# The University of York 

Discussion Papers in Economics

| No. 13/03 |
| :---: |
| Does Sequentiality Impede Convergence? |
| John D. Hey and Daniela Di Cagno |
|  |

Department of Economics and Related Studies University of York

Heslington
York, YO10 5DD

# Does Sequentiality Impede Convergence? 

John D Hey ${ }^{1}$ and Daniela Di Cagno ${ }^{2}$


#### Abstract

Inspired by the conjecture that the necessity of trading through money in monetarised economies might hinder convergence to competitive equilibrium, and hence, for example, cause unemployment, we experimentally investigate behaviour in sequential markets. In order to evaluate the properties of these markets, we compare their behaviour to behaviour in simultaneous markets, where money does not intervene. As the trading mechanism might be a compounding factor, we investigate two kinds of mechanism: the double auction, where bids, asks and trades take place in continuous time throughout a trading period; and the clearing house, where bids and asks are placed once in a trading period, and which are then cleared by an aggregating device. We thus have four treatments, the pairwise combinations of simultaneous/sequential with double auction/clearing house. We find that: convergence is faster under simultaneous trading, implying that the necessity of using money to facilitate trade hinders convergence; that sequential trading is noisier than simultaneous trading; and that the volume of trade and realised surpluses are higher with the double auction than the clearing house. We suspect that the double auction, although on the surface more complicated for subjects to understand, enables them better to realise their desired trades. We also confirm the conjecture that inspired these experiments: that the necessity to use money in trading hinders convergence to competitive equilibrium, lowers realised trades and surpluses, and hence may cause unemployment.


JEL Classifications: C92, D40, E24
Keywords: clearing house mechanism, double auction mechanism, experimental markets, money, sequential trade, simultaneous trade.

Acknowledgements: The authors would like to express their gratitude to Andrea Lombardo for writing the software in Visual Studio for these experiments. We also thank LUISS for use of their purpose-built laboratory, run under the auspices of CESARE.

Corresponding author: Hey, Department of Economics and Related Studies, University of York, Heslington, York YO10 5DD, UK, john.hey@york.ac.uk

[^0]
## 1. Introduction

As Clower famously said in 1967, as part of the then ongoing 'Keynesian Revolution' (partly initiated by Leijonhufvud, 1968): "Money buys goods and goods buy money; but goods do not buy goods". This aphorism seemed to have been forgotten as part of the demise of Keynes' ideas, but is now perhaps becoming back into economists' thoughts as a consequence of recent events. The key idea is that, in money-based economies, goods cannot be bartered directly for each other; instead money has to be used as a go-between. This may interfere with convergence to equilibrium, particularly, as Clower thought, in the labour market: firms do not employ workers as they cannot see the extra sales generated by them doing so. Involuntary unemployment may result.

In Hey and Di Cagno (1998) we reported on an experiment to test Clower's conjecture, using a sequential market with the double auction trading mechanism. We did indeed see a departure from convergence to the competitive equilibrium, but that experiment was partial in that it did not compare the sequential outcome with the simultaneous outcome. Moreover we felt that the lack of convergence might have resulted from the trading mechanism that we used, rather than from the sequentiality of the trading; we felt that the double auction mechanism may have been confusing for the subjects (despite the fact that many experiments ${ }^{3}$ have successfully demonstrated convergence with the double auction mechanism in a simultaneous environment). Hence the present experiment, in which we have four treatments, with each of simultaneous and sequential trading paired with each of two trading mechanisms - double auction and clearing house. We chose the clearing house mechanism ${ }^{4}$ as we felt that it was simpler for subjects to understand. With this mechanism, instead of trading being continuous throughout the trading period, buyers and sellers place bids and asks just once within each trading period. In a simultaneous context ${ }^{5}$ these bids and asks both consist of a price quantity pair $(p, q)$ : for buyers this indicates that they are willing to pay up to the price $p$ for up to the quantity $q$; for sellers this indicates that they are willing to

[^1]accept down to the price $p$ for up to the quantity $q$. These bids and asks are then aggregated (by the computer) and a clearing price is announced; this price is such that the aggregate demand at that price is equal to the aggregate supply: all buyers with a price $p$ less than or equal to the clearing price can buy up to their amount $q$ and all sellers with a price more than or equal to the clearing price can sell up to their amount $q$. There may be some buyers with unsatisfied demand at that price, and there may be some sellers with unsatisfied supply, but these buyers or sellers are indifferent between buying or selling these unsatisfied units at the clearing price.

This mechanism is, on the surface, easier for subjects to understand, and certainly less frenetic than the double auction mechanism: subjects have the whole of the trading period (in our experiment three minutes) to decide on their bids and asks; in contrast, in a double auction market, trading is continuous and usually brisk: agents may be overwhelmed by the activity in the market and perhaps respond like zero-intelligence traders (see Gode and Sunder 1993) ${ }^{6}$.

We shall see that our conjecture about the two market mechanisms is not confirmed by the evidence; on the other hand Clower's conjecture is - for both mechanisms.

The paper is organised as follows: in section 2 we describe the general nature of the problems that our subjects had to tackle; we then show in section 3 what economic theory has to say about its solution; we then give more experimental detail in section 4, before analysing the results of the experiment in section 5 . Section 6 concludes.

## 2. The Experimental Environment

We keep the environment as simple as possible, yet staying faithful to Clower's insight. There are two goods, $X$ and $Y$. There are two types of traders: Type $X$ and Type $Y$ and there are $n$ of each Type ${ }^{7}$. Trading is divided up into trading days. In each day, Type $X$ traders are endowed with a quantity $\underline{x}$ of Good X, but none of Good Y; mutatis mutandis Type Y traders are endowed with none of Good X but

[^2]a quantity $£$ of Good $Y$. Trade takes place throughout the day and the payment to each subject depends upon the amounts of the two goods they end up with at the end of the day. To be specific if a trader of either type ends the day with $x$ of $\operatorname{Good} X$ and $y$ of $\operatorname{Good} Y$ their payment for that day will be $10 V(x y)$ in euro cents ${ }^{8}$. Clearly if either type of agent does not trade in any day, they end up with zero payment for that day.

We had four treatments, namely each of simultaneous and sequential paired with each of double auction and clearing house. We had three sessions of each treatment (with different parameters see later). We use the following notation (where the $i=1,2,3$ refers to a particular session of that treatment):

|  | Double auction | Clearing house |
| :---: | :---: | :---: |
| Simultaneous | SDi | SCi |
| sequentiaL | LDi | LCi |

In the simultaneous treatments, each trading day is independent of all the others and there is no money. In the sequential treatments, however, there is (experimental) money and trade must be carried out using this (experimental) money. Accordingly in the sequential treatments, we divided up each trading day into a morning, an afternoon and an evening: in the morning the market for Good X was open and agents could buy and sell Good X using (experimental) money; in the afternoon the market for Good $Y$ was open and agents could buy and sell Good $Y$ using (experimental) money; in the evening accounting was done and the agents informed as to how much real money they had earned for that day. The experimental money used in the trading process had no value, however; all agents were endowed with a stock of experimental money at the beginning of the experimental session but it was worthless at the end.

A moment's reflection will realise that there is a potential problem here: if the subjects knew the number of trading days that the experiment would last, and if they could perform backward induction, no trade would ever take place: since experimental money is worthless at the end, no

[^3]Type Y would want to accept any experimental money on the afternoon of the final day; as a consequence no Type $X$ would accept any money in the morning of the final day, and so on backwards. To solve this problem, and to make the experiment more realistic, we had to make the number of days that the experiment lasted random. Ideally we would have preferred to have a stationary mechanism so that the probability of any day being the final day, given that the experiment had lasted to that day, would be a fixed number, but there are two problems with this: first, subjects seem to have difficulty in understanding the mechanism (if we say the probability of the experiment finishing at the end of any day is 0.1 , they get increasingly nervous at and after day 10, even though there is no need to be); second if we implement it honestly, we could end up with a session having very few days, thus giving us very few observations. We adopted a compromise: we said that the experiment would last at least 18 days, and that then and thereafter the probability would be one-half that the experiment would finish at the end of any day. In practice, 5 of the 12 sessions lasted 18 periods, 5 lasted 19 periods and 2 lasted 20 periods.

As we have already noted, we ran three different sessions of each treatment. These differed in terms of the $\underline{x}$ and $\underline{y}$. Specifically, in sessions $i=1, \underline{x}=\underline{y}=40$; in sessions $i=2, \underline{x}=60$ and $\underline{y}=30$; and in sessions $i=3, \underline{x}=30$ and $\underline{y}=60$. We wanted to see if changes in the initial endowments affected convergence.

## 3. Some Economic Theory

Here we specify the stationary equilibrium. We consider each day as a whole. Let us denote by $p$ and $q$ the (absolute) prices of Good $X$ and Good $Y$. Type $X$ subjects want to maximise $10 v(x y)$ subject to $p \underline{x}=p x+q y ;$ the solution to this is $x^{*}=\underline{x} / 2$ and $y^{*}=(p \underline{x}) /(2 q)$. Type $Y$ subjects want to maximise $10 v(x y)$ subject to $q y=p x+q y$; the solution to this is $x^{*}=(q y) /(2 p)$ and $y^{*}=y / 2$. Given that there are equal numbers of each type, equilibrium implies that, either $(p \underline{x}) /(2 q)=y / 2$, or $\underline{x} / 2=(q y) /(2 p)$, and hence that the relative price of Good $Y$ in the stationary equilibrium, $q / p$, is equal to $x / y$. Thus the good relatively lower in supply is relatively higher priced. In our three sessions, this stationary
equilibrium relative price of Good Y is 1 in sessions 1, 2 in sessions 2, and 0.5 in sessions 3 . Our experiment is partly to see if actual relative prices converge to these. We note that in this static competitive equilibrium, the payment to any subject on any given day is given by $5 \mathrm{~V}(\underline{x} y)$.

## 4. Some Experimental Detail

The experiment was carried out in the purpose-built CESARE ${ }^{9}$ laboratory at LUISS in Rome. It was run using software written in Visual Studio by Andrea Lombardo. Subjects were recruited from a register using ORSEE (Greiner 2004). Instructions were in Italian; an English translation can be found in the Appendix (not to be published) and online at http://www.york.ac.uk/economics/research/research-clusters/experimental-economics/research/ongoing-projects/\#tab-4. The software included a calculator which enables subjects to see the real money earnings for any end-of-day holdings of the two goods. There were a total of 12 sessions, three of each treatment, with 10 subjects in each session. In any one treatment, all parameters were fixed. No communication was allowed between the subjects. After subjects arrived they were given written instructions and any questions were answered. Subjects were aware only of their endowments of the two goods and not the endowments of the other subjects in the experimental session. The experiment then started and continued until the computer randomly determined when it was over. Subjects were paid in cash and, after signing a receipt, were free to go. No subject participated in more than one session. Subjects earned on average $€ 31.59$. Different treatments lasted different amounts of time, with the sequential treatments taking longer.

## 5. Results

### 5.1 Prices

[^4]The key results concerning the pattern of prices during the periods of the experiment can be found in Figure 1. Means and standard deviations can be found in Table 1. If we start with the conventional treatment - the Simultaneous Double Auction, SD - we see from the top left hand graph that the relative price of Good $Y$ converges rapidly to the theoretical predictions (1 for SD1, 2 for SD2 and 0.5 for SD3). The first of these is particularly rapid, but this may be because of some kind of focal point effect (equality of prices). This may also account for the initial stages of SD2 and SD3 - starting off around 1 before almost converging to their theoretical values; SD3 is slightly high at the end, but not by much. The Simultaneous Clearing House, SC, in the top-right, is almost as good, though once again the third session is slightly above its theoretical value, and slightly more so that the Simultaneous Double auction.

When we get on to the sequential markets, things change. The bottom-lower graph in Figure 1 shows that prices are erratic, particularly for LD1. The mean price in LD1 is in between the mean price in LD2 and LD3, as it should be, and the mean prices in LD2 and LD3 are not too far from their theoretical values, but the variances are high - indicating that the sequentiality is hindering convergence to equilibrium. Interestingly the Sequential Clearing house (in the bottom-right) is somewhat less erratic and LC1 and LC2 on average are close to their theoretical values, but in LC3 the relative price of Good $Y$ is well below what it should be.

We suspect that the sharp upturn in the relative price of Good $Y$ in the Sequential Double Auction may have been a consequence of subjects getting apprehensive about the end of the experiment, and, in particular, with Type $Y$ subjects getting increasingly reluctant to sell (in exchange for probably worthless experimental money).

### 5.2 Volumes

One feature that we would expect from prices being away from equilibrium is that trading volumes are different from those that we would expect. Figure 2 shows trading volumes, expressed as a percentage of the volume in the static competitive equilibrium, for both Good $X$ (the thinner lines) and Good $Y$ (the thicker lines); in Figure 3 total volumes are shown. Means and standard deviations
are, once again, shown in Table 1. We should note that there is no reason why this measure might not be above $100 \%$ - if there is 'too much' trade.

Looking first at Figure 2, we see that in the Simultaneous Double Auction treatment, volumes are generally close to $100 \%$ (Figure 3 confirms this) with no obvious tendency for one good to have a higher volume than the other. The same is true for the Simultaneous Clearing house, though it takes somewhat longer to get close to $100 \%$ efficiency. Things change dramatically, though, with the Sequential treatments, where trading volumes are well below $100 \%$, both for the Double auction and the Clearing House, though the latter is more erratic. There is no obvious tendency for one Good to be traded more than the other. Figure 3 confirms these general results.

### 5.3 Payments

Payments to subjects per period are shown in Figures 4 and 5, the former differentiated by Type and the latter being averages of the two Types. Summaries are also presented in Table 2. In both the Figures and the Table, we present actual payments as a percentage of the payments in the static competitive equilibrium: these latter are $€ 2.00$ in sessions 1 and $€ 2.12^{10}$ in sessions 2 and 3 . It follows from the definition of these variables that the maximum the average can be in all cases is 100 . However one Type may receive more than 100 - though it has to be at the expense of the other Type. However there is no clear indication from Figure 4 or from Table 3 that one Type was consistently doing better than the other.

In Figure 4 it is clear that in the Simultaneous Double auction payments to subjects are around what they should be in the static competitive equilibrium and there is no obvious sign that one Type was paid more than the other. The latter is also true in the Simultaneous Clearing house, but payments in general were a lot lower than in the Simultaneous Double Auction. The same is true in the Sequential treatments, where payments on average to the subjects in the Clearing house treatment were a lot lower than in the Double auction. We note that payments were also more erratic in the Sequential Double auction as compared with the Simultaneous Double auction. Going from

[^5]Simultaneous to Sequential with the Double auction sees a sizeable decrease in average payments to subjects, while there was only a small decrease in the average payments to subjects with the Clearing house. However this analysis ignores a trend effect: with the Simultaneous Clearing house the trend is upwards throughout the periods of trading, almost reaching 100 by the end, while the Sequential Clearing house starts higher but ends up well below 100 at the end. Interestingly in the Double auction, Type $Y$ subjects tend to be paid more than Type $X$, though the position is not clear with the Clearing house.

## 6. Conclusions

One clear message emerges from these experiments: sequentiality hinders convergence to equilibrium. As a consequence, realised trading volumes in the sequential treatments are lower than they would be in the static competitive equilibrium, and, of necessity, realised payments/surpluses are lower. Moreover, switching to a Clearing House mechanism does not remove the inefficiencies resulting from sequential trading. However, we should note that the reduction in payments in the Clearing House is much smaller than the reduction for the Double Auction, but mainly because the Clearing House starts from a lower base. Indeed, we see markedly lower payments in the Clearing House treatment than in the Double Auction treatment - a result markedly different from that reported by Friedman (1993). It is not clear what caused these differences, though it should be noted that in Friedman's experiments, trading was always between a good (with a stated value) and real money; in contrast we have trading between two goods (either directly or indirectly) the value of which depended upon the combinations of the two goods. Moreover in Friedman's experiments, which were simultaneous, the price of the trade was always explicit, while in ours the price was implicit in terms of the ratio of the quantities.

The bottom line is the finding that trading volumes, and payments, in the Sequential treatments are lower than in the Simultaneous treatments, and hence lower than they could/should be in the competitive equilibrium. This finding confirms Clower's conjecture: that the necessity of trading
through money may cause lack of trade, and hence, in particular, create involuntary unemployment. Sequentiality does indeed impede convergence.

## References

Clower, R.W. (1967). "A Reconsideration of the Microfoundations of Monetary Theory". Economic Inquiry. 6, 1-8.

Friedman, D. (1998). "How Trading Institutions Affect Financial Market Performance: Some Laboratory Experiments". Economic Inquiry. 31, 410-435.

Gode, D. K. and Sunder, S. (1993). "Allocative Efficiency of Markets with Zero-Intelligence Traders: Market as a Partial Substitute for Individual Rationality". Journal of Political Economy. 101, 119-137. Leijonhufvud, A. (1968). On Keynesian Economics and the Economics of Keynes. Oxford: Oxford University Press.

Greiner, B. (2004), "The Online Recruitment System ORSEE 2.0-A Guide for the Organization of Experiments in Economics". University of Cologne, Working Paper Series in Economics 10.

Hey J. D. and Di Cagno D. (1998), "Sequential Markets: An Experimental Investigation of Clower's Dual Decision Hypothesis". Experimental Economics. 1, 63-87.

Smith, V.L. (1962), "An Experimental Study of Competitive Market Behavior". Journal of Political Economy. 70, 111-137.

Table 1: Summary statistics on prices and volumes (actual and theoretical)

| Treatment | Session | Number of periods | Endowment of good $X$ of each of the 5 Type X subjects | Endowment of good $Y$ of each of the 5 Type X subjects | Theoretical relative price of Good Y | Actual average relative price of Good Y (*) | Actual average trading volume (*!) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| SD | 1 | 19 | 40 | 40 | 1 | $\begin{gathered} 0.92 \\ (0.07) \\ \hline \end{gathered}$ | $\begin{aligned} & 103.92 \\ & (11.49) \\ & \hline \end{aligned}$ |
|  | 2 | 18 | 60 | 30 | 2 | $\begin{gathered} \hline 1.84 \\ (0.37) \\ \hline \end{gathered}$ | $\begin{aligned} & 109.76 \\ & (7.03) \\ & \hline \end{aligned}$ |
|  | 3 | 20 | 30 | 60 | 0.50 | $\begin{gathered} 0.63 \\ (0.08) \end{gathered}$ | $\begin{aligned} & 97.38 \\ & (8.70) \end{aligned}$ |
| SC | 1 | 18 | 40 | 40 | 1 | $\begin{gathered} 0.97 \\ (0.04) \\ \hline \end{gathered}$ | $\begin{gathered} 93.11 \\ (18.92) \\ \hline \end{gathered}$ |
|  | 2 | 19 | 60 | 30 | 2 | $\begin{gathered} 1.94 \\ (0.34) \end{gathered}$ | $\begin{gathered} \hline 84.29 \\ (18.53) \end{gathered}$ |
|  | 3 | 18 | 30 | 60 | 0.50 | $\begin{gathered} 0.74 \\ (0.05) \\ \hline \end{gathered}$ | $\begin{gathered} 78.45 \\ (15.41) \end{gathered}$ |
| LD | 1 | 18 | 40 | 40 | 1 | $\begin{gathered} 1.46 \\ (0.40) \\ \hline \end{gathered}$ | $\begin{gathered} \hline 46.61 \\ (12.35) \end{gathered}$ |
|  | 2 | 19 | 60 | 30 | 2 | $\begin{gathered} 2.07 \\ (0.51) \end{gathered}$ | $\begin{gathered} 75.15 \\ (13.02) \\ \hline \end{gathered}$ |
|  | 3 | 18 | 30 | 60 | 0.50 | $\begin{gathered} 0.67 \\ (0.17) \end{gathered}$ | $\begin{gathered} \hline 74.11 \\ (13.16) \end{gathered}$ |
| LC | 1 | 20 | 40 | 40 | 1 | $\begin{gathered} 0.90 \\ (0.11) \\ \hline \end{gathered}$ | $\begin{gathered} \hline 63.33 \\ (15.91) \\ \hline \end{gathered}$ |
|  | 2 | 19 | 60 | 30 | 2 | $\begin{gathered} 2.26 \\ (0.72) \end{gathered}$ | $\begin{gathered} \hline 65.18 \\ (15.21) \end{gathered}$ |
|  | 3 | 19 | 30 | 60 | 0.50 | $\begin{gathered} \hline 0.24 \\ (0.06) \end{gathered}$ | $\begin{gathered} \hline 53.88 \\ (15.85) \end{gathered}$ |

[^6]Table 2: Means (and standard deviations) of average payments to subjects expressed as a percentage of the payments in the static equilibrium

| Treatment | Type | Session 1 | Session 2 | Session 3 |
| :---: | :---: | :---: | :---: | :---: |
| SD | X | 95.88 | 94.70 | 86.50 |
|  |  | $(8.76)$ | $(8.08)$ | $(6.77)$ |
|  | Y | 87.60 | 88.27 | 103.93 |
|  |  | $(7.99)$ | $(11.84)$ | $(6.05)$ |
|  | Both | 91.74 | 91.48 | 95.21 |
|  |  | $(5.41)$ | $(4.47)$ | $(2.44)$ |
| SC | X | 87.40 | 67.05 | 71.86 |
|  |  | $(15.96)$ | $(21.00)$ | $(12.53)$ |
|  | Y | 58.87 | 85.42 | 74.63 |
|  |  | $(15.99)$ | $(17.48)$ | $(16.12)$ |
|  | Both | 73.14 | 76.23 | 73.24 |
|  |  | $(11.78)$ | $(17.65)$ | $(10.49)$ |
|  | X | 70.27 | 82.28 | 77.65 |
|  |  | $(8.31)$ | $(11.52)$ | $(17.22)$ |
|  | Y | 87.06 | 88.15 | 93.12 |
|  |  | $(11.15)$ | $(11.28)$ | $(16.08)$ |
|  | Both | 78.66 | 85.21 | 85.38 |
|  |  | $(6.57)$ | $(7.70)$ | $(4.96)$ |
| LC | X | 74.89 | 82.94 | 52.27 |
|  |  | $(19.94)$ | $(21.18)$ | $(17.83)$ |
|  | Y | 71.03 | 71.33 | 89.18 |
|  |  | $(19.98)$ | $(19.33)$ | $(13.71)$ |
|  | Both | 72.96 | 77.13 | 70.72 |
|  |  | $(8.40)$ | $(10.38)$ | $(10.40)$ |

*: Standard deviations in parentheses

Figure 1: The Relative Prices of Good $Y$ in the 12 sessions. (Key: $A B i$ is relative price in treatment $A B$ session i)


Figure 2: Trading Volumes of Good $X$ and of Good $Y$ (as a percentage of those in the static equilibrium) in the 12 sessions (Key: ZABi is trading volume of Type $Z$ in treatment $A B$ session $i$, Type $Y$ is thicker)


Figure 3: Total Trading Volumes (as a percentage of those in the static equilibrium) in the 12 sessions (Key: $A B i$ is total trading volume in treatment $A B$ session i)


Figure 4: Payments (as a percentage of those in the static equilibrium) to Type $X$ and of Type $Y$ in the 12 sessions (Key: ZABi is payments to Type $Z$ in treatment $A B$ session $i$, Type $Y$ is thicker)


Figure 5: Total Payments (as a percentage of those in the static equilibrium) in the 12 sessions (Key: $A B i$ is total trading volume in treatment $A B$ session i)


# Appendix: not to be published: Instructions for the Simultaneous Double Auction 

## CESARE

## Centro di Economia Sperimentale a Roma Est

Welcome to this experiment on the economics of market decision making. The Italian Ministry of Education, MIUR, has provided the funds for the experiment. 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 immediately after the end of the experiment.

## INTRODUCTION

In this experiment we are going to simulate a market in which you can trade two goods - Good $X$ and Good Y - in a sequence of (experimental) market days. Each (experimental) market day consists of a morning and an evening: in the morning the market is open and you can trade Good $X$ for Good $Y$; in the evening, book-keeping is done and the amount of real money that you have earned for that particular day is calculated. Your earnings for any particular day of the experiment depend upon the amounts of the two goods with which you end up in that day. Your earnings for the entire experiment consist of the sum of the earnings on each and every day.

## THE NUMBER OF DAYS THAT THE EXPERIMENT WILL LAST

The actual number of market days that the experiment will last will be determined by chance. However, there will definitely be at least 18 days in the experiment. After that point, at the end of every day that the experiment continues, the computer will generate at random a number which is either zero or one, each with probability one-half. If the number is 0 the experiment will stop at that point; if the number is 1 the experiment will continue for a further day. So the experiment will definitely last at least 18 days, but it may last for 19 , or 20 , or 21 , or $22, \ldots$ days. The number of days that it will last is thus determined at random by the computer.

## THE SUBJECTS

There are two types of subjects in this experiment: Type $X$ subjects who are endowed with Good X each day but not with Good $Y$; Type $Y$ subjects who are endowed with Good $Y$ each day but not with Good X. Your daily endowment will be the same on each day that the experiment lasts and you will be told your daily endowment before the experiment starts.

## THE MARKET

In the morning the market is open. In this market, Type $X$ subjects (those who are endowed with Good $X$ ) are potential sellers of Good $X$ and potential buyers of Good $Y$, while Type $Y$ subjects (those who are endowed with Good $Y$ ) are potential buyers of Good $X$ and potential sellers of Good $Y$.

## YOUR PAYMENT

Your payment for each day of the experiment is determined by the amounts of the two goods with which you end up at the end of that day. More precisely, if you end up with a quantity $x$ of Good $X$ and a quantity $y$ of Good $Y$ you will be paid $10 V(x y)$ pence. (The symbol $V$ indicates the square root.) For example, if you end up with 10 of Good $X$ and 10 of Good $Y$ you will be paid 10 V 100 pence $=100$ pence $=€ 1$. 00 . If you end up with 8 of Good $X$ and 18 of Good $Y$ you will be paid $10 \sqrt{ } 144$ pence $=120$ pence $=€ 1.20$. Note that if you end up with zero of either good you will be paid nothing. As noted already, your payment for the experiment as a whole is the sum of the payments for each of the days that the experiment has lasted.

Please note that you cannot carry stocks of the goods over from one day to the next.

## THE TRADING MECHANISM

The trading mechanism used in this experiment is what is called the double auction mechanism. Do not worry if you have not encountered this before - it is easy to understand. It is a continuous process, with trading taking place continuously throughout the trading period. At any time during the trading period Type $X$ subjects (those endowed with Good $X$ ) can make a bid consisting of a quantity of Good $X$ and a quantity of Good $\mathrm{Y}-\left(q_{x} q_{Y}\right)$, while Type Y subjects (those endowed with Good Y ) can similarly make a bid consisting of a quantity of Good $X$ and a quantity of $\operatorname{Good} Y-\left(q_{x}, q_{Y}\right)$. While these look the same, the interpretation is different. For a Type $X$ subject a bid $\left(q_{x}, q_{y}\right)$ means that that subject is willing to offer up to $q_{x}$ units of Good $X$ in exchange for at least $q_{Y}$ units of Good $Y$. For a Type $Y$ subject a bid ( $q_{x} q_{Y}$ ) means that that subject is willing to offer up to $q_{\gamma}$ units of Good $Y$ in exchange for at least $q_{X}$ units of Good $X$. We note that only integer values are allowed for the quantities in the bids. Obviously sellers must hold the number of units that they wish to sell. Any such bids will be posted on all screens for all subjects to see. At any time, subjects can accept all or part of any posted bid. Partial acceptance by a Type $Y$ subject of a bid ( $q_{x} q_{r}$ ) posted by a Type $X$ subject means that the Type $Y$ subject is willing to supply up to $q_{r}$ units of Good $Y$ accepting in exchange units of Good $X$ at the rate $q_{X} / q_{r}$. Similarly, partial acceptance by a Type $X$ subject of a bid ( $q_{x} q_{Y}$ ) posted by a Type $Y$ subject means that the Type $X$ subject is willing to supply up to $q_{x}$ units of Good $X$ accepting in exchange units of Good $Y$ at the rate $q_{V} / q_{x}$. After acceptance or partial acceptance, the good is traded and accounts adjusted by the computer. This bidding, asking and acceptance process continues throughout the trading period, which lasts for 4 minutes each day.

## ACCOUNTING

As we have already noted: each subject will be told how many units of the two goods that they have traded; the computer will carry out the appropriate book-keeping. At the end of each day you will be told how many units of the two goods you have ended up with and the earnings implied by these amounts.

PRACTICE SESSIONS
In order that you fully understand the experiment, you will be allowed two practice days before the experiment proper starts. The earnings you get in these practice days will not count towards your earnings.

## timekeeping

Each market session will last four minutes. A clock on all subjects' screens in the top right hand corner of the screen will display the time left (in minutes and seconds) to the end of that particular session. You will always know how much time is left at any point.

OTHER
If you are unsure about any aspect of this experiment please ask one of the experimenters. We hope you find it fruitful.

# Appendix: not to be published: Instructions for the Simultaneous Clearing House 

## CESARE

## Centro di Economia Sperimentale a Roma Est

Welcome to this experiment on the economics of market decision making. The Italian Ministry of Education, MIUR, has provided the funds for the experiment. 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 immediately after the end of the experiment.

## INTRODUCTION

In this experiment we are going to simulate a market in which you can trade two goods - Good $X$ and Good $Y$ - in a sequence of (experimental) market days. Each (experimental) market day consists of a morning and an evening: in the morning the market is open and you can trade Good $X$ for Good $Y$; in the afternoon, book-keeping is done and the amount of real money that you have earned for that particular day is calculated. Your earnings for any particular day of the experiment depend upon the amounts of the two goods with which you end up in that day. Your earnings for the entire experiment consist of the sum of the earnings on each and every day.

## THE NUMBER OF DAYS THAT THE EXPERIMENT WILL LAST

The actual number of market days that the experiment will last will be determined by chance. However, there will definitely be at least 18 days in the experiment. After that point, at the end of every day that the experiment continues, the computer will generate at random a number which is either zero or one, each with probability one-half. If the number is 0 the experiment will stop at that point; if the number is 1 the experiment will continue for a further day. So the experiment will definitely last at least 18 days, but it may last for 19 , or 20 , or 21 , or $22, \ldots$ days. The number of days that it will last is thus determined at random by the computer.

## THE SUBJECTS

There are two types of subjects in this experiment: Type $X$ subjects who are endowed with Good $X$ each day but not with Good $Y$; Type $Y$ subjects who are endowed with Good $Y$ each day but not with Good X. Your daily endowment will be the same on each day that the experiment lasts. You will be told your Type and your daily endowment before the experiment starts.

## THE MARKET

In the morning the market is open. In this morning market, Type $X$ subjects (those who are endowed with Good $X$ ) are potential sellers of Good $X$ and potential buyers of Good $Y$, while Type $Y$ subjects (those who are endowed with Good $Y$ ) are potential buyers of Good $X$ and potential sellers of Good $Y$.

## YOUR PAYMENT

Your payment for each day of the experiment is determined by the amounts of the two goods with which you end up at the end of that day. More precisely, if you end up with a quantity $x$ of Good $X$ and a quantity $y$ of Good $Y$ you will be paid $10 V x y$ pence. (The symbol $v$ indicates the square root.) For example, if you end up with 10 of Good $X$ and 10 of Good $Y$ you will be paid $10 \sqrt{ } 100$ pence $=100$ pence $=€ 1$. 00 . If you end up with 8 of Good $X$ and 18 of Good $Y$ you will be paid 10 V 144 pence $=120$ pence $=€ 1.20$. Note that if you end up with zero of either good you will be paid nothing. As noted already, your payment for the experiment as a whole is the sum of the payments for each of the days that the experiment has lasted.

Please note that you cannot carry stocks of the goods over from one day to the next.

## THE TRADING MECHANISM

The trading mechanism used in this experiment is what is called the clearing house mechanism. Do not worry if you have not encountered this before - it is easy to understand. Type $X$ subjects - those who are endowed with Good $X$ - are asked to make a bid consisting of a quantity of Good $X$ and a quantity of Good $Y$ - ( $q_{X}, q_{Y}$ ). Similarly Type $Y$ subjects - those who are endowed with Good $Y$ - are asked to make a bid consisting of a quantity of Good $X$ and a quantity of $\operatorname{Good} Y-\left(q_{X}, q_{Y}\right)$. The Type $X$ 's bid will be interpreted to mean that this subject is willing to trade at most $q_{X}$ units of Good $X$ in exchange for at least $q_{Y}$ units of Good $Y$; if a Type $X$ subject does not want to trade, then no bid should be entered. The Type $Y$ 's bid will be interpreted to mean that this subject is willing to trade at most $q_{Y}$ units of Good $Y$ in exchange for at least $q_{X}$ units of Good X; if a Type Y subject does not want to trade, then no bid should be entered. We note that only integer values are allowed for the quantities in the bids. Of course, sellers must actually have the units of the good they are intending to sell. There is a pre-determined time for entering bids and asks, and the computer will display the remaining time. If a subject does not enter a bid, the computer will interpret this as the subject not wanting to trade. When the time has elapsed, the computer will calculate the equilibrium exchange rate between the two goods and the traded quantities in the market. The equilibrium exchange rate will be determined as the exchange rate at which the quantities offered for sale are equal to the quantities demanded for purchase, for both goods. The computer will then inform each subject of the amounts they have bought and the amounts of the other good that they have sold. It is important to note: (1) that a buyer may not be able to buy all the quantity he or she bid for if the implicit exchange rate in the bid is lower than the equilibrium exchange rate or the quantity offered by the sellers is not sufficiently high; (2) that a buyer may pay less than the number of units offered if the equilibrium exchange rate is lower than the exchange rate in the bid; (3) that a seller may not be able to sell all the quantity he or she offered if the exchange rate implicit in the bid is higher than the equilibrium exchange rate or if the quantity demanded by the buyers is not sufficiently high; (4) that a seller may get more than the number of units asked for if the equilibrium exchange rate is higher than the exchange rate implicit in the bid. We note that the equilibrium prices and quantities will be integers.

## ACCOUNTING

As we have already noted: each subject will be told how many units of the two goods that they have traded. The computer will carry out the appropriate book-keeping. At the end of each day you will be told how many units of the two goods you have ended up with and the earnings implied by these amounts.

## PRACTICE SESSIONS

In order that you fully understand the experiment, you will be allowed two practice days before the experiment proper starts. The earnings you get in these practice days will not count towards your earnings.

## TIMEKEEPING

Each market session will last four minutes. A clock on all subjects' screens in the top right hand corner of the screen will display the time left (in minutes and seconds) to the end of that particular session. You will always know how much time is left at any point. If you do not enter a bid during the time allowed, your bid will be taken to be zero.

## OTHER

If you are unsure about any aspect of this experiment please ask one of the experimenters. We hope you find it fruitful.

# Appendix: not to be published: Instructions for the Sequential Double Auction 

## CESARE

## Centro di Economia Sperimentale a Roma Est

Welcome to this experiment on the economics of market decision making. The Italian Ministry of Education, MIUR, has provided the funds for the experiment. 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 immediately after the end of the experiment.

## INTRODUCTION

In this experiment we are going to simulate two markets in which you can buy or sell two goods Good $X$ and Good $Y$ - in a sequence of (experimental) market days. Each (experimental) market day consists of a morning, an afternoon and an evening: in the morning the market for Good X is open and you can buy or sell Good X using (experimental) money; in the afternoon the market for Good Y is open and you may buy or sell Good $Y$ using (experimental) money; in the evening, book-keeping is done and the amount of real money that you have earned for that particular day is calculated. Your earnings for any particular (experimental) day of the experiment depend upon the amounts of the two goods with which you end up in that day. Your earnings for the entire experiment consist of the sum of the earnings on each and every day. The actual experimental money used to facilitate trade during the experiment becomes worthless at the end of it.

## THE NUMBER OF DAYS THAT THE EXPERIMENT WILL LAST

The actual number of market days that the experiment will last will be determined by chance. However, there will definitely be at least 18 days in the experiment. After that point, at the end of every day that the experiment continues, the computer will generate at random a number which is either zero or one, each with probability one-half. If the number is 0 the experiment will stop at that point; if the number is 1 the experiment will continue for a further day. So the experiment will definitely last at least 18 days, but it may last for 19 , or 20 , or 21 , or $22, \ldots$ days. The number of days that it will last is thus determined at random by the computer.

## THE SUBJECTS

There are two types of subjects in this experiment: Type $X$ subjects who are endowed with Good $X$ each day but not with Good $Y$; Type $Y$ subjects who are endowed with Good $Y$ each day but not with Good X. Your daily endowment will be the same on each day that the experiment lasts and you will be told your daily endowment before the experiment starts. In addition all subjects are endowed at the beginning of the experiment with some experimental money: this is to facilitate trade only and becomes worthless at the end of the experiment.

## THE MARKETS

In the morning the market for Good $X$ is open. In this morning market, Type $X$ subjects (those who are endowed with Good $X$ ) are potential sellers of the good while Type $Y$ subjects (those who are endowed with Good $Y$ ) are potential buyers of the good. In the afternoon the market for Good $Y$ is open. In this afternoon market, Type $X$ subjects (those who are endowed with Good $X$ ) are potential buyers of the good while Type $Y$ subjects (those who are endowed with Good $Y$ ) are potential sellers of the good. The trading rules are described below.

Your payment for each day of the experiment is determined by the amounts of the two goods with which you end up at the end of that day. More precisely, if you end up with a quantity $x$ of Good $X$ and a quantity $y$ of Good $Y$ you will be paid $10 V(x y)$ pence. (The symbol $V$ indicates the square root.) For example, if you end up with 10 of Good $X$ and 10 of Good $Y$ you will be paid $10 \vee 100$ pence $=100$ pence $=€ 1$. 00 . If you end up with 8 of Good $X$ and 18 of Good $Y$ you will be paid $10 \vee 144$ pence $=120$ pence $=€ 1.20$. Note that if you end up with zero of either good you will be paid nothing. As noted already, your payment for the experiment as a whole is the sum of the payments for each of the days that the experiment has lasted.

Please note that you cannot carry stocks of the goods over from one day to the next - experimental money alone can be held from one day to the next.

## THE TRADING MECHANISM

The trading mechanism used in this experiment is what is called the double auction mechanism. Do not worry if you have not encountered this before - it is easy to understand. It is a continuous process, with trading taking place continuously throughout the trading period. At any time during the trading period potential buyers can make a bid consisting of a price and a quantity - $(p, q)$ - and potential sellers can make an ask consisting also of a price and a quantity - $(p, q)$. A bid $(p, q)$ means that that buyer is willing to pay up to a price $p$ for up to $q$ units of the good. Likewise, an ask $(p, q)$ means that the seller is willing to accept any price down to $p$ for up to $q$ units of the good. We note that only integer values are allowed for the prices and quantities in the bids and asks. Obviously sellers must hold the number of units that they wish to sell and buyers must have the experimental money necessary to pay for the bid (namely pq). Any such bids and asks will be posted on all screens for all traders to see. At any time, buyers can accept all or part of any posted ask and sellers can accept all or part of any posted bid. Partial acceptance of a bid ( $p, q$ ) by some seller means that the seller will sell up to $q$ units of the good at the price $p$. Similarly partial acceptance of an ask $(p, q)$ by some buyer means that the buyer will buy up to $q$ units of the good at the price $p$. After acceptance or partial acceptance, the good is traded and accounts adjusted by the computer. This bidding, asking and acceptance process continues throughout the trading period.

## ACCOUNTING

As we have already noted: each buyer will be told how many units they have bought and the prices that they paid at the end of each market; each seller will be told how many units they have sold and the prices that they received at the end of each market; The computer will carry out the appropriate book-keeping. At the end of each day you will be told how many units of the two goods you have ended up with and the earnings implied by these amounts, and the amount of experimental money with which you end up the day.

## PRACTICE SESSIONS

In order that you fully understand the experiment, you will be allowed two practice days before the experiment proper starts. The earnings you get in these practice days will not count towards your earnings. Your endowment of experimental money will be put back to its original amount at the end of the practice days and before the experiment proper starts.

## TIMEKEEPING

Each market session (morning and afternoon) will last four minutes. A clock on all subjects' screens in the top right hand corner of the screen will display the time left (in minutes and seconds) to the end of that particular session. You will always know how much time is left at any point.

## OTHER

If you are unsure about any aspect of this experiment please ask one of the experimenters. We hope you find it fruitful.

# Appendix: not to be published: Instructions for the Sequential Clearing House 

## CESARE

## Centro di Economia Sperimentale a Roma Est

Welcome to this experiment on the economics of market decision making. The Italian Ministry of Education, MIUR, has provided the funds for the experiment. 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 immediately after the end of the experiment.

## INTRODUCTION

In this experiment we are going to simulate two markets in which you can buy or sell two goods Good $X$ and Good $Y$ - in a sequence of market days. Each market day consists of a morning, an afternoon and an evening: in the morning the market for Good $X$ is open and you can buy or sell Good $X$ using (experimental) money; in the afternoon the market for Good $Y$ is open and you may buy or sell Good $Y$ using (experimental) money; in the evening, book-keeping is done and the amount of real money that you have earned for that particular day is calculated. Your earnings for any particular day of the experiment depend upon the amounts of the two goods with which you end up in that day. Your earnings for the entire experiment consist of the sum of the earnings on each and every day. The actual experimental money used to facilitate trade during the experiment becomes worthless at the end of it.

## THE NUMBER OF DAYS THAT THE EXPERIMENT WILL LAST

The actual number of market days that the experiment will last will be determined by chance. However, there will definitely be at least 18 days in the experiment. After that point, at the end of every day that the experiment continues, the computer will generate at random a number which is either zero or one, each with probability one-half. If the number is 0 the experiment will stop at that point; if the number is 1 the experiment will continue for a further day. So the experiment will definitely last at least 18 days, but it may last for 19 , or 20 , or 21 , or $22, \ldots$ days. The number of days that it will last is thus determined at random by the computer.

## THE SUBJECTS

There are two types of subjects in this experiment: Type $X$ subjects who are endowed with Good X each day but not with Good Y; Type Y subjects who are endowed with Good Y each day but not with Good X. Your daily endowment will be the same on each day that the experiment lasts. You will be told your Type and your daily endowment before the experiment starts. In addition all subjects are endowed at the beginning of the experiment with some experimental money: this is to facilitate trade only and becomes worthless at the end of the experiment.

## THE MARKETS

In the morning the market for Good $X$ is open. In this morning market, Type $X$ subjects (those who are endowed with Good $X$ ) are potential sellers of the good while Type $Y$ subjects (those who are endowed with Good $Y$ ) are potential buyers of the good. In the afternoon the market for Good $Y$ is open. In this afternoon market, Type $X$ subjects (those who are endowed with Good $X$ ) are potential buyers of the good while Type $Y$ subjects (those who are endowed with Good $Y$ ) are potential sellers of the good. The trading rules are described below.

Your payment for each day of the experiment is determined by the amounts of the two goods with which you end up at the end of that day. More precisely, if you end up with a quantity $x$ of Good $X$ and a quantity $y$ of Good $Y$ you will be paid $10 V(x y)$ pence. (The symbol $V$ indicates the square root.) For example, if you end up with 10 of Good $X$ and 10 of Good $Y$ you will be paid $10 \sqrt{ } 100$ pence $=100$ pence $=€ 1.00$. If you end up with 8 of Good $X$ and 18 of Good $Y$ you will be paid $10 \vee 144$ pence $=120$ pence $=€ 1.20$. Note that if you end up with zero of either good you will be paid nothing. As noted already, your payment for the experiment as a whole is the sum of the payments for each of the days that the experiment has lasted.

Please note that you cannot carry stocks of the goods over from one day to the next - experimental money alone can be held from one day to the next.

## THE TRADING MECHANISM

The trading mechanism used in this experiment is what is called the clearing house mechanism. Do not worry if you have not encountered this before - it is easy to understand. Buyers are asked to make a bid consisting of a price and a quantity $-(p, q)$. Sellers are asked to make an ask consisting also of a price and a quantity $-(p, q)$. The buyer's bid will be interpreted to mean that the buyer is willing to buy up to the stated quantity at no more than the stated price; if a buyer does not want to buy at any price, then no bid should be entered. The seller's ask will be interpreted to mean that the seller is willing to sell up to the stated quantity at no less than the stated price; if a seller does not want to sell at any price, no ask should be entered. We note that only integer values are allowed for the prices and quantities in the bids and asks. Of course, buyers must have the (experimental) money with which to finance the purchase; likewise sellers must actually have the units of the good they are intending to sell. There is a pre-determined time for entering bids and asks, and the computer will display the remaining time. If a buyer does not enter a bid, the computer will interpret this as the buyer being unwilling to buy at any price. If a seller does not enter an ask, the computer will interpret this as the seller being unwilling to sell at any price. When the time has elapsed, the computer will calculate the equilibrium price and the traded quantity in the market. The equilibrium price will be determined as the price at which the quantities offered for sale are equal to the quantities demanded for purchase. The computer will then inform each buyer of the amounts they have bought and the price which they paid and will inform each seller of the amounts they have sold and the price which they received. It is important to note: (1) that a buyer may not be able to buy all the quantity he or she bid for if the price in the bid is lower than the equilibrium price or the quantity offered by the sellers is not sufficient; (2) that a buyer may pay less than the price in the bid if the equilibrium price is lower than the price in the bid; (3) that a seller may not be able to sell all the quantity he or she asked for if the price in the ask is higher than the equilibrium price or the quantity demanded by the buyers is not sufficient; (4) that a seller may get more than the price in the ask if the equilibrium price is higher than the price in the ask. We note that the equilibrium prices and quantities will be integers. Occasionally there will be more than one equilibrium price; in such cases the computer will chose one of these at random.

## ACCOUNTING

As we have already noted: each buyer will be told how many units they have bought and the price that they paid at the end of each market; each seller will be told how many units they have sold and the price that they received at the end of each market. The computer will carry out the appropriate book-keeping. At the end of each day you will be told how many units of the two goods you have ended up with and the earnings implied by these amounts, and the amount of experimental money with which you end up the day.

PRACTICE SESSIONS
In order that you fully understand the experiment, you will be allowed two practice days before the experiment proper starts. The earnings you get in these practice days will not count towards your earnings.

Your endowment of experimental money will be put back to its original amount at the end of the practice days.

## TIMEKEEPING

Each market session (morning and afternoon) will last four minutes. A clock on all subjects' screens in the top right hand corner of the screen will display the time left (in minutes and seconds) to the end of that particular session. You will always know how much time is left at any point. If you do not enter a bid or ask during the time allowed, your bid or ask will be taken to be zero

## OTHER

If you are unsure about any aspect of this experiment please ask one of the experimenters. We hope you find it fruitful.


[^0]:    ${ }^{1}$ University of York, UK
    ${ }^{2}$ LUISS, Rome, Italy

[^1]:    ${ }^{3}$ Starting with the classic paper of Smith (1962).
    ${ }^{4}$ The performance of this relative to the double auction mechanism, in a simultaneous context, has been studied by Friedman (1993).
    ${ }^{5}$ Though our context these have to be modified appropriately (see later).

[^2]:    ${ }^{6}$ Not that this is necessarily bad for market convergence in a simple setting.
    ${ }^{7}$ In the experiment we put $n$ equal to 5 . We deliberately made the numbers of each type the same, and made the total number of subjects in each session sufficiently high to avoid any monopolistic possibilities.

[^3]:    ${ }^{8}$ The experiment was conducted in Italy and subjects were paid in euro. There are 100 centesimi in a euro. A euro is currently worth about $£ 0.81$ or $\$ 1.31$.

[^4]:    ${ }^{9}$ CEntro Sperimentale A Roma Est: http://static.luiss.it/hey/cesare/index.htm

[^5]:    ${ }^{10}$ It should be noted that we chose the various endowments to make these as nearly equal across sessions to make it fair to the subjects.

[^6]:    *: Standard deviations in parentheses
    !: Expressed as a percentage of the volumes in the static equilibrium

