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Cross-market Rebalancing and Financial Contagion in the Laboratory

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Abstract
We present an experimental study of financial contagion due to cross-market rebalancing. Subjects trade three assets with an automaton representing a fringe of noise traders. The three assets' fundamental values are independent of each other. Their payoff depends on the asset values, the prices at which they buy or sell and, moreover, on their portfolio composition. Theory predicts that when the first asset is hit by a negative shock, for portfolio rebalancing, subjects should buy in the second market and sell in the third, thus transmitting the shock from the first market to the third. The aggregate behavior that we observe in the laboratory is extremely close to that predicted by theory. Although in the experiment there is heterogeneity among subjects' behavior, the prices in the three markets are remarkably similar to those theoretically predicted.

Keywords
Financial contagion, cross-market rebalancing, financial crises

JEL Codes
G11, G14, G15, F32

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1 Introduction

Financial crises in one country often spread to other, unrelated economies, a phenomenon known as financial contagion. Given the pervasiveness of the phenomenon in recent years, a lot of theoretical and empirical work has been devoted to its understanding. Theoretical analyses have pointed out different mechanisms that can lead to contagion. Work on financial markets data has documented and measured different instances of contagion.

The theoretical literature has identified three main channels of contagion in financial markets: informational spillovers, correlated liquidity shocks, and cross-market rebalancing[1].

Informational spillovers refer to traders updating their beliefs and positions in one market on the basis of the information they infer from the price change in another (King and Wadhwani, 1990). Correlated liquidity shocks occur when agents, hit by a liquidity shock in one market, also liquidate assets in other markets in order to meet a call for additional collateral, thus transmitting the shock to other markets (Calvo, 1999). Finally, contagion happens through cross-market rebalancing when traders hit by a shock in one market need to rebalance their portfolios of assets: a shock in market A (say an emerging market) may require changing the position in market B (say a developped market) and this may imply rebalancing the postion in market C (say another emerging market). The shock may thus transmit from market A to market C although the two markets' fundamentals are not related.

In this paper we focus exclusively on the cross-market rebalancing channel of contagion. We use the methods of experimental economics to shed light on the empirical validity of this channel. There are no studies that try to test or estimate this mechanism of contagion. Our purpose is to offer a first analysis, using data coming from the controlled environment of a laboratory experiment. The purpose is to understand whether rabalancing motives are not only theoretically interesting but also relevant in the behavior of human subjects. While our study

[1] We focus on contagion in financial markets, and do not discuss here contagion due to linkages among financial institutions (like in, e.g., Allen and Gale, 2000), or contagion due to simultaneous speculative attacks (e.g., Corsetti et al., 1999; Kaminsky and Reinhart, 2000; Rigobon, 2002).

cannot serve in assessing the relevance of this channel of contagion in specific episodes of financial crises, it can offer insights on how the mechanism works, since in the laboratory we can test the theoretical predictions by controlling for variables that are unobservable in true financial markets.

Our experiment is inspired by the work of Kodres and Pritsker (2002). They study cross-market rebalancing in a rational expectations, CARA-Normal model. Their model builds on Grossman and Stiglitz (1980) and extends it to a multi-asset economy. To implement that model in the laboratory would be difficult, given that agents are assumed to have a CARA utility function, the asset values are distributed according to normal distributions and there are three types of traders. Instead of trying to design the experiment to replicate literally Kodres and Pritsker (2002), we used a different strategy. We constructed a model that still requires agents to rebalance their portfolios, but in a much simpler set-up that experimental subjects could easily understand.

In our laboratory market, subjects trade three assets with an automaton representing a fringe of noise traders. The assets' fundamental values are independent of each other. Our experimental subjects' profits, however, depend not only on the assets' fundamental values but also on the portfolio composition. In particular, having long positions on the first asset implies that the optimal position on the second asset is short and on the third is long. Similarly, when subjects are short in the first market, they should optimally be long in the second and short in the third. This means that a negative shock in the first market (e.g., a shock that lowers the first asset fundamental value) theoretically leads agents to sell in that market, buy in the second and sell in the third.

The behavior of subjects in the laboratory could deviate from equilibrium predictions in different ways. Human subjects could neglet or barely consider the need for rebalancing. Or, on the contrary, they could overreact to shocks in the first market, thus making contagion even more severe than theoretically predicted. The results from our experiment are, instead, very encouraging for the theoretical analysis: the prices that we observe in the three markets are extremely close to the equilibrium ones. While heterogeneity among subjects is observed, the aggregate behavior is very similar to that predicted in equilibrium.

The structure of the paper is as follows. Section 2 describes the theoretical framework and its predictions. Section 3 presents the experiment. Section 4 illustrates the results. Section 5 concludes. The Appendix contains the instructions.

2 The Theoretical Framework

2.1 The Model Structure

Our experiment, inspired by the work of Kodres and Pritsker (2002), aims to test experimentally the "cross-market rebalancing" channel of financial contagion. Kodres and Pritsker (2002) study cross-market rebalancing in a rational expectations, CARA-Normal model. To implement that model in the laboratory would be difficult, given that agents are assumed to have a CARA utility function, the asset values are distributed according to normal distributions and there are three types of traders. Instead of trying to design the experiment to replicate literally Kodres and Pritsker (2002), we used a different strategy. We constructed a model that requires agents to rebalance their portfolios in a much simpler set-up, which experimental subjects could easily understand.

In our model, there are three markets -labelled A, B and C- where traders can trade three assets which we denote again by A, B and C. In each market, traders face the following price schedule:

$$p^K = E(V^K) + \frac{1}{n}\sum_{i=1}^{n} x_i^K \quad (1)$$

where V^K (K=A, B, C) is the asset value, p^K is the asset price, and x_i^K is the quantity (number of shares) of asset K bought or sold by agent *i*. Overall, there are n of these traders in the economy. We will refer to these traders as informed traders. The price schedule can be interpreted as representing the net supply of noise traders, who trade for exogenous, unmodelled, reasons. The net supply of these noise traders is price elastic. In particular, if the net demand they receive from informed traders is positive ($\frac{1}{n}\sum_{i=1}^{n} x_i^K > 0$), the price will be greater than the asset unconditional expected value. If it is negative, the price will, instead, be lower. Note also that the net demand function is identical in all three markets.

The three markets open sequentially. First traders trade in market A, then in market B and, finally in market C. When market A opens, all n informed traders, independently and simultaneously, place a buy or sell order for asset A. The order to buy or sell cannot exceed 50 units. After trades have been placed, they are aggregated and the price of asset A is determined as just discussed. Market A then closes, and traders move to trade in market B, where the same trading rule applies. Market B then closes and traders trade in the last market, following again the same rules.

Apart from opening at different times, the three markets also differ for the asset values. Asset A can take two values, 0 or 100, with the same probability. The value of assets B and C is instead always equal to 50. One way to interpret the fact that asset A value is not fixed is that it is affected by shocks. The reason we refer to the n traders as informed traders is that they know the value of asset A. In particular, they receive information about the positive or negative shock on the value of asset A. Note that, given these asset values and the limits on the buy and sell orders, the price in the three markets is never negative and never higher than 100.

An informed trader maximizes the following payoff function:

$$(V^A - p^A)x_i^A + (V^B - p^B)x_i^B + (V^C - p^C)x_i^C - (x_i^A + x_i^B)^2 - (x_i^B + x_i^C)^2 \quad (2)$$

Traders have an informational reason to trade. Since the value of asset A changes, and they receive (perfect) information on it, they can make a profit in market A. Note, in fact, that, although the noise traders adjust the price to the net-demand they receive, the price does not fully aggregate the information revealed by the market order. A positive demand can indeed only occur when the asset value is 100. Therefore, a rational, uninformed, trader would only sell at a price not lower than 100. The price implied by the price function, instead, is lower than 100 unless each trader buys the highest possible amount of 50 units. Similarly, a negative demand can only occur when the asset value is 0, but, according to the above price function, the price reaches 0 only when each trader sells all 50 units.

While there are informational reasons to trade in market A, what motivates informed traders to trade in markets B and C is "portfolio rebalancing." In both these markets, the informed traders have no informational advantage on the noise traders, since the asset values are given. Moreover, since the price function has a positive slope, and the price is equal to the expected value when the demand is zero, buying or selling implies a loss in these markets for the informed traders.

From the payoff function, however, it is clear, that the informed traders may still decide to trade in markets B and C, to lower the losses due to the last two terms of the payoff. These last two terms are the way in which we model portfolio rebalancing reasons in our economy. Essentially, informed traders are penalized if they hold long positions on both assets A and B, or are short on both assets. Similarly for their positions on assets B and C. In Kodres and Pritsker (2002) portfolio rebalancing motives arise from the asset values having correlated risks. Since agents in their economy are risk averse, when their exposure to a risk factor increases because of a change in their position in a market, they find it optimal to lower their exposure by modifying their position in another. In our model there is no risk associated to the assets, since their values are known to the informed traders. The quadratic loss function is a simple way to introduce in a different way portfolio rebalancing motives.

As we said, while in market A noise traders suffer an informational disadvantage, this is not the case in the other markets. Nevertheless, as a starting point, we have assumed that the price function is the same in all three markets. One interpretation of the positive slope of the price function in markets B and C is that it reflects (unmodelled) asymmetric information in these markets. In the model of Kodres and Pritsker (2002), noise traders may misconstrue the order flow in the market as being information based. A higher net demand may be wrongly interpreted as reflecting positive information received by informed traders. For this reason, a higher demand, although due to rebalancing reasons and not having any information content, may result in a higher price. Similarly, in our model, even in markets B and C, informed traders have to trade at a disadvantageous price, which makes rebalancing costly. Whether rebalancing is more or less costly (and contagion effects more or less pronounced), depends, of course, on the price elasticity. To study the effect of price elasticity, we will contrast the case just discussed with one in which in market B the price schedule is

$$p^B = E(V^B) + \frac{1}{10n}\sum_{i=1}^{n} x_i^B \qquad (3)$$

In this case, the price function in market B is relatively inelastic, compared to the other two markets. As a result, rebalancing in this market is now less costly. Under the above interpretation, market B is characterized by a lower degree of asymmetric information.

This set up is inspired by one of the cases analyzed by Kodres and Pritsker (2002). They interpret markets A and C as emerging markets and market B as a developed market. It is interesting to observe that the presence of a developed market, with less asymmetric information (i.e., a lower price elasticity) exacerbates the contagious effects of portfolio rebalancing. Since now rebalancing in market B will be less costly, informed traders will trade more aggressively in market A, rebalancing more in markets B and, then, in C. The shock in market A will therefore have a stronger effect on the price of asset C, as we will show in the next section.

2.2 Equilibrium Predictions

Given the sequential structure of the game, we find the equilibrium by backward induction. Table 1 shows the quantity that each trader buys or sells in the three markets for both the cases of $V^A = 0$ and $V^A = 100$. The first row refers to the case in which the price elasticity is the same in all three markets, while the second to the case in which the price of asset B is less elastic. Note that a quantity with the sign minus means that the quantity is sold.

Let us start by considering the first case (labelled as T1). When $V^A = 100$, obviously informed traders buy asset A and the equilibrium price (74.39) is above the unconditional expected value. For cross-market rebalancing reasons, traders sell in market B and buy in market C. Prices in markets A and C co-move. The positive shock in the first market produces a price increase also in market C although the two asset values are uncorrelated. Similarly, when $V^A = 0$, informed traders sell asset A and the equilibrium price (25.61) is lower than the unconditional expected value.

	$V^A=100$						$V^A=0$					
	market A		market B		market C		market A		market B		market C	
T1	p_A	q_A	p_B	q_B	p_C	q_C	p_A	q_A	p_B	q_B	p_C	q_C
	74.39	24.39	37.19	-12.8	58.3	8.26	25.61	-24.4	62.8	12.8	41.7	-8.26
	market A		market B		market C		market A		market B		market C	
T2	p_A	q_A	p_B	q_B	p_C	q_C	p_A	q_A	p_B	q_B	p_C	q_C
	79.74	29.74	47.89	-21.09	63.6	13.6	20.26	-29.7	52.1	21.1	36.4	-13.6

Table 1. Equilibrium predictions

To rebalance their portfolios, traders buy in market B and sell in market C. The negative shock in the first market transmits itself to market C.

In equilibrium, a negative shock in market A -i.e., $V^A = 0$ - pushes the price approximately 49 percent below the asset unconditional expected value. Because of portfolio rebalancing, the price in market B exceeds the asset value by 26 percent, whereas the price of asset C is 16 percent lower than the asset value.

When price elasticity in market B is lower (this case is labelled as T2 in the table), rebalancing becomes less costly. Anticipating this, when $V^A = 100$, informed traders buy a higher number of asset A and the equilibrium price in this market (79.74) is higher than in the previous case. The quantity sold in market B reaches now approximately 21 units, while the price in this market only moves from 50 to 47.89. Given the high number of units sold in market B, informed traders buy almost 14 units of asset C. The effect of the positive shock in market A on asset C is now significantly higher than before, since the price of asset C jumps to 63.61. The figures for the case of $V^A = 0$ are analogous. Traders sell asset A pushing the price approximately 59 percent below the asset's unconditional expected value. The price in market B exceeds the asset value by only 4 percent, whereas the price of asset C is 27 percent lower than the asset value.

3 The Experiment

In the laboratory, we implemented the model just described. We conducted two treatments, corresponding to the two different parameter specifications illustrated above. In Treatment 1, the price function was the same in all three markets ($p^K = E(V^K) + \frac{1}{n}\sum_{i=1}^{n} x_i^K$), while in Treatment 2 we changed the price function in market B to $p^B = E(V^B) + \frac{1}{10n}\sum_{i=1}^{n} x_i^B$. Apart from the price function, the two treatments were otherwise identical.

The sessions started with written instructions (in Appendix) given to all subjects. We explained to participants that they all received the same instructions. Subjects could ask clarifying questions, which we answered privately. The experiment was run at the ELSE laboratory at UCL in the Summer 2009 and in the Winter 2010. We recruited subjects from the College undergraduate population across all disciplines. They had no previous experience with this experiment. In total, we recruited 100 subjects to run 10 sessions (5 for each treatment). The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

The experiment consisted of 20 rounds of trading. Let us explain the procedures for each round.

In a round, the 10 participants had the opportunity to trade in three markets, exactly as explained in the previous section. To trade, subjects were provided with an endowment of 50 units of each asset (in the instructions called "good") and of 15,000 liras (a fictitious currency that was exchanged at the end of the experiment in British Pounds). In odd rounds the value of asset A was set equal to 0, while in even rounds it was set equal to 100 liras. This was explained in the instructions and, moreover, the asset value was always displayed on the computer screen. In odd rounds subjects could sell asset A, inputting an integer between 0 and 50. Similarly, in even rounds, they could buy, again a quantity between 0 and 50. We explained the price function in the instructions. Not only we presented and explained the formula, we also used some numerical examples and provided subjects with a table illustrating the price that would have occurred for many combinations of the quantities bought (or sold) by the subject himself and the aggregate net demand of all other participants. After all 10 subjects had made their trading decision for asset A, they observed a screen reporting the individual decisions of all participants, the price, and their own profit in market A. Furthermore, they were also informed of the (provisional) penalty that they would suffer just for their trade in market A (i.e., assuming no trade in the other markets).

Subjects could then make their trades in market B. They were allowed to buy and sell, independently of whether the round was odd or even. Subjects could input a number between 0 and 50 and then click on a "buy" or "sell" button. After they had all made their decision, they observed a feedback screen containing indication of individual decisions, price, profit in market B, and, finally, the penalty suffered because of the exposures in markets A and B, and the provisional penalty for the exposures in markets B and C (assuming no trade in market C). The procedure for market C was identical. The round was concluded with a summary feedback indicating the quantities bought or sold by the subject in each market, the resulting prices and profits, the two penalties and the total payoff.

The total per-round payoff only depended on the profit in each market and on the penalty terms. It did not depend on the endowments. This is because the endowments of assets and liras that we gave to subjects at the beginning of the round were taken back at the end[2].

Clearly, because of the quadratic penalty terms, it could well happen that in a round a subject had a (large) negative total profit. In this case, the payoff for that round was set equal to zero. In other words, subjects knew that if they made a loss in a round, the profit for that round was considered to be zero. This is to avoid that subjects could end the experiment with a negative payoff[3]. After the 20th round, we summed up all the per-round payoffs and we converted them into pounds. In addition, we gave subjects a show-up fee of £5. Subjects were paid in private, immediately after the experiment. Given the different parameters, we used two different exchange rates in the two treatments, £1=100 liras in Treatment 1 and £1=200 liras in Treatment 2. On average, subjects earned £25 for a 1.5 hour experiment.

4 Results

4.1 Aggregate results

We start the presentation of our results by discussing the aggregate outcomes in the three markets. For the sake of exposition, we consider first Treatment 1.

Table 2 reports the quantities bought or sold on average in each market and the resulting prices when the value of asset A was 100 (i.e., in even rounds). To facilitate the comparison with the equilibrium predictions, it also reports the

[2] The endowments had the only purpose of making the experiment more intutitive, avoiding short positions.

[3] It is easy to verify that this floor does not change subjects' incentives in a single round. The only concern, given that the experiment is repeated for many rounds, is that subjects could collude with, e.g., some subjects not trading in a round in order to let others trade at a particularly favorable price. This was, however, never observed in the data.

difference between actual and equilibrium values. When the actual quantity bought or sold is higher than the equilibrium one, the difference is reported as a positive value. If it is lower, it is reported as a negative value. Similarly, a positive (negative) difference in prices means that the observed price is higher (lower) than the theoretical one.

Treat. 1	**market A**		**market B**		**market C**	
V^A = 100	p_A	q_A	p_B	q_B	p_C	q_C
Average	74.67	24.67	37.87	-12.13	57.23	7.23
Difference	0.28	0.28	-0.68	-0.67	-1.03	-1.03

Table 2. Average values and differences in Treatment 1 when $V^A = 100$

The average quantities traded in the three markets in the laboratory are very similar to the equilibrium ones. As a result, the actual prices differ from the equilibrium prices for less than 1 lira, a quite remarkable result. Table 3 reports the same results for the case of $V^A = 0$. The overall picture is the same, with tiny distances between actual and equilibrium decisions. The slight difference is that the deviation in market B is higher, with a price of asset B differing from the equilibrium one by almost 3 liras.

Treat. 1	**market A**		**market B**		**market C**	
V^A = 0	p_A	q_A	p_B	q_B	p_C	q_C
Average	26.72	-23.28	60.03	10.03	41.56	-8.44
Difference	-1.11	-1.11	-2.78	-2.77	0.18	0.18

Table 3. Average values and differences in Treatment 1 when $V^A = 0$

The fact that the behavior for $V^A = 0$ and $V^A = 100$ is almost identical is perhaps not surprising, since the quantities to be traded are identical, except for the sign. We decided to run the experiment with the value of asset A alternating between 0 and 100 (although the idea of contagion typically refers to crises more than to booms), for two reasons. First, we thought it would make the experiment more interesting and enjoyable for the subjects, thus lowering the chance of boredom effects in the laboratory. Second, one could suspect that subjects would have a higher ability to buy than to sell, a conjecture which actually does not find support in our data.

In Table 4 we report the distances between actual and equilibrium values distinguishing between the first and the second half of the experiment. Although typically the distances in the second half are even lower, also in the first part the actual prices are almost identical to the equilibrium prices, indicating that learning was not the crucial factor in driving our results.

$V^A = 0$	market A		market B		market C	
	p_A	q_A	p_B	q_B	p_C	q_C
Average (round 1-10)	27.25	-22.75	59.40	9.40	41.32	-8.68
Difference	-1.64	-1.64	-3.41	-3.40	0.42	0.42
Average (round 10-20)	26.19	-23.81	60.67	10.67	41.79	-8.21
Difference	-0.58	-0.58	-2.14	-2.13	-0.05	-0.05
$V^A = 100$	market A		market B		market C	
	p_A	q_A	p_B	q_B	p_C	q_C
Average (round 1-10)	74.99	24.99	37.36	-12.64	56.33	6.33
Difference	0.60	0.60	-0.17	-0.16	-1.93	-1.93
Average (round 10-20)	74.36	24.36	38.38	-11.62	58.12	8.12
Difference	-0.03	-0.03	-1.19	-1.18	-0.14	-0.14

Table 4. Results distinguishing between first and second half of the experiment

While the average behavior in the overall experiment is remarkably similar to the theoretical one, one may wonder whether there was heterogeneity across rounds. The answer is that in all three markets the price variability was extremely low.

$V^A = 0$	market A		market B		market C		$V^A = 100$	market A		market B		market C	
Round	p_A	q_A	p_B	q_B	p_C	q_C	*Round*	p_A	q_A	p_B	q_B	p_C	q_C
1	28.70	-21.30	64.26	14.26	39.84	-10.16	2	77.2	27.2	39.84	-10.16	55.94	5.94
3	25.14	-24.86	59.30	9.30	42.94	-7.06	4	74.78	24.78	35.96	-14.04	55.96	5.96
5	29.30	-20.70	56.90	6.90	43.24	-6.76	6	75.9	25.9	36.72	-13.28	56.4	6.4
7	25.24	-24.76	57.78	7.78	38.40	-11.60	8	75.86	25.86	35.02	-14.98	57.48	7.48
9	27.88	-22.12	58.74	8.74	42.18	-7.82	10	71.2	21.2	39.28	-10.72	55.86	5.86
11	27.12	-22.88	61.56	11.56	43.28	-6.72	12	73.78	23.78	39.2	-10.8	54.34	4.34
13	25.12	-24.88	58.70	8.70	37.66	-12.34	14	74.22	24.22	40.7	-9.3	57.6	7.6
15	28.80	-21.20	59.40	9.40	42.34	-7.66	16	74.22	24.22	39.18	-10.82	57.36	7.36
17	25.70	-24.30	60.96	10.96	41.28	-8.72	18	74.2	24.2	37.22	-12.78	60.6	10.6
19	24.20	-25.80	62.72	12.72	44.40	-5.60	20	75.36	25.36	35.58	-14.42	60.72	10.72
max	29.30	-20.70	64.26	14.26	44.40	-5.60	***max***	77.20	27.20	40.70	-9.30	60.72	10.72
min	24.20	-25.80	56.90	6.90	37.66	-12.34	***min***	71.20	21.2	35.02	-14.98	54.34	4.34
st. dev.	1.86	1.86	2.30	2.30	2.24	2.24	***st. dev.***	1.61	1.61	2.00	2.00	2.05	2.05
Eq.	25.61	-24.39	62.81	12.80	41.74	-8.26	***Eq.***	74.39	24.39	37.19	-12.80	58.26	8.26

Table 5. Average result for each round in Treatment 1

Table 5 reports the average results (both prices and aggregate net-demands) for each round, and, moreover, the standard deviations, the minimum and the maximum values over all rounds. It is immediate to observe that the aggregate outcomes were close to equilibrium outcomes basically in all rounds.

Let us now move to Treatment 2. In this treatment subjects should realize that they can trade more aggessively in market A, since the later cost of rebalancing will be lower. This is actually what happens. As one can immediately see from Tables 6 and 7, the average quantities and the prices in market A are again remarkably close to the equilibrium ones. The sign of the difference between actual and theoretical quantities is negative, indicating that subjects buy or sell on average less than optimal, but the value of this difference is very small.

Similarly, the average quantities bought or sold in markets B and C resemble the equilibrium values. As a result, the contagious effect from the shock in market A on the price in market C is basically what one would theoretically expect.

Treat. 2	**market A**		**market B**		**market C**	
$V^A = 100$	p_A	q_A	p_B	q_B	p_C	q_C
Average	78.38	28.38	48.01	-19.88	66.19	16.19
Difference	-1.36	-1.36	-0.12	-1.21	2.58	2.58

Table 6. Average values and differences in Treatment 2 when $V^A = 100$

Treat. 2	**market A**		**market B**		**market C**	
$V^A = 0$	p_A	q_A	p_B	q_B	p_C	q_C
Average	22.61	-27.39	51.82	18.19	35.63	-14.37
Difference	-2.35	-2.35	-0.29	-2.90	0.76	0.76

Table 7. Average values and differences in Treatment 2 when $V^A = 100$

Also in this treatment learning does not play a big role, with only negligeable differences between the first and the second part of the experiment. Looking at individual rounds, one can notice that behavior is rather homogeneous. Interestingly, however, that while in markets A and B the quantities bought and sold are rarely higher than the theoretical ones, in market C it is more common to observe that subjects over-react, asking quantities higher than theoretically predicted. This overreaction can be even more appreciated if one notices that, since subjects buy (sell) less in market B, of course, they should sell (buy) even less than in equilibrium in market C. In particular, for $V^A = 100$, given the average quantity 19.88 sold in market B, they should buy 11.79 in market C. For $V^A = 0$, given the average quantity 18.19 bought in market B, they should sell 11.01 in market C. The difference between these two values and the quantities actually traded in market C are 4.4 and 3.37, respectively.

As a result of this behavior, the observed price in market C is in some instances further away from the unconditionally expected value than the theoretical price. These are instances in which portfolio rebalancing creates slightly more contagious effects than theory predicts.

4.2 Individual decisions

We now turn our attention from aggregate variables to individual decisions. Figures 1 and 2 show the distributions of subjects' purchases (sales) in market A when V^A was equal to 100 (respectively, to 0) for Treatment 1.

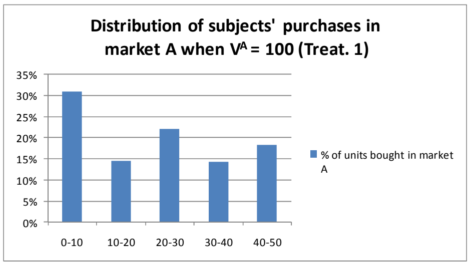

Figure 1. Distribution of subjects' purchases when $V^A = 100$

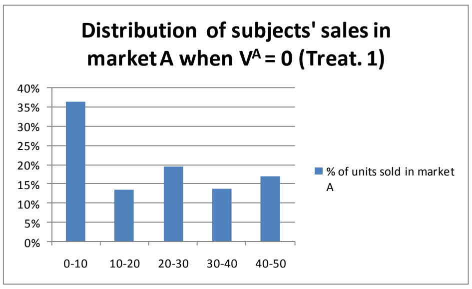

Figure 2. Distribution of subjects' purchases when $V^A = 0$

Let us focus, first, on the case of $V^A = 100$. As one can see from Figure 1, subjects' purchases are quite dispersed, with 31 percent of buy orders not higher than 10 units, and with 18% of buy orders not lower than 40 units. Similarly, when V^A was equal to zero, 36 percent of the times subjects only sold a small number of units (at most ten), and 17 percent of the time they sold large quantities (at least 40). In words, there was a large fraction of decisions to trade cautiously, buying or selling much less than in equilibrium; and a non negligible fraction of decisions to trade large amounts, which largely exceeded the equilibrium outcome.

One may wonder whether this heterogeneity in decisions in market A comes from heterogeneous behavior across subjects or from each subject behaving differently across rounds. To answer this question, we looked at extreme decisions, that is, decisions to trade just few units or many units. The result is that few subjects explain a large proportion of extreme decisions. Indeed, when $V^A = 100$, 51 percent of decisions to buy not more than ten units are only due to ten subjects (20 percent of the participants), while the decisions of other ten subjects alone account for 56 percent of buy orders of at least 40 units. The results for $V^A = 0$ are similar, with the behavior of ten subjects explaining 43 percent of decisions to sell at most ten units and the behavior of ten subjects explaining 38 percent of decisions to sell at least 40 units.

Given this behavior in market A it is not surprising that individual decisions are heterogenous also in markets B and C. After all, even theoretically, different amounts traded in market A will require different levels of rebalancing in the other two markets. Figure 3 shows the distributions of subjects' orders in market B, again for Treatment 1.

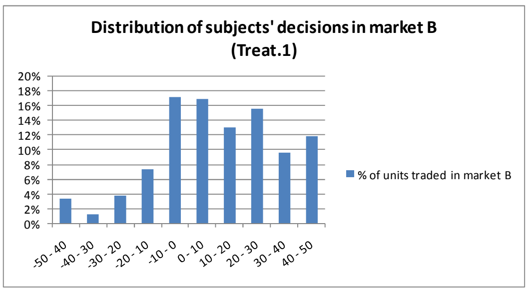

Figure 3. Distribution of subjects' decisions in market B

For simplicity's sake, we have considered together the two cases of $V^A = 0$ and $V^A = 100$, since, similarly to what observed in market A, the subjects' decisions were not very different in the two cases. In the histogram in Figure 3 we have aggregated buy orders with sell orders of the same size. For instance, the last bar represents purchases (if $V^A = 0$) or sales (if $V^A = 100$) of size higher than 40. The right part of the histogram (last five bars) represents correct decisions to rebalance the portfolio, buying after selling in market A, or selling after buying in market A. Rebalancing is correct in the sign in 67 percent of the cases. Of the remaining 33 percent of cases, 17 percent are orders of modest size (less than ten units), whereas the other 16 percent represents more severe deviations from equilibrium.

The results for market C are reported in the histogram in Figure 4.

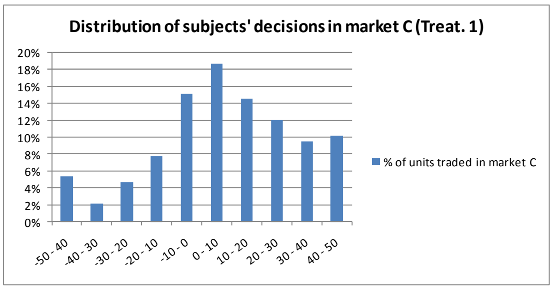

Figure 4. Distribution of subjects' decisions in market C

This histogram shows the size of buy (sell) orders in market C when the value of asset A was 100 (0). The overall picture is similar to that of market B, with a significant dispersion of decisions, 65 percent of orders of the size predicted by theory, 15 percent of orders of wrong sign but small size and 20 percent of more severe deviations from equilibrium. One has, however, to be careful in defining a decision in this market as correct or wrong, since the "correct decision" depends on whether the subject had sold or bought in market B. Indeed, if a subject had (correctly or incorrectly) bought in market B, then to increase his payoff he should have certainly sold, and viceversa[4]. When we count the number of correct

[4] Given that on average actual decisions were correct, a subject who had made a mistake in market B would have two advantages by rebalancing in market C: he would lower the penalty, and he would earn a profit, since the price of asset C would move in a favorable way.

decisions conditioning on the choice in market B, we find that correct decisions in market C amount to 80 percent of decisions in that market.

Let us go back to decisions in market A and ask how heterogeneity in trades affected individual payoffs. Considering market A alone, it is clear that, since the overall quantity traded was close to the symmetric equilibrium, subjects who traded aggressively outperformed subjects who traded cautiously. Essentially, these subjects took advantage of other subjects trading only small quantities. We have regressed the individual payoffs in market A (i.e., not taking into account the other two markets and the penalty terms) on the average quantities that subjects bought (if $V^A = 100$) or sold (if $V^A = 0$) in that market. The results are shown in Table 8. An increase of 1 unit in the quantity traded implies a statistically significant increase of £4.81 in the payoff in market A.

Dependent Variable: PROFITSA
Method: Least Squares
Date: 05/16/10 Time: 10:38
Sample: 1 50
Included observations: 50

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.304328	5.357628	1.006850	0.3101
QA	4.813878	0.207268	23.22541	0.0000

R-squared	0.918287	Mean dependent var	119.8732
Adjusted R-squared	0.916584	S.D. dependent var	51.40692
S.E. of regression	14.84723	Akaike info criterion	8.272682
Sum squared resid	10581.13	Schwarz criterion	8.349162
Log likelihood	-204.0170	Hannan-Quinn criter.	8.301806
F-statistic	539.4196	Durbin-Watson stat	1.311328
Prob(F-statistic)	0.000000		

Table 8. Relation between individual payoffs obtained in market A and quantities traded in that market

A regression of the total payoffs at the end of the experiment (excluding the show up fee) on the quantities traded in market A shows again a positive and statistically significant relation. An increase of 1 unit in the quantity traded in market A implies an increase of £1.30 in the total payoff, as shown in Table 9.

Dependent Variable: TOTPROFITS
Method: Least Squares
Date: 05/16/10 Time: 10:16
Sample: 1 50
Included observations: 50

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.735839	7.351491	-0.780228	0.4391
QA	1.295055	0.284403	4.553567	0.0000

R-squared	0.301567	Mean dependent var	26.06186
Adjusted R-squared	0.287119	S.D. dependent var	24.12902
S.E. of regression	20.37268	Akaike info criterion	8.905445
Sum squared resid	19922.22	Schwarz criterion	8.981926
Log likelihood	-220.6361	Hannan-Quinn criter.	8.934569
F-statistic	20.73515	Durbin-Watson stat	1.300910
Prob(F-statistic)	0.000036		

Table 9. Relation between total payoffs and quantities traded in market A

Regressing the total payoffs with the exclusion of payoffs in market A on quantities traded in market A does not give a statistically significant relation. Subjects who traded more aggressively in market A do not seem to be different from the others in their ability to rebalance their portfolio.

The results in Treatment 2 offer, overall, a similar picture to Treatment 1, once one takes into account that in this treatment even theoretically subjects should trade more in market A and rebalance more in the other two markets.

Market A is again characterized by heterogeneity in subjects' decisions (see Figure 5 and 6). A notable difference with the previous treatment is that the percentage of subjects choosing to trade less than 10 units is significantly lower (less then 20 percent versus more than 30 percent), perhaps not surprising given that subjects had incentives to trade more.

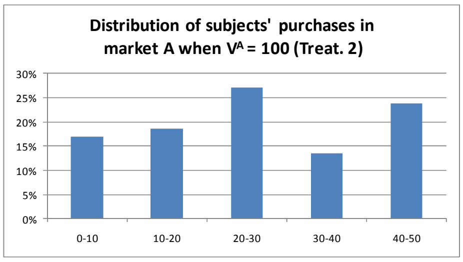

Figure 5. Distribution of subjects' purchases when $V^A = 100$

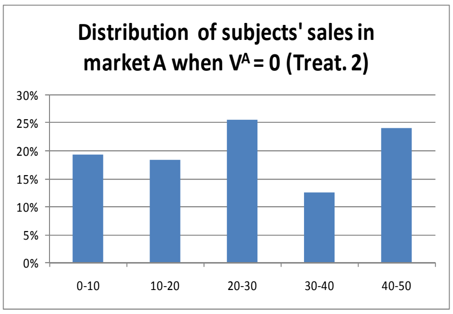

Figure 5. Distribution of subjects' purchases when $V^A = 0$

The ability of subjects to rebalance correctly is similar to that in the previous treatment. In market B, 80 percent of decisions were correct in sign, 10 percent were incorrect but of small size and 10 percent represents more relevant deviations from equilibrium.

In market C, 76 percent of orders were of the size predicted by theory, 9 percent of orders were of wrong sign but small size and 15 percent represented more severe deviations from equilibrium. Conditioning on the choice in market B, we find that correct decisions in market C amount to 88 percent of decisions in that market.

The analysis of the relation between payoffs and quantities traded in the three markets reveals a pattern similar to that of Treatment 1, although the effect of higher trade in market A is less sizeable. The regression of the individual payoffs in market A on the average quantities that subjects traded in that market shows that an increase of 1 unit in the quantity traded implies a statistically significant increase of £4.21 in the payoff in market A. An increase of 1 unit in the quantity traded in market A implies an increase of £0.49 in the total payoff. As in the previous treatment, the ability of subjects to rebalance does not seem to be related to their trading behavior in market A.

Dependent Variable: PROFITSA
Method: Least Squares
Date: 05/16/10 Time: 12:14
Sample: 1 50
Included observations: 50

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.002799	6.184123	-0.000453	0.9996
QA	4.207023	0.209515	20.07963	0.0000

R-squared	0.893617	Mean dependent var	118.3492
Adjusted R-squared	0.891401	S.D. dependent var	40.16135
S.E. of regression	13.23494	Akaike info criterion	8.042776
Sum squared resid	8407.855	Schwarz criterion	8.119257
Log likelihood	-199.0694	Hannan-Quinn criter.	8.071900
F-statistic	403.1995	Durbin-Watson stat	2.685371
Prob(F-statistic)	0.000000		

Table 10. Relation between individual payoffs obtained in market A and quantities traded in that market

Dependent Variable: TOTPROFITS
Method: Least Squares
Date: 05/16/10 Time: 12:13
Sample: 1 50
Included observations: 50

Variable	Coefficient	Std. Error	t-Statistic	Prob
C	1.146399	4.149478	0.276275	0.7835
QA	0.491898	0.140582	3.499004	0.0010

R-squared	0.203227	Mean dependent var	14.98446
Adjusted R-squared	0.186628	S.D. dependent var	9.846745
S.E. of regression	8.880498	Akaike info criterion	7.244770
Sum squared resid	3785.436	Schwarz criterion	7.321251
Log likelihood	-179.1193	Hannan-Quinn criter.	7.273895
F-statistic	12.24303	Durbin-Watson stat	2.609899
Prob(F-statistic)	0.001018		

Table 11. Relation between total payoffs and quantities traded in market A

Conclusions

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Appendix

Instructions

Welcome to our study! We hope you will enjoy it.

You're about to take part in a study on decision making with 9 other participants. Everyone in the study has the same instructions. Go through them carefully. If something in the instructions is not clear and you have questions, please, do not hesitate to ask for clarification. Please, do not ask your questions loudly or try to communicate with other participants. We will be happy to answer your questions privately.

Depending on your choices and those of the other participants, you will earn some money. You will receive the money immediately after the experiment.

Outline of the Study

In the study, you will be asked to buy or sell in sequence three goods: A, B and C. First, you will buy or sell good A in market A; then good B in market B and, finally, good C in market C.

The values of the goods are expressed in a fictitious currency called "lira", which will be converted into pounds at the end of the experiment according to the following exchange rate:

£1=200 liras.

This means that for any 200 liras that you earn, you will receive one pound.

In each market, you will trade with a computer (and not among yourselves). In particular, you will be asked to choose the quantity you want to buy from the computer or sell to it. The computer will set the price at which each of you can buy or sell based on the decisions of all participants.

The Rules

The experiment consists of 20 rounds. The rules are identical for all rounds. All of you will participate in all rounds.

Each round is composed of three steps. In the first step, you trade in market A. Then market A closes and market B opens. Finally, when market B closes, market C opens.

At the beginning of every round we will provide you with an endowment of 50 units of each good (that is, 50 units of good A, 50 of good B and 50 of good C) and with 15,000 liras, which you can use to buy or sell.

At the end of each round, you will receive information about how much you earned in that round, and then you will move to the next round.

Procedures for each round

At the beginning of each round, you trade good A in market A.

Market A

The value of good A can be either 0 or 100 liras**. In all the odd rounds (1-3-5…) the value is 0; in all the even rounds (2-4-6…) the value is 100.**

Your trading decision

In market A, you are asked to choose how many units you want to buy or sell. You can sell up to 50 units (which is your initial endowment of good A), and buy at most 50 units.

When the value of the good is 0, you will be asked to indicate how many units you want to sell. When the value of the good is 100, you will be asked to indicate how many units you want to buy.

In the screen, there is a Box where you indicate the number of units of good A that you want to buy or sell by clicking on the BUY or SELL button.

The price

After all of you have chosen, the computer will calculate the price of good A in the following way:

$$Price_A = 50 + 1/10 * (Total_A),$$

where

$Total_A$ = $Total_A$ Bought – $Total_A$ Sold

$Total_A$ Bought = sum of the units of the good A bought by all those who decide to buy;

$Total_A$ Sold = sum of the units of the good A sold by all those who decide to sell.

Example 1:

Assume that the value of good A is 100 and that the quantities of good A bought by the participants are as follows:

Participant	Units Bought	Units Sold	$Total_B$
1	45		
2	10		
3	30		
4	15		
5	30		
6	20		
7	26		
8	50		
9	18		
10	8		
Total A	**252**	**0**	**252**

Since the $Total_A$ is equal to [$Total_A$ Bought] - [$Total_A$ Sold] = 252 - 0 = 252, the price will be:

$$Price_A = 50+1/10 * (Total_A) = 50+1/10*(252) = 75.2$$

Example 2:

Assume that the value of good A is 0 and that all participants decide to sell 15 units, so that $Total_A$ is equal to [$Total_A$ Bought] - [$Total_A$ Sold] = 0 - 150 = -150. The price will be:

$$Price_A = 50+1/10 * (Total_A) = 50+1/10*(-150) = 35$$

In general, the more participants want to buy, the higher the price you will have to pay for each unit. The more participants want to sell, the lower the price you will receive for each unit.

To help you to familiarize with the way the computer sets the price, we provide you with a table (Table 1, at the end of these instructions) where you can see the price of the good given some possible combinations of your choices and those of the other participants.

After everyone has made his/her decision and the computer has computed the price, on the screen you will see a summary of your decision, the decisions of the other participants, and the resulting price and earnings.

After that, you will start trading in market B.

Market B

The value of good B is 50 in all rounds.

Your trading decision

Exactly as before, you will simply be asked to choose how many units of good B you want to buy or sell. You can sell up to 50 units, that is, your initial endowment of good B, and buy at most 50 units.

In the screen, there is a Box where you indicate the number of units of good B that you want to buy or sell, by clicking on the BUY or SELL button.

Note that in market B, differently to market A, since the value is 50 in any given round you will have to decide whether you want to buy or sell.

The price

After all of you have chosen, the price of good B is computed in a slightly different way from how it was computed in market A, that is,

$$Price_B = 50 + \mathbf{1/100} * (Total_B)$$

where

$Total_B$ = $Total_B$ Bought – $Total_B$ Sold

$Total_B$ Bought = sum of the units of the good B bought by all those who decide to buy;

$Total_B$ Sold = sum of the units of the good B sold by all those who decide to sell.

Note, that, in Market B, Total is multiplied by 1/100 (i.e., it is divided by 100), instead of being multiplied by 1/10 as it was in market A (i.e., in Market A, it was divided by 10).

Example 1:

The value of good B is 50. Assume that the quantities of it bought/sold by the participants are as follows:

Participant	Units Bought	Units Sold	$Total_B$
1	30		
2	25		
3	40		
4	35		
5	20		
6	45		
7	27		
8		16	
9	50		
10	40		
Total B	**312**	**16**	**296**

As $Total_B$ is equal to [$Total_B$ Bought] - [$Total_B$ Sold] = 312 - 16 = 296, the price will be:

$$Price_B = 50+1/100 * (Total_B) = 50+1/100*(296) = 52.96$$

Example 2:

Assume that all participants decide to sell 35 units, so that $Total_B$ is equal to [$Total_B$ Bought] - [$Total_B$ Sold] = 0 - 350 = -350. The price will be:

$$Price_B = 50+1/100 * (Total_B) = 50+1/100*(-350) = 46.5$$

Note that, like for the price of good A, the more participants want to buy, the higher the price you will have to pay for each unit. The more participants want to sell, the lower the price you will receive for each unit. However, the price in market B moves away from 50 by less for a given level of units bought and sold, because Total is divided by 100 and not by 10 (as it was in market A). Again, to help you to familiarize with the way the computer sets the price, you can consult Table 2 at the end of the instructions to see the price corresponding to different combinations of your choice and those of the other participants.

After everyone has made his/her decision and the computer has computed the price, on the screen you will see a summary of your decision, the decisions of the other participants, and the resulting price and earnings. After that, you will start trading in market C.

<u>Market C</u>

<u>The value of good C is 50 in all rounds.</u>

Your trading decision

Analogously to market B, you will simply be asked to choose how many units of good C you want to buy or sell. You can sell up to 50 units, that is, your initial endowment of good C, and buy at most 50 units.

In the screen, there is a Box where you indicate the number of units of good C that you want to buy or sell, by clicking on the BUY or SELL button.

Note that in market C, as it was in market B, since the value is 50 in any given round you will have to decide whether you want to buy or sell.

The price

After everyone has made his/her decision, the computer will compute the price of good C with the same rule **as for good A**, that is,

$$Price_C = 50 + 1/10 * (Total_C)$$

where

$Total_C = Total_C$ Bought – $Total_C$ Sold

$Total_C$ Bought = sum of the units of the good C bought by all those who decide to buy;

$Total_C$ Sold = sum of the units of the good C sold by all those who decide to sell.

Note that in market A and C the price is computed according to the same rule (whereas the price in market B was computed according to a slightly different rule, as explained above).

Note that, similarly to markets A and B, the more participants want to buy, the higher the price you will have to pay for each unit. The more participants want to sell, the lower the price you will receive for each unit. As for market A, Table 1 at the end of the instructions gives you the prices corresponding to different combinations of your choice and those of the other participants.

After everyone has made his/her decision and the computer has computed the price, on the screen you will see a summary of your decision, the decisions of the other participants, and the resulting price and earnings.

After that, you will receive a summary of your trading activity in the entire round and you will learn your per-round payoff.

Per-Round Payoff

As we said, at the beginning of each round we give you an endowment of 50 units of each good and of 15,000 liras so that you can sell the goods (if you want) or buy more of them (by spending your liras). At the end of the round, we will take these endowments back, so that your payoff only depends on the profits or losses made while trading and not on the endowment.

In particular, your payoff will depend on two components:

1. The earning you made in each market;
2. Two "penalty terms".

The per-round payoff will be equal to:

$$Earning_A + Earning_B + Earning_C - Penalty\_1 - Penalty\_2$$

Let us see what these terms are.

1. The earning in market A is computed in the following way:

- if you BUY,

$Earning_A = (Value_A - Price_A) * (\text{Units of A good you bought})$.

This is because for each unit that you buy you receive the value of the good but you have to pay the price;

- if you SELL,

$Earning_A = (Price_A - Value_A) * (\text{Units of A good you sold})$.

This is because for each unit that you sell you receive a price and you will lose the value of the good you owned.

Similarly, for market B,

- $Earning_B = (Value_B - Price_B) * (\text{Units of B good you bought})$ if you BUY
- $Earning_B = (Price_B - Value_B) * (\text{Units of B good you sold})$, if you SELL

And for market C,

- $Earning_C$ = ($Value_C$ - $Price_C$) * (Units of C good you bought), if you BUY
- $Earning_C$ = ($Price_C$ - $Value_C$) * (Units of C good you sold), if you SELL

2. The "penalty terms" are the following:

- Penalty_1= $(units_A+units_B)^2$
- Penalty_2= $(units_B+units_C)^2$

where $units_A$, $units_B$, $units_C$ are your trading "exposure" in each market. What is your trading exposure? It is the number of units you decided to buy if you bought, or, with a negative sign, the number of units you decided to sell if you sold.

How to interpret the penalty terms? Consider Penalty_1. If the sum of $units_A+units_B$ is equal to 0 the penalty is zero, meaning you are not penalized. If it is different from 0, then you will pay a penalty. Note that it does not matter whether the term is higher or lower than 0, since the penalty term is squared. Note also, that the more this sum is different from 0, the higher the penalty term. That is, your Penalty_1 will be the greater the further away your **combined** trading exposure in market A and B is from zero.

The same is true for Penalty_2=$(units_B+units_C)^2$. That is, your Penalty_2 will be the greater the further away your **combined** trading exposure in market B and C is from zero.

Note that Penalty_1 only depends on your combined trading exposure in markets A and B, whereas Penalty_2 only depends on your combined trading exposure in market B and C.

Example 1

For instance, if in market A you bought 20 units, in market B you sold 10 units and in market C you bought 5 units, then the penalty terms will be:

- Penalty_1= $(units_A+units_B)^2 = (20\text{-}10)^2 = (10)^2 = 100$
- Penalty_2= $(units_B+units_C)^2 = (-10+5)^2 = (-5)^2 = 25$

Therefore, we will subtract 125 (Penalty_1+Penalty_2=100+25) from the earnings you got trading in the 3 markets A, B and C.

Example 2

If in market A you sold 35 units, in market B you sold 30 units and in market C you sold 20 units, then the penalty terms will be:

- Penalty_1= $(units_A+units_B)^2 = (-35\text{-}30)^2 = (-65)^2 = 4225$
- Penalty_2= $(units_B+units_C)^2 = (-30\text{-}20)^2 = (-50)^2 = 2500$

Therefore, we will subtract 6725 (Penalty_1+Penalty_2=4225+2500) from the earnings you got trading in the 3 markets A, B and C.

To sum all up, the per-round payoff is the sum of the trading earnings in the three markets and the two Penalties:

- $Earning_A$ + $Earning_B$ + $Earning_C$ - Penalty_1 - Penalty_2

Note, however, that if this sum is lower than zero (that is, you have made a loss and not a profit), then your per-round payoff will be set equal to zero. This guarantees that, in each round, you never lose money.

Payment

To determine your final payment, we will sum up your per-round payoffs for all the 20 rounds. We will then convert this sum into pounds at the exchange rate of 200 liras = £1. That is, for every 200 liras you have earned in the experiment you will get 1 pound. Moreover, you will receive a participation fee of £5 just for showing up on time. We will pay you in cash (in private) at the end of the experiment.