008) to test other treatment variables in order to take advantage of some call market characteristics. The results of these studies supported Van Boening et al. (1993).

As stated previously, subject experience is the only factor shown to consistently eliminate price bubbles. Dufwenberg, Lindqvist, and Moore (2005) conducted a study with a mixture of experienced and inexperienced traders in order to find evidence for a lower bound of the proportion of experienced traders required to eliminate bubbles. They ran a series of four consecutive asset markets employing a continuous double auction trading institution. In the fourth iteration, a fraction of the experienced subjects were replaced with inexperienced subjects. They find that with as few as 1/3 of traders being experienced on average there were no significant differences from when all traders were experienced. An interesting aspect of their data that is particularly relevant to our motivation for the tâtonnement institution is that in every instance the experienced traders "led" the market. That is, experienced traders were always the first to enter the market and in only a single instance was an inexperienced trader the second trader to enter. Therefore, one interpretation is that the inexperienced traders were able to learn from the experienced traders, i.e., acquire the knowledge that the experienced traders gained over

[6] Tables 1 and 2 within the Results section provide a comparison of experimental designs and bubble measures across studies.

the three previous markets, and thus averting a price bubble that is typically observed when all subjects are inexperienced. The tâtonnement institution allows for a group of all (initially) inexperienced traders to learn from each other within each period of trading.

The main contribution of our study is to show that trading institutions matter for the formation of bubbles and that bubbles are eliminated under the tâtonnement, a trading institution which has not been previously studied in the experimental literature on long-lived asset markets.[7] Furthermore, our study also provides a meta-analysis of several existing studies, which is interesting in its own.

3. The Experiment

The experiment consisted of four sessions conducted between September and October 2004 and one session conducted in May 2009 in the New Zealand Experimental Economics Laboratory (NZEEL) at the University of Canterbury in Christchurch, New Zealand. Twelve traders for each session were recruited from undergraduate courses throughout the university. Some of the subjects had participated in previous experiments, but none had experience with asset markets. Each subject only took part in a single session of the study. The experiment was computerized and used the z-Tree software package.[8] Trade was denominated in "francs" which were converted to New Zealand dollars at the end of the experiment at the predetermined publicly known conversion rate of 600 francs to 1 NZD. On average, sessions lasted approximately 2.5 hours including

[7] There are studies that explore the convergence of tâtonnement to the competitive equilibrium and its efficiency properties (e.g., Joyce (1984), Bronfman et al. (1996)). Pouget (2007) compares the performance of Tâtonnement and Call Market in a common value environment with gains from trade and asymmetric information. He finds that the market experiences a higher allocative efficiency under the Tâtonnement.

[8] See Fischbacher (1999) for a discussion of the z-Tree software package.

initial instructional period and payment of subjects. Subjects earned 26.80 NZD on average.[9]

At the beginning of the experiment, subjects were endowed with 10 units of the asset and a cash balance of 10,000 francs. The asset had a finite life of 15 periods. At the end of each trading period, each unit of the asset in a subject's inventory paid an uncertain dividend that was equally likely to be 0, 8, 28, or 60 francs (e.g., Smith et al.,1988; King et al., 1993; Caginalp et al., 2000; Lei et al., 2001; Haruvy and Noussair, 2006; Noussair and Tucker, 2006; Hussam et al., 2008). Therefore, the average dividend paid per unit of the asset held in each period equaled 24 francs. The dividend was independently drawn each period. After the final dividend payment in period 15, the asset was worthless. Therefore, the fundamental value of the asset at any given time during the market equaled 24 francs times the number of periods remaining.

Table 1 compares our design to several other treatments available in the literature such as Smith et al. (1988), Van Boeing et al. (1993), Lei at al. (2001), Dufwenberg et al. (2005), and Haruvy et al. (2008). We categorize the data into seven groups, based on the trading institution and experience level.[10] For instance, group 1 consists of the data collected under our experiment, which employs non-experienced subjects and a tâtonnement trading institution, as indicated in the first four columns of the table. Other columns provide information regarding the number of sessions and important features of the experimental design.

[9] At the time of the experiment, the adult minimum wage in New Zealand was 9.00 NZD per hour (1 NZD = 0.6708 USD).
[10] We will make reference to these groupings of experiments as indicated by column 1 throughout the rest of the text.

The last column of Table 1 provides the cash per asset (CPA) ratio as defined by Caginalp et al. (1998), i.e., $q = (S - D)/S$ where S is the initial total value of assets and D is the initial total amount of cash. Caginalp et al. showed that the greater the initial total value of cash relative to initial total value of assets in a market the greater will be average period transaction prices and thus the higher will be the probability of a bubble. As indicated by the CPA ratio calculations, our design is the second most cash rich of all the listed studies with $q = -1.78$. In other words, in our design, cash holdings exceed the value of the assets, priced at the highest fundamental value, by 178%. With the exception of Lei, Noussair, and Plott (2001), this is in sharp contrast with other designs, where cash holdings are lower (as indicated by positive q) than the value of the assets. Therefore, our experimental design provides an environment that favors price bubble formation.

Table 1. Experiments Varying by Trading Institutions and Experience

Group	Trading Institution	Experience	Paper	Other Design Features						
				Number of			Initial (average)		Expected Dividend	CPA Ratio
				Sessions	Periods	Subjects	Working Capital per Trader	Asset Endowment per Trader		
1	Tâtonnement	n	LPT (2009)	5	15	12	10,000	10	24	-1.78
2a	Double Auction	n	LNP (2001) LNP (2001) LNP (2001)	1 2 1	15 12 12	7 7 7	100,000 100,000 10,000	10 10 10	24 30 30	-26.78 -26.78 -1.78
2b	Double Auction	n	SSW (1988) VWL (1993) VWL (1993) DLM (2005)	1 1 1 10	15 15 15 10	12 15 14 6	6.80 7.20 7.20 4.00	2.33 2 2 4	0.16 0.25 0.25 0.10	-0.22 0.04 0.04 0.00
3	Call Market	n	VWL (1993) VWL (1993) HLN (2007)	1 1 6	15 15 15	15 12 9	7.20 7.20 292	2 2 2	0.25 0.25 12	0.04 0.04 0.19
4	Double Auction	x	SSW (1988) VWL (1993) VWL (1993) DLM (2005)	1 1 1 10	15 15 15 10	9 15 14 6	5.85 7.20 7.20 4.00	2 2 2 4	0.24 0.25 0.25 0.10	0.19 0.04 0.04 0.00
5	Call Market	x	VWL (1993)	1 1	15 15	15 12	7.20 7.20	2 2	0.25	0.04
6	Double Auction	xx	SSW (1988) VWL (1993) VWL (1993) DLM (2005)	1 1 1 10	15 15 15 10	9 15 14 6	5.85 7.20 7.20 4.00	2 2 2 4	0.24 0.25 0.25 0.10	0.19 0.04 0.04 0.00
7	Call Market	xx	VWL (1993)	1 1	15 15	15 12	7.20 7.20	2 2	0.25	0.04 0.04

1. Experience: n = no experience; x = once experienced; xx = twice-experienced. 2. Paper: LPT = Lugovskyy, Puzzello, and Tucker; LNP= Lei, Noussair and Plott; SSW = Smith, Suchanek, and Williams; VWL = Van Boening, Williams, and LaMaster; DLM = Dufwenberg, Lindqvist, and Moore; HLN = Haruvy, Lahav, and Noussair

Subjects were provided an "Average Holding Value Sheet" within their instructions packet that illustrated the value of the stream of dividend payments from a given period to the end of the experiment.[11] Although the dividend process was explained in detail within the instructions, there was no suggestion of a relationship between the dividend process and prices at which one should be willing to make transactions.

The trading institution employed in all markets was the tâtonnement. In each period, subjects were allowed either to buy or to sell units of X as long as they had sufficient cash on hand to cover the purchase or sufficient inventory of assets to make the sale. The specifics of the tâtonnement trading institution used within our experiment are as follows. At the beginning of each period, the computer announced a randomly drawn initial price from a uniform distribution on the interval [0, 500].[12] Each subject decided how many units of X that they wanted to buy or sell at this given price by placing bids or asks respectively. The computer aggregated individual decisions and compared the market quantity demanded (Q_D) to the market quantity supplied (Q_S). If the market cleared ($Q_D = Q_S$), then the process stopped and transactions were completed. If the market did not clear at the initial random price, then the price would adjust in the appropriate direction.[13] Specifically, we employed a "proportional" adjustment rule, which can be thought of as proceeding in two stages (see also Joyce, 1984, 1998).

In the first stage, the price adjusts proportionally according to the following rule: $P_t = P_{t-1} + \gamma_t \left(Q_{D,t-1} - Q_{S,t-1} \right)$, where $\gamma_t \in \{10, 5, 2.5, 1, 0.5, 0.25, 0.05\}$ is the adjustment

[11] A copy of the instructions is provided in the Appendix.
[12] The maximum fundamental value in period 1 was equal to 360 francs.
[13] The price is adjusted upward in case of excess demand and downward in case of excess supply.

factor and subscript t is the iteration of adjustment. The initial adjustment factor is 10 and decreases to the next lower value unless we observe either an excess supply or an excess demand twice in a row, i.e., unless $\left(Q_{D,t}-Q_{S,t}\right)$ is of the same sign as $\left(Q_{D,t-1}-Q_{S,t-1}\right)$.[14] For small levels of excess supply/demand (or in the second stage), the price adjustment rule is replaced by $P_t=P_{t-1}+1$ if $0<\gamma_t\left(Q_{D,t-1}-Q_{S,t-1}\right)<1$, and by $P_t=P_{t-1}-1$ if $-1<\gamma_t\left(Q_{D,t-1}-Q_{S,t-1}\right)<0$.

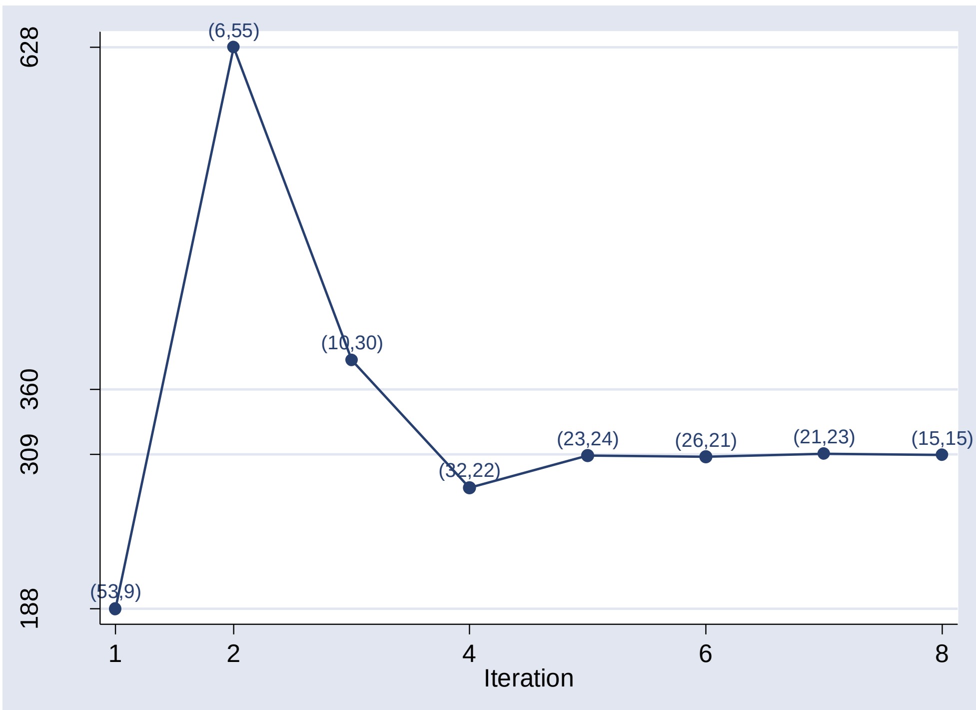

Figure 1. Pricing rule iterations in period 1 of Session 1

Figure 1 illustrates how the price adjustment rule works via the data collected in period 1 of session 1. At the initial price of P_1=188, aggregate demand is $Q_{D,1}$=53 and aggregate supply is $Q_{S,1}$=9. In the next iteration, the price is P_2=188+10(53-9)=628. At P_2=628, aggregate demand is $Q_{D,2}$=6 and aggregate supply is $Q_{S,2}$=55, which implies that

[14] In general, as the number of iterations increases, it takes a larger gap between aggregate quantity demanded and supplied to significantly adjust the price.

the adjustment factor used in the iteration will be 5, so that P_3=383. The same process continues for all other prices in the iteration sequence of the period. Subjects had access to flow information so they could see the aggregate demand and supply of stocks in every iteration of every period.

We did not implement an "improvement rule."[15] That is, following each price announcement, players were free to submit new bids and asks, without any constraints on their behavior from prior iterations. As a result, it is possible that the price adjustment process may result in an infinite number of oscillations around a narrow region of prices. For any given announced price, participants could choose any amount to buy or sell irrespective of their decisions in the previous adjustment iteration (there is no improvement rule). In order to avoid the oscillating prices, we employed a manual closing rule if $Q_D \neq Q_S$ within several iterations. More specifically, if according to the price adjustment mechanism, the price changed by only one franc and remained in a region of three francs for four periods in a row, then the period was concluded manually.[16] The process for manual conclusion of a period was as follows. An announcement was made by the experimenter that a manual conclusion was to be conducted and the subjects were not to enter an amount to buy or sell into the computer for the current iteration announced price. On Bidding Sheets provided to them within the instructions, subjects had to write the announced price given by the computer for this iteration and the amount of X that they wanted to buy or sell at this price. The experimenter then collected these sheets and totaled the amount of X that people wanted

[15] This is consistent with the Tâtonnement institution employed in the Tokyo Grain Exchange.
[16] Examples of the criteria for implementing the manual closing rule is if the price went from 100, to 101, back to 100, then back to 101, or if the price went from 100, to 101, to 102, then back to 101.

to buy and sell. If $Q_D = Q_S$, then the transactions were made according to the bids/asks made. If $Q_D > Q_S$, then the units sold were randomly allocated to the buyers. If $Q_D < Q_S$, then the units bought were randomly divided among the sellers. Once the allocation was determined for the period, the experimenter redistributed the Bidding Sheets back to the subjects who then entered the amount assigned to them to buy/sell into the computer, which concluded the period.

4. Results

We compare our results to several other treatments available in the literature such as Smith et al. (1988), Van Boeing et al. (1993), Lei at al. (2001), Dufwenberg et al. (2005), and Haruvy et al. (2008). We categorize the data into seven groups, based on the trading institution and experience level. The description of groups and corresponding experiments is provided in Table 1.

We start by comparing the observed price deviations from fundamental values across experiments. For this purpose, we normalize the fundamental values and prices across studies so that the first period fundamental value in all experiments is rescaled to 100. That is, in period *t*, the normalized fundamental value and normalized price are defined as

$$f_t^{100} = \frac{100}{f_1} f_t \quad \text{and} \quad P_t^{100} = \frac{100}{f_1} P_t .$$

For example, in our experiment, the fundamental value is 360 in period 1 and 240 in period 6. The normalized fundamental values are 100 and 240*100/360=67, respectively.

Figure 2 depicts the time series of normalized prices and fundamentals in our experiment.[17] Each period of the experiment is provided on the horizontal axis and (normalized) market clearing prices are indicated on the vertical axis. According to Figure 2, the prices in Sessions 1, 2, and 5 remain close to the fundamental value, while the prices in Sessions 3 and 4 display departures from the fundamental value.

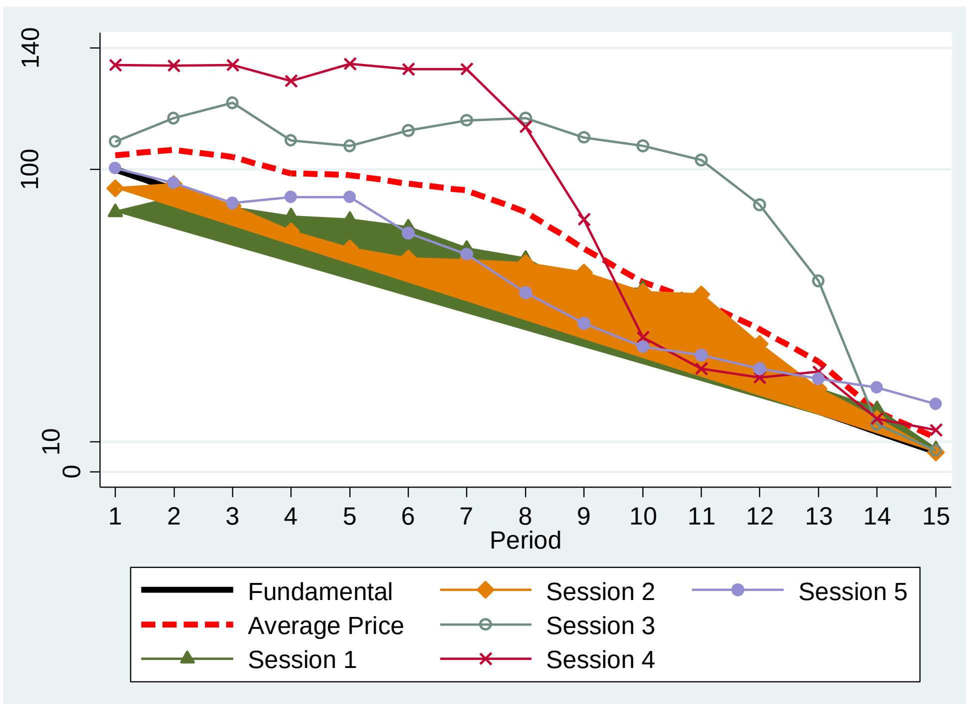

Figure 2. Normalized Prices and Fundamental in Tâtonnement, Inexperienced

If judged only by Figure 2, it appears the tâtonnement trading institution only partially succeeds in attenuating bubbles, since in two out of five sessions we observe price deviations from the fundamental value typical of a bubble. However, a careful evaluation of bubble size, as pointed out by the definition of a bubble itself, should

[17] Corresponding quantities and numbers of iterations per period are provided in Appendix A.

involve two dimensions, i.e., transaction prices and quantities.[18] As we will show, once both factors are taken into account, the tâtonnement trading institution appears to have quite a strong dampening effect on the bubble phenomenon. In particular, the trade volumes in each of our sessions are much lower than the corresponding quantities in the previous experiments.[19] Before substantiating this claim (see also Table 2), let us have a look at normalized prices under other trading institutions.

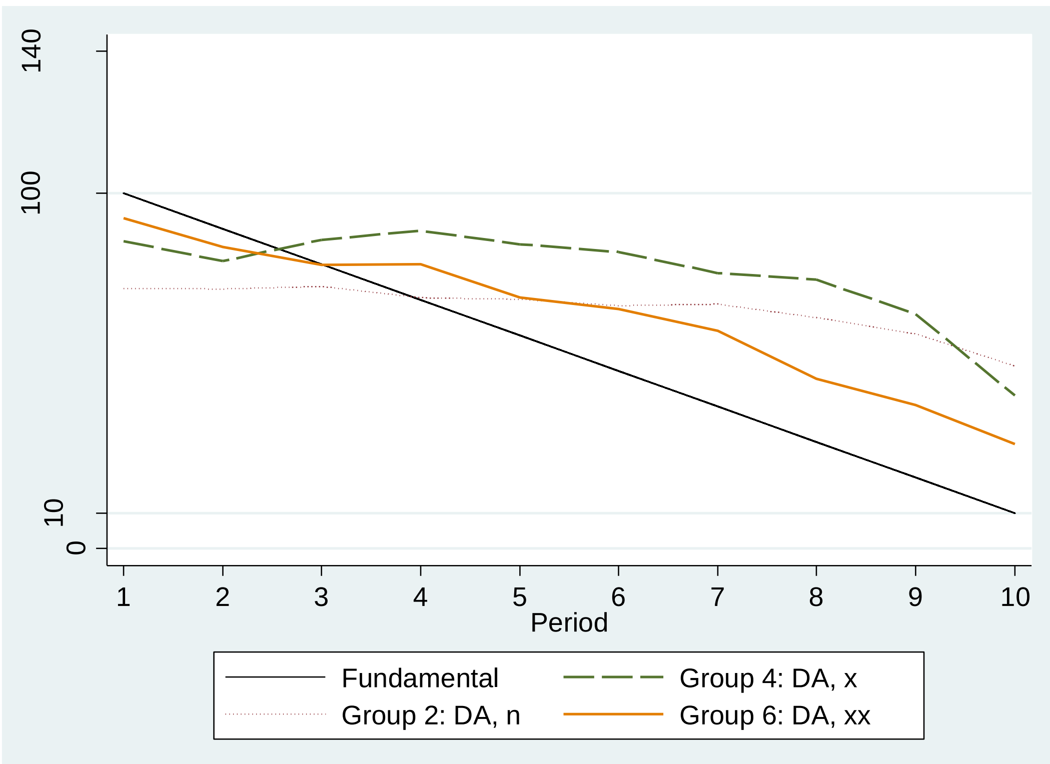

Figure 3a. Average Normalized Price (10 Periods).

[18] A bubble is "trade in *high volumes* at prices that are considerably at variance with intrinsic values (italics ours)" (see King et al., 1993).

[19] The typical price adjustment process presented in Figure 1 shows that the tâtonnement trading institution does not result in lower turnover values simply due to the nature of the institution reducing bidding activity. For announced prices sharply different than the fundamental values, most of the periods show extreme excess supply or demand, i.e., all participants on one side of the market. Therefore just as theory predicts, the market exhibits large amounts of activity when prices deviate sharply from fundamental values and low activity for prices close to fundamental values.

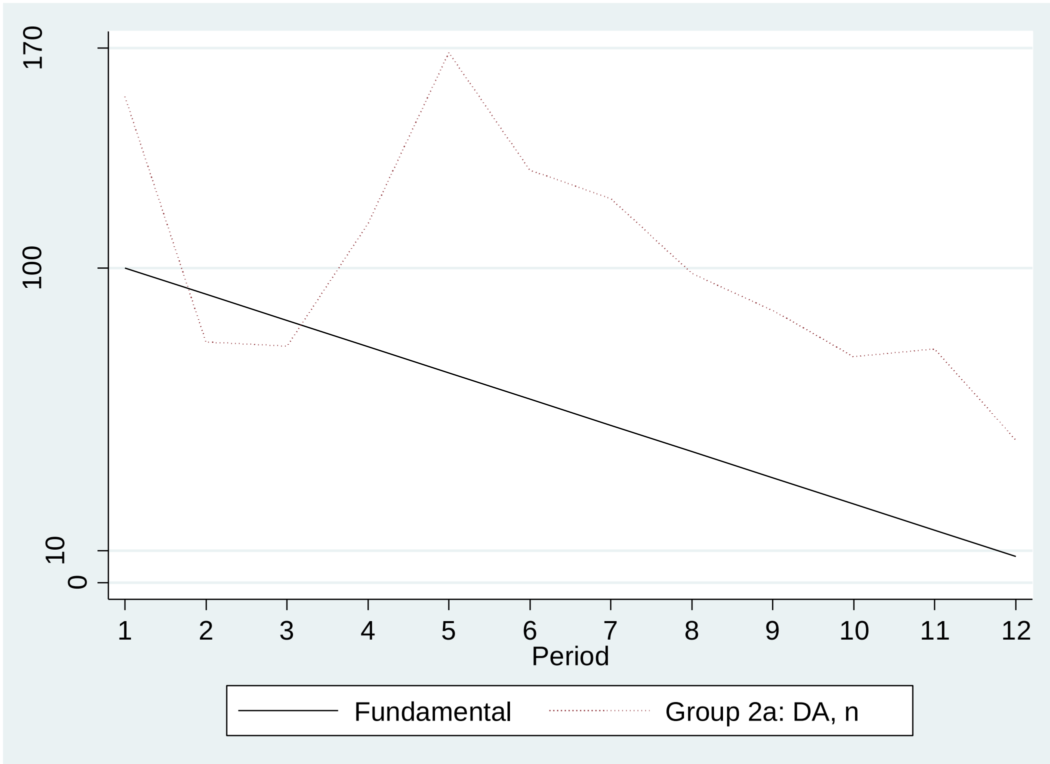

Figure 3b. Average Normalized Price (12 Periods).

Figures 3a and 3b depict average normalized prices across groups identified in Table 1 for experiments with duration of 10 and 12 periods, respectively. Clearly, they indicate that experience plays a key role in the formation of bubbles as average prices are closer to fundamental value the higher is the experience level of subjects.

Furthermore, Figure 4 also compares average normalized prices, collected under tâtonnement, with average normalized prices collected under double auctions in experiments with 15 periods.[20] Similarly, Figure 5 compares our data, collected under tâtonnement with the data collected under call markets consisting of 15 periods.

[20] We do not include this comparison in Figure 4 because the design of Dufwenberg et al. (2005) consists of 10 periods.

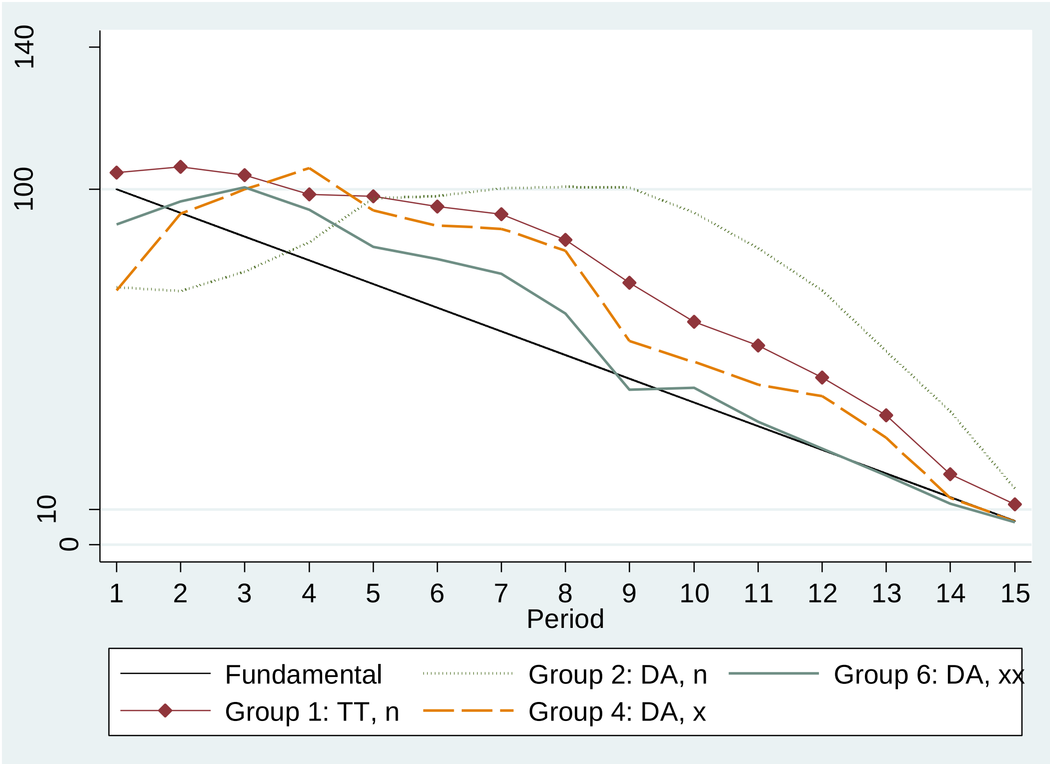

Figure 4. Average Normalized Price (15 Periods): Tâtonnement vs. Double Auction

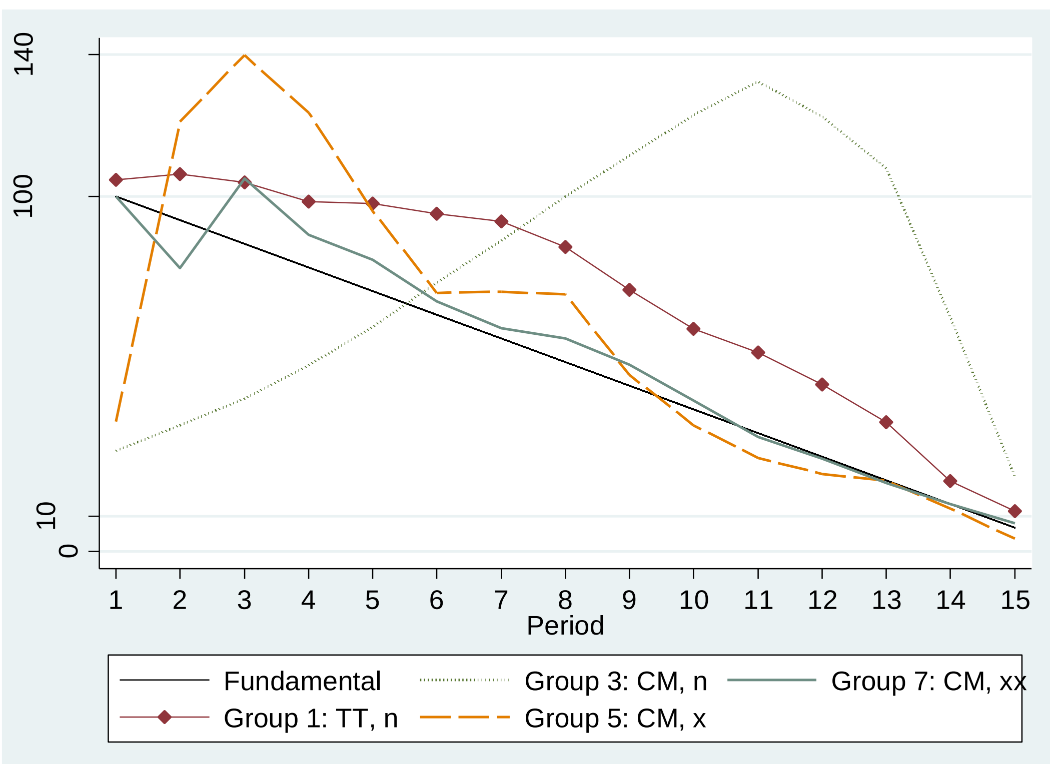

Figure 5. Average Normalized Price (15 Periods): Tâtonnement vs. Call Market

Figures 4 and 5 clearly indicate that the price patterns of the tâtonnement are remarkably closer to the fundamental value than those of the call market and double auction non-experienced sessions. What's more, the price patterns of the tâtonnement are also comparable with those of experienced and double-experienced subjects of both the double auction and call market institutions, which are typically acknowledged as a no-bubble environment.

To confirm the impression that the tâtonnement trading institution has an attenuating effect on asset price bubbles, we employ measures of bubbles' magnitude used in laboratory markets by King et al. (1993), Van Boening et al. (1993), Porter and Smith (1995), and Dufwenberg et al. (2005). However, in order to compare measures *across* different studies (e.g., with different duration and dividend process), we perform appropriate modifications. In particular, we normalize the turnover by the number of periods, and the normalized absolute price deviation by the number of periods and the first period fundamental value. The definition of these measures is provided below.

- The *Haessel-R^2* (W. Haessel, 1978) measures goodness-of-fit between observed (mean prices) and fundamental values. It is appropriate, since the fundamental values are exogenously given. The Haessel-R^2 tends to 100% as trading prices tend to fundamental values.
- The *Normalized Price Amplitude* is defined as the difference between the peak and the trough of the period price relative to the fundamental value,[21] normalized by the initial fundamental value, f_1 (in our markets f_1 = 360). In other words, price amplitude equals $A = \frac{100\%}{f_1} * \left[\max_t \left(P_t - f_t \right) - \min_t \left(P_t - f_t \right) \right]$, where P_t is the

[21] In the double auction case, mean period prices are used as trades occur at different prices within a period.

market clearing price[22] and f_t is the fundamental value in period *t*. A high Price Amplitude suggests large price swings relative to fundamental value, and is evidence that prices have departed from fundamental values.

- The *Normalized Absolute Price Deviation* is defined as the sum, over all transactions, of the absolute deviations of prices from the fundamental value, divided by the Total Number of Shares outstanding: $D = 100\% * \sum_{t=1}^{T} n_t \left|P_t - f_t\right| / \left(f_1 * TSU * T\right)$, where n_t is the number of units traded in period *t*, *TSU* is the total stock of units, and *T* is the time horizon length.[23] A high Normalized Absolute Deviation corresponds to a high volume of trading activity at prices deviating from fundamental values.
- The *Normalized Turnover* is defined as the total number of transactions over the life of the asset divided by the total stock of units: $TR = 100\% * \left(\sum_t n_t\right) / \left(T * TSU\right)$, *TSU* is the total stock of units and *T* is the time horizon length. A high Turnover indicates a high volume of trade, suggesting heterogeneous expectations or decision errors prompting trade.

In Table 2, the impression that bubbles are substantially reduced under tâtonnement is confirmed by statistical analysis. That is, our study demonstrates that a way to impede bubble formation is to use a tâtonnement (TT) trading institution instead of double auction (DA) or call markets (CM).

[22] In the double auction, P_t denotes the average transaction price.

[23] Note, that the corresponding measure under the double auction trading institution is $D = \sum_t \sum_i \left|P_{it} - f_t\right| / \left(T * f_1 * TSU\right)$, where P_{it} is the individual price in transaction *i* of period *t*.

Table 2. Bubble Measures by Trading Institution and Experience.

Group (as labeled in Table 1)		N of Sessions	Average Bubble Measures			
			Haessel R^2, %	Normalized Absolute Price Deviation, %	Normalized Price Amplitude, %	Normalized Turnover, %
G1	TT, n	5	84.5	1.7	45.0	8.7
G2a	DA, n	4	33.4	36.3	220.5	45.4
G2b	DA, n	13	36.0	15.4	85.4	52.0
G3	CM, n	8	29.6	8.1	189.6	15.5
G4	DA, x	13	49.6	13.8	80.1	40.9
G5	CM, x	2	60.2	1.7	118.3	10.0
G6	DA, xx	13	69.6	6.4	55.1	32.2
G7	CM, xx	2	88.1	0.6	48.1	12.3
z-Value G1=G2a (TT vs. DA,n)			2.21**	-2.45**	-1.96**	-2.46**
z-Value G1=G2b (TT vs. DA,n)			2.22**	-3.12***	-2.02**	-3.21***
z-Value G1=G3 (TT vs. CM,n)			2.34**	-2.93***	-2.93***	-2.64***
z-Value G1=G4 (TT vs. DA,x)			2.02**	-3.02***	-2.22**	-3.21***
z-Value G1=G5 (TT vs. CM,x)			1.55	-0.39	-1.94*	-0.39
z-Value G1=G6 (TT vs. DA,xx)			0.84	-2.32**	-0.84	-3.01***
z-Value G1=G7 (TT vs. CM,xx)			0.00	0.78	0.00	-1.78*

*10% significance level; ** 5% significance level, *** 1% significance level.

Specifically, Table 2 presents the relevant average bubble measures across sessions by trading institution and experience level. It also reports the results of Mann-Whitney nonparametric tests where the corresponding bubble measure for each session serves as one unit of observation. These statistics clearly indicate that bubble measures are significantly smaller under tâtonnement than under any other trading institution reported in previous studies where subjects had no experience. Furthermore, the bubble measures obtained in our sessions are comparable and in many cases even dominate the magnitudes obtained in experiments with experienced and twice-experienced subjects. This finding is important because experiments with twice-experienced subjects are typically used as a non-bubble benchmark in the literature. Thus, bubbles are greatly reduced under the tâtonnement trading institution. These results are particularly strong since our design is much more conducive to bubble formation than most of existing studies given our relatively cash rich initial endowments (see also the CPA data in Table 1).

4. Conclusions

In this paper we have studied the impact of a tâtonnement trading institution on bubble formation in experimental asset markets. As suggested by several studies, bubbles appear to be extremely robust to changes in the experimental environment. The only factor that appears to reduce bubbles is experience. Our study suggests that trading institutions matter and contribute to magnify or dampen the formation of bubbles. In particular, we find that tâtonnement, as opposed to double auctions and call markets, appears to facilitate learning about the equilibrium price or fundamental values of an asset. Furthermore, tâtonnement plays a key role in the elimination/reduction of bubbles in experimental settings.

In view of the recent financial crisis, institutional re-design of field financial markets is an important topic. This paper suggests that experiments will be a useful part of the debate. In regards to this, a design of a tâtonnement trading institution to be employed in the field (e.g., closer to the one employed in the Tokyo Grain Exchange) is left for further research.

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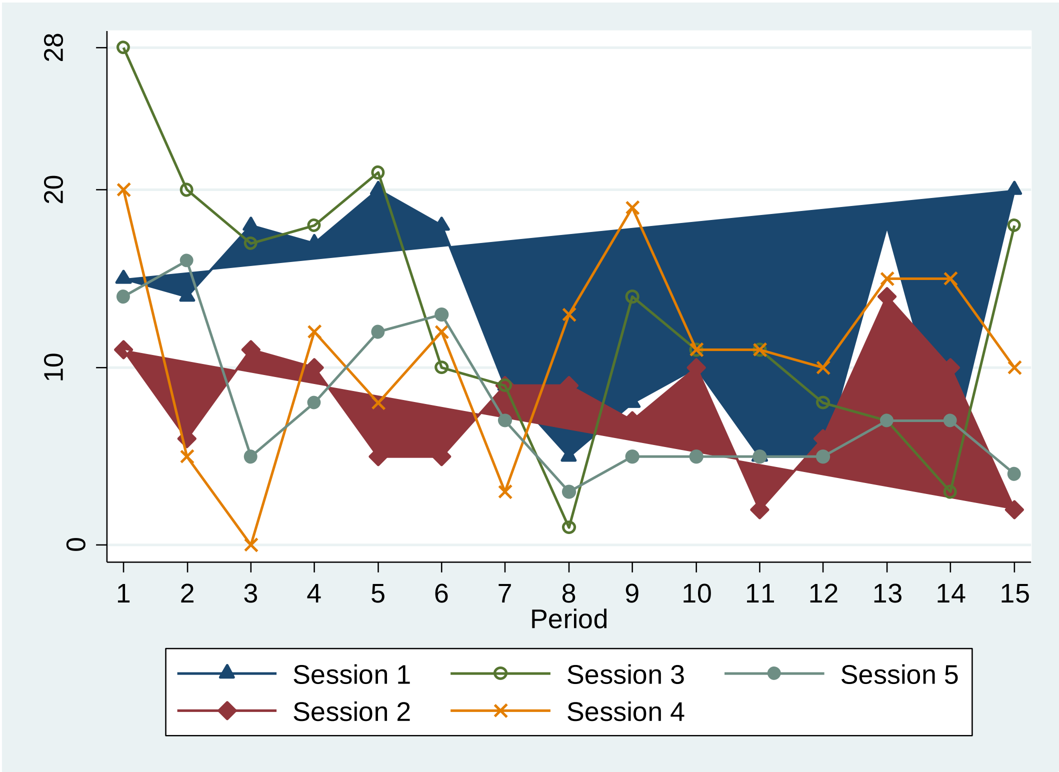
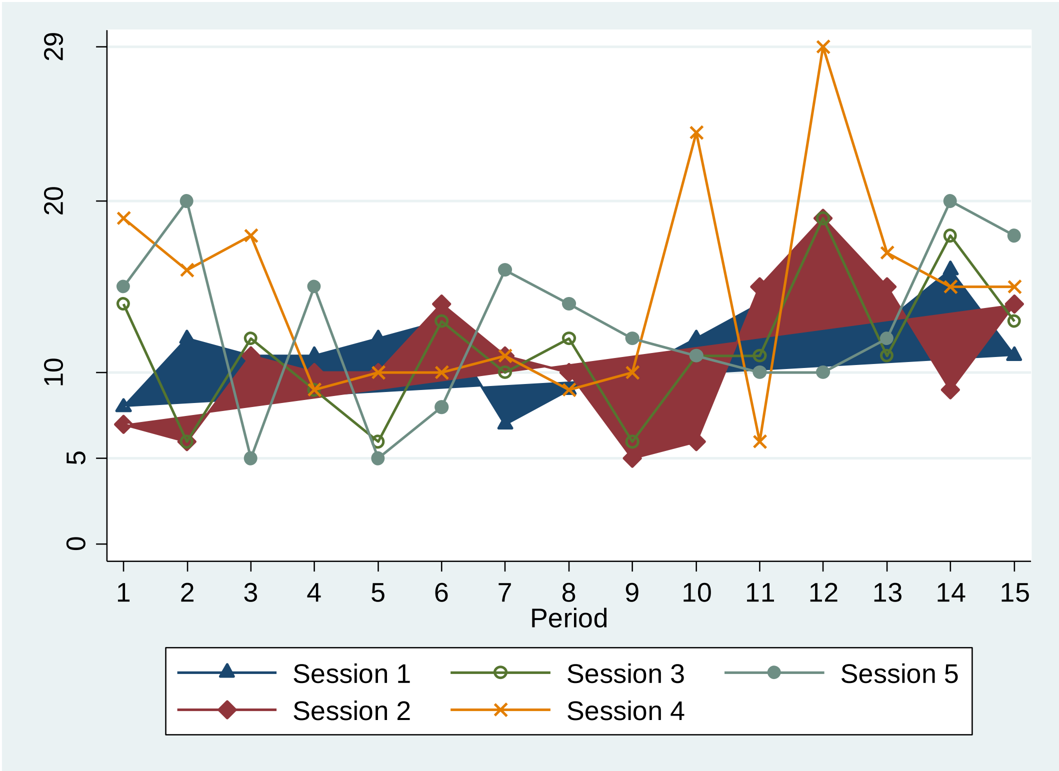
Appendix A. **Quantity and Number of Iterations per Period in Tâtonnement, Inexperienced**





Appendix B

General Instructions

This is an experiment in the economics of market decision-making. The instructions are simple and if you follow them carefully and make good decisions, you might earn a considerable amount of money, which will be paid to you in cash at the end of the experiment. The experiment will consist of *fifteen* trading periods in which you will have the opportunity to buy and sell in a market. The currency used in the market is francs. All trading and earnings will be in terms of francs.

________ francs = 1 NZ dollar

Your francs will be converted to dollars at this rate, and you will be paid in dollars when you leave the lab today. The more francs you earn, the more dollars you earn.

In each period, you may buy and sell units of a good called X in a market. X can be considered an asset with a life of 15 periods, and your inventory of X carries over from one trading period to the next. Each unit of X in your inventory at the end of *each* trading period pays a dividend to you. The dividend paid on each unit is the same for every participant.

You will not know the exact value of the dividend per unit until the end of each trading period. The dividend is determined by chance at the end of each period by a random number generator. The dividend in each period has an equally likely chance of being 0, 8, 28, or 60. The information is provided in the table below.

Dividend	→	0	8	28	60
Likelihood	→	25%	25%	25%	25%

The average dividend per period for each unit of X is 24 francs.

The dividend draws in each period are independent. That means that the likelihood of a particular dividend in a period is not affected by the dividend in previous periods.

2. Your Earnings

At the beginning of the experiment, you will be given 10,000 francs in your Cash inventory. Your earnings for the entire experiment are equal to your Cash inventory at the end of period 15.

All dividends you receive are added to your Cash inventory.

All money spent on purchases is subtracted from your Cash inventory.

All money received from sales is added to your Cash inventory.

Example of earnings from dividends: if you have 6 units of X at the end of period 3 and the dividend draw is 8 francs (which has a 25% chance of occurring), then your dividend earnings for period 3 are equal to 6 units x 8 francs = 48 francs.

3. Average Value Holding Table

You can use your **AVERAGE HOLDING VALUE TABLE** (attached at the end of this document) to help you make decisions. It calculates the average amount of dividends you will receive if you keep a unit of X until the end of the experiment. It also describes how to calculate how much in future dividends you give up on average when you sell a share at any time. The following describes each of the columns in the table.

1. *Ending Period*: period 15 is the last trading period within the experiment, and thus the last period for which to receive a dividend payment. After the final dividend payment in period 15, each unit of X is worthless.

2. *Current Period*: the period during which the average holding value is being calculated. For example, in period 1, the numbers in the row corresponding to "Current Period 1" are in effect.

3. *Number of Remaining Dividend Payments*: the number of times that a dividend can be received from the current period until the final period (period 15). That is, it indicates the number of random asset payment draws remaining in the lifetime of the asset. It is calculated by taking the total number of periods, 15, subtracting the current period number, and adding 1, because the dividend is also paid in the current period.

4. *Average Dividend Value per Period*: the average amount of each dividend. As we indicated earlier, the average dividend in each period is 24 francs per unit of X.

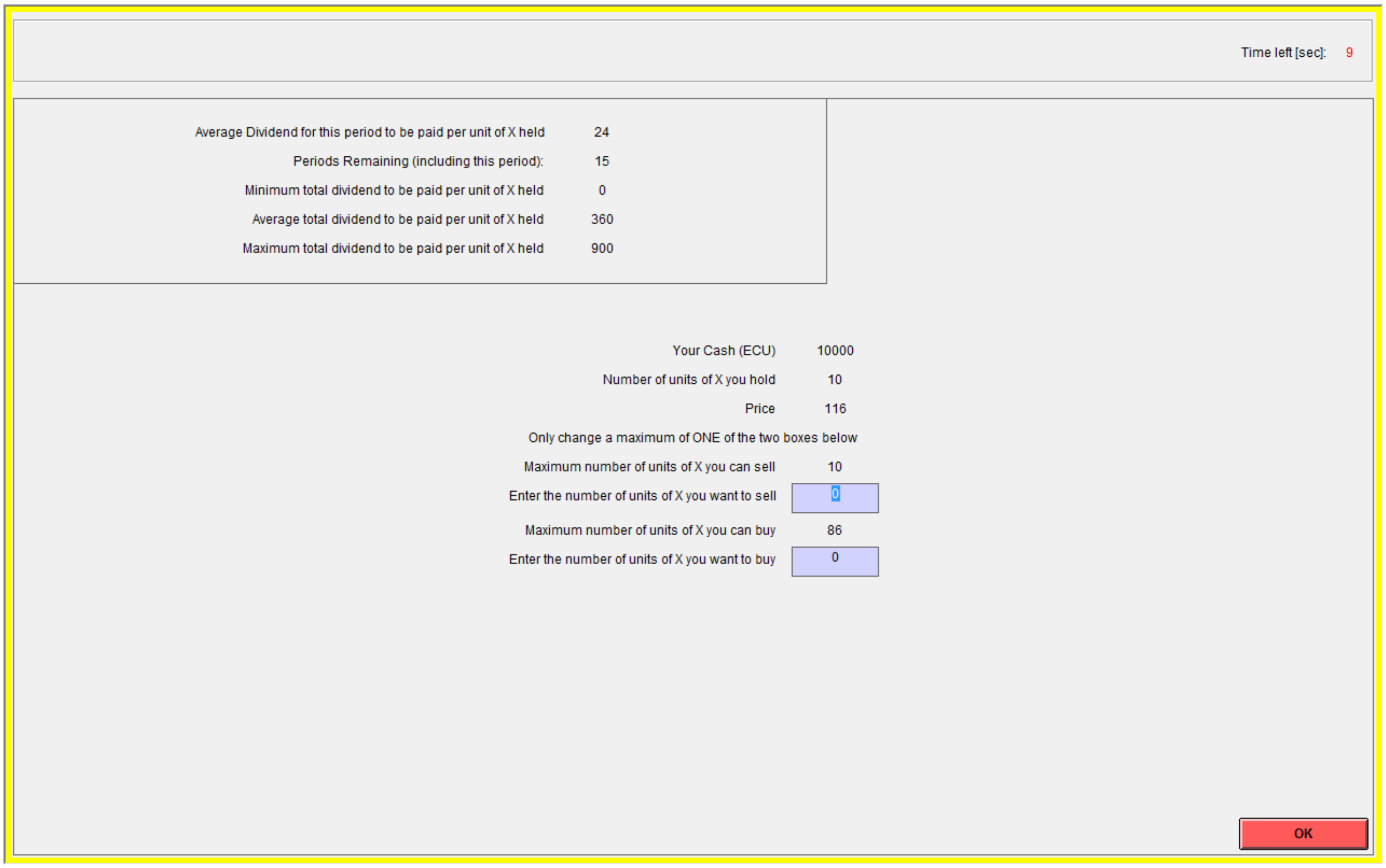
5. *Average Holding Value per Unit of Inventory*: the average value of holding a unit of X for the remainder of the experiment. That is, for each unit of X you hold in your inventory for the remainder of the experiment, you receive on average the amount listed in column 5. The number in Average Holding Value is calculated by multiplying the Number of Remaining Dividend Payments with the Average Dividend Payment per Period.

Please have a look at the table now and make sure you understand it. The following example may help in your understanding.

Suppose for example that there are 7 periods remaining. Since the dividend paid on a unit of X has a 25% chance of being 0, a 25% chance of being 8, a 25% chance of being 28, and a 25% chance of being 60 in any period, the dividend is on average 24 per period for each unit of X. If you hold a unit of X for 7 periods, the total dividend paid on the unit over the 7 periods is on average 7*24 = 168.

4. Market and Trading Rules

At the beginning of the experiment, you will have an initial inventory of 10 units of X and 10,000 francs. The experiment will consist of 15 periods. In each period, each participant will have an opportunity to place offers to sell OR buy units of X. At the beginning of the period, the computer will announce a randomly drawn initial price (from the uniform distribution on the interval [0,500]). To place an offer to buy (sell) units of X at this announced price level, enter how many units of X you would like to buy (sell) at this announced price level and select the buy (sell) button on your screen. Your offer to sell is limited by your Inventory of X, and your offer to buy cannot exceed 10 units. The computer totals all the offers to buy and all the offers to sell. An example of the bidding screen is provided below.



If the total number of units that participants offer to buy is greater than the total number of units that participants offer to sell, then the program increases the announced price level and each participant may then make offers to buy or sell at this higher price level.

If the total number of units that participants offer to buy is less than the total number of units that participants offer to sell, then the program decreases the announced price level and each participant may then make offers to buy or sell at this lower price level.

In both cases, the price adjustment made by the program is proportional to the difference between the total number of units participants offer to buy and the total number of units that participants offer to sell.

If the total number of units that participants offer to buy equals the total number of units that participants offer to sell, then the period is over and the offers placed by each participant at this price level are transacted. Each participant records the number of units that they bought (sold) and their earnings for the period.

Manual Conclusion of Period: If the price changes by one franc and remains in a region of three francs for four periods in a row (for example, if the price went from 100, to 101, back to 100, then back to 101, OR if the price went from 100, to 101, to 102, then back to 101), then we will conclude the period manually. The manual period conclusion process is as follows: the computer will show a screen announcing the manual conclusion of a period.

DO NOT CLICK THE **[ENTER]** BUTTON UNTIL THE EXPERIMENTER INSTRUCTS YOU TO DO SO!!!

On your BIDDING SHEET provided, write the price given by the computer for this price adjustment iteration and the amount of X that you want to buy OR sell. Note that if you want to sell, the amount written on the BIDDING SHEET cannot be more than your available inventory of X. The experimenter will then collect these sheets and total the amount of X that people want to buy and sell. If these amounts are equal, then the transactions will be made according to the bids made. If the amount offered to buy is greater than the amount offered to sell, then the units sold will be randomly allocated to the buyers. If the amount offered to sell is greater than the amount offered to buy, then the units bought will be randomly divided among the sellers. Once the allocation is determined for the period, the experimenter will return your BIDDING SHEETS back to you with the amount assigned to you to buy/sell. The experimenter will then instruct your to click the [ENTER] button to proceed to the bidding screen. Please enter the amount to buy/sell indicated on your BIDDING SHEETS into the computer in order to conclude the period.

5. Calculating your earnings

END OF PERIOD CASH = BEGINNING OF PERIOD CASH
+ DIVIDEND PER UNIT
x NUMBER OF UNITS HELD AT THE END OF PERIOD
+ SALES
- EXPENDITURES ON PURCHASES

PERIOD EARNINGS = END OF PERIOD CASH – BEGINNING OF PERIOD CASH

Subsequent periods should be recorded similarly. Your earnings for this experiment are given by the cash on hand at the end of period 15.

Example of period earnings. Suppose that in period 10 your BEGINNING OF PERIOD CASH is 3,000 francs and your INVENTORY at the beginning of period 10 is 7 units of X. If in period 10 you sell 2 units of X at a price of 200 francs and the dividend draw is 8 francs, then in period 10:

SALES= 2*200=400

INVENTORY (at the end of period 10) = 7- 2 = 5

PERIOD DIVIDEND EARNINGS = DIVIDEND PER UNIT * NUMBER OF UNITS IN INVENTORY = 8 * 5 = 40.

END OF PERIOD CASH = 3,000 +40+ 2*200 = 3,440

PERIOD EARNINGS = END OF PERIOD CASH – BEGINNING OF PERIOD CASH = 3,440 – 3,000 = 440.

6. Quiz

Question 1: Suppose that you purchase a unit of X in period 5.

a. What is the average dividend payment on the unit of X for period 5? _____
b. If you hold that unit of X till the end of the experiment (11 periods including the current period), what is the average total dividend paid on the unit of X? _____
c. What is the maximum possible dividend paid on the unit of X till the end of the experiment (11 periods including the current period)? _____
d. What is the minimum possible dividend paid on the unit of X till the end of the experiment (11 periods including the current period)? _____

Question 2: Suppose that you purchase a unit of X in period 15.

a. What is the average dividend payment on the unit of X for period 15? _____
b. If you hold that unit of X till the end of the experiment (1 period including the current period), what is the average total dividend paid on the unit of X? _____
c. What is the maximum possible dividend paid on the unit of X till the end of the experiment (1 period including the current period)? _____
d. What is the minimum possible dividend paid on the unit of X till the end of the experiment (1 period including the current period)? _____

Question 3: At the beginning of the period, the computer will announce a randomly drawn initial price between 0 and 500 francs.

a. If, at the announced price, the total number of units that participants offer to buy is greater than the total number of units that participants offer to sell, then will the program increase or decrease the announced price level? _____

b. If, at the announced price, the total number of units that participants offer to buy is less than the total number of units that participants offer to sell, then will the program increase or decrease the announced price level? _____

Question 4: What is the value of the asset after the final dividend payment in period 15? ______

AVERAGE HOLDING VALUE TABLE

Ending Period	Current period	Number of Remaining Dividend Payments	*	Average Dividend Value Per Period	=	Average Holding Value Per Unit of Inventory
15	1	15	*	24	=	360
15	2	14	*	24	=	336
15	3	13	*	24	=	312
15	4	12	*	24	=	288
15	5	11	*	24	=	264
15	6	10	*	24	=	240
15	7	9	*	24	=	216
15	8	8	*	24	=	192
15	9	7	*	24	=	168
15	10	6	*	24	=	144
15	11	5	*	24	=	120
15	12	4	*	24	=	96
15	13	3	*	24	=	72
15	14	2	*	24	=	48
15	15	1	*	24	=	24

BIDDING SHEET

(1) ENTER THE PERIOD OF MANUAL CONCLUSION	(2) ENTER THE PRICE GIVEN BY COMPUTER	(2) CIRCLE WHETHER YOU WANT TO BUY OR SELL	(3) ENTER NUMBER OF UNITS WANTED TO BUY OR SELL	(4) NUMBER OF UNITS ALLOCATED
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
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		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		
		BUY / SELL		

PERIOD EARNINGS SHEET

(1) PERIOD	(2) BEGINNING CASH	(3) +SALES -PURCHASES	(4) INVENTORY AT THE END OF PERIOD	(5) DIVIDEND PER UNIT	(6) PERIOD DIVIDEND EARNINGS	(7) END CASH	(8) BEGINNING CASH	(9) PERIOD EARNINGS
1	10,000						10,000	
2								
3								
4								
5								
6								
7								
8								
10								
11								
12								
13								
14								
15								