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Financial contagion in the laboratory: The cross-market rebalancing channel

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ABSTRACT

We present the results of the first experimental study of financial markets contagion. We develop a model of financial contagion amenable to be tested in the laboratory. In the model, contagion happens because of cross-market rebalancing, a channel for transmission of shocks across markets first studied by Kodres and Pritsker (2002). Theory predicts that, because of portfolio rebalancing, a negative shock in one market transmits itself to the others, as investors adjust their portfolio allocations. The theory is supported by the experimental results. The price observed in the laboratory is close to that predicted by theory, and strong contagion effects are observed. The results are robust across different market structures. Moreover, as theory predicts, lower asymmetric information in a ("developed") financial market increases the contagion effects in ("emerging") markets.

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.

The theoretical literature on contagion in financial markets has identified several channels of contagion.[1] In King and Wadhwani (1990), informational spillovers lead traders to trade in one market on the basis of the information they infer from price changes in another. Informational spillovers are also present in Cipriani and Guarino (2008), in which contagion occurs because trading activity in one market creates an informational cascade in another. In Calvo (1999), correlated liquidity shocks – which occur when agents, hit by a liquidity shock in one market, need to liquidate their position across markets in order to meet a margin call – generate contagion across markets (see also Yuan, 2005). In Kyle and Xiong (2001), financial contagion is due to wealth effects. In Fostel and Geanakoplos (2008) financial contagion arises as a result of the interplay between market incompleteness, agents' heterogeneity and margin requirements. In Kodres and Pritsker (2002), contagion happens through cross-market rebalancing, when traders hit by a shock in one market need to rebalance their portfolios of assets. Consider an economy with three markets: *A*, *B* and *C*; assume that *A* and *B* share exposure to one macroeconomic risk factor, whereas *B* and *C* share exposure to a different macroeconomic factor. A shock in market *A* may prompt investors to rebalance their portfolios in market *B* (because of their common risk exposure), which in turns prompts investors to rebalance their portfolios in *C*. As a result, the shock transmits itself from *A* to *C*, although the two markets do not share exposure to the same risk factor (i.e., their fundamentals are independent).

The purpose of this paper is to analyze the cross-market rebalancing channel of contagion in a laboratory. We do so in order to understand whether rebalancing motives are not only theoretically interesting, but also able to generate contagion effects with human subjects.

Kodres and Pritsker (2002) study cross-market rebalancing in a rational expectations, CARA-Normal model. Their model builds on Grossman and Stiglitz (1980), extending it to a multi-asset economy. To implement their model in the laboratory would be difficult, given that agents are assumed to have a CARA utility

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[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).

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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 Kodres and Pritsker (2002) literally, 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 subjects could easily understand. We implemented the model in the laboratory with three treatments. In the first two treatments,which we label the "baseline treatments", subjects trade three assets with an automaton representing a fringe of uninformed traders. The assets' fundamental values are independent of each other. Portfolio rebalancing motives arise because subjects' payoffs depend not only on the return to their investment, but also on the composition of their portfolios. Optimal portfolio weights are exogenously imposed by the experimenters to create meaningful contagion effects. In the third treatment, we studied the rebalancing channel with a different market mechanism. In particular, subjects with the same payoff function as in the previous treatments traded in a multi-unit double auction market. They exchanged the assets among themselves, some of them being informed traders and others being uninformed traders.

The results from our experiment are very encouraging for the theoretical analysis. In all the three treatments, the prices that we observe in the laboratory are very close to the equilibrium ones. As a result, very strong contagion effects are observed between the two periphery markets. Therefore, the experimental analysis lends credibility to the idea that the rebalancing channel is an important element in creating cross-market contagion.

An important implication of the Kodres and Pritsker (2002) model is that the degree of asymmetric information in a (developed economy's) financial center affects the severity of contagion effects across emerging markets. Lower asymmetric information, by making the price less elastic, decreases the costs of rebalancing; as a result, the transmission of shocks from one periphery market to the other is more pronounced. Therefore, as markets in developed economies become more transparent (i.e., as the degree of asymmetric information decreases), contagion effects among emerging markets become stronger. We tested this prediction in the laboratory, by running treatments with different price elasticities in the financial center. The experimental results support the theory: as the price in the financial center becomes less elastic, contagion effects in the periphery become more pronounced.

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 and some robustness checks.

2. The theoretical framework

2.1. The portfolio rebalancing channel

Our experiment, inspired by the work of Kodres and Pritsker (2002), aims to test experimentally the "cross-market rebalancing" channel of financial contagion. In Kodres and Pritsker (2002), because traders need to rebalance their portfolios, contagion arises even when traditional channels of contagion (such as correlated information, correlated liquidity shocks or wealth effects) are absent. We give the intuition behind their result through a simple example (taken from Kodres and Pritsker, 2002).

There are three assets traded in the economy, A, B and C, whose liquidation values take the form

$$V_A = \theta_A + \beta_A f_1 + \eta_A$$
$$V_B = \beta_{B,1} f_1 + \beta_{B,2} f_2$$
$$V_C = \theta_C + \beta_C f_2 + \eta_C$$

where f_1 and f_2 represent shared macroeconomic risk factors; β_A,β_B and β_C are the risk factors' marginal effects on the assets; θ_A and θ_C represent country-specific private information; and η_A and η_C country-specific risk factors (on which private information is not available). All the random variables are independently distributed.

Note that countries A and C (which Kodres and Pritsker interpret as emerging, periphery economies) share no common macroeconomic factor; moreover, they are not linked by either correlated information, or by correlated liquidity shocks. Nevertheless, one can show that investors' need to adjust their portfolios leads to shocks transmitting themselves from one periphery market to the other. This happens because, although A and C share no risk factors, they are both linked to B (which Kodres and Pritsker interpret as a developed financial market), and B acts as a conduit for shock transmission.

Suppose that informed traders receive information that makes them decrease their expected value in market A; that is, there is a negative information shock in market A. Their optimal response is to sell asset A, thus lowering their exposure to risk factor f_1 below its optimal level. Optimal portfolio considerations will lead them to increase their exposure to f_1 by buying asset B, thus raising its price. This, however, increases their exposure to risk factor f_2 above its optimal level, thus leading them to sell asset C. As a result, the price in market C will drop. Therefore, a negative shock in market A leads to an increase in the price of asset B (the financial center) and to a decrease in the price of asset C (the other periphery economy).

Note that informational asymmetry in market B plays a crucial role in the transmission of the shock. If there is more informational asymmetry in B, its price increases by more with the order flow and cross market rebalancing becomes more expensive.[2] Because of this, there will be less rebalancing from A to B and from B to C. This reduces market C sensitivity to shocks in market A, that is, the severity of contagion. In contrast, a decrease in informational asymmetry in market B makes contagion more severe. Kodres and Pritsker (2002) comment that "steps that reduce information asymmetries in developed markets may have the unintended consequence of enhancing developed market's role as a conduit for contagion among emerging markets".

As we mentioned in the Introduction, Kodres and Pritsker (2002) use a rational expectations, CARA-Normal model (which extends Grossman and Stiglitz, 1980) with three types of traders. Because implementing their model in the laboratory would be difficult, we developed a simple model, which captures the same intuition, but is amenable to experimental testing. We describe this model in the following section.

2.2. The model structure

We present a simple model of portfolio rebalancing that can be easily brought to the laboratory. In our model, there are three markets – labeled, as above, A, B and C – where traders trade three assets denoted by the same letters. The three markets open sequentially. First traders receive information about the fundamental value in market A and adjust their position accordingly. Then, they adjust their portfolio by trading first in market B and afterwards in market C.[3]

[2] Intuitively, noise traders interpret the order flow in market B (e.g., a high demand) as having informational content. As a result, they respond more to changes in the order flow (because it affects their conditional expectation of the asset value).

[3] We preferred to have markets open sequentially rather than simulatenously, so that subjects in the experiment could concentrate on one market at a time. One concern one can have with the sequential structure is that it requires solving a backward induction problem, making the game perhaps more complicated. We will comment more on this when discussing our results.

The fundamental value of each of the three assets (V^J, J = A, B, C) can be 0, 50, or 100, with equal probabilities. There are two types of traders in the market: informed and uninformed traders. Both types of traders trade in all the three markets. Let us discuss informed traders first. There are N informed traders, who receive a perfectly informative signal about the values of the three assets. Each informed trader chooses the quantities x_i^A, x_i^B and x_i^C to maximize the following payoff function:

$$(V^A - p^A)x_i^A + (V^B - p^B)x_i^B + (V^C - p^C)x_i^C - \left(x_i^A + x_i^B - F_1^*\right)^2 - \left(x_i^B + x_i^C - F_2^*\right)^2, \tag{1}$$

where x_i^J is the quantity (number of shares) of asset J bought $\left(x_i^J > 0\right)$ or sold $\left(x_i^J < 0\right)$ by informed trader i, and p^J is the price of asset J. Observe that the payoff function is made up of two parts. The first three terms (which we call *Trading Profit*) represent the gain made by trader i when buying or selling an asset (i.e., the difference between the asset fundamental value and its price, times the quantity purchased or sold). The last two terms (which we call *Portfolio Imbalance Penalty*) $\left(-\left(x_i^A + x_i^B - F_1^*\right)^2 - \left(x_i^B + x_i^C - F_2^*\right)^2\right)$ represent the penalty for holding an "unbalanced" portfolio. Note that F_1^* is the optimal exposure to a common risk factor to assets A and B, and F_2^* the optimal exposure to a common risk factor to assets B and C. The term $\left(x_i^A + x_i^B - F_1^*\right)^2$ penalizes investors for excessive (or too little) exposure to the risk factor common to A and B, whereas $\left(x_i^B + x_i^C - F_2^*\right)^2$ penalizes investors for excessive (or too little) exposure to the risk factor common to B and C.

The *Portfolio Imbalance Penalty* is a reduced form way of adding portfolio balance considerations in the informed traders' payoff function.[4] It introduces the same type of optimal portfolio concerns that triggers contagion in the Kodres and Pritsker (2002) model outlined above; as a result, traders' optimal demand does not depend only on the expected value of an asset, but also on the optimal exposure to different risk factors. Because of this, informed traders have an incentive to rebalance between A and B, and between B and C in the same way as in Kodres and Pritsker (2002). At the same time, with this setup subjects in the laboratory do not have to solve a complex optimal portfolio problem.

As we shall see, informed traders have both informational and non informational reasons to trade. Informational reasons play a role in market A, where informed traders (who know asset A's true value) can earn a profit by buying the asset at a price which is below (above) its fundamental value. Non-informational reasons play out in market B and C, when traders buy or sell the assets in order to minimize rebalancing costs.

Let us now discuss uninformed traders. Uninformed traders trade for unmodelled, liquidity reasons. Their aggregate net-supply schedule is price elastic, and given by

$$K^J[p^J - E(V^J)],$$

where V^J ($J = A,B,C$) is the asset value, p^J is the asset price, and K^J is a positive parameter. $E(V^J)$ represents the asset's unconditional expected value, which is equal to 50 in the three markets. The above expression implies that uninformed traders supply the asset whenever its price is above its expected fundamental value and demand it whenever it is below. The parameter K^J measures how elastic the uninformed traders' net supply function is to changes in the price. The higher K^J, the more the net supply responds to changes in the price of asset J.

One reason why uninformed trader's net supply is price sensitive is (unmodelled) asymmetric information in the markets. This interpretation is particularly relevant because in Kodres and Pritsker (2002) the degree of asymmetric information determines the severity of contagion. In particular, if asymmetric information between informed and uninformed traders is severe, uninformed traders interpret the order flow in the market (e.g., a higher price) as having informational content.[5] As a result, they respond more to changes in the asset price (because it affects their conditional expectation on the asset value), and the net-supply function will be more elastic. As we shall see, this makes contagion less pronounced.

In each market J, in equilibrium, net supply from uninformed traders equals net demand from informed traders whenever

$$K^J(p^J - E(V^J)) = \sum_{i=1}^{N} x_i^J.$$

This means that in each market J the price schedule that informed traders face is

$$p^J = E(V^J) + \frac{1}{K^J}\sum_{i=1}^{N} x_i^J. \tag{2}$$

In particular, if the net demand from informed traders is positive $\left(\sum_{i=1}^{N} x_i^J > 0\right)$, the price is greater than the asset unconditional expected value. If it is negative, the price is, instead, lower.[6]

2.3. Laboratory implementation

We brought our model to the laboratory with three different treatments. The main difference among them is the market structure that we implemented in the laboratory. In the first two treatments, subjects played the role of informed traders trading against an automaton; subjects chose their quantities demanded in a game akin to a Cournot game. This setup had the great advantage of being simple and easy for subjects to understand. In the third treatment, instead, we used a market mechanism closer to how trading occurs in actual financial markets; specifically, subjects played both the roles of informed and uniformed traders, and exchanged the assets among themselves through a multi-unit double auction.

Let us start by describing the implementation of the first two treatments. Ten subjects acted as informed traders ($N = 10$). Markets opened sequentially. An automaton took the other side of the market, representing a fringe of uninformed traders. Subjects were presented with the equilibrium price schedule (2), and each submitted his net demand order. Traders were paid according to the payoff function (1) with $F_1^* = F_2^* = 0$.

We ran the experiment for two sets of realization of the fundamentals: in odd rounds we set $V^A = 0$, $V^B = 50$, $V^C = 50$; whereas in even rounds we set $V^A = 100$, $V^B = 50$, $V^C = 50$.[7]

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[4] We thank Laura Kodres for suggesting this implementation strategy.

[5] That is, although this is not in the model, one can interpret the elasticity of their net supply as reflecting their belief that the order flow come either from informed traders or from noise traders (who trade purely for liquidity reasons). A similar interpretation can be found in Kodres and Pritsker (2002).

[6] Note that this is almost the same price schedule that appears in the standard Cournot oligopoly model. In a Cournot model, however, the price schedule for a firm depends on the consumer's demand; here, instead, $\sum_{i=1}^{N} x_i^J$ refers to the net-demand by the informed traders themselves (which is equivalent to the uninformed traders net-supply).

[7] Note that, although in the model the asset values equal 0, 50 and 100 with equal probabilities, in the experiment we only considered these specific realizations. This is not a problem since subjects in the experiment played the role of informed traders who knew the asset values and uninformed traders were played by an automaton. Moreover, 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) because we though it would make the experiment more interesting and enjoyable for the subjects, thus lowering the chance of boredom effects in the laboratory. Moreover, one could suspect that subjects would have a higher ability to buy than to sell, a conjecture which, as we shall see, does not find support in our data.

In Treatment 1 ($T1$), K^J was set equal to 10 in all markets; in Treatment 2 ($T2$), K^J was set equal to 10 in markets A and C, but equal to 100 in market B. That is, in Treatment 1, the net-supply function in all the three markets was

$$p^J = 50 + \frac{1}{10}\sum_{i=1}^{N} x_i^J,$$

and in Treatment 2, it was the same but for market B, where it was

$$p^B = 50 + \frac{1}{100}\sum_{i=1}^{N} x_i^B.$$

In words, the net-supply function in market B was more elastic than in Treatment 1.

In Treatment 3 ($T3$), instead of having an exogenous net-supply schedule, we had $M = 10$ subjects acting as informed traders. We gave uninformed traders the following payoff function:

$$(p^A - 50)q_i^A - \frac{1}{2}(q_i^A)^2 + (p^B - 50)q_i^B - \frac{1}{2}(q_i^B)^2 + (p^C - 50)q_i^C - \frac{1}{2}(q_i^C)^2,$$

where, for each market, the first term is the subject's expected profit from trading the asset, and the second term is the quadratic cost of holding a different position from the initial endowment of zero.[8] Note that, in contrast to our notation for informed traders, $q_i^J > 0$ means that the uninformed trader is supplying the asset, whereas $q_i^J < 0$ means that he is demanding it. An uninformed trader's net-supply schedule is, therefore, given by

$$q_i^J = p^J - 50.$$

By aggregating across the 10 uninformed traders, we obtain the following aggregate net-supply function:

$$Q^J = \sum_{i=1}^{M} q_i^J = 10(p^J - 50) = K^J(p^J - E(V^J)),$$

which is the same net-supply function that we had in Treatment 1.

Note that, in Treatment 3, similarly to the other two treatments, informed traders valued asset A either 0 of 100 and assets B and C always 50. In contrast to the previous treatments, however, the value was randomly determined at the beginning of each round, and only informed traders were informed about it. This allowed us to study whether private information was reflected by the price.

2.4. Equilibrium predictions

Given the sequential structure of the game, we find the equilibrium by backward induction. We compute both the Cournot and the competitive equilibrium. Given that in our laboratory implementation there are 10 informed traders, the two equilibria are extremely similar; therefore, in the rest of this section, we discuss the Cournot equilibrium prices and quantities only. Table 1 shows the quantity that each informed trader buys or sells in the three markets: the upper part of the table refers to $V^A = 0$ and the lower one to $V^A = 100$.[9] The first row refers to Treatments 1 and 3, where $K^J = 10$ in all three markets; whereas the second row refers to Treatment 2, where $K^A = K^C = 10$ and $K^B = 100$.

Let us first consider Treatments 1 and 3. When $V^A = 0$, informed traders sell asset A and the equilibrium price (25.61) is lower than the unconditional expected value (50). To rebalance their portfolios, informed traders buy in market B and sell in market C. The low realization of asset A's value (which can be interpreted as a negative shock in the market) transmits itself to market C. The equilibrium price in market C is lower than the fundamental value although the asset values in market A and C are independent. Similarly, when $V^A = 100$, informed traders buy asset A and the equilibrium price (74.39) is above the asset's unconditional expected value. For cross-market rebalancing reasons, traders sell in market B and buy in market C; as a result, prices in markets A and C comove.

Table 1
Equilibrium predictions.

	Market A p^A (x_i^A)	Market B p^B (x_i^B)	Market C p^C (x_i^C)
$V_A = 0$, $V_B = 50$, $V_C = 50$			
$T1 - T3$	25.61(−24.39)	62.81 (12.80)	41.74 (−8.26)
$T2$	20.26 (−29.74)	52.11 (21.09)	36.39 (−13.61)
$V_A = 100$, $V_B = 50$, $V_C = 50$			
$T1 - T3$	74.39 (24.39)	37.19 (−12.80)	58.26 (8.26)
$T2$	79.74 (29.74)	47.89 (−21.09)	63.61 (13.61)

The table shows the equilibrium prices and quantities traded in each market.

A low realization of the asset value in market A – i.e., $V^A = 0$ – pushes the price of the asset approximately 49% below its unconditional expected value. Because of portfolio rebalancing, the price in market B exceeds the asset value by 26%, whereas the price of asset C is 16% lower than the asset value.

In Treatment 2, since price elasticity in market B is lower, rebalancing becomes less costly. For this reason, 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 Treatments 1 and 3. The quantity sold in market B reaches approximately 21 units, while the price 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 high realization of the fundamental in market A on asset C is now significantly higher than before, with the price of asset C jumping to 63.61. The figures for the case of $V^A = 0$ are analogous. Traders sell asset A pushing the price approximately 59% below the asset unconditional expected value. The price in market B exceeds the asset value by only 4%, whereas the price of asset C is 27% lower than the asset value.[10]

As we mentioned before, Treatment 2 is inspired by an important observation by Kodres and Pritsker (2002). They interpret markets A and C as emerging markets and market B as a developed market. Moreover, they link the degree of price elasticity in a market to the degree of asymmetric information. The presence of a developed market with less asymmetric information (i.e., a lower price elasticity) exacerbates the contagious effects of portfolio rebalancing.

3. The experiment

We now describe the experimental procedures. As we mentioned above, in the first two treatments subjects, acting as informed traders, simply chose quantities to buy or sell to an automaton in each market. In the third treatment, instead, ten subjects acted as informed traders and ten as uninformed traders. They exchanged the three assets among themselves in a multi-unit double auction.

For each treatment we ran five sessions, recruiting a total of 200 subjects. The experiment was run at the ELSE laboratory at UCL in

[8] Note that giving subjects the above payoff function is tantamount to assuming that, in the economy, uninformed traders value the assets 50 in all markets (e.g., because of private values).

[9] Of course, the equilibrium quantities in the two cases only differ for the sign. A negative sign means that the quantity is sold by an informed trader.

[10] For comparison, when $V^A = 100$, in Treatments 1 and 3, the competitive equilibrium prices are $p^A = 76.19$, $p^B = 35.714$ and $p^C = 59.52$; in Treatment 2, they are $p^A = 82.17$, $p^B = 47.674$ and $p^C = 65.504$.

the Summer 2009, Winter 2010 and Fall 2012. We recruited subjects from the college undergraduate population across all disciplines. Subjects had no previous experience with this experiment. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

3.1. The baseline treatments

Each session of the baseline treatments consisted of 20 rounds of trading. The experimental currency was called Lira, and was exchanged at the end of the experiment into British Pounds.

Let us explain the procedures for each round. At the beginning of each session we distributed written instructions to the subjects (see Appendix). We explained to subjects that they all received the same instructions (in an attempt to make the game common knowledge). Subjects could ask clarifying questions, which we answered privately.

In each round, the ten participants traded in the three markets (*A*, *B* and *C*), which opened sequentially. Subjects played as informed traders, whereas the net supply from uninformed traders was provided by an automaton. Before trading in each market, subjects were provided with an endowment of 50 units of each asset (in the instructions called "good") and of 15,000 liras.

Subjects were told that in the odd rounds of the experiment, the value of asset *A* was set equal to 0, whereas in the even rounds, it was set equal to 100 liras. Moreover, they were told that in markets *B* and *C* the value of the asset was equal to 50.[11] The payoff function described in Section 2 was carefully described in the instructions. We explained it both analytically and by presenting some numerical examples; we also 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 (see the instructions in Appendix).

At the beginning of each round, subjects decided how many units of asset *A* they wanted to sell (in odd rounds, when its value was 0) or to buy (in even rounds, when its value was 100). They did so by inputting a number between 0 and 50 on the screen. After all 10 subjects had made their trading decision for asset *A*, they observed a screen reporting the individual decisions of all participants, the equilibrium price, and each subject's own *Trading Profit* in market *A* (i.e., the difference between the fundamental value and the trading price times the quantity sold or purchased). Furthermore, they were also informed of the (provisional) *Portfolio Imbalance Penalty* that they would suffer for their trade in market *A* (i.e., assuming no trade in the other markets).[12]

After trading in market *A*, subjects could trade in market *B*. They had to decide how many units of the asset they wanted to buy or sell. They did so by inputting a number between 0 and 50 and then clicking on a "buy" or "sell" button. After they had all made their decision, they observed a feedback screen reporting the individual decisions, the equilibrium price, *Trading Profit* in market *B*, and, finally, the *Portfolio Imbalance Penalties* suffered because of the exposures in markets *A* and *B*, and the (provisional) *Portfolio Imbalance Penalties* suffered because of 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 sum of the *Trading Profit* in each market and on two *Portfolio Imbalance Penalties*. The initial endowments of assets and liras that we gave to subjects at the beginning of the round were taken back at the end.[13] Moreover, we avoided that subjects ended with a negative payoff by setting the payoff in each round to zero whenever it was negative (subjects were explained of this in the instructions).[14] It is easy to verify that setting a negative payoff equal to zero does not change subjects' incentives (similarly to what happens in a standard Cournot game), and, as a result, the equilibrium predictions. This is true because in equilibrium, agents' payoffs are positive: as a result, any agent will choose the same equilibrium profit-maximizing quantities independently on the off-equilibrium payoffs (as long as these are lower than the equilibrium ones).[15]

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. On average, subjects earned £25 for a 1.5 h experiment.

3.2. The MUDA treatment

In the two baseline treatments, we tested the Kodres and Pritsker's (2002) rebalancing channel of contagion by designing a very simple experimental game. Having an experimental setup that would be easy for the subjects to understand was a key driver of our design choice for the first two treatments. Nevertheless, one can wonder whether our results are robust to a different trading mechanism which is closer to how trading occurs in actual financial markets, and, more importantly, in which the net supply function is not generated by an automaton.

To this purpose, in the third treatment, we used a different trading mechanism, a multi-unit double auction (MUDA). In a MUDA, subjects trade in continuous time, posting buy and sell limit orders for multiple units. Orders are automatically matched by a computer, in a similar fashion to what happens in an order-driven market with a limit-order book.

The MUDA is a rather complex trading mechanism: each subject trades on both sides of the market, can act at any point in time during a trading session, and can choose both the price and the quantity to offer. Nevertheless, it is a well established experimental trading protocol (for an early analysis, see Plott and Gray, 1990). Importantly for the purposes of our experiment, the MUDA allows us to endogenize the fringe of uninformed traders, which is played by human subjects. In a nutshell, this additional treatment serves two purposes: understanding whether the results described in the previous section hold in a different trading mechanism that resembles more closely actual financial markets; and understanding whether substituting liquidity traders with an automaton, as we have done in Treatments 1 and 2, is an innocuous experimental design choice.

[11] As we mentioned above, this is slightly different from the model above, where the three assets take values 0, 50, and 100 with equal probability. For the purposes of our study, the difference is, however, immaterial.

[12] That is, we told them the value of $-(x_i^A + x_i^B)^2 - (x_i^B + x_i^C)^2$, given their choice of x_i^A, and assuming that the choices of x_i^B and x_i^C were zero.

[13] The endowments of cash and assets had the only purpose of making the experiment more intuitive, by letting subjects buy and sell without having to borrow or taking a short position.

[14] Because of the quadratic penalty terms, negative payoffs were a likely outcome if players played off-equilibrium strategies.

[15] The only concern, given that the experiment is repeated for many rounds, is that subjects could collude with some subjects not trading in a round in order to let others trade at a particularly favorable price. This, however, should not happen according to the theory (as the game is finite), and was never observed in the data.

Let us now describe the procedures.[16] Each of the five sessions consisted of 10 rounds of trading. In each round, the 20 participants traded in the three markets (*A*, *B* and *C*), which opened sequentially. Ten subjects played as informed traders (in the experiment, they were referred to as "green participants") and ten as uninformed traders (referred to as "blue participants"). Each subject had the same chance of being selected as an informed or an uninformed trader. Subjects kept the same role throughout the experiment.[17] Before trading in each market, subjects were given an endowment of 50 units of the asset and 15,000 liras, exactly as in the previous treatments.

The value of asset *A* was equal to either 0 or 100 (with the same probability) to green participants (the value was the same for all of them). Green participants knew how much asset *A* was worth to them, whereas blue participants did not know green participants' asset valuation.[18] The value of asset *A* was 50 for the blue participants. The value of assets *B* and *C* was also worth 50 for all subjects.

Green and blue participants differed not only for the value of asset *A*, but also for the way in which their payoffs were computed. For green participants, the payoff was identical to that described in the previous treatments, that is, it was the sum of the trading profit in each market and the portfolio rebalancing penalties. For blue participants, the payoff was also the sum of two components: the trading profit in each market, and a penalty for the exposure in each market, set equal to $\frac{1}{2}\left(q_i^J\right)^2$. As we mentioned above, given $M = 10$, this penalty function implies that the theoretical aggregate net supply in each market was identical to that in the previous treatments.

In each session, markets opened in sequence. Trading started in market *A* and lasted 220 s. Subjects could choose prices and quantities to buy or sell using the trading platform described in the Appendix. During the trading session, subjects could use their endowment of cash and units of the good, but were not allowed to go short. Both blue and green subjects could post any positive bid or ask prices for any trade size that respected their budget constraint. A trade was automatically executed whenever a new offer to buy (sell) was at a weakly higher (lower) price than an outstanding offer to sell (buy). Otherwise, the new offer became an outstanding offer in the book. Note that a new order could be partially executed (if there were not enough outstanding offers in the book), or executed at different prices (if the size of the best buy or sell offer was smaller than the incoming order).

Once the 220 s had passed, subjects received some feedback: they learned their trading profits, and the loss due to their exposures to market *A* (for green participants their provisional exposures, computed assuming no exposure to market *B*). After receiving the feedback, subjects traded in market *B*, and, after receiving additional feedback, in market *C*. The trading protocol and the length of trading activity was the same for the three markets.

Procedures to pay subjects were identical to those for the other treatments. To give the same expected payoff to green and blue participants, we used two different exchange rates: £1 = 100 liras for green participants and £1 = 200 liras for blue participants. On average, subjects earned £29 for a 3-h experiment.

4. Results

Let us know describe the results. Recall, that in some rounds of the experiment V^A was 0, and in others it was 100. The theoretical predictions are symmetric for the two cases. For instance, in Treatments 1 and 3, when $V^A = 0$, each informed trader sells 24.39 units in market *A*, buys 12.80 units in market *B*, and sells 8.26 units in market *C*; when $V^A = 100$, informed traders trade the same quantities, but the direction of trade is inverted. Analogously, when $V^A = 0$, the equilibrium prices in the three markets are 25.61, 62.81 and 41.47; when $V^A = 100$, they are 74.39, 37.19, and 58.26; in both cases, the distance from V^A is 25.61, 62.81 and 41.47.

Because of this, in order to simplify the description of the results, we report them as if the fundamental value of asset *A* were always zero in all the rounds; that is, for all rounds in which $V^A = 100$, we report the quantities with the opposite sign, and the prices as distances from 100. From now on, whenever we refer to quantities and prices, they should be interpreted as having being computed after this transformation.

Let us start by analyzing the experimental results for Treatment 1. In the top panel of Fig. 1, the black dashed line reports, for each round of trading in market *A*, the quantities bought or sold per-subject, averaged across sessions. The other two panels report the same information for markets *B* and *C*. The black solid lines represent the theoretical counterparts. It is immediate to note that the quantities traded in the laboratory are very close to the theoretical ones in all the three markets; this is true in all rounds of the experiment, starting from the very first ones. Indeed, in market *A*, the average quantity sold across all rounds is 23.98, versus a theoretical counterpart of 24.39 (see Table 2); using the Mann–Whitney test on the session averages, we cannot reject the null hypothesis that the difference between the two numbers is zero (p-value = 0.62).[19] In market *B*, the average quantity traded across rounds is 11.08 versus a theoretical counterpart of 12.80; although the difference is statistically significant, it is rather small (1.72 out of 50 units available per subject). In market *C*, the average traded quantity is 7.84 versus a theoretical counterpart of 8.26, a difference that is not statistically significant (p-value = 0.62).

Given that the quantities traded were very close to the theoretical ones, it is not surprising that so were the prices. This is illustrated in Fig. 2.

In the top panel of Fig. 2, the dashed black line reports, for each round of trading, the average price across sessions in market *A*. In the other two panels, we report the same information for markets *B* and *C*. The solid black lines represent model's predictions. Similarly to quantities, prices are always very close to the theoretical ones in all the three markets. Indeed, in market *A*, the average price across all rounds is 26.02, versus a theoretical counterpart of 25.61 (see Table 3). We cannot reject the null hypothesis that the difference between the two numbers is zero (p-value = 0.62). In market *B*, the average price across rounds is 61.08 versus a theoretical counterpart of 62.08, a difference that although statistically significant is very small. In market *C*, the average price is 43.17 versus

[16] As with Treatments 1 and 2, also Treatment 3 started with subjects reading the instructions. Before reading the instructions, however, in this treatment subjects listened to a 15-min Power Point presentation, illustrating the main points of the experiment. After the presentation and after reading the instructions, subjects were requested to answer a brief questionnaire. Subjects could also ask clarifying questions, which an experimenter answered privately. None of the subjects had difficulties in answering the questionnaire, with the exception of one subject in Session 4. We let this subject try for one round (in which he was inactive), after which he did not take part in the study.

[17] We chose not to have subjects change role during the experiment, so that they had more opportunities to learn how to play.

[18] In the previous treatments, the value of asset A was 0 in odd rounds and 100 in even rounds. In this treatment, with subjects acting as uninformed traders, we thought it was important that only informed traders knew the value the asset had for them, whereas uninformed traders had to infer it from the pattern of trading activity. Note that, of course, all subjects knew that the value of the asset was 50 for blue participants in market *A*, and 50 for all participants in markets *B* and *C*.

[19] All tests referred to in the paper are Mann–Whitney tests on session averages. We complement the non-parametric analysis with a panel data estimation reported in Appendix B. The results of the panel estimation are similar to those of the tests commented here: the null that theoretical predictions and experimental outcomes are the same can never be rejected (for any of the markets and of the treatments) in the panel.

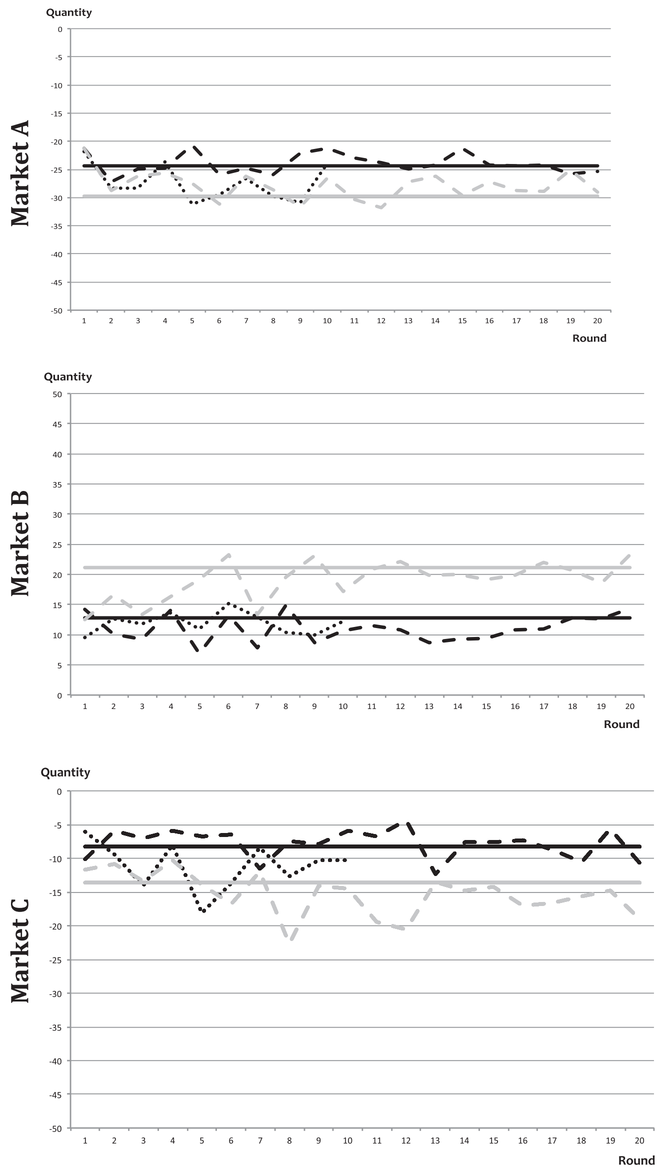

Fig. 1. The figure shows the average per-capita quantity in each round of the experiment for the three markets. The dashed black line is the average observed in *T*1 and the dotted black line is the average observed in *T*3. The dashed gray line is the average observed in *T*2. The solid lines are the equilibrium predictions for *T*1–*T*3 (black line) and for *T*2 (gray line).

41.74; the difference is small and is not statistically significant (p-value = 0.62).

The empirical results are very similar to the equilibrium predictions, although subjects had to solve a non-trivial backward induction problem. The deviation from the theoretical predictions are very similar (and very small) in all markets, irrespective of whether $V^A = 0$ or $V^A = 100$. We report the results disaggregated by the realization of the fundamentals in the Appendix. The implication is that subjects do not exhibit a higher level of rationality when they are buying an asset as opposed to when they are selling it (which could happen if selling is a less familiar activity than buying). In other words, there are no behavioral biases making contagion more severe in times of crisis.

Figs. 1 and 2 also report the results for Treatment 3. Remember that the equilibrium predictions are the same as those of Treatment 1 (solid black line). The dotted lines, instead, represent the experimental results.[20] Since during the 220 s of trading activity, a subject could buy and sell many times, for each round, we consider the aggregate net quantity bought *by informed traders* and the corresponding average price.[21] Once computed the per-round prices and quantities, in the charts we report the same statistics as in Treatment 1.

Table 2
Average quantities across rounds.

	Market *A*	Market *B*	Market *C*
Treatment 1			
Average	−23.98	11.08	−7.84
p-Value	0.62	0.004	0.62
Treatment 2			
Average	−27.89	19.04	−15.28
p-Value	0.12	0.12	0.12
Treatment 3			
Average	−27.56	12.09	−10.84
p-Value	0.12	0.62	0.004
T1 vs T2: *p*-value	0.04	0.00	0.004
T1 vs T3: *p*-value	0.19	0.48	0.12

The table shows the average quantities traded in each market. The *p*-value refers to the test of the hypothesis that the observed quantity is different from the theoretical prediction. The last two rows present the *p*-values for the hypotheses that the quantities are different across treatments.

Similarly to Treatment 1, the results in Treatment 3 are close to the theoretical predictions in all three markets. As Figs. 1 and 2 show, prices and quantities move in the right direction in all three markets (i.e., subjects correctly rebalance their portfolios). Furthermore, the average prices and quantities across all rounds are very close and mostly not significantly different from their theoretical counterparts (see Tables 2 and 3).[22] In particular, the average price was 23.52 in market *A*, 55.51 in market *B*, and 44.49 in market *C* (versus theoretical predictions of 25.61, 62.81, and 41.74), thus showing significant contagion effects due to rebalancing motives. As customary in experiments on double auction markets, we also considered the average price in the last minute of trading in each market, which is an indicator of where the price converged. The results are remarkably similar to the ones described above. In particular, the prices in the three markets were 21.41, 56.34 and 44.16. Of course, since the results in Treatments 1 and 3 are close to the same theoretical prediction they are also very close to each other. Indeed, the differences between prices an quantities in the two treatments are not significant, with the exception of the price in market *B* (see Tables 2 and 3).

Some further considerations are in order. First, in Treatment 3, subjects chose both prices and quantities; in contrast to Treatment 1, the aggregate quantity did not pin down the price, as the net supply of the assets was endogenous. It is, therefore, even more remarkable that the results are relatively close to the equilibrium ones in all three markets for both prices and quantities.

Second, and more importantly, the rebalancing channel of contagion works in this MUDA treatment as well as it does in the simpler market structure of Treatment 1: a positive (negative) shock in market *A* leads to a drop (an increase) in price in market *B* and to a rally (a crisis) in market *C*.

Third, in Treatment 3, there was asymmetric information between subjects, which complicated the environment faced by sub-

[20] Remember that there are only 10 rounds of trading in Treatment 3.

[21] We compute simple averages. Weighting by the transaction size gives nearly identical results.

[22] The exceptions are the quantity in market *C*, where the difference is 2.58 and significant; and the price in market *B*, where the difference is 7.3 and also significant.

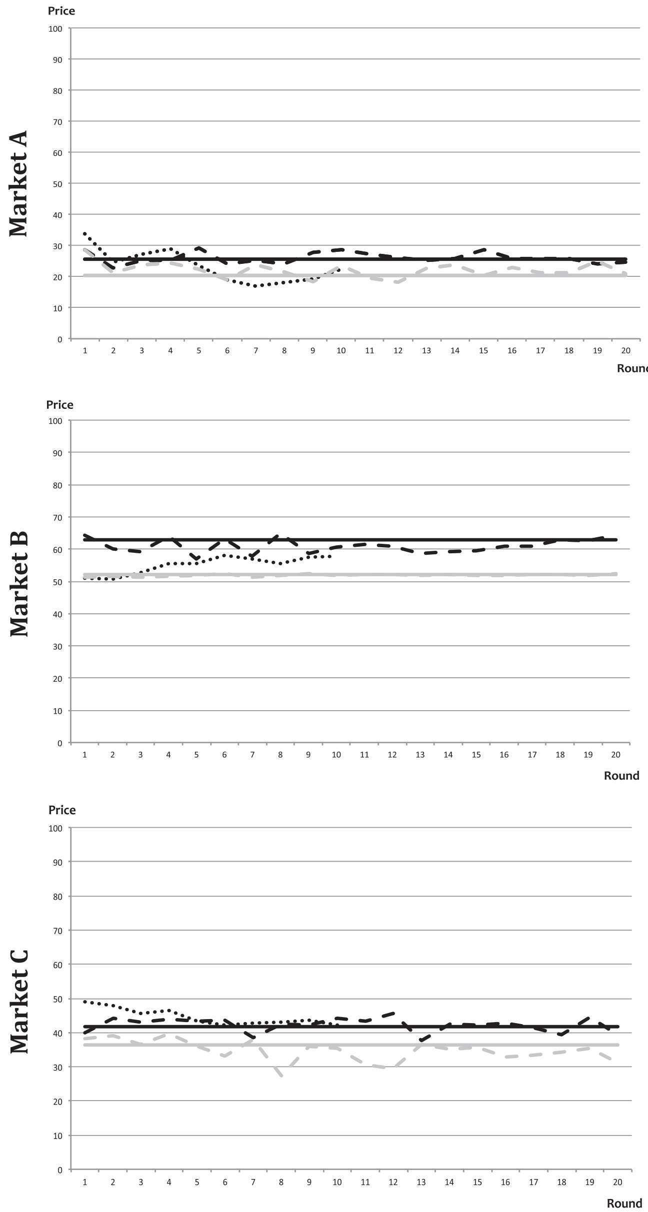

Fig. 2. The figure shows the average price in each round of the experiment for the three markets. The dashed black line is the average observed in $T1$ and the dotted black line is the average observed in $T3$. The dashed gray line is the average observed in $T2$. The solid lines are the equilibrium predictions for $T1$–$T3$ (black line) and for $T2$ (gray line).

Table 3
Average prices across rounds.

	Market *A*	Market *B*	Market *C*
Treatment 1			
Average	26.02	61.08	43.17
p-Value	0.62	0.00	0.62
Treatment 2			
Average	22.12	51.90	34.72
p-Value	0.12	0.12	0.12
Treatment 3			
Average	23.52	55.51	44.49
p-Value	0.62	0.00	0.12
$T1$ vs $T2$: *p*-value	0.04	0.004	0.004
$T1$ vs $T3$: *p*-value	0.62	0.01	0.08

The table shows the average prices in each market. The *p*-value refers to the test of the hypothesis that the observed price is different from the theoretical prediction. The last two rows present the *p*-values for the hypotheses that the prices are different across treatments.

jects. This, however, did not prevent rebalancing and contagion from occurring in the laboratory.

Let us now move to the description of the experimental results in Treatment 2. Recall that in this treatment, since the price elasticity in market *B* (the "financial center") is lower, rebalancing from market *A* to market *C* is less expensive. As a result, subjects should realize that they can trade more aggressively in market *A*. This is actually what happens in the laboratory, as one can immediately see from Figs. 1 and 2 (gray lines) and Tables 2 and 3 (for the average results across all rounds).

Note that, as theory predicts, subjects trade more aggressively in market *A* than they do in Treatment 1; they sell, on average, 27.89 units as opposed to only 23.98 in Treatment 1, a statistically significant difference (*p*-value = 0.04). As a result, the incentive to rebalance from *B* to *C* is stronger: the quantity traded raises to 19.04 in market *B* and to 15.28 in market *C* (the p-values for the null that these quantities are the same as in Treatment 1 are 0.00 and 0.00). Because of the higher rebalancing, the price of asset *C* is further away from its fundamental value than in Treatment 1, 43.17 versus 34.72, a statistically significant difference (*p*-value = 0.004). That is, there is a stronger contagion effect from *A* to *C* due to the rebalancing channel from one market to the other. Our experimental results support the hypothesis advanced by Kodres and Pritsker (2002) that when the degree of asymmetric information in developed economies diminishes, contagion effects across developing countries become stronger.

Finally, although in Treatment 2 the equilibrium is different, the empirical quantities and prices are extremely close to the theoretical ones, as was the case for the other treatments. The Mann–Whitney test for the hypotheses that the average prices or quantities are the same as in the Cournot equilibrium cannot reject the null hypothesis in any of the markets.

5. Conclusions

This paper tests the rebalancing channel of contagion, first proposed by Kodres and Pritsker (2002), with a laboratory experiment. We develop a simple model which can be brought to the laboratory, and then test its predictions. The experimental data are supportive of the theory. Rebalancing from one market to the other is very strong in the laboratory, creating significant contagion effects. The results are remarkably robust across different market structures. The theoretical predictions are supported in a simple experimental set up akin to a Cournot game as well as in a multi-unit double auction. Moreover, the experimental data support the idea that a decrease in asymmetric information in the developed financial center increases the transmission of financial shocks across developing markets. Overall, our results show that the rebalancing channel of financial contagion as described in the rational expectation framework of Kodres and Pritsker (2002) is not only theoretically appealing but also able to capture human subjects actual behavior. While our results are encouraging, an important issue that our study cannot address is in which markets this channel of contagion is more relevant. This is an issue left for future research.

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Appendix A. Additional tests

See Tables A.1, A.2 and A.3.

Table A.1
Average quantities and prices when the value of asset A was 100.

	Market *A* p^A (x_i^A)	Market *B* p^B (x_i^B)	Market *C* p^C (x_i^C)
Treatment 1			
Average	74.67 (24.67)	37.87 (−12.13)	57.23 (7.23)
p-Value	0.62 (0.62)	0.62 (0.62)	0.62 (0.62)
Treatment 2			
Average	78.38 (28.38)	48.01 (−19.88)	66.19 (16.19)
p-Value	0.12 (0.12)	0.62 (0.62)	0.12 (0.12)
Treatment 3			
Average	77.62 (25.49)	44.46 (−10.92)	55.40 (10.12)
p-Value	0.62 (0.12)	0.004 (0.12)	0.12 (0.004)

The table shows the average prices (quantities) traded in each market. The *p*-value refers to the test of the hypothesis that the observations are different from the theoretical prediction.

Table A.2
Average quantities and prices when the value of asset A was 0.

	Market *A* p^A (x_i^A)	Market *B* p^B (x_i^B)	Market *C* p^C (x_i^C)
Treatment 1			
Average	26.72 (−23.28)	60.03 (10.03)	41.56 (−8.44)
p-Value	0.62 (0.62)	0.004 (0.004)	0.62 (0.62)
Treatment 2			
Average	22.61 (−27.39)	51.82 (18.19)	35.63 (−14.37)
p-Value	0.62 (0.62)	0.12 (0.12)	0.62 (0.62)
Treatment 3			
Average	25.23 (−30.67)	55.46 (13.84)	44.34 (−11.93)
p-Value	0.62 (0.12)	0.004 (0.62)	0.12 (0.004)

The table shows the average prices (quantities) traded in each market. The *p*-value refers to the test of the hypothesis that the observations are different from the

Table A.3
Tests that the Differences between the Actual and the Equilibrium Prices and Quantities are the Same between Treatments.

	Market *A* p^A (x_i^A)	Market *B* p^B (x_i^B)	Market *C* p^C (x_i^C)
V = 0			
T1 vs *T2*: *p*-value	0.62 (0.62)	0.004 (0.92)	0.62 (0.62)
T1 vs *T3*: *p*-value	0.62 (0.19)	0.02 (0.02)	0.04((0.07)
T2 vs *T3*: *p*-value	0.62 (0.08)	0.004 (0.08)	0.02 (0.19)
V = 100			
T1 vs *T2*: *p*-value	0.48 (0.48)	0.62 (0.92)	0.12 (0.12)
T1 vs *T3*: pp-value	0.62 (0.92)	0.01 (0.36)	0.36 (0.26)
T2 vs *T3*: *p*-value	0.48 (0.12)	0.003 (0.77)	0.04 (0.62)
Combined			
T1 vs *T2*: *p*-value	0.76 (0.76)	0.004 (0.62)	0.48 (0.48)
T1 vs *T3*: *p*-value	0.27 (0.12)	0.01 (0.77)	0.02 (0.19)
T2 vs *T3*: *p*-value	0.19 (0.19)	0.004 (0.62)	0.12 (0.37)

The table shows the *p*-values for the test of the hypothesis that the differences between the actual and the equilibrium prices and quantities are the same between treatments.

Table B.1
Panel regression for quantities.

Dependent variable: $Q - Q^{Eq}$			
	Market *A*	Market *B*	Market *C*
Treatment 1	2.199 (0.181)	−1.049 (0.198)	−0.348 (0.775)
Treatment 2	0.495 (0.523)	−0.845 (0.285)	0.909 (0.108)
Treatment 3	−1.436 (0.379)	1.216 (0.243)	−0.384 (0.724)
R^2	0.0215	0.0228	0.0008
T1 = *T2*	0.088	0.809	0.286
T1 = *T3*	0.129	0.004	0.983

Table B.2
Panel Regression for Prices.

Dependent variable: $P - P^{Eq}$			
	Market *A*	Market *B*	Market *C*
Treatment 1	0.696 (0.019)	−1.049 (0.198)	−0.609 (0.597)
Treatment 2	0.495 (0.523)	−0.085 (0.285)	0.909 (0.108)
Treatment 3	2.607 (0.164)	1.559 (0.423)	−0.841 (0.393)
R^2	0.0451	0.0246	0.0141
T1 = *T2*	0.819	0.220	0.211
T1 = *T3*	0.278	0.241	0.876

Appendix B. Panel estimation

The tables report the results of a panel data estimation. We regressed the per-round difference between the quantity actually traded and the equilibrium prediction on the treatment conditions. We did so separately, market by market. The standard errors are clustered at the session level. P-values for the test that a coefficient is equal to 0 are reported in parenthesis. The null hypothesis that theoretical predictions and experimental outcomes are the same can never be rejected, for any of the markets and of the treatments in the panel. Moreover, we cannot reject the null hypothesis that the differences between actual and theoretical quantities and prices are the same across treatments (see Tables B.1 and B.2).

Appendix C. Instructions for Treatment 1

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

You're about to take part in a study on decision making with nine 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.

C.1. 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:

$$£1 = 100 \text{ liras}.$$

This means that for any 100 liras that you earn, you will receive 1 GBP.

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.

C.2. 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.

C.3. Procedures for each round

A 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.

C.3.1. 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.

C.3.2. 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 and $Total_A Sold$ = 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	$Total_A$
1	45		
2	10		
3	30		
4	15		
5	30		
6	20		
7	26		
8	50		
9	18		
10	8		
Tot	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 (see Table C.1) 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.

C.3.3. 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 is computed in an identical way to the price of good *A*, that is,

$$Price_B = 50 + 1/10 \, * \, (Total_B),$$

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

Example 1. The value of good *B* is 50. Assume that the quantities of it bought/sold by the participants are as follows:

Table C.1
Prices of goods given your choices and those of the other participants.

Your choice	Average units bought/sold by each of the other participants?																			
	5	10	15	20	25	30	35	40	45	50	−5	−10	−15	−20	−25	−30	−35	−40	−45	−50
5	55.00	59.50	64.00	68.50	73.00	77.50	82.00	86.50	91.00	95.50	46.00	41.50	37.00	32.50	28.00	23.50	19.00	14.50	10.00	5.50
10	55.50	60.00	64.50	69.00	73.50	78.00	82.50	87.00	91.50	96.00	46.50	42.00	37.50	33.00	28.50	24.00	19.50	15.00	10.50	6.00
15	56.00	60.50	65.00	69.50	74.00	78.50	83.00	87.50	92.00	96.50	47.00	42.50	38.00	33.50	29.00	24.50	20.00	15.50	11.00	6.50
20	56.50	61.00	65.50	70.00	74.50	79.00	83.50	88.00	92.50	97.00	47.50	43.00	38.50	34.00	29.50	25.00	20.50	16.00	11.50	7.00
25	57.00	61.50	66.00	70.50	75.00	79.50	84.00	88.50	93.00	97.50	48.00	43.50	39.00	34.50	30.00	25.50	21.00	16.50	12.00	7.50
30	57.50	62.00	66.50	71.00	75.50	80.00	84.50	89.00	93.50	98.00	48.50	44.00	39.50	35.00	30.50	26.00	21.50	17.00	12.50	8.00
35	58.00	62.50	67.00	71.50	76.00	80.50	85.00	89.50	94.00	98.50	49.00	44.50	40.00	35.50	31.00	26.50	22.00	17.50	13.00	8.50
40	58.50	63.00	67.50	72.00	76.50	81.00	85.50	90.00	94.50	99.00	49.50	45.00	40.50	36.00	31.50	27.00	22.50	18.00	13.50	9.00
45	59.00	63.50	68.00	72.50	77.00	81.50	86.00	90.50	95.00	99.50	50.00	45.50	41.00	36.50	32.00	27.50	23.00	18.50	14.00	9.50
50	59.50	64.00	68.50	73.00	77.50	82.00	86.50	91.00	95.50	100.00	50.50	46.00	41.50	37.00	32.50	28.00	23.50	19.00	14.50	10.00
−5	54.00	58.50	63.00	67.50	72.00	76.50	81.00	85.50	90.00	94.50	45.00	40.50	36.00	31.50	27.00	22.50	18.00	13.50	9.00	4.50
−10	53.50	58.00	62.50	67.00	71.50	76.00	80.50	85.00	89.50	94.00	44.50	40.00	35.50	31.00	26.50	22.00	17.50	13.00	8.50	4.00
−15	53.00	57.50	62.00	66.50	71.00	75.50	80.00	84.50	89.00	93.50	44.00	39.50	35.00	30.50	26.00	21.50	17.00	12.50	8.00	3.50
−20	52.50	57.00	61.50	66.00	70.50	75.00	79.50	84.00	88.50	93.00	43.50	39.00	34.50	30.00	25.50	21.00	16.50	12.00	7.50	3.00
−25	52.00	56.50	61.00	65.50	70.00	74.50	79.00	83.50	88.00	92.50	43.00	38.50	34.00	29.50	25.00	20.50	16.00	11.50	7.00	2.50
−30	51.50	56.00	60.50	65.00	69.50	74.00	78.50	83.00	87.50	92.00	42.50	38.00	33.50	29.00	24.50	20.00	15.50	11.00	6.50	2.00
−35	51.00	55.50	60.00	64.50	69.00	73.50	78.00	82.50	87.00	91.50	42.00	37.50	33.00	28.50	24.00	19.50	15.00	10.50	6.00	1.50
−40	50.50	55.00	59.50	64.00	68.50	73.00	77.50	82.00	86.50	91.00	41.50	37.00	32.50	28.00	23.50	19.00	14.50	10.00	5.50	1.00
−45	50.00	54.50	59.00	63.50	68.00	72.50	77.00	81.50	86.00	90.50	41.00	36.50	32.00	27.50	23.00	18.50	14.00	9.50	5.00	0.50
−50	49.50	54.00	58.50	63.00	67.50	72.00	76.50	81.00	85.50	90.00	40.50	36.00	31.50	27.00	22.50	18.00	13.50	9.00	4.50	0.00

Notes:
1. Positive numbers indicate purchases, negative numbers indicate sales.
2. The table shows the price given your choice and the average choice of the other participants. For instance, suppose you choose 20 and the other participants on average choose 30. This means that, since on average the other nine participants want to buy 30, the total demanded quantity is $20 + 30 * 9 = 290$ and the price is $50 + 1/10 * (290) = 79$.

Participant	Units Bought	Units Sold	$Total_B$
1	10		
2	15		
3	6		
4	35		
5		20	
6	2		
7	24		
8		16	
9	25		
10	20		
Tot	137	36	101

As $Total_B$ is equal to $Total_B\ Bought - Total_B\ Sold = 137 - 36 = 101$, the price will be:

$$Price_B = 50 + 1/10 * (Total_B) = 50 + 1/10 * (101) = 60.1$$

Example 2. Assume that all participants decide to sell 15 units, so that $Total_B$ is equal to $Total_B\ Bought - Total_B\ Sold = 0 - 150 = -150$. The price will be:

$$Price_B = 50 + 1/10 * (Total_B) = 50 + 1/10 * (-150) = 35$$

Note that, like for the price of good *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. In particular, since the price is set in an identical way to that of good *A*, you can consult the table at the end of the instructions (see Table C.1) 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*.

Market C: The value of good *C* is 50 in all rounds.

C.3.4. 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.

C.3.5. 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* and *B*, 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 and $Total_C$ *Sold* = sum of the units of the good *C* sold by all those who decide to sell.

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 the other markets, the table 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.

C.4. 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,

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

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,

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

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*,
   - $EarningB = (ValueB - PriceB) * (Units\ of\ B\ good\ you\ bought)$, if you BUY
   - $EarningB = (PriceB - ValueB) * (Units\ of\ B\ good\ you\ sold)$, if you SELL
   And for market *C*,
   - $EarningC = (ValueC - PriceC) * (Units\ of\ C\ good\ you\ bought)$, if you BUY
   - $EarningC = (PriceC - ValueC) * (Units\ of\ C\ good\ you\ sold)$, if you SELL
2. The "penalty terms" are the following:
   - $Penalty\_1 = (unitsA + unitsB)^2$
   - $Penalty\_2 = (unitsB + unitsC)^2$

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$Penalty_2 = (unitsB + unitsC)^2$. 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:

- $Penalty\_1 = (unitsA + unitsB)^2 = (20 - 10)^2 = (10)^2 = 100$
- $Penalty\_2 = (unitsB + unitsC)^2 = (-10 + 5)^2 = (-5)^2 = 25$

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:

- $Penalty\_1 = (unitsA + unitsB)^2 = (-35 - 30)^2 = (-65)^2 = 4225$
- $Penalty\_2 = (unitsB + unitsC)^2 = (-30 - 20)^2 = (-50)^2 = 2500$

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:

- $EarningA + EarningB + EarningC - Penalty\_1 - Penalty\_2$

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.

C.5. 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 100 liras = £1. That is, for every 100 liras you have earned in the experiment you will get 1 lb. 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.

Appendix D. Instructions for Treatment 3

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

You are about to take part in a study on decision making with 19 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.

D.1. Outline of the study

In the study, you will be asked to trade in sequence three goods: *A*, *B* and *C*. First, you will trade 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 exchanged into pounds at the end of the study according to a predetermined exchange rate.

The study consists of 10 rounds. The rules are identical for all rounds. All of you will participate in all rounds.

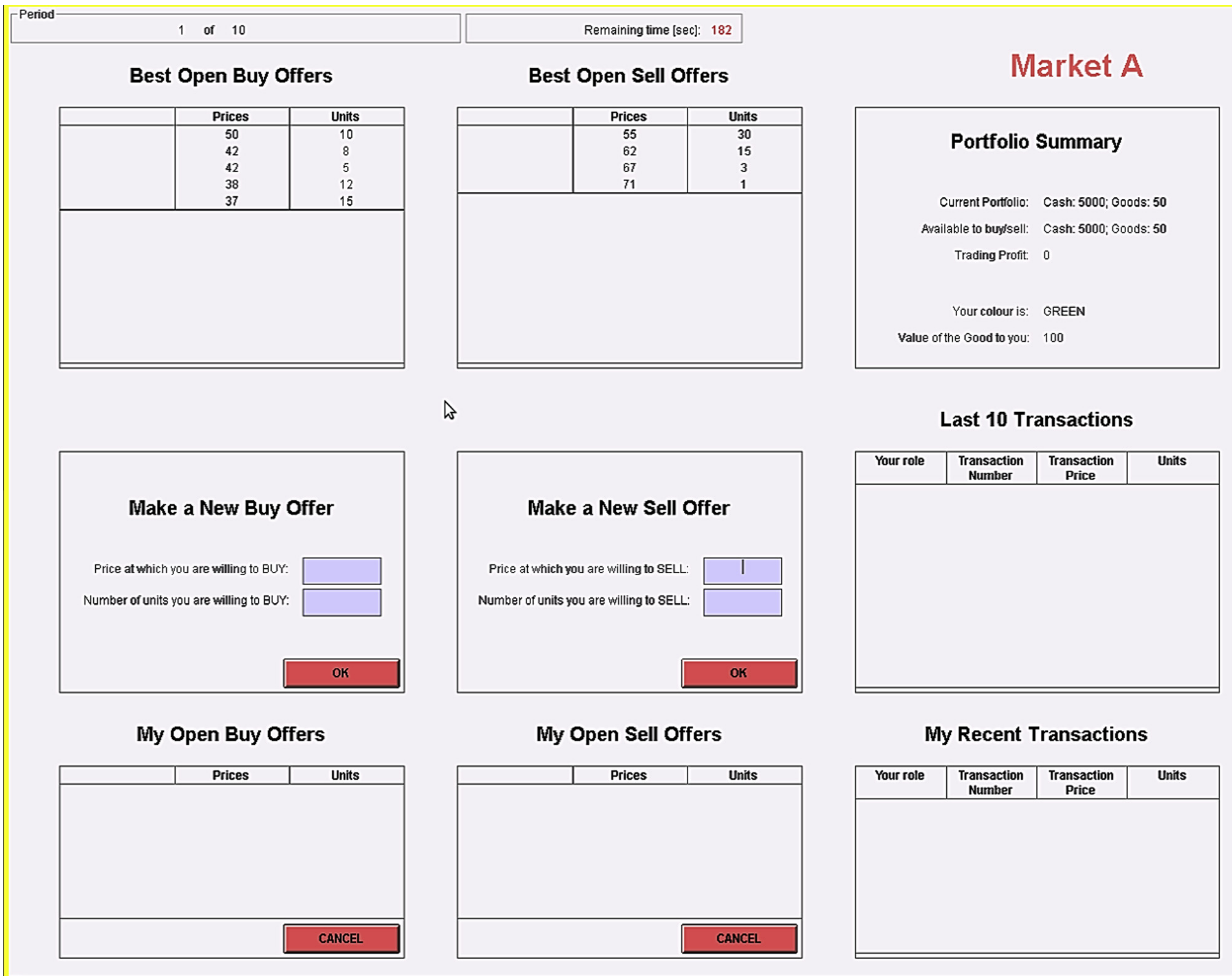

Fig. D1.

In each round you trade in three markets that open and close in sequence. First, you trade good *A* in market *A*. Then market *A* closes, and market *B* opens (i.e., you trade good *B* in market *B*). Finally, market *B* closes, and you trade in market *C*.

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.

D.2. Procedures for each round

D.2.1. Green and Blue participants

In each round of the study, each of you will be assigned a color: Green or Blue. In each round, there will be 10 Blue and 10 Green participants. The computer will randomly determine whether you are Blue or Green. You have the same chance of being Blue or Green. You remain a Blue or a Green trader throughout the entire experiment.

Blue and Green participants do exactly the same thing: they buy and sell the goods in the three markets. The only difference is in how the goods are worth to them and how their payoff is computed.

As we said, at the beginning of each round, you start by trading good A. We will now describe how the value of good A is determined and how it is traded.

Market A: The value of good *A* is different depending on whether you are a Blue or a Green participant. In particular, it is worth:

- always 50 liras for Blue participants;
- either 0 or 100 liras for Green participants. In each round, the computer will randomly determine whether the value for the Green participants is 0 or 100 through a mechanism simulating the toss of a coin. In other words, the chances of the value being 0 or 100 in each round are 50–50. Note that in each round the value is the same for *all Green participants*.Note also that whether the value in a round is 0 or 100 does not depend on the value in previous rounds.

Green participants know how much good *A* is worth to them. They learn whether the value is 0 or 100 at the beginning of each round.

Blue and Green participants trade good *A* among themselves for 220 s. At the end of the 220 s, all participants receive information on the outcomes of their trading activity.

Let us illustrate how you will trade the good. In Fig. D1 you see a screen-shot of the trading platform on your computer. In the upper part of the screen, there are two boxes showing the existing Buy Offers and Sell Offers. In the lower part, there are buttons that you can use to buy or sell, and two boxes, one where you can insert the quantity you want to buy or sell, and another where you can insert the price at which you are willing to do so.

On the top right-hand side you can see your holdings of cash and units of good *A* (i.e., your portfolio, in the box "Portfolio Summary"). In the middle of the right-hand side (box "Last 10 Transactions"), you see a continuously updated history of the prices at

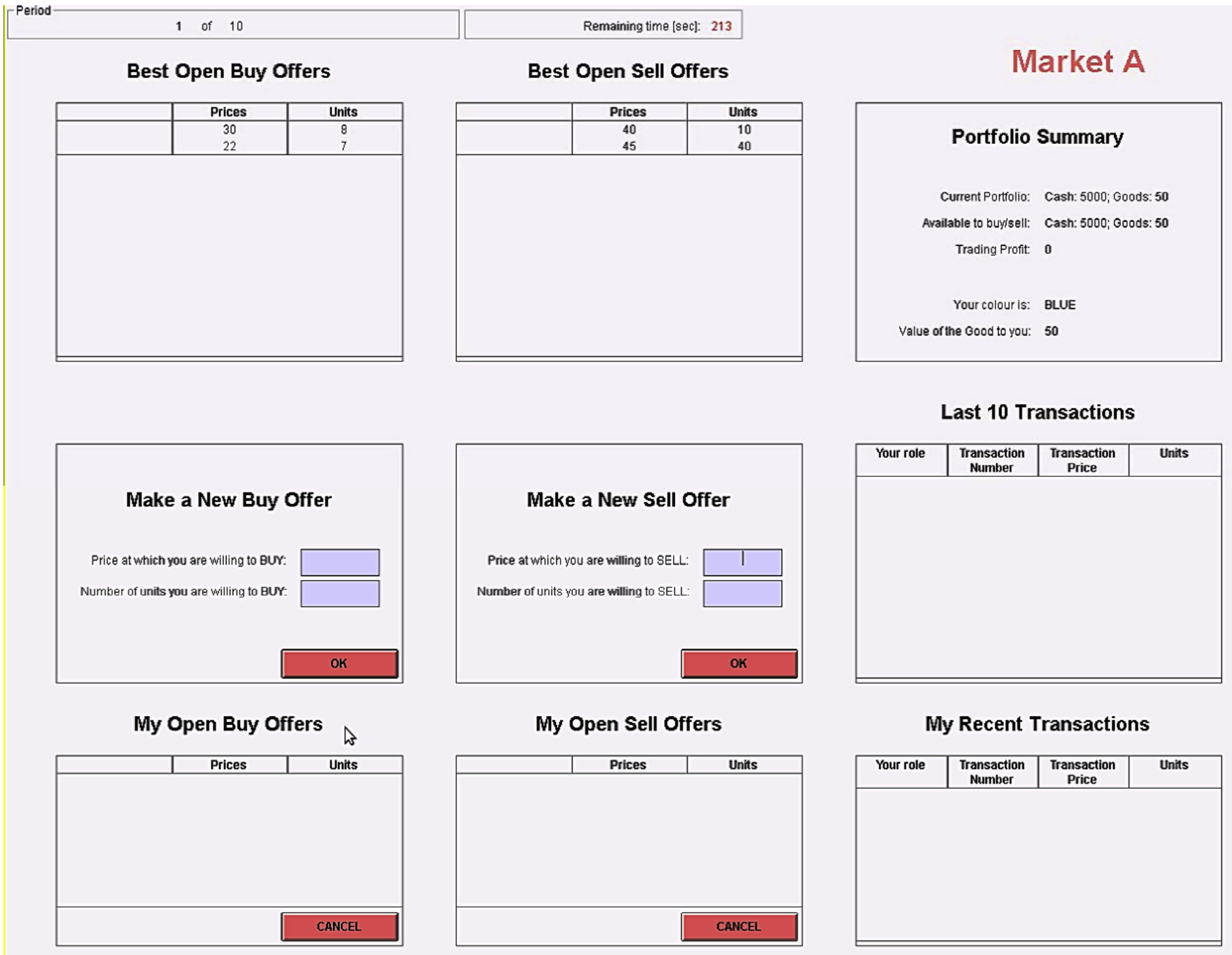

Fig. D2.

which the good is traded. In the lower box of the right-hand part of the screen ("My Recent Transactions"), you can see the transactions you have executed in the round.

D.2.2. Initial endowment

At the beginning of every round we will provide you with an endowment of 50 units of good *A* and with 5000 liras, which you can use to buy or sell.

You can use your endowment to trade good *A* during the round. The box "Portfolio Summary" is updated whenever you buy or sell units of the good. When you buy the good, the number of units of the good in your portfolio (see line "Current Portfolio") increases by the number of units you have bought, and the amount of liras decreases by the amount you have paid. Similarly when you sell the good.

D.2.3. How to sell or buy

Buying and selling is very simple. Look at the box "Make a New Sell Offer", in the middle of the screen. If you want to sell good *A*, you simply enter:

- the number of units you want to sell;
- the minimum price at which you want to sell them.

Then you click on the button SELL and your offer appears immediately in the box "Best Open Sell Offers", (top section of the screen, in the middle), where open sell offers are collected. The open sell offers are ordered with the lowest price being on the top of the list.

When you enter a sell offer, the line "Available to buy/sell" in the "Portfolio Summary" box is updated to reflect that the units you offered to sell cannot be offered for sale twice. When your offer gets executed (we will explain in a second how), your "Current Porftolio" line in the "Porfolio Summary" box will get updated (as we had mentioned before).

Similarly, if you want to buy good *A*, you simply enter:

- the number of units you want to buy;
- the maximum price at which you want to buy them

in the box "Make a New Buy Offer", in the middle left-part of the screen. Then you click on the button BUY and your offer appears immediately in the column "Best Open Buy Offers" (top section of the screen, on the left), where all open buy offers are collected. The open buy offers are ordered with the highest price being on the top of the list. You can easily identify your own buy offers because they are marked with a button that gives you the opportunity to cancel them, if you so wish.

Your own offers are also listed in the boxes "My Open Buy Offers" and "My Open Sell Offers", on the bottom of the screen. You are always allowed to withdraw your buy or sell offer that have not been executed. These two boxes allow you to do so. Just click on Cancel on the order you want to withdraw.

When and how does a trade take place? A trade is possible if the lowest Sell Price is lower than the highest Buy Price. In this situation, one participant is willing to pay more for good *A* than another participant asks for it. This situation is recognized by the system and trading takes place automatically. We will illustrate how trading occurs through a series of examples. Go over them carefully, and you will learn how to trade in this market.

Example 1. Look at Fig. D1. The lowest Sell Price is 55 liras for 30 units of good *A* and the highest Buy Price is 50 liras for 10 units of good *A*. Then, no trade is possible. If you are willing to buy 10 units at 55 liras, you enter a Buy Price of 55 liras for 10 units into the system. The system recognizes that a trade is now possible for 10 units and the trade takes place: that is, the seller receives $55 * 10 = 550$ liras from you and you (the buyer) receive 10 units of the good from the seller.

The transaction always occurs at the pre-existing price. For instance, even if you enter a Buy Price of 61 in the system, since there is a pre-existing sell order at a price of 55, the transaction will occur at 55 liras–not at 61. In other words, if you see a Sell Price at which you are willing to buy, it is enough that you enter a Buy Price equal or greater than that in order to buy the good.

Example 2. In Fig. D2, the highest Buy Price is 30 liras for 8 units of good *A*. If you are willing to sell at 30 liras, then you enter a Sell Price lower than or equal to 30 liras into the system and the number of units you want to sell. Suppose you want to sell 8 units at a price of 30. The system recognizes that a trade is possible and trade takes place: that is, you (the seller) receive $30 * 8 = 240$ liras from the buyer and the buyer receives 8 units of the good from you.

Obviously, if you want to sell fewer than 8 units you are free to do so. You do so by entering a sell offer for, say, 5 units at a price of 30. In this case, the system will automatically execute the trade and you will receive $30 * 5 = 150$ liras from the buyer.

Example 3. Look at Fig. D2, and consider the two best sell offers. There is an outstanding offer to sell 10 units of good *A* at a price of 40, and another outstanding offer to sell 40 units at a price of 45. Suppose that you are willing to buy 20 units, and you submit an offer to buy 20 at a price of 45. The system will match your buy request with the best existing sell offers. Therefore, you will buy the first 10 units at a price of 40 and the second 10 units at the price of 45.

As we said before, the list of recent prices at which a transaction took place appears in the box "Last 10 Transaction" in the middle part of the right-hand section of the screen. The most recent transaction prices are on the top of the list. Your own transactions are identified in the box at the bottom so that you can keep track of your previous decisions.

After 200 s have passed, market *A* shuts down. On the screen you will see your payoff for your trading activity in market *A*. After that, you will start trading in market *B*.

Market B: Trading in market *B* follows the same rules as in market *A*. Again, we will provide you with an endowment of 50 units of good *B* and with 5000 liras, which you can use to buy or sell. An important difference with market *A*, however, is that the value of good *B* is 50 liras in all rounds *for both Green and Blue participants*.

As in market *A*, trading in market *B* lasts 200 s. When this time has elapsed, market *B* shuts down. On the screen you will see your payoff for your trading activity in markets *A* and *B*. After that, you will start trading in market *C*.

Market C: Trading in market *C* follows the same rules as in market *A* and *B*. Again, we will provide you with an endowment of 50 units of good *C* and with 5000 liras. In contrast with market *A* and exactly as in market *B*, the value of good *C* is 50 liras in all rounds for both Green and Blue participants.

As in markets *A* and *B*, trading in market *C* lasts 200 s. When this time has elapsed, market *C* shuts down. On the screen you will see your payoff for your trading activity in markets *A*, *B* and *C*. At this point, the current round of the game ends, and you start the next round. The game ends at round 10.

D.3. Per-round payoff

Your final payoff is the sum of the payoffs in the 10 rounds. In each round, the per-round payoff is made up of two components:

- The earning you made in each market (*A*, *B* and *C*);

minus

- One "Penalty Term".

We will first describe how to compute the earning made in each market, and then we will describe the penalty term.

D.3.1. Market earnings

As we said, in each round we give you an endowment of 50 units of each good and of 5000 liras for each market 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. As a result, the earning in market *A* is computed in the following way.

Whenever you buy at a certain price you have to pay that price for each unit. At the same time, you will receive the value of the good for each unit. Therefore,

- when you BUY, you gain or lose

$$(Value_A - Price_A) * (Units\ of\ good\ A\ that\ you\ bought).$$

For instance, let us assume that you are a Green participant, and the value of the good is 100. If you buy 10 units at the price of 70, you earn $(100 - 70) * 10 = 300$ liras. If instead the value is 0, then your earning is $(0 - 70) * 10 = -700$, that is, you lose 700 liras. If you are a Blue participant, the value of the good is always 50, and your earning is $(50 - 70) * 10 = -200$, that is you lose 200.

Similarly, whenever you sell at a certain price you receive that price for each unit but are forgoing the value of the good for each unit. Therefore,

- when you SELL, you gain or lose

$$(Price_A - Value_A) * (Units\ of\ good\ A\ that\ you\ sold).$$

For instance, let us assume that you are a Green participant, and the value of the good is 100. When you sell 10 units at the price of 70, your earning is $(70 - 100) * 10 = -300$ liras, that is, you lose 300 liras. If instead the value is 0, then you earn $(70 - 0) * 10 = 700$ liras. If you are a Blue participant, the value of the good is always 50 and you earn $(70 - 50) * 10 = 200$.

The computations of your earnings in market *B* are similar. Remember that the value of good *B* is always 50 *for both green and blue participants*. Therefore,

- when you BUY, you gain or lose

$$(Value_B - Price_B) * (Units\ of\ good\ B\ that\ you\ bought)$$
$$= (50 - Price_B) * (Units\ of\ good\ B\ that\ you\ bought).$$

- when you SELL, you gain or lose

$$(Price_B - Value_B) * (Units\ of\ good\ B\ that\ you\ sold)$$
$$= (Price_B - 50) * (Units\ of\ good\ B\ that\ you\ sold).$$

The earning in market *C* is computed in the same way as in market *B*. Since the value of good *C* is always the same *for both green and blue participant*:

- when you BUY, you gain or lose

$$(Value_C - Price_C) * (Units\ of\ good\ C\ that\ you\ bought)$$
$$= (50 - Price_C) * (Units\ of\ good\ C\ that\ you\ bought).$$

- when you SELL, you gain or lose

$$(Price_C - Value_C) * (Units\ of\ good\ C\ that\ you\ sold)$$
$$= (Price_C - 50) * (Units\ of\ good\ C\ that\ you\ sold).$$

D.3.2. Penalty term for Green participants

The Penalty term is computed differently for Green and Blue participants. For Green participants, the Penalty Terms is the sum of two penalties:

- $Penalty\_1 = (unitsA + unitsB)^2$
- $Penalty\_2 = (unitsB + unitsC)^2$

where units*A*, units*B*, units*C* are the participant's trading "exposure" in each market. What is your trading exposure? It is the total number of units you bought (with a positive sign) or sold (with a negative sign) in the market at the end of trading activity (i.e., after 200 s). Consider for instance market *A*. Suppose that you are a Green participant and at the end of the round, you have 70 units of good *A* in the portfolio. Since you had an endowment of 50 units, this means that during the 200 s of trading you bought 20 units of good *A*. This is your exposure in market *A*. Suppose instead you have 35 units in your portfolio. This means that you have sold 15 units out of your endowment. Your exposure in market *A* is then −15.

How to interpret the Penalty Term for Green participants? 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 the further away this sum is 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. Note also that it does not matter whether your combined exposure is positive or negative, since the penalty term is squared. That is, you will pay the same penalty if unit*A* + unit*B* is 10 as if it is negative 10.

The same is true for $Penalty\_2 = (unitsB + unitsC)^2$. 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*.

When you finish trading in Market *A*, your provisional *Penalty_1* will be shown to you on the screen. It is provisional, since the penalty also depends on your activity in Market *B*. When you finish trading in Market *B*, on the screen you will see the final *Penalty_1* and the provisional *Penalty_2*. *Penalty_2* is only provisional, since it will then depend also on the activity in Market *C*.

Example 1. For instance, let us say that you are a Green participant and in market *A* you bought 20 units, in market B you sold 10 units and in market C you bought 5 units. Then your penalty terms will be:

- $Penalty\_1 = (unitsA + unitsB)^2 = (20 - 10)^2 = (10)^2 = 100$
- $Penalty\_2 = (unitsB + unitsC)^2 = (-10 + 5)^2 = (-5)^2 = 25$

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:

- $Penalty\_1 = (unitsA + unitsB)^2 = (-35 - 30)^2 = (-65)^2 = 4225$
- $Penalty\_2 = (unitsB + unitsC)^2 = (-30 - 20)^2 = (-50)^2 = 2500$

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*.

D.3.3. Penalty Term for Blue participants

For Blue participants, the Penalty Term is the sum of three penalties:

- $Penalty\_1 = \frac{1}{2}(unitsA)^2$
- $Penalty\_2 = \frac{1}{2}(unitsB)^2$
- $Penalty\_3 = \frac{1}{2}(unitsC)^2$

where units*A*, units*B*, units*C* are your trading "exposure" in each market. What is your trading exposure? It is just the total number of units you bought (with a positive sign) or sold (with a negative sign) in each market during the 220 s of trading. Consider for instance market *A*. Suppose at the end of the round you have 70 units of good *A* in the portfolio. Since you had an endowment of 50 units, this means that overall you bought 20 units of good *A*. This is your exposure in market *A*. Suppose instead you have 35 units in your portfolio. This means that you have sold 15 units out of your endowment. Your exposure in market *A* is then −15.

How to interpret the penalty terms? Consider *Penalty_1*. If units*A* is equal to 0 (that is, your final portfolio is equal to the original endowment of 50) the penalty is zero, meaning you are not penalized. If it is different from 0, then you will pay a penalty. Note that the more your final holdings of asset *A* is different from your original endowment (50), the higher the penalty term. That is, your *Penalty_1* will be the greater the further away from zero your trading exposure in market *A*. Note that since the Penalty_1 is squared it does not matter whether you end up with a higher or a lower number of goods than the original endowment (that is, it does not matter whether units*A* is positive or negative). That is, you will pay the same penalty if your final holding of good *A* is 60 (units*A* = 10 units since you end up with 10 units more than the original endowment of 50) as if it is 40 (units*A* = −10 since you end up with 10 units below the original endowment).

The same comments holds true for*Penalty_2* and for *Penalty_3*. That is, your *Penalty_2* will be the greater the further away your trading exposure in markets *B* is from zero; *Penalty_3* will be the greater the further away your trading exposure in markets *C* is from zero.

Your penalty in each market will be shown to you on the screen, soon after the trading activity in that market ends.

Example 1. You are a Blue participant and in market *A* you bought 20 units, in market *B* you sold 10 units and in market *C* you bought 5 units. Your Penalty Term will be the sum of Penalty 1, 2 and 3, that is:

- $Penalty\_1 = \frac{1}{2}(unitsA)^2 = \frac{1}{2}(20)^2 = 200$
- $Penalty\_2 = \frac{1}{2}(unitsB)^2 = \frac{1}{2}(-10)^2 = 50$
- $Penalty\_3 = \frac{1}{2}(unitsC)^2 = \frac{1}{2}(5)^2 = 12.5$

Therefore, we will subtract 262.5 (*Penalty_1* + *Penalty_2* + *Penalty_3*) from the earnings you got trading in the 3 markets *A*, *B* and *C*.

Example 2. You are a Blue participant and in market *A* you sold 35 units, in market *B* you sold 30 units and in market *C* you sold 20 units, then your Penalty Term will be the sum of:

- $Penalty\_1 = \frac{1}{2}(unitsA)^2 = \frac{1}{2}(-35)^2 = 612.5$
- $Penalty\_2 = \frac{1}{2}(unitsB)^2 = \frac{1}{2}(-30)^2 = 450$
- $Penalty\_3 = \frac{1}{2}(unitsC)^2 = \frac{1}{2}(-20)^2 = 200$

Therefore, we will subtract 1262.5 (*Penalty_1* + *Penalty_2* + *Penalty_3*) from the earnings you got trading in the 3 markets *A*, *B* and *C*.

D.3.4. No per-round loss

To sum it all up, the per-round payoff is the sum of the trading earnings in the three markets and Penalty Term

- *EarningA* + *EarningB* + *EarningC* − *PenaltyTerm*

where, however, the Penalty Term is computed differently according to whether you are a Green or a Blue participant.

If in a round, the sum of the market earnings and the Penalty Term 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.

D.4. Payment

To determine your final payment, we will sum up your per-round payoffs for all the 10 rounds. We will then exchange this sum into pounds at the exchange rate of 100 liras = £1 for Green participants, and at the exchange rate of 200 liras = £1 for blue participants. That is, if you are a Green participant, for every 100 liras you have earned in the experiment you will get 1 GBP. If you are a Blue participant, for every 200 liras you have earned in the experiment you will get 1 GBP. The exchange rate have been chosen so that on average Green and Blue participants can earn a similar amount of money.

Moreover, both Green and Blue participants 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.

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