Competition and Equilibration in Financial Markets

Thesis by

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In Partial Fulfillment of the Requirements

for the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

2004

(Defended 26 September, 2003)

Acknowledgements

I would like to thank all those whose ideas and support made this thesis possible. First and foremost I would like to thank my advisor and chair of my dissertation committee, Peter Bossaerts. He gave me tremendous help, inspiration, and guidance during the entire time that I spent as a graduate student at Caltech. He has been incredibly generous with his time, ideas, and insightful comments. I enjoyed every moment learning and working with him.

I am deeply indebted to the other members of my dissertation committee: Tom Palfrey, Charlie Plott, and Bill Zame. Their questions, detailed comments, and advice are greatly appreciated. I would also like to express my appreciation to Debrah Meloso for the useful comments and discussions.

The Division of the Humanities and Social Sciences at Caltech has provided a stimulating environment, work flexibility and financial support to make it possible to complete this dissertation. Financial support for this project was also provided by my advisor Peter Bossaerts through the NSF grant SES 0079374, and the R. G. Jenkins Family Fund. I am especially grateful to the personnel of the Caltech Laboratory for Experimental Finance, the Laboratory for Experimental Economics and Political Science, the Caltech Social Science Experimental Laboratory, and the California Social Science Experimental Laboratory, who helped me in conducting the experimental part of my research. Special thanks to Tihomir Asparouhov and Travis Maron for their programming assistance.

I am of course very grateful to all my colleagues and friends here at Caltech. Among them, I would especially like to thank Serena (she knows why), Chris, Jernej, Carla, and Brian who have witnessed most of my inevitable ups and downs in the last couple of years, and have been such an incredible source of support, fun, and laughter throughout.

Finally I must thank my husband, Tihomir, my mom, Denka, and my two sons Delian and Pavel. Their patience, support, and unconditional love have always been my inspiration.

The responsibilities for the content of this dissertation are entirely mine.

Abstract

The research presented in this thesis aims at understanding some of the principles by which aggregate patterns in competitive markets emerge as a result of the interactions between economic agents. Experiments are used in every step as a bridge between theory and its target applications. Each of the three self-contained chapters focuses on a different aspect of equilibrium or equilibration in a competitive framework.

The objective of the first chapter is to examine the validity of the Rothschild-Stiglitz' equilibrium in the context of a simple model of lending under adverse selection. In experiments I develop a particular market structure and study to what extent it generates the theoretical predictions. In the baseline part of the study where equilibrium exists, the outcomes of the theory are strongly supported by the data. The inconclusive findings from the controversial non-existence of equilibrium part of the study lead to the idea that perhaps instead of judging models by whether their outcome predictions are observed, a step back should be made and the basic principles that are in place independent of the final outcome should be studied. Discovering several such basic principles in the data is the objective of the second chapter of this thesis. In the context of lending, the main finding is that lenders introduce contracts that are sometimes very different from the contracts already offered in the marketplace, thus rejecting the hypothesis of local dynamics.

In the third chapter experimental evidence that security prices do not respond to pressure from their own excess demand, unlike the traditional Walrasian tatonnement model predicts, is presented. Instead, prices respond to excess demand of all securities, despite the absence of a direct link between markets. A model of price pressure that explains these findings is proposed.

Contents

Introduction

Economic agents often face situations in which they must interact without being fully aware of their environment. They might lack information about other parties' characteristics such as endowments or preferences, or be simply unable to enumerate the other agents present in the economy. This is especially true when many agents seeking gains from trade get together in an organized marketplace and engage in exchange of assets or commodities. While general equilibrium theory is a suitable tool for analyzing such situations, it does not tell a very realistic story for how equilibria are achieved. Usually a Walrasian tatonnement or non-tatonnement argument is given despite the fact that there is no Walrasian auctioneer present in the actual markets. If the economy is complicated by asymmetric information frictions, then even the fabled auctioneer cannot be resorted to in describing the equilibration process as there is no general consensus of what equilibrium concept should be used in this setup in the first place. The research presented in this thesis aims at understanding some of the principles by which aggregate patterns in competitive markets emerge as a result of the interactions between economic agents (whose behavior is not "orchestrated" by anyone—be the Walrasian auctioneer or a benevolent social planner). Thus the nature of this work is mainly descriptive. Experiments are used in every step as a bridge between theory and its target applications. Each of the three self-contained chapters focuses on a different aspect of equilibrium or equilibration in a competitive framework.

The objective of the first chapter is to examine the validity of the Rothschild-Stiglitz' (henceforth RS) equilibrium in the context of a simple model of lending under adverse selection. The original RS equilibrium is adapted to allow for multiple contracts to be offered by a single lender. It is well known that slight changes in the degree of agents' (in this case lenders) sophistication assumed for the analysis of adverse selection environments can have significant effects on predicted outcomes. This is what has been widely explored by numerous authors as a reaction to the seminal RS paper and its claim that markets with adverse selection can have robust regions of non-existence of equilibrium. When equilibrium as defined by RS exists, however, almost all of the models' outcome predictions coincide: from all possible loan contracts only two are viable, and they separate the projects being financed by quality (in the lending interpretation). In experiments I develop a particular market structure and study to what extent it generates the theoretical predictions. In the non-controversial case when the adapted RS equilibrium exists, the RS theory's (and therefore almost all other theories') outcome prediction is confirmed. The contracts traded are clearly separated in two clusters around the two equilibrium contracts. The entrepreneurs with high-risk projects take bigger loans and bear higher credit spreads than the low-risk-project entrepreneurs. However, when equilibrium in the adapted RS sense does not exist, in two out of four sessions loan trading appears to stabilize around the original RS equilibrium pair. In the other two sessions, however, markets never settle down.

The finding that when most of the theories agree the outcome of the experiments confirms the theoretical implications is very reassuring. At the same time, the results from the second group of experiments clearly show that more conclusive empirical evidence is needed before determining which of the abundance of theoretical models is more relevant. Perhaps instead of judging models by whether their outcome predictions are observed, a step back should be made and the basic principles that are in place independent of what the final outcome of the model is should be studied. Discovering such basic principles in the data is the objective of the second chapter of this thesis.

The different notions of equilibrium all have their own logic and some may be more persuasive theoretically than others, but it is ultimately the data that should determine which is more relevant. The experiments in which equilibrium eventually obtains provide a unique testbed to discriminate between the key principles about equilibration dynamics that have been proposed as alternatives to the ones outlined in the RS' paper. These are: (i) pooling contracts are expected to be taken disproportionately by agents who have more to gain; (ii) insurers (lenders) only consider offering contracts that are close to those already available in the marketplace. In the original RS equilibrium, different types of agents take pooling contracts in the population proportion, and insurers (or lenders) consider offering any contract, not only marginally improving ones. The data from the experiments does not support either of the above hypothesis. When a pooling contract is offered, it is taken by the two types of agents in their proportion in the population independent of their gains from trade. Lenders also do not take only local steps in the process of approaching equilibrium. The relevance of those results expands beyond the scope of markets with adverse selection. Aggregate patterns of equilibration paths can differ substantially depending on the assumption of local vs. global adjustments that agents make when approaching equilibrium in markets with symmetric information as well. With plenty of experimental data from such markets the issue of the nature of adjustments should be further investigated.

In the third chapter experimental evidence that security prices do not respond to pressure from their own excess demand, unlike the traditional Walrasian tatonnement model predicts, is presented. Instead, prices respond to excess demand of all securities, despite the absence of a direct link between markets. A model of price pressure that explains these findings is proposed. In this model, agents set order prices that reflect the marginal valuation of desired future holdings, called "aspiration levels." In the short run, as agents encounter difficulties executing their orders, they scale back their aspiration levels. Marginal valuations, order prices, and hence, transaction prices change correspondingly. The model makes a specific prediction about the nature of cross-security effects: the covariance between a security's transaction price and another security's excess demand will be proportional to the corresponding payoff covariance. This additional prediction is fully borne out by the data. To be consistent with one's own principles, however, further investigation is needed in order to discriminate between the above proposed individual behavior and the one outlined in Bossaerts (2002) as both models make observationally equivalent aggregate predictions in the present experimental setup.

Bibliography

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Chapter 1

Competition in Lending

1.1 Introduction

Beginning with the seminal papers of Ross (1977) and Leland-Pyle (1977), corporate finance has asked about the choice of financial contracts (e.g., debt, equity) in environments with asymmetric information. In particular, this literature asks whether the financial contracts offered will separate firms into different risk categories. This paper uses an experimental environment to study the financial contracts offered and chosen, and the separation of firms, when lenders compete.

The experiments are built on a variation of the familiar Rothschild-Stiglitz (1977) (henceforth RS) model of markets with adverse selection. Risk-averse entrepreneurs need outside financing for projects of differential quality, known only to them. Risk-neutral lenders provide financing contracts called loans.[1] Lenders know the proportion of the high-risk projects in the pool of projects but do not know the quality of the individual projects. Loans are distinguished by the amount of the required investment they cover, i.e., by their leverage. Lenders can compete on the terms (interest payment) of any of the loans. We allow lenders to offer more than one contract, so it is natural to think about equilibrium in menus of contracts in addition to the RS notion of equilibrium in single contracts.

Two experimental environments are considered. In the first environment the RS

[1]The actors in the RS model are labeled "insurance companies" and "potential policyholders" rather than "lenders" and "entrepreneurs" but the difference is only one of interpretation.

equilibrium in single contracts exists, is constrained Pareto-optimal, and coincides with the equilibrium in menus of contracts. In this setting we find strong support for the theoretical predictions. In particular, the contracts offered separate the two types of projects: the high-risk projects are financed with bigger loans but higher interest payments than the low-risk projects. In the second environment the RS equilibrium in single contracts exists but is not Pareto-optimal; the equilibrium in menus of contracts does not exist. The experimental findings for this setup are mixed. In two out of four sessions the RS equilibrium contracts are reached. In the other two, cross-subsidized pairs of contracts are temporarily traded but markets never settle down.[2]

Rothschild-Stiglitz (1977) offers a notion of competitive equilibrium in markets with adverse selection; an equilibrium is

> a set of contracts such that, when customers choose contracts to maximize expected utility, (i) no contract in the equilibrium set makes negative expected profits; and (ii) there is no contract outside the equilibrium set that, if offered, will make a nonnegative profit.

RS restrict the lenders to offer single contracts. We allow them to offer menus of contracts, and adapt the notion of competitive equilibrium; an equilibrium in the adapted sense is

> a set of contracts such that, when customers choose contracts to maximize expected utility, (i) no contract in the equilibrium set makes negative expected profits; and (ii') there is no menu of contracts outside the equilibrium set that, if offered, will make a total nonnegative expected profit.

An equilibrium according to the latter notion exists exactly when the RS equilibrium exists (which it may not) and is Pareto-optimal, in which case the two coincide.[3]

In experiments we develop a particular market structure and study to what extent it generates the theoretical predictions of the above equilibrium notion.

[2] A "cross-subsidized" pair of contracts is a pair in which one contract makes a positive expected profit and the other makes at most an offsetting expected loss.

[3] Other notions of equilibrium have also been offered; see Wilson (1977), Miyazaki (1977), and Riley (1979) among others. All these reduce to the RS equilibrium when it exists and is Pareto-optimal.

Two parameterizations of the adapted RS model are implemented in the experimental markets. In the first environment, called the Baseline environment, a situation where competitive equilibrium predicts an optimal provision of contracts is examined. In the second environment, called the the Non-Existence environment, we change the parameters in a way so that competition would drive out the optimal contracts, theoretically that is, and we calibrate the results against the outcomes from the benchmark experiments.

The purpose is twofold. On one hand we aim to discover whether markets attain equilibrium in the non-controversial case where the latter (exists and) is Pareto-optimal. On the other hand we question whether competition really stands in the way of Pareto-optimality when the Pareto-optimal outcome cannot be supported in equilibrium. One appealing alternative principle is that suboptimal contracts are ultimately eliminated from the markets. The purpose of the second part of the study is to discover whether such principle can actually provide a better description of the market outcomes than competitive equilibrium does.

The use of experimental as opposed to field data prevents econometric complications due to the confounding effects of estimating the parameters of the model and ascertaining whether equilibrium occurs. In addition, the important ingredients of the model can be isolated, while others are replaced with alternatives that facilitate evaluation of the success of the experiment with respect to the basic questions that are being asked. Because of the difficulty of measuring and controlling risk attitudes of human subjects, for example, we choose to substitute leverage-dependent payoff schedules for uncertainty in the final payoffs of the projects. That is, rather than assuming that human subjects make decisions under uncertainty based on a specific expected-utility function with common parameters, we give them payoffs that correspond to the expected utility they would get from each of the contracts if they really had the hypothesized risk attitudes.

In the Baseline environment we find that the traded contracts are clearly separated in two clusters around the two equilibrium contracts. The cross-tabulation of the types of projects within the clusters shows that the contracts indeed separate the two types of projects: the entrepreneurs owning the high-risk projects take bigger loans and bear higher credit spreads than the entrepreneurs with the low-risk projects. We do not observe cross-subsidization in any of the experimental sessions within this environment. There is indication of small positive profits from contracts traded with the entrepreneurs with low-risk projects that we attribute to the failure of high-risk-project entrepreneurs to always pick their equilibrium contract when indifferent between contracts. Thus, the results strongly support the Rothschild-Stiglitz type of equilibrium in the benchmark treatment.

In the Non-Existence environment, cross-subsidization occurs in two out of four sessions but is quickly destroyed as competition predicts. We observe instability and lack of separation in these two sessions. In the other two, the RS equilibrium in single contracts is eventually reached. The traded contracts separate the two types of projects.

Thus, when the adapted RS equilibrium exists, i.e., when the original RS equilibrium is Pareto-optimal, it predicts outcomes in experiments. When not, the evidence we obtain in favor of any of the alternatives of the RS equilibrium notion is unconvincing. The latter finding is important, because it means that the separating contracts studied in the corporate finance literature following the seminal papers of Ross (1977) and Leland-Pyle (1977) are questionable in a competitive framework where lenders offer the contracts.

There are a few related experimental papers. The closest is Posey and Yavas (1999). It studies experimental insurance markets where sellers can compete on the prices of only two insurance contracts. The sellers move first and offer contracts; the buyers move second and choose (in fact, the buyers' decisions are made by computers). Posey and Yavas find strong support that the two contracts are priced to generate zero expected profits, thus supporting one element of the RS theory. In our experiments, the contract space is substantially enriched. In addition, we do not computerize the buyers' side. We use a different market microstructure, namely the open book, which has been shown to induce more competition. Another paper, Miller and Plott (1985), studies adverse selection in experimental double-auction markets. Because of its great complexity, the underlying theoretical model does not give a unique prediction for the market equilibrium, which perhaps explains why the results are mixed, with both pooling and separation emerging. Whenever separation obtains, the level of the signal is not at its optimal level. Our experimental markets are closer to the theory, and therefore, simpler. Finally, Cadsby, Frank and Maksimovic (1990) study separation in the context of a signaling model. We investigate the issue of separating within a screening model.

The remainder of the paper is organized as follows. The next section provides the model and the theoretical results. Section 1.3 goes over the experimental design, while Section 1.4 describes the laboratory markets. The results of the experiments are in Section 1.5. Section 1.6 concludes the paper.

1.2 The Model

Consider an economy consisting of entrepreneurs and lenders.[4] Each entrepreneur has an exclusive access to an investment opportunity, or a project, requiring initial investment of I. Both the initial investment, and the payoff from the project are expressed in terms of the only consumption good available in the economy. If the project succeeds (fails), its payoff is X_u (X_d), $X_u > X_d \geq 0$.

Entrepreneurs can be of each of two possible types: high-risk and low-risk.[5] Agents of the high-risk type have probability p_h of leading their firm to a low final payoff, X_d, while this probability is equal to p_l for the low-risk type, with $p_h > p_l$.[6] The proportion of the high-risk entrepreneurs is equal to λ. Project failures happen independently across entrepreneurs. All entrepreneurs are assumed to have the same Bernoulli utility function $U(x)$, strictly increasing and concave; $U'(x) > 0, U''(x) < 0$. All of them are expected utility maximizers, and all have the same initial endowment of wealth, W. Entrepreneurs can choose whether or not to invest in the project, and they can

[4] The number of the entrepreneurs in the economy can be finite or infinite.

[5] Or, alternatively the projects are of differential quality: high-risk and low-risk. Each entrepreneur is then associated with the quality of her project.

[6] Note that the term "risk" here is not used as a mean-preserving spread. The payoff distribution of the low-risk project first order stochastically dominates the high-risk project's payoff distribution.

consume everything that they have not invested.

Definition 1.2.1. A generalized loan contract is a triple (L, F_u, F_d), where L is the amount loaned (or the value of the loan contract), F_u is the face value of the loan if the project succeeds, and F_d is the face value of the loan when the project fails.

Generalized loan contracts are offered by the lenders whose objective is to maximize expected profits. The lenders face adverse selection as they cannot distinguish between high and low-risk entrepreneurs. A contract (L, F_u, F_d) entitles the entrepreneur to receive L from the lender before the project is undertaken, and obliges him to pay back to the lender an amount equal to F_u or F_d if the outcome of the project is X_u or X_d correspondingly. Let $S \subset \mathbb{R}^3$ denote the set of generalized loan contracts available to the lenders. Lenders can offer any number of contracts from the set S. The market for loans is competitive in the sense that there is free entry. Each entrepreneur is allowed to take at most one loan contract from those offered implying exclusivity of the loan contracts.

Definition 1.2.2. A contract $(L, F_u, F_d) \in S$ is feasible if $F_d \leq X_d$, and $F_u \leq X_u$.

The parameters of the model, $W,\ I,\ p_h,\ p_l,\ X_u,\ X_d,\ \lambda$, the set S, and the function U are all public information. Whether or not a project is undertaken is verifiable, as is the outcome of the project.

A variation of the the notion of equilibrium introduced by Rothschild-Stiglitz (1977) is employed. The original definition of equilibrium, which we call equilibrium in single contracts, is stated below.

Definition 1.2.3. Equilibrium in single contracts is a set of feasible contracts such that when entrepreneurs choose contracts to maximize expected utility, (i) no contract in the equilibrium set makes negative expected profits; and (ii) there is no contract outside the equilibrium set that, if offered, will make a nonnegative profit.

A natural notion of equilibrium when lenders are allowed to offer more than one contract is the following variation of the RS' equilibrium:

Definition 1.2.4. Equilibrium in menus of contracts is a set of feasible contracts such that when entrepreneurs choose contracts to maximize expected utility, (i) no contract in the equilibrium set makes negative expected profits; and (ii') there is no menu of contracts outside the equilibrium set that, if offered, will make a total nonnegative expected profit.[7]

It is easily seen that (ii') implies (ii), therefore the following holds:

Proposition 1.2.5. *The contracts that satisfy the definition of equilibrium in menus of contracts are a subset of the contracts that satisfy the definition of equilibrium in single contracts.*

Definition 1.2.6. An allocation of contracts between the lenders and the entrepreneurs is (constrained)[8] Pareto-optimal if a benevolent central planner who possesses the same information as the lenders cannot allocate feasible contracts between the lenders and the entrepreneurs that would make everybody weakly better off and at least one agent (a lender or an entrepreneur) strictly better off.

RS consider $S = \mathbb{R}^3_+$ and demonstrate that the equilibrium in single contracts might not be Pareto-optimal. Whenever this is the case, there are a continuum of Pareto-improving pairs of contracts. In each such pair, the contract designed for the high-risk agents loses money (in expectation) while the one for the low-risk agents makes positive expected profit with an overall non-negative expected profit from the two contracts. Such pairs will be called cross-subsidized pairs of contracts. From all of those RS consider the one that leads to zero-profits for the lenders. From the definitions of Pareto-optimality and equilibrium in menus of contracts, the following proposition follows:

Proposition 1.2.7. *The equilibrium in menus of contracts exists if and only if the equilibrium in single contracts exists and is Pareto-optimal.*

[7] The RS' notion of equilibrium (and consequently its variation) is extremely parsimonious. The lenders' objective does not enter directly in the definition. It is implicitly assumed that lenders try to maximize expected profits and that competition wipes out the expected profits to their minimum, and this is the condition that enters in the definition. We are trying to understand *how* and *which* contracts emerge in a competitive situation. Skipping the formal modelling of the first question, RS' model directly addresses the second.

[8] "Constrained" is suppressed later in the text as this is the only notion of Pareto-optimality used in this paper.

Note that $L \leq I$ is not imposed, so that loans serve a consumption-smoothing role in addition to financing part of the investment cost.[9] After obtaining a contract (L, F_u, F_d) and investing in the project, an entrepreneur consumes $W+L-I$ independently of the outcome of the project. In addition to that, the net output of the project, $X_u - F_u$ if it succeeds, or $X_d - F_d$ if it fails, is also consumed. The total consumption in the good state is thus $C_u = W - I + X_u + L^h - F_u^h$, while it is $C_d = W - I + X_d + L^h - F_d^h$ in the failure state. The following conditions must be satisfied by any contract in the equilibrium set that is taken by an entrepreneur whose probability of failure is p.

$$W + L - I \geq 0 \qquad (c1)$$

$$F_u \leq X_u \qquad (c2)$$

$$F_d \leq X_d \qquad (c3)$$

$$(1-p)U(C_u) + pU(C_d) \geq U(W) \qquad (IR)$$

Condition $(c1)$ ensures that the loan amount combined with the initial wealth is sufficient to cover the investment cost. $(c2)$ and $(c3)$ are the feasibility constraints. The (IR) constraint imposes that the entrepreneur's expected utility is weakly greater with the loan contract than without.

In what follows we briefly characterize equilibria in the economy with $S = \mathbb{R}^3_+$.[10]

1.2.1 Benchmark Case: Identical Entrepreneurs

If all agents' probability of failure is p, the equilibrium contract maximizes the entrepreneurs' utility subject to a zero profit constraint for the lenders. Equivalently,

$$L = (1-p)F_u + pF_d \qquad (c4)$$

[9] The analysis with the restriction $L \leq I$ is essentially the same, only the final allocations will be Pareto-dominated by the allocations obtained without the constraint.

[10] For the purposes of the experiments we will have a finite set of possible contracts. However, first solving the case with $S = \mathbb{R}^3_+$, and then choosing the discrete grid for the actual contracts greatly simplifies the equilibrium computations.

Thus the equilibrium contract solves

$$\begin{aligned} &\operatorname*{Max}_{L,F_u,F_d} (1-p)U(C_u) + pU(C_d) \\ \text{s.t.} \quad &(\text{c1}),\ (\text{c2}),\ (\text{c3}),\ (\text{c4}),\ (\text{IR}) \end{aligned} \tag{1.1}$$

It is easily shown that (L, F_u, F_d) is such that:

$$\begin{aligned} &0 \leq F_d \leq X_d \\ &F_u = X_u - X_d + F_d \\ &L = (1-p)F_u + pF_d, \quad L \geq I - W \end{aligned}$$

Without loss of generality, we take $F_d = X_d$.[11] This leads to the equilibrium contract $(L^*, F_u^*, F_d^*) = ((1-p)X_u + pX_d, X_u, X_d)$. Note that entrepreneurs invest only in non-negative net profit projects. The standard result that the lenders take all the risk and the entrepreneurs enjoy the entire expected net profit of the projects is obtained here as well.

1.2.2 Adverse Selection: Two Types of Entrepreneurs

As shown earlier, an equilibrium in menus of contracts exists if and only if the equilibrium in single contracts exists and is Pareto-optimal. Therefore the equilibrium in menus is found by deriving the equilibrium in single contracts first and then checking the outcome for Pareto-optimality.[12]

We assume that if an equilibrium in single contracts exists, it is a separating one.[13] Let (L^h, F_u^h, F_d^h) and (L^l, F_u^l, F_d^l) denote the contracts offered to the high and the low-risk-type agents correspondingly (the consumption in the up and down states is denoted C_u^i, and C_d^i, $i \in \{h, l\}$ correspondingly). In equilibrium a contract

[11] This is a standard loan contract with face value of the loan equal to F_u and value of the loan L.

[12] See Rothschild-Stiglitz (1977) for a more detailed treatment of Pareto-optimality of the equilibrium in single contracts.

[13] Unlike in the original RS treatment here this is indeed an assumption, as shown later in the text.

(L^i, F_u^i, F_d^i), $i \in \{h, l\}$ must satisfy conditions $(c1)$, $(c2)$, $(c3)$, and (IR) (which we denote $(c1i)$, $(c2i)$, $(c3i)$, and (IRi)) in addition to:

$$L^i \leq (1-p_i)F_u^i + p_i F_d^i \qquad (c4i)$$

$(c4i)$ is the condition that the lenders do not lose money on the contract offered to the i-risk entrepreneurs, $i \in \{h, l\}$.

Observe that if the separating equilibrium exists, the high-risk type agents must get their optimal allocation subject to the zero-profit constraint of the lenders (implying $C_u^h = C_d^h = C^h$). Again, without loss of generality $F_d^h = X_d$, so that the equilibrium contract for the high-risk types becomes the one described in the benchmark treatment with $p = p_h$. When (IRh) and (IRl) are temporarily dropped, and that both risk classes undertake their projects in equilibrium is assumed, the incentive compatibility condition (IC) that the equilibrium contracts should satisfy can be written as

$$U(C^h) \geq (1-p_h)U(C_u^l) + p_h U(C_d^l)$$

(IC) states that the high-risk entrepreneurs prefer the contract designed for them to the contract designed for the low-risk entrepreneurs.

The (IC) condition is binding in equilibrium. Also, assume that (cl1) does not bind (and therefore (cl4) does[14]). Denote the binding conditions with primes. Then the equilibrium contracts must solve the maximization problem below:

$$\underset{L^l, F_u^l, F_d^l}{\text{Max}} (1-p_l)U(C_u^i) + p_l U(C_d^l) \qquad (1.2)$$
$$s.t. \ (IC)' \& (c4l)'$$

[14]This is the assumption guaranteeing that pooling contracts do not exist in this environment. Consider the following example $X_u = 100$, $X_d = 20$, $I = 50$, $W = 15$, $p_h = 2/5$, $p_l = 1/5$, $U(x) = -e^{-bx}$, where $b = 0.008$. Assuming a separating solution and solving for it leads to $F_u^l - F_d^l = 18.5401$. Therefore the largest possible L^l is equal to 34.8321, and therefore $W + L^l < I$. However there is a pooling contract that provides the low-risk entrepreneurs with amount just enough to cover the investment. The RS argument for non-existence of pooling equilibrium does not work in this case because skimming the low-type agents requires offering a lower loan, which would not be enough to cover the investment cost.

Once derived, the solution should be checked against the IR constraints. Lastly, one should check whether λ is such that the separating equilibrium in single contracts can be sustained, and if so, whether it is Pareto-optimal. Only if all these conditions are satisfied then the equilibrium in menus of contracts exists.

1.3 Experimental Design

1.3.1 Parametrization of the Model

The utility functions of the entrepreneurs are taken to be affine transformations of $U(x) = x - \frac{1}{2}bx^2$, where $b = 0.008$. The low-risk entrepreneurs have utility function $U_l(x) = 20U(x) - 522$, while for the high-risk entrepreneurs it is $U_h(x) = 10U(x) - 121$.[15] The initial wealth of the agents is $W = 0$. If successful, the project brings $X_u = 100$, while in the case of failure the payoff from the project is $X_d = 0$.

The high-risk entrepreneurs' probability of failure is $p_h = 7/9$, while this probability is $p_l = 5/9$ for the low-risk agents. For simplicity, the cost of the investment, I, is taken to be zero. Each lender is given the utility function $U_L(x) = 10x$.

When $S = \mathbb{R}^3$, the lowest fraction of the high risk type agents, λ, for which the equilibrium in single contracts can be sustained is $\lambda = 0.47$. When $\lambda \geq 0.47$, the equilibrium contract for the high-risk entrepreneurs is $(L^{h*}, F_u^{h*}, F_d^{h*}) = (22.22, 100, 0)$.[16] The equilibrium contract designed for the low-risk agents is $(L^{l*}, F_u^{l*}, F_d^{l*}) = (10.22, 23, 0)$.

For the values of the parameter λ used in the experimental design, the equilibrium in single contracts under the above parametrization is *not* (constrained) Pareto-optimal. The set of Pareto-dominating contracts depends on the value of λ. For example, if $\lambda = 6/11$ then the zero-profit optimal pair of contracts is $(L^l, F_u^l, F_d^l) = (14.66, 40.05, 0)$, and $(L^h, F_u^h, F_d^h) = (24.84, 100, 0)$.

Whenever the equilibrium in single contracts is not Pareto-optimal, the equilibrium

[15] We use linear transformations of this function in the experiments in order to calibrate the actual payoffs of the participants so that they earn approximately the same (dollar) amount in equilibrium. Of course none of the results are affected if agent's utility functions are affinely transformed.

[16] The high-risk agents smooth their consumption completely and consume 22.22 units of the good independent the outcome of the project.

in menus of contracts does not exist. Therefore in the above parametrization the equilibrium in menus of contracts does not exist if $S = \mathbb{R}^3$. In the Baseline environment, however, the contract space is discretized in such a way, that the RS' equilibrium-in-single-contracts pair is preserved, but all pairs that Pareto-dominate it are removed. This restores the existence of the equilibrium in menus of contracts with respect to the newly chosen set of available contracts, S'. Thus, in the Baseline environment, the equilibrium in single contracts, the equilibrium in menus of contracts, and the Pareto-optimal pairs all coincide. In the Non-existence environment, the contract space S' is enriched to S'' as to include two pairs that Pareto-dominate the equilibrium-in-single-contracts pair. Thus, in the second environment, which we call the Non-existence environment, the equilibrium in single contracts is the pair of contracts $(22.22, 100, 0)$, and $(10.22, 23, 0)$; there are two pairs of contracts that Pareto-dominate this equilibrium pair; and, the equilibrium in menus of contracts does not exist.

In the experimental design both the loan and the repayment take integer values. Thus, the equilibrium contracts become $(L^{h*}, F_u^{h*}, F_d^{h*}) = (22, 100, 0)$, and $(L^{l*}, F_u^{l*}, F_d^{l*}) = (10, 23, 0)$. The discretization of the problem and the rounding of the payoffs create a second possible equilibrium contract for the high-risk entrepreneurs, namely $(L^{h*}, F_u^{h*}, F_d^{h*})' = (21, 95, 0)$.

Because the repayment F_d is always equal to zero, a contract is fully determined by the values of L and F_u, or equivalently by the values of $F_u - L$ and F_u. For the purposes of our experimental design, we define a contract by the pair $(\alpha, \beta) = (F_u, F_u - L)$. We refer to the quantity $F_u - L$ as a "credit spread." Figure 1.1 shows the grid of contracts used in the Baseline experiments in the (α, β) plane. Figure 1.2 is the grid for the Non-existence environment.

1.3.2 Conjectures

The parametrization of the model described above is used to formulate a number of conjectures, to be tested empirically later on.

(A) The entrepreneurs can be separated by their risk type based on the loan contracts they take. High-risk entrepreneurs take bigger loans and bear higher credit spreads than the low-risk entrepreneurs.

(B) Lenders make zero expected profits on every contract they offer.

We expect (A) and (B) to be confirmed in the Baseline environment. For the Non-existence environment, we formulate the following conjectures:

(C) The contracts traded stabilize around the equilibrium-in-single-contracts pair.

(D) The contracts traded stabilize around the Pareto-optimal pair, which involves cross-subsidization.

1.3.3 Certainty Equivalent Payoffs

Because of the difficulty of measuring and controlling risk attitudes of human subjects, we substitute leverage-dependent payoff schedules for uncertainty in the final payoffs of the projects. That is, rather than assuming that human subjects make decisions under uncertainty based on a specific expected-utility function with common parameters, we give them payoffs that correspond to the expected utility they would get from each of the contracts if they really had the hypothesized risk attitudes.

The expected utility functions of the two entrepreneur types as well as the lender are tabulated as a functions of $(\alpha, \beta) = (F_u, F_u - L)$. $U_i(\alpha, \beta) = E(U_i(x)|(\alpha, \beta)) = (1 - p_i)U_i(100 - \beta) + p_i U_i(\alpha - \beta)$ is the expected utility of an entrepreneur of type $i,\ i = h, l$ upon obtaining the contract (α, β). Similarly, a lender gets $U_L(\alpha, \beta, i) = E(U_L(x)|(\alpha, \beta), i) = (1 - p_i)U_L(\alpha) - U_L(\alpha - \beta)$ in expectation after loaning (α, β) to a type $i,\ i = h, l$ agent.

1.3.4 The Laboratory Markets

In the Baseline environment, the possible contracts are given by

$\alpha \in \{8, 16, 20, 23, 26, 34, 44, 55, 65, 75, 85, 95, 100, 105, 110\} = (\alpha_i)_{i=1}^{15}$,

$\beta \in \{4, 7, 10, 13, 14, 17, 23, 29, 35, 41, 53, 56, 59, 62, 71, 74, 77, 78, 79, 81, 84, 87, 93\}$

$= (\beta_i)_{i=1}^{23}$.

In the Non-existence environment we use

$\alpha \in \{16, 20, 23, 26, 34, 35.6, 40.05, 44, 55, 65, 75, 85, 95, 100, 105, 110\} = (\alpha_i)_{i=1}^{16}$,
$\beta \in \{7, 10, 13, 14, 17, 22.3, 23, 25.39, 29, 35, 41, 53, 56, 59, 62, 71, 74, 75.16, 75.95,$
$76.65, 78, 79, 81, 84, 87\} = (\beta_i)_{i=1}^{25}$.

The experiments are conducted as market experiments. The contracts are called "financial instruments," or "securities," and they can be bought and sold in the experimental markets. There are fifteen financial instruments in the Baseline environment defined by $\alpha_1, ..., \alpha_{15}$, and called "$A$," "$B$," "$C$," ..., "$O$" in the actual experiments. The market for the financial instrument "A" is called market A, for "B" it is market B, and so on. Each financial instrument can be traded at twenty three possible "prices", corresponding to $\beta_1, ..., \beta_{23}$. and called 1, 2, ..., 23 in the experiments.[17] The equilibrium contracts in this notation are $D4 = (\alpha_4, \beta_4) = (23, 13)$, and $M18 = (100, 78)$ or $L16 = (95, 74)$. The contacts in the Non-existence environment are defined in a similar fashion. The financial instruments are called "A," "B," ..., "P," and the prices go from 1 to 25. The equilibrium in single contracts is represented by $C3$, and $N21$ or $M17$. There are two pairs that Pareto-dominate the RS equilibrium outcome. Those pairs are $(G8, N18)$, and $(F6, N19)$. The currency in which all contracts are denominated is called francs. The earnings of each participant are converted to dollars at a pre-announced rate in the end of each experiment.

Each experimental session consists of ten to fourteen identical trading periods with length from two to five minutes. The entrepreneurs in the experiments are called "buyers," while the lenders are "sellers." Each buyer can be of one of the two possible types—Red or Blue, corresponding to the high-risk and the low-risk entrepreneurs.[18] Each seller is allowed to offer any number of financial instruments and at any price. The buyers, on the other hand, can buy at most one financial instrument per period. Moreover, buyers cannot send "buy orders" to the market, they can only match existing "sell offers."[19]

Each buyer is presented with a payoff table (see Figure 1.3 for the payoff table of

[17] (α_1, β_1) is represented by $A1$, (α_2, β_1) by $B1$, and so on.

[18] Whether a participant in an experiment is a buyer or a seller is determined randomly in the beginning of the experiment. The type of a given buyer can change from period to period but the proportion of Red buyers is constant throughout the periods.

[19] The instructions for the Baseline environment can be found in the Appendix.

the Blue buyers, and Figure 1.4 for the payoff table of the Red Buyers) in which the expected payoffs $U_i(\alpha, \beta)$, $i \in \{h, l\}$ are tabulated. Similarly, each seller is presented with a payoff table that indicates for each financial instrument and price the possible payoff depending on what type of buyer buys the financial instrument at that price (see Figure 2.1 for the payoff table of the sellers).[20] That is, the function $U_L(\alpha, \beta, i)$, $i \in \{l, h\}$ is tabulated and presented to the sellers. The total payoff for a seller in a given period is equal to the sum of the payoffs from the individual transactions.

Every participant's total earnings from an experimental session equal the cumulative earnings from all periods.

1.4 Summary of the Sessions

1.4.1 Baseline Environment

The Baseline environment study consists of seven experimental sessions. Four of the experimental sessions were conducted at the California Institute of Technology (CIT). We call those sessions BCIT1, BCIT2, BCIT3, and BCIT4. Two sessions were conducted at Sofia University (SU), Bulgaria. We call those BSU1, and BSU2. The last session within the Baseline environment was at UCLA, and we call it BUSLA.

All subjects participating from Caltech were Caltech undergraduate students taking introductory Economics class. A large majority of the participants at Sofia University were students either in the Department of Mathematics and Informatics of SU, or in the Department of Physics of SU. The rest were students from other departments of SU or other universities in Sofia, Bulgaria. The participants at the UCLA site were students enrolled for the 2002 Summer term at UCLA. The summary of the Baseline sessions is presented in Table 1.1.

The sessions BCIT1, BCIT2, BSU1, and BSU2 were organized as open outcry markets. The rest were organized as computerized markets. In the manually run

[20]Each cell of the payoff table of the sellers consists of four entries. The payoff from a transaction with a Blue buyer is given in bold blue, while with Red is in bold red. In parenthesis, beneath the sellers' possible payoffs are the corresponding buyers' payoffs.

sessions, either on a screen (for BCIT1 and BCIT2), or on the blackboard (for BSU1, and BSU2) was a table like the one in Figure 1.6. If a seller wanted to send a sell order to the market, the seller had to raise her ID number, announce the market, the price, as well as the number of units she wanted to sell at this market and price. Buyers could only accept offers. In order to accept an offer, a buyer had to raise his ID number, and announce the market and the price of the offer he wanted to accept. In the manually conducted experiments the book was organized in chronological order. When a buy order came, the contract that was sold first was the one that was offered first. In the computerized experiments a seller was picked at random when a given contract was offered by more than one seller.

The sending of sell and buy orders in the computerized experiments was done by clicking on the cells of a table similar to the one used for the manual experiments.[21] In Table 1.2 we present the exchange rates for the seven session as well as the average payoffs for the sellers and the buyers.[22]

1.4.2 Non-Existence Environment

This part of the study differs from the previous one only in the discretization of the contract space. Among the new contracts included in the grid of contracts are two pairs that Pareto-dominate the equilibrium-in-single-contracts pair of contracts. We ran four sessions within the Non-existence environment. All sessions were conducted at UCLA, and we call them NUSLA1, NUSLA2, NUSLA3, and NUSLA4. All experiments were computerized.[23] All sessions had 23 participants: six sellers, and seventeen buyers. In all sessions nine of the buyers were Red-type and eight were Blue-type

[21] Instructions and screens for the experiments we discuss here can be viewed at http://eeps4.caltech.edu/market-020919 and use identification ID:1 and password:a to login as a viewer. As a viewer you will not have a payoff but you will be able to see the trading screen as well as all the forms.

[22] At the time the experiments were run, the exchange rate between US dollars and Bulgarian levs was 2.11 levs per dollar. According to the estimate of the Bulgarian "Podkrepa" Labor Confederation, at this time, people with minimum wage in Bulgaria disposed of USD 1.08 per day, while for those with medium wage the amount was USD 3.80 per day.

[23] Instructions and screens for the experiments we discuss here can be viewed at http://eeps4.caltech.edu/market-020917. Use identification:1 and password:a to login as a viewer.

(i.e., for the Non-existence environment we had $\lambda = 9/17$ in all sessions). Following one practice period, there were fourteen periods in each session. In Table 1.3 we present the exchange rates as well as the average payoffs for the sellers and the buyers in these four sessions.

1.5 Results

1.5.1 Baseline Environment

This section includes the results from all Baseline sessions. To test conjecture (A), we first test the null hypothesis the data comes from a bivariate normal distribution versus the alternative that the data comes from a mixture of two bivariate normal distributions, i.e.,

$$H_0 : (\alpha, \beta) \sim N(\mu, \Sigma_0)$$

$$vs.$$

$$H_1 : (\alpha, \beta) \sim (1-\theta)N(\mu_1, \Sigma_1) + \theta N(\mu_2, \Sigma_2),$$

where $\mu_i = (\mu_{i\alpha},\ \mu_{i\beta}),\ i = 1,\ 2.$

Note: the mixture model maximum log likelihood estimates are based on the EM algorithm, which is standard for estimating mixture models.

The null hypothesis can be rejected in favor of the alternative at the 95% confidence level (with a p-value of less than 0.001). If the theoretical predictions of our model hold, the estimate of the mixture parameter θ should not be significantly different than the weighted average of the proportions of Red buyers in all Baseline sessions, $\bar{\lambda}$. The mixture parameter's estimate is $\hat{\theta} = 0.5566$. The 95% confidence interval for the parameter θ is $(0.5247, 0.5886)$, and $\bar{\lambda} = 0.5581$ falls in it.

The above clearly shows that the data is separated in two clusters. Moreover, the data is split between the two clusters in the right proportions. It remains to show that the clusters are homogeneous, i.e., one is consisting mainly of transactions with Red buyers while the other of transactions with Blue buyers. Table 1.4 shows the cross-tabulation by buyers' types as well as the estimators of the mean parameters of the two clusters.

Figure 1.7 shows the three-dimensional stem plot of all trades in the Baseline sessions along with the indifference curves of the entrepreneurs (passing through the equilibrium loan contracts), and the zero profit lines for the lenders. The indifference curves are solid lines, with the high-risk entrepreneurs' curve crossing the low-risk entrepreneurs' from above. The dotted lines are the corresponding (expected) zero-profit lines for the lenders. The bottom part of the figure shows the contracts traded in the α-β plane without accounting for the frequency with which each contract was traded. The graphs clearly show the separation by clusters. The high-risk contracts were traded mostly on the "high-risk" zero-profit line. The low-risk contracts were traded slightly below the "low-risk" zero-profit line, i.e., at a profit for the sellers. To test our conjecture (B), we test the hypotheses (Hl_0): $\mu_{1\beta} - p_l\mu_{1\alpha} = 0$ vs. (Hl_1): $\mu_{1\beta} - p_l\mu_{1\alpha} \neq 0$, and (Hh_0): $\mu_{2\beta} - p_h\mu_{2\alpha} = 0$ vs. (Hh_1): $\mu_{2\beta} - p_h\mu_{2\alpha} \neq 0$. ($Hl_0$) states that the mean contract in Cluster 1 traded on zero profit for the lenders (assuming homogeneity of the clusters). The second one, (Hh_0) states that the mean contract in Cluster 2 made zero-profits for the lenders. Using all periods in the Baseline sessions, we reject (Hl_0) at the 95% level (t-statistic of 28.3). We also reject (Hh_0) at the 95% level (t-statistic of -8.7).[24]

As it usually takes some time for the markets to equilibrate (if they ever do), we perform the analysis from above on the data from the last three periods of all Baseline experiments.[25] Table 1.5 shows the cross tabulation by types of buyers as well as the estimators of the means of the two clusters.

The separation of the buyers by types in the two clusters is evident from the results in Table 1.5. From the 132 contracts in Cluster 2, 122 were among the two

[24]If instead of using the separation by cluster, we use the actual types of the entrepreneurs, i.e., if we test whether the contracts with high-risk entrepreneurs and the contracts with low-risk entrepreneurs yield zero profits each for the lenders, we obtain similar results (the corresponding t-statistics are 19.86 and -9.8).

[25]For the last three periods, the 95% confidence interval for the parameter θ is (0.4565, 0.5788), and $\bar{\lambda}$ falls in it.

equilibrium contracts designed for the red buyers (84 were M18 and 38 were L16). As the above shows, the contracts designed for the Red buyers were essentially the two equilibrium contracts. As for the Blue buyers, the sellers offered contracts that were slightly more "expensive" than the equilibrium contract. The mean low-risk contract traded was $(\mu_{1\alpha}, \mu_{1\beta}) = (30, 20)$, providing consumption of 10 and 80 in the case of failure and success of the project. The equilibrium consumptions are 10 and 87 correspondingly. When we test the hypotheses (Hl_0) vs. (Hl_1), and (Hh_0) vs. (Hh_1), we still reject (Hl_0) in favor of (Hl_1). However, (Hh_0) cannot be rejected at the 95% confidence level. Thus, the lenders make zero profit on the contracts designed for the high-risk entrepreneurs but they make profits on the ones designed for the low-risk entrepreneurs. We attribute this to the fact that in equilibrium the high-risk-type entrepreneurs are indifferent between the contracts designed for them and the contract designed for the low-risk agents. If sellers have any doubts that the high-risk entrepreneurs are going to choose the "right" contract, they are going to offer to the low-risk agents a contract at slightly worse terms as to insure that the high-risk agents do not choose it. The equilibrium contract for the low-risk agents was traded 17 times in the last three periods. The contract that was traded most often was F7=(34, 23). Note that it provides payoff of 79 francs for the Red buyers as opposed to the 80 francs that they get from their equilibrium contracts. Figure 1.8 shows the three-dimensional stem plot of the trades from the last three periods.

It is interesting to note that although the average payment in Bulgaria was at least ten times higher in real terms than the average payment in the US, there were no significant differences between the structures of the clusters for the two data sets.

Overall, the results from the Baseline environment provide strong support for our conjecture (A). They also support our conjecture (B) if we account for the positive probability that the high-risk entrepreneurs might have of choosing the contract designed for the low-risk entrepreneurs when indifferent between the two contracts.

1.5.2 Non-Existence Environment

Here, as in the Baseline environment, we test the null hypothesis that the data comes from a bivariate distribution versus the alternative that the data comes from a mixture of two bivariate normal distributions. The former is rejected at the 95% confidence level (again with a p-value less than 0.001). The proportion of the Red-type buyers in this environment was $\lambda = 9/17$ in all sessions. If there is separation by risk types we should expect the data to be split between the two clusters in ratio of $(1 - \lambda) : \lambda$, or θ should not be significantly different from 9/17. The estimate of the mixture parameter is $\hat{\theta} = 0.35$. The 95% confidence interval for θ is $(0.3187, 0.3812)$ and $\lambda = 9/17$ is well beyond this interval. Thus, at this stage, the econometrician who only knows the proportion of the high-risk entrepreneurs and the contracts that were traded in the market will be able to reject the prediction that the trades can be used to separate the entrepreneurs by their risk types. The cross-tabulation of types within the two clusters is shown in Table 1.6.

Although the separation of the data in two clusters is evident, unlike in the Baseline environment, the two clusters here are not homogeneous (as expected after inspecting the ratio of the trades in the two clusters).

We perform the same cross-tabulation for the last three periods of all Non-existence environment experiments as we did for the Baseline experiments. The results are in Table 1.7, and they still do not show separation in types between the two clusters. Figure 1.9 and Figure 1.10 show the three-dimensional stem plots of the trades from all periods and from the last three periods correspondingly.

In two of the four experiments under the Non-existence environment, the contracts traded converged to the original equilibrium contracts. In the other two sessions, however, we temporarily observed trading of cross-subsidized pairs of contracts. In one of them the pair was (F8,I11), while in the other it was (E6, O23). In both sessions this happened very close to the end of the experimental session as reflected in the analysis of the last three periods only.

Thus, in the Non-existence sessions we cannot support conjecture (A). Two of the experiments support (A), while the other two clearly reject it. The overall conclusion is that the entrepreneurs cannot be separated by their risk types based on the loan contracts they take (we do not test conjecture (B) as we would be interested in it only if (A) held). Conjecture (C) received mixed support while conjecture (D) can be clearly rejected as in the two sessions when we observed cross-subsidization, it was very quickly destroyed.

1.6 Conclusion

This paper examines a simple model of adverse selection in the context of competitive provision of loans. The notion of equilibrium that is employed is an extension of the Rothschild-Stiglitz equilibrium to allow for multiple contracts to be offered by a single lender (we refer to the original and the adapted notions as equilibrium in single contracts and equilibrium in menus of contracts correspondingly). Experiments are used to test the validity of its predictions. In equilibrium, the model makes the strong prediction that from all possible loan contracts, only two are viable. Moreover, competition does not necessarily push the loans and repayments to their optimal levels. When it does not coincide with the equilibrium in single contracts, the Pareto-optimal pair involves cross-subsidization between contracts.

As a first approach the model is tested with a benchmark scenario in which the Pareto-optimal and the equilibrium contracts coincide. We find that the traded contracts are clearly separated in two clusters around the two equilibrium contracts. The cross tabulation of types within clusters shows that the contracts indeed separate the two types of entrepreneurs: the high-risk entrepreneurs take bigger loans and bear higher credit spreads than the low-risk entrepreneurs. Cross-subsidization is not observed in any of the experimental sessions within this environment. Thus, the results strongly support Rothschild-Stiglitz in the benchmark case.

Next, the model is tested in the case where the equilibrium in single contracts pair is not Pareto-optimal. Temporary cross-subsidization occurs in two out of four sessions. In the other two sessions the equilibrium in single contracts is eventually reached. Thus, the results for this environment are mixed, showing that further theoretical and experimental investigation is needed.

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Tables, Figures, and Instructions for the Experiments

Table 1.1: Summary of the Sessions

	Exp.	Date	#Sellers	#Red	#Blue	λ^a	#Periods	Computerized
1	BCIT1	5/25/01	4	5	4	5/9	10	no
2	BCIT2	6/25/01	4	5	4	5/9	10	no
3	BCIT3	6/3/02	6	8	7	8/15	11	yes
4	BCIT4	7/18/02	5	9	5	9/14	12	yes
5	BSU1	8/17/01	6	6	5	6/11	10	no
6	BSU2	8/18/01	6	6	5	6/11	10	no
7	BUCLA	9/19/02	6	9	8	9/17	14	yes

[a] the average proportion of Red buyers in all Baseline experiments (weighted by the number of buyers in each session) was $\bar{\lambda} = 0.5581$

Table 1.2: Summary of the Payoffs in the Baseline Environment

	Exp.	Exchange Rate Seller	Exchange Rate Red	Exchange Rate Blue	Average Payoff Sellers	Average Payoff Buyers
1	BCIT1	\$0.05	\$0.03	\$0.03	\$15	\$18
2	BCIT2	\$0.05	\$0.02	\$0.02	\$15	\$19
3	BCIT3	\$0.10	\$0.03	\$0.03	\$34	\$27
4	BCIT4	\$0.10	\$0.03	\$0.05	\$46	\$32
5	BSU1	Lv0.10	Lv0.04	Lv0.04	Lv34	Lv31
6	BSU2	Lv0.09	Lv0.03	Lv0.03	Lv34	Lv26
7	BUCLA	\$0.04	\$0.02	\$0.03	\$29	\$22

Table 1.3: Summary of the Payoffs in the Non-existence Environment

	Exp.	Exchange Rate Seller	Exchange Rate Red	Exchange Rate Blue	Average Payoff Sellers	Average Payoff Buyers	
NUCLA1	9/5/02	\$0.06	\$0.02	\$0.025	\$49	\$28	\$21
NUCLA2	9/9/02	\$0.04	\$0.02	\$0.03	\$35	\$28	\$26
NUCLA3	9/11/02	\$0.04	\$0.02	\$0.03	\$15	\$29	\$34
NUCLA4	9/17/02	\$0.04	\$0.02	\$0.03	\$47	\$27	\$13

Table 1.4: Baseline environment, all periods: Distribution of types by cluster

	blue	red	$\hat{\mu}_{i\alpha}$	$\hat{\mu}_{i\beta}$
Cluster 1	360	60	29	20
Cluster 2	50	475	94	71

Table 1.5: Baseline environment, last three periods: Distribution of types by cluster

	blue	red	$\hat{\mu}_{i\alpha}$	$\hat{\mu}_{i\beta}$
Cluster 1	107	16	30	20
Cluster 2	4	128	99	76

Table 1.6: Non-existence environment, all periods: Distribution of types by cluster

	blue	red	$\hat{\mu}_{i\alpha}$	$\hat{\mu}_{i\beta}$
Cluster 1	417	183	34	24
Cluster 2	9	314	95	73

Table 1.7: Non-existence environment, last three periods: Distribution of types by cluster

	blue	red	$\hat{\mu}_{i\alpha}$	$\hat{\mu}_{i\beta}$
Cluster 1	95	43	33	23
Cluster 2	0	64	97	76

Figure 1.1: Baseline Environment: The Discrete Grid of Contracts

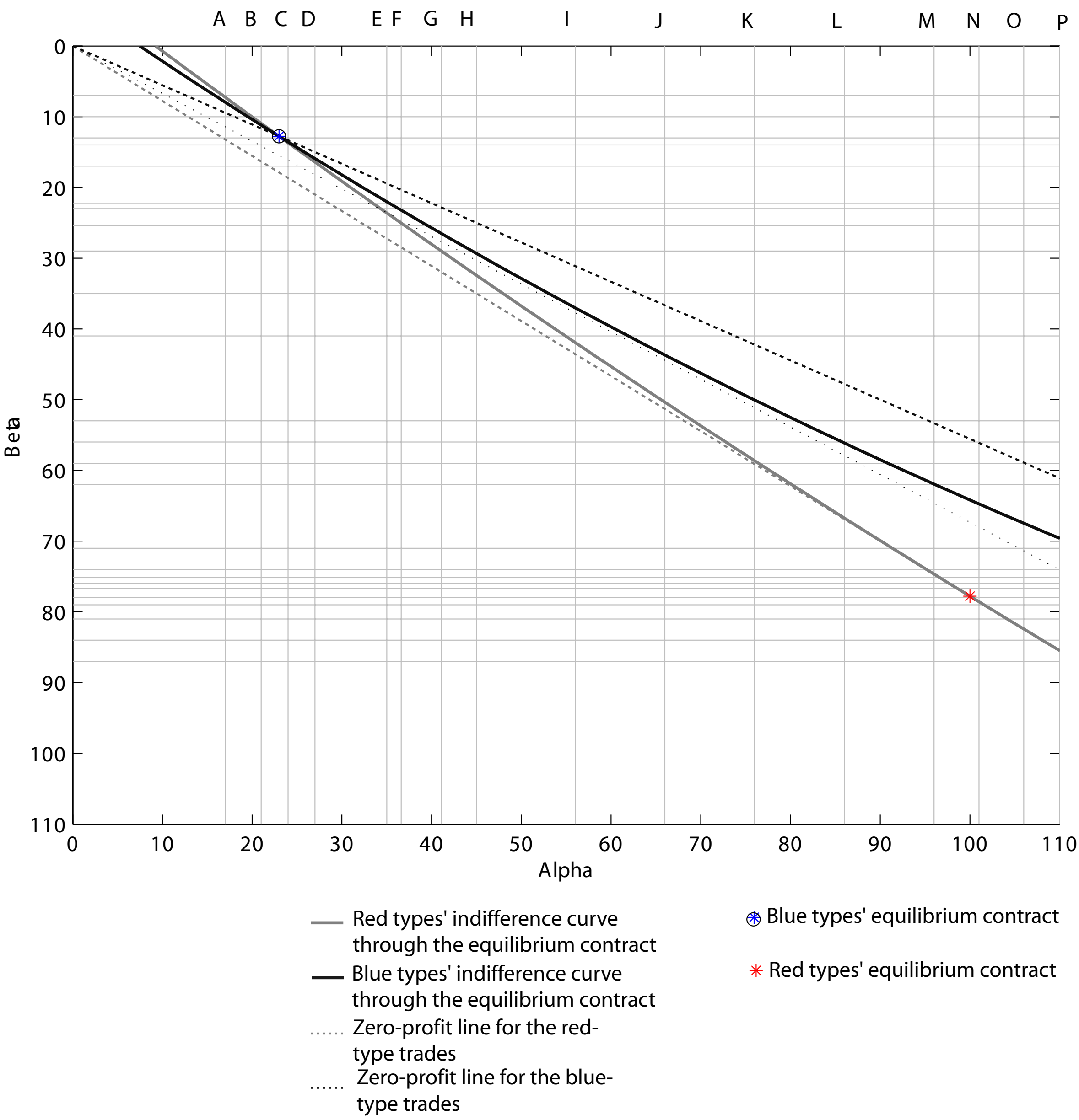


Figure 1.2: Non-existence Environment: The Discrete Grid of Contracts

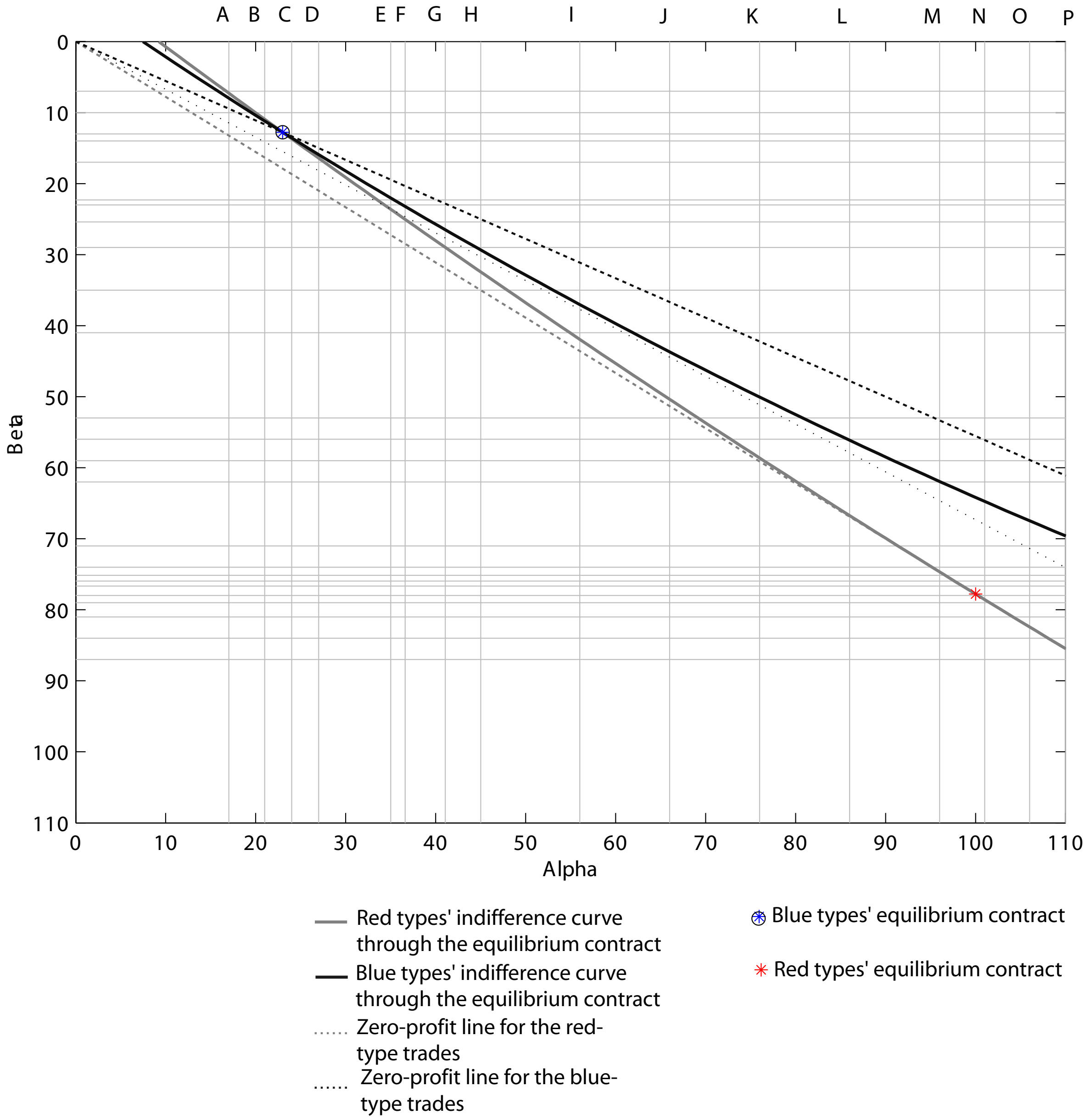


Figure 1.3: Baseline: The Payoff Table for the Blue Buyers

blue	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	47	131	170	199	227	297	377	455	516	568	612	647	661	672	682
2	8	94	134	164	192	265	347	428	492	547	593	631	646	659	670
3	-32	55	97	127	156	231	316	400	467	524	573	613	630	644	657
4	-74	15	58	89	119	196	284	370	440	500	552	594	612	628	642
5	-89	2	45	76	106	184	273	360	431	492	544	588	606	623	637
6	-133	-40	4	36	67	147	238	329	402	466	521	567	587	604	620
7	-225	-128	-82	-48	-15	68	165	262	340	409	470	521	544	564	582
8	-323	-222	-174	-138	-104	-16	87	189	272	347	413	470	495	518	538
9	-427	-322	-271	-234	-198	-106	2	110	199	279	350	412	440	466	489
10	-536	-427	-374	-336	-298	-201	-88	26	120	205	282	349	380	408	434
11	-773	-655	-598	-556	-515	-410	-286	-161	-56	40	127	206	241	275	306
12	-835	-715	-657	-615	-573	-466	-339	-211	-103	-5	85	166	203	238	271
13	-900	-777	-718	-675	-632	-523	-394	-262	-152	-51	42	125	164	200	234
14	-1032	-906	-844	-800	-755	-642	-507	-370	-254	-148	-50	39	80	119	156
15	-1171	-1040	-976	-930	-884	-766	-627	-483	-362	-250	-147	-53	-9	32	72
16	-1242	-1109	-1045	-997	-951	-830	-688	-542	-419	-304	-198	-101	-56	-13	27
17	-1315	-1180	-1114	-1066	-1019	-896	-751	-602	-476	-359	-250	-151	-104	-60	-18
18	-1339	-1203	-1138	-1089	-1042	-919	-773	-623	-496	-377	-268	-168	-121	-76	-34
19	-1364	-1227	-1161	-1113	-1065	-941	-794	-643	-515	-396	-286	-185	-137	-92	-49
20	-1414	-1276	-1209	-1160	-1112	-986	-838	-685	-555	-434	-322	-219	-171	-125	-81
21	-1490	-1350	-1282	-1232	-1183	-1056	-904	-748	-616	-492	-378	-272	-222	-175	-130
22	-1568	-1425	-1356	-1306	-1256	-1126	-972	-814	-678	-552	-435	-326	-276	-227	-180
23	-1727	-1581	-1509	-1457	-1405	-1272	-1113	-948	-807	-676	-553	-439	-386	-335	-285

Figure 1.4: Baseline: The Payoff Table for the Red Buyers

red	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	41	99	127	147	166	216	272	326	369	406	436	461	470	479	485
2	17	76	105	125	145	196	254	310	355	394	426	452	463	472	480
3	-9	53	82	103	123	176	235	294	341	381	415	443	455	465	474
4	-35	28	58	80	101	155	216	277	325	368	404	434	446	457	467
5	-43	20	50	72	93	147	210	271	320	363	400	430	443	455	464
6	-70	-6	25	48	70	125	190	253	304	349	387	420	433	446	456
7	-126	-59	-26	-3	20	79	147	214	269	318	360	396	412	426	439
8	-185	-114	-81	-56	-32	30	102	173	232	284	330	370	387	403	418
9	-247	-173	-138	-112	-87	-22	53	129	191	247	297	341	360	378	394
10	-311	-235	-198	-171	-144	-77	2	82	148	208	261	308	330	350	368
11	-449	-367	-327	-298	-269	-195	-109	-21	53	120	181	236	261	284	306
12	-485	-401	-361	-331	-302	-227	-138	-48	27	96	159	216	242	266	289
13	-522	-437	-395	-365	-335	-259	-168	-76	1	72	136	195	222	247	271
14	-599	-510	-467	-436	-405	-325	-231	-135	-54	21	89	151	180	207	233
15	-678	-586	-542	-509	-477	-394	-297	-196	-112	-33	39	105	135	164	192
16	-718	-625	-580	-547	-514	-430	-331	-228	-142	-61	13	80	112	142	170
17	-759	-665	-619	-585	-552	-467	-365	-261	-172	-90	-14	55	88	119	148
18	-773	-678	-632	-598	-565	-479	-377	-272	-183	-100	-23	47	80	111	141
19	-787	-692	-645	-611	-578	-491	-389	-283	-193	-110	-33	38	71	103	133
20	-816	-719	-672	-638	-604	-516	-412	-305	-214	-130	-51	21	55	87	117
21	-859	-760	-713	-678	-643	-554	-449	-339	-247	-160	-80	-6	29	62	93
22	-902	-803	-754	-719	-684	-593	-486	-374	-280	-191	-109	-33	2	36	69
23	-992	-889	-839	-803	-767	-673	-562	-446	-348	-256	-170	-90	-53	-17	17

Figure 1.5: Baseline: The Payoff Table for the Sellers

	A		B		C		D		E		F		G		H		I		J		K		L		M		N		O	
1	-22 (41)	-4 (47)	-84 (99)	-49 (131)	-116 (127)	-71 (170)	-139 (147)	-88 (199)	-162 (166)	-104 (227)	-224 (216)	-149 (297)	-302 (272)	-204 (377)	-388 (326)	-266 (455)	-466 (369)	-321 (516)	-543 (406)	-377 (568)	-621 (436)	-432 (612)	-699 (461)	-488 (647)	-738 (470)	-516 (661)	-777 (479)	-543 (672)	-816 (485)	-571 (682)
2	8 (17)	26 (8)	-54 (76)	-19 (94)	-86 (105)	-41 (134)	-109 (125)	-58 (164)	-132 (145)	-74 (192)	-194 (196)	-119 (265)	-272 (254)	-174 (347)	-358 (310)	-236 (428)	-436 (355)	-291 (492)	-513 (394)	-347 (547)	-591 (426)	-402 (593)	-669 (452)	-458 (631)	-708 (463)	-486 (646)	-747 (472)	-513 (659)	-786 (480)	-541 (670)
3	38 (-9)	56 (-32)	-24 (53)	11 (55)	-56 (82)	-11 (97)	-79 (103)	-28 (127)	-102 (123)	-44 (156)	-164 (176)	-89 (231)	-242 (235)	-144 (316)	-328 (294)	-206 (400)	-406 (341)	-261 (467)	-483 (381)	-317 (524)	-561 (415)	-372 (573)	-639 (443)	-428 (613)	-678 (455)	-456 (630)	-717 (465)	-483 (644)	-756 (474)	-511 (657)
4	68 (-35)	86 (-74)	6 (28)	41 (15)	-26 (58)	19 (58)	-49 (80)	2 (89)	-72 (101)	-14 (119)	-134 (155)	-59 (196)	-212 (216)	-114 (284)	-298 (277)	-176 (370)	-376 (325)	-231 (440)	-453 (368)	-287 (500)	-531 (404)	-342 (552)	-609 (434)	-398 (594)	-648 (446)	-426 (612)	-687 (457)	-453 (628)	-726 (467)	-481 (642)
5	78 (-43)	96 (-89)	16 (20)	51 (2)	-16 (50)	29 (45)	-39 (72)	12 (76)	-62 (93)	-4 (106)	-124 (147)	-49 (184)	-202 (210)	-104 (273)	-288 (271)	-166 (360)	-366 (320)	-221 (431)	-443 (363)	-277 (492)	-521 (400)	-332 (544)	-599 (430)	-388 (588)	-638 (443)	-416 (606)	-677 (455)	-443 (623)	-716 (464)	-471 (637)
6	108 (-70)	126 (-133)	46 (-6)	81 (-40)	14 (25)	59 (4)	-9 (48)	42 (36)	-32 (70)	26 (67)	-94 (125)	-19 (147)	-172 (190)	-74 (238)	-258 (253)	-136 (329)	-336 (304)	-191 (402)	-413 (349)	-247 (466)	-491 (387)	-302 (521)	-569 (420)	-358 (567)	-608 (433)	-386 (587)	-647 (446)	-413 (604)	-686 (456)	-441 (620)
7	168 (-126)	186 (-225)	106 (-59)	141 (-128)	74 (-26)	119 (-82)	51 (-3)	102 (-48)	28 (-20)	86 (-15)	-34 (79)	41 (68)	-112 (147)	-14 (165)	-198 (214)	-76 (262)	-276 (269)	-131 (340)	-353 (318)	-187 (409)	-431 (360)	-242 (470)	-509 (396)	-298 (521)	-548 (412)	-326 (544)	-587 (426)	-353 (564)	-626 (439)	-381 (582)
8	228 (-185)	246 (-323)	166 (-114)	201 (-222)	134 (-81)	179 (-174)	111 (-56)	162 (-138)	88 (-32)	146 (-104)	26 (30)	101 (-16)	-52 (102)	46 (87)	-138 (173)	-16 (189)	-216 (232)	-71 (272)	-293 (284)	-127 (347)	-371 (330)	-182 (413)	-449 (370)	-238 (470)	-488 (387)	-266 (495)	-527 (403)	-293 (518)	-566 (418)	-321 (538)
9	288 (-247)	306 (-427)	226 (-173)	261 (-322)	194 (-138)	239 (-271)	171 (-112)	222 (-234)	148 (-87)	206 (-198)	86 (-22)	161 (-106)	8 (53)	106 (2)	-78 (129)	44 (110)	-156 (191)	-11 (199)	-233 (247)	-67 (279)	-311 (297)	-122 (350)	-389 (341)	-178 (412)	-428 (360)	-206 (440)	-467 (378)	-233 (466)	-506 (394)	-261 (489)
10	348 (-311)	366 (-536)	286 (-235)	321 (-427)	254 (-198)	299 (-374)	231 (-171)	282 (-336)	208 (-144)	266 (-298)	146 (-77)	221 (-201)	68 (2)	166 (-88)	-18 (82)	104 (26)	-96 (148)	49 (120)	-173 (208)	-7 (205)	-251 (261)	-62 (282)	-329 (308)	-118 (349)	-368 (330)	-146 (380)	-407 (350)	-173 (408)	-446 (368)	-201 (434)
11	468 (-449)	486 (-773)	406 (-367)	441 (-655)	374 (-327)	419 (-598)	351 (-298)	402 (-556)	328 (-269)	386 (-515)	266 (-195)	341 (-410)	188 (-109)	286 (-286)	102 (-21)	224 (-161)	24 (53)	169 (-56)	-53 (120)	113 (40)	-131 (181)	58 (127)	-209 (236)	2 (206)	-248 (261)	-26 (241)	-287 (284)	-53 (275)	-326 (306)	-81 (306)
12	498 (-485)	516 (-835)	436 (-401)	471 (-715)	404 (-361)	449 (-657)	381 (-331)	432 (-615)	358 (-302)	416 (-573)	296 (-227)	371 (-466)	218 (-138)	316 (-339)	132 (-48)	254 (-211)	54 (27)	199 (-103)	-23 (96)	143 (-5)	-101 (159)	88 (85)	-179 (216)	32 (166)	-218 (242)	4 (203)	-257 (266)	-23 (238)	-296 (289)	-51 (271)
13	528 (-522)	546 (-900)	466 (-437)	501 (-777)	434 (-395)	479 (-718)	411 (-365)	462 (-675)	388 (-335)	446 (-632)	326 (-259)	401 (-523)	248 (-168)	346 (-394)	162 (-76)	284 (-262)	84 (1)	229 (-152)	7 (72)	173 (-51)	-71 (136)	118 (42)	-149 (195)	62 (125)	-188 (222)	34 (164)	-227 (247)	7 (200)	-266 (271)	-21 (234)
14	588 (-599)	606 (-1032)	526 (-510)	561 (-906)	494 (-467)	539 (-844)	471 (-436)	522 (-800)	448 (-405)	506 (-755)	386 (-325)	461 (-642)	308 (-231)	406 (-507)	222 (-135)	344 (-370)	144 (-54)	289 (-254)	67 (21)	233 (-148)	-11 (89)	178 (-50)	-89 (151)	122 (39)	-128 (180)	94 (80)	-167 (207)	67 (119)	-206 (233)	39 (156)
15	648 (-678)	666 (-1171)	586 (-586)	621 (-1040)	554 (-542)	599 (-976)	531 (-509)	582 (-930)	508 (-477)	566 (-884)	446 (-394)	521 (-766)	368 (-297)	466 (-627)	282 (-196)	404 (-483)	204 (-112)	349 (-362)	127 (-33)	293 (-250)	49 (39)	238 (-147)	-29 (105)	182 (-53)	-68 (135)	154 (-9)	-107 (164)	127 (32)	-146 (192)	99 (72)
16	678 (-718)	696 (-1242)	616 (-625)	651 (-1109)	584 (-580)	629 (-1045)	561 (-547)	612 (-997)	538 (-514)	596 (-951)	476 (-430)	551 (-830)	398 (-331)	496 (-688)	312 (-228)	434 (-542)	234 (-142)	379 (-419)	157 (-61)	323 (-304)	79 (13)	268 (-198)	1 (80)	212 (-101)	-38 (112)	184 (-56)	-77 (142)	157 (-13)	-116 (170)	129 (27)
17	708 (-759)	726 (-1315)	646 (-665)	681 (-1180)	614 (-619)	659 (-1114)	591 (-585)	642 (-1066)	568 (-552)	626 (-1019)	506 (-467)	581 (-896)	428 (-365)	526 (-751)	342 (-261)	464 (-602)	264 (-172)	409 (-476)	187 (-90)	353 (-359)	109 (-14)	298 (-250)	31 (55)	242 (-151)	-8 (88)	214 (-104)	-47 (119)	187 (-60)	-86 (148)	159 (-18)
18	718 (-773)	736 (-1339)	656 (-678)	691 (-1203)	624 (-632)	669 (-1138)	601 (-598)	652 (-1089)	578 (-565)	636 (-1042)	516 (-479)	591 (-919)	438 (-377)	536 (-773)	352 (-272)	474 (-623)	274 (-183)	419 (-496)	197 (-100)	363 (-377)	119 (-23)	308 (-268)	41 (47)	252 (-168)	2 (80)	224 (-121)	-37 (111)	197 (-76)	-76 (141)	169 (-34)
19	728 (-787)	746 (-1364)	666 (-692)	701 (-1227)	634 (-645)	679 (-1161)	611 (-611)	662 (-1113)	588 (-578)	646 (-1065)	526 (-491)	601 (-941)	448 (-389)	546 (-794)	362 (-283)	484 (-643)	284 (-193)	429 (-515)	207 (-110)	373 (-396)	129 (-33)	318 (-286)	51 (38)	262 (-185)	12 (71)	234 (-137)	-27 (103)	207 (-92)	-66 (133)	179 (-49)
20	748 (-816)	766 (-1414)	686 (-719)	721 (-1276)	654 (-672)	699 (-1209)	631 (-638)	682 (-1160)	608 (-604)	666 (-1112)	546 (-516)	621 (-986)	468 (-412)	566 (-838)	382 (-305)	504 (-685)	304 (-214)	449 (-555)	227 (-130)	393 (-434)	149 (-51)	338 (-322)	71 (21)	282 (-219)	32 (55)	254 (-171)	-7 (87)	227 (-125)	-46 (117)	199 (-81)
21	778 (-859)	796 (-1490)	716 (-760)	751 (-1350)	684 (-713)	729 (-1282)	661 (-678)	712 (-1232)	638 (-643)	696 (-1183)	576 (-554)	651 (-1056)	498 (-449)	596 (-904)	412 (-339)	534 (-748)	334 (-247)	479 (-616)	257 (-160)	423 (-492)	179 (-80)	368 (-378)	101 (-6)	312 (-272)	62 (29)	284 (-222)	23 (62)	257 (-175)	-16 (93)	229 (-130)
22	808 (-902)	826 (-1568)	746 (-803)	781 (-1425)	714 (-754)	759 (-1356)	691 (-719)	742 (-1306)	668 (-684)	726 (-1256)	606 (-593)	681 (-1126)	528 (-486)	626 (-972)	442 (-374)	564 (-814)	364 (-280)	509 (-678)	287 (-191)	453 (-552)	209 (-109)	398 (-435)	131 (-33)	342 (-326)	92 (2)	314 (-276)	53 (36)	287 (-227)	14 (69)	259 (-180)
23	868 (-992)	886 (-1727)	806 (-889)	841 (-1581)	774 (-839)	819 (-1509)	751 (-803)	802 (-1457)	728 (-767)	786 (-1405)	666 (-673)	741 (-1272)	588 (-562)	686 (-1113)	502 (-446)	624 (-948)	424 (-348)	569 (-807)	347 (-256)	513 (-676)	269 (-170)	458 (-553)	191 (-90)	402 (-439)	152 (-53)	374 (-386)	113 (-17)	347 (-335)	74 (17)	319 (-285)

Figure 1.6: Baseline: The Trading Table

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1																1
2																2
3																3
4																4
5																5
6																6
7																7
8																8
9																9
10																10
11																11
12																12
13																13
14																14
15																15
16																16
17																17
18																18
19																19
20																20
21																21
22																22
23																23
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	

Figure 1.7: Baseline Environment: The distribution of trades for all periods

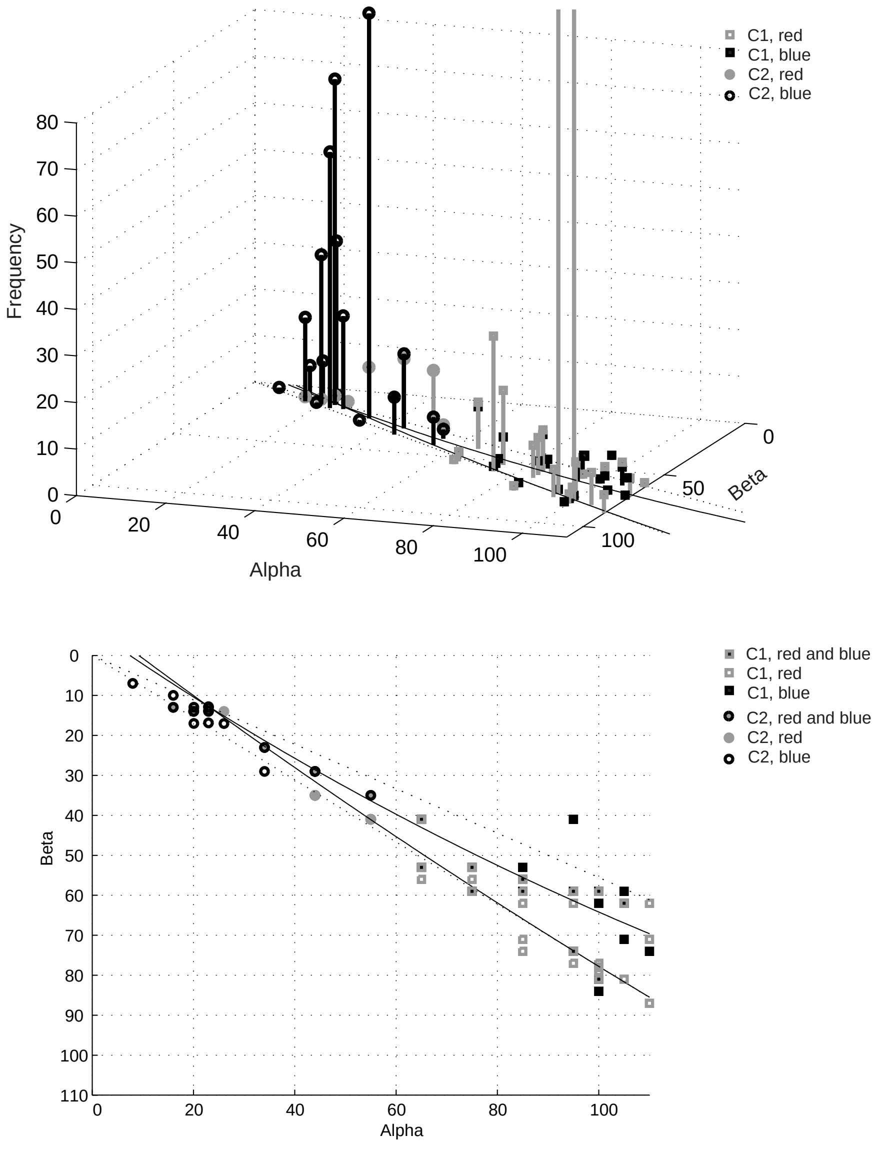


Figure 1.8: Baseline Environment: The distribution of trades for the last three periods

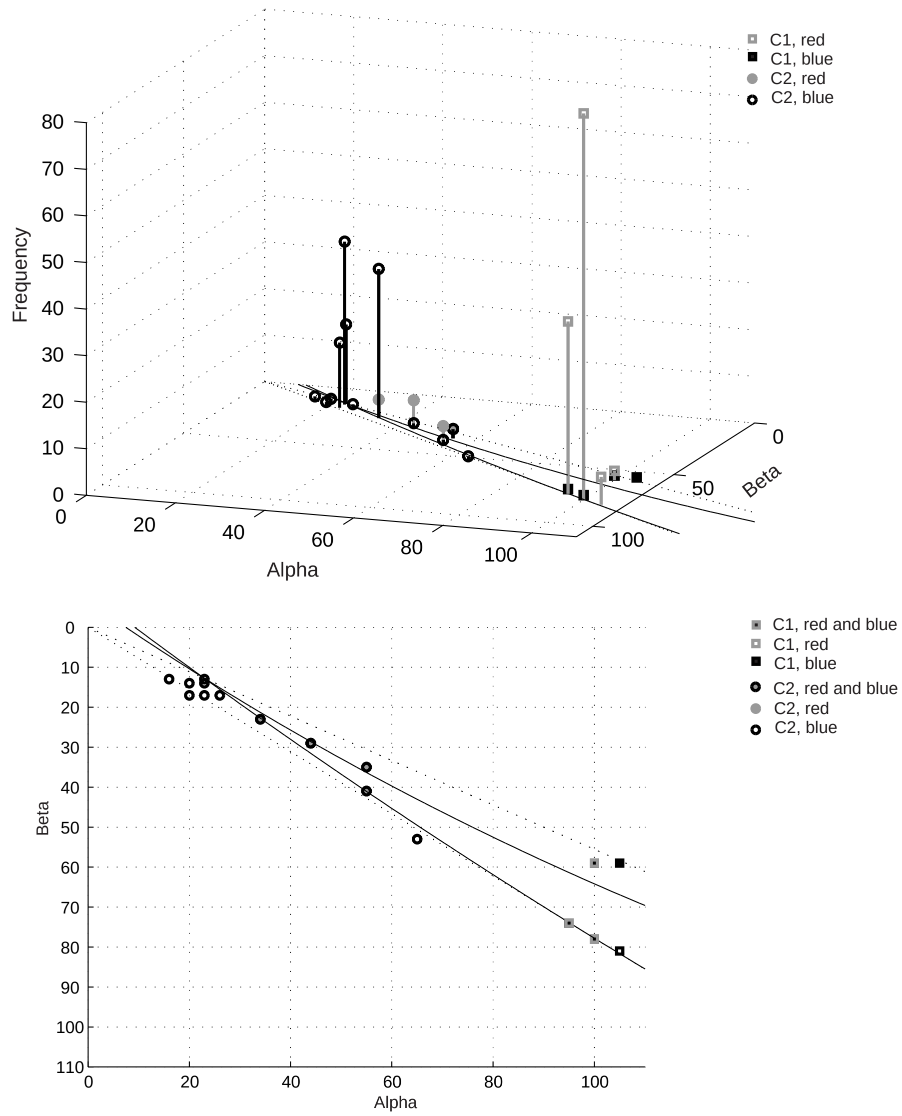
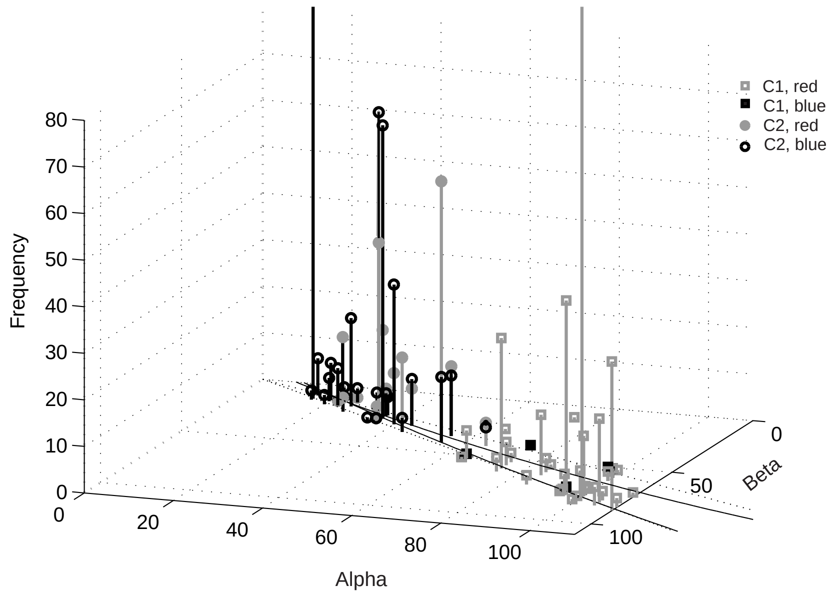


Figure 1.9: Non-existence Environment: The distribution of trades for all periods



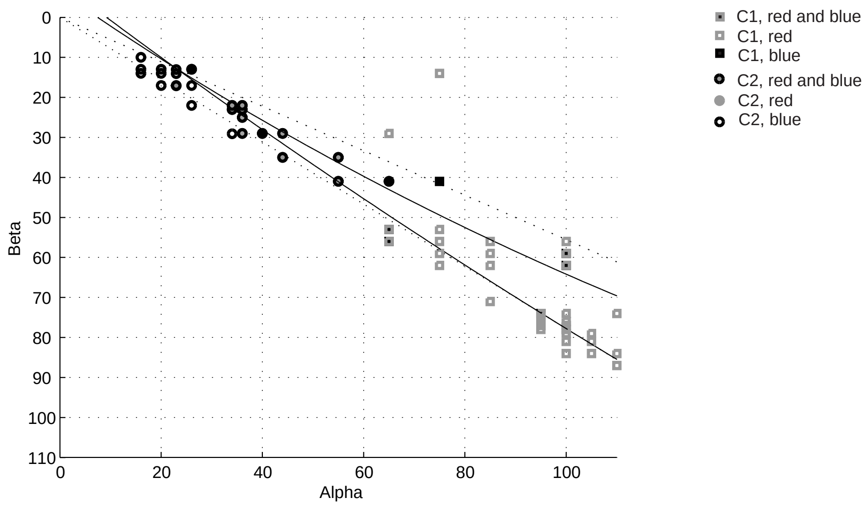
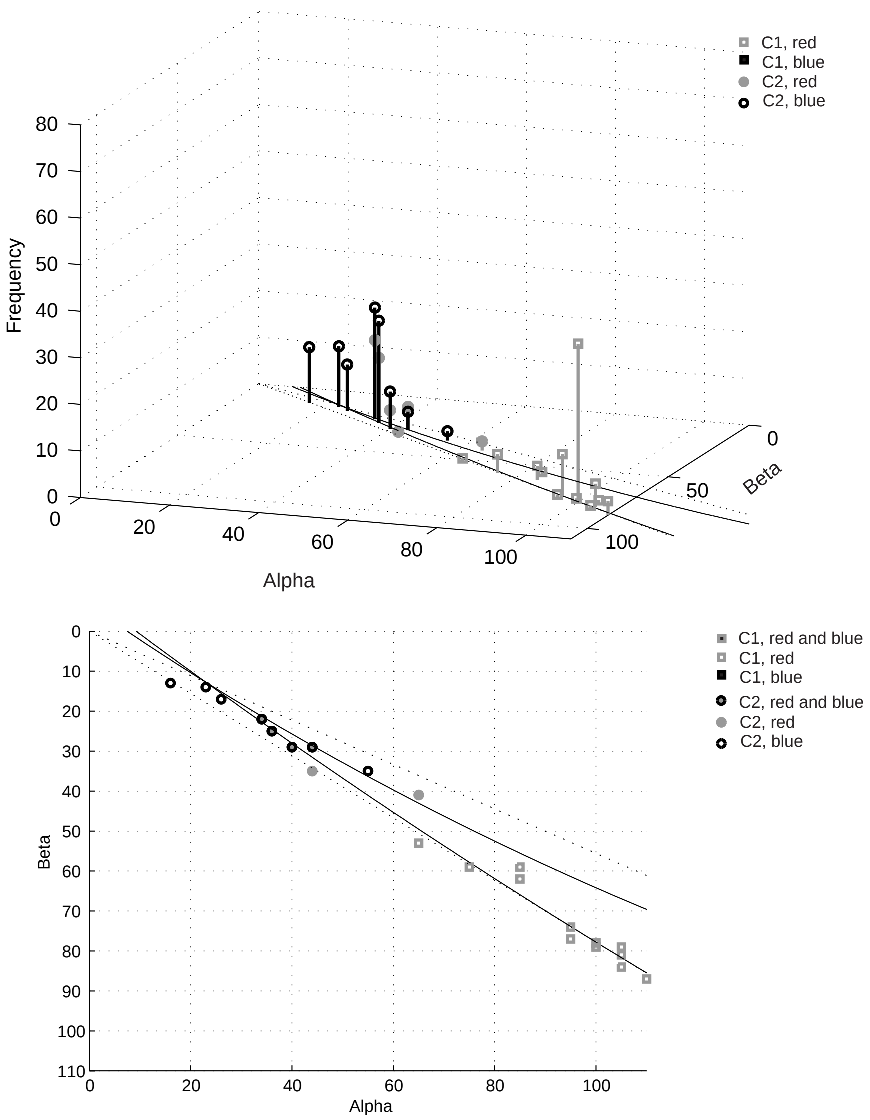


Figure 1.10: Non-existence Environment: The distribution of trades for the last three periods



INSTRUCTIONS

I.MARKET SETUP AND HOW TO MAKE MONEY

There are fifteen markets in this experiment. All fifteen markets involve securities referred to as A, B, C, D, E, F, G, H, I, J, K, L, M, N, and O.

The markets are going to be conducted in 10 to 15 periods. Periods will last 2-5 minutes each. You will be told before each period how long this period will be. We will have one practice period before starting the actual ones. The payoff from the practice period WILL NOT be added to your total payoff for the experiment. In each period all fifteen markets are operating. The currency that is used in all markets is called "francs".

Your actions in a given period influence your payoff for that period ONLY. After a period is finished you realize your payoff and a new period is initiated. Your total earnings in the end of the experiment are the sum of your earnings across periods. You can check your earnings at any time by clicking on the link HISTORY on the trading screen.

The participants in the market are divided into two groups: sellers and buyers. Whether you are going to be a seller or a buyer is going to be determined in the beginning of the experiment and it WILL NOT change until the end of it. You can find out whether you are a buyer or a seller by clicking on the "Participate in the Sale" link. The information is in the upper left corner of the screen. The description of the role of each participant in the market follows (we are going to refer to any buyer as "he", and to any seller as "she"):

-BUYERS: There are two types of buyers referred to as RED type and BLUE type. In each period there are 9 RED buyers and 8 BLUE buyers, and these numbers do not change across periods. Every buyer will be able to see his type on the announcement board in the bottom of the screen. Please, DO NOT hit the reload button at any time otherwise you will lose important information on the message board.

Buyers can only BUY securities. Each buyer is allowed to buy AT MOST ONE security per period. (Note: it is not one security from each market—it is ONE security overall!)

A payoff table determines the payoff. There are two different payoff tables, one for the RED type buyers, and one for the BLUE type. You can see links to them on the top of the screen when you click on the “Participate in the Sale” link. You are also given hard copies of those tables. The payoff of each buyer depends on the security bought AND on the price paid, and it is possible to have negative payoffs. If by the end of a period a buyer has not obtained a security he automatically receives a default payoff equal to 12 francs independently of the type. The total payoff from the experiment for a given buyer is the sum of the payoffs from all periods during the experiment.

A payoff table determines the payoff. There are two different payoff tables, one for the RED type buyers, and one for the BLUE type. You can see links to them on the top of the screen when you open the “Participate in the Sale” page. You are also given hard copies of those tables. Each buyer is given both tables. Tables have columns A, B, C, ... , O, denoting the names of the securities, and rows 1, 2, 3, ... , 23, denoting the possible prices of those securities. If a buyer is RED type for a given period the RED-type payoff table is to be used in that period. Similarly if you are a BLUE type buyer, the BLUE-type payoff table is to be used in this period. The payoff of each buyer depends on the security bought (column) AND on the price paid (row), and it is possible to have negative payoffs. If by the end of a period a buyer has not obtained a security he automatically receives a default payoff equal to 12 francs independently of the type. The total payoff from the experiment for a given buyer is the sum of the payoffs from all periods during the experiment.

At the end of the experiment, each franc will be converted to dollars. The conversion rate is going to be announced privately to each buyer in the beginning of the experiment. You will be able to find it on the message board in the bottom of your screen. Below are parts of the tables presented to the buyers. [Tables Here]

For example, if you are a RED type of buyer and you choose to buy security C at price 5, your payoff for the period is going to be 50 francs. If you are a BLUE type of buyer and you choose to buy C at price 5, your payoff is going to be 45 francs. As can be seen from the tables, you can have negative payoff if you trade certain securities at certain prices depending on your type.

-SELLERS: Sellers can offer securities to the buyers. Sellers are allowed to offer and sell as many securities as they want. The sellers only know that each period there are 9 RED and 8 BLUE types of buyers in the market. They do not know which of the buyers are RED and which are BLUE.

If a seller does not participate in any transaction during a given period her payoff for that period is 0 francs. However, a seller can increase or possibly decrease her payoff by participating in a transaction.

The payoff from each transaction is determined from a payoff table. The payoff depends on which security was sold, at what price, as well as on the TYPE of the buyer to whom it was sold. At the time the seller makes her offer(s), she does not know what type of buyer(s) will accept her offer(s).

In addition to the payoff from the table, there are 15 francs commission that a seller gets from her FIRST contract sold, i.e., if you are a seller, and you sell 2 contracts with payoffs of 10 and 20 francs, 15 francs are added to the first one and thus your total payoff becomes 45 (10+15+10) francs. Below is a part of the table presented to the sellers: [Table Here]

The columns of the table A, B, C, ..., O denote the names of the securities, while the rows 1, 2 ,3 ..., 23 denote the possible prices for those securities. Each cell of the sellers' payoff table consists of four entries. The payoff from transactions with buyers of type BLUE is in bold BLUE. The payoff from transactions with buyers of type RED is in bold RED. The payoffs of the buyers are given in parenthesis below the corresponding seller's payoff (in red for the RED buyers and blue for the BLUE buyers).

Thus, if you are a seller and you offer, say, 1 unit of C at price 5, your payoff would depend on what type of buyer (if any) is going to buy this unit. If it is bought by a RED buyer, your payoff from the transaction is -16 francs. The buyer's payoff is 50 (given in red in parenthesis). If a BLUE type of buyer buys your unit, your payoff from the transaction is 29 francs. The blue buyer's payoff is 45 francs. You will not know the types of the buyers who participated in transactions with you until the end of the period. Only after the end of the period, the types of the buyers will be revealed and payoffs will be realized.

The total payoff (in francs) from the experiment for a given seller is the sum of the payoffs from all periods during the experiment.

At the end of the experiment your total payoff will be converted to dollars at an exchange rate that is going to be privately announced in the beginning of the experiment. You will be able to find it on the message board in the bottom of your screen.

IMPORTANT!!! Anybody (buyer or seller) who has negative total earnings for more than two periods in a row will be excluded from further trading and will receive nothing at the end of the experiment.

II. GLOSSARY OF IMPORTANT MARKET ELEMENTS

OFFERS:

Buyers and sellers, open the "Participate in the Sale" web page.

SELLERS:

Each cell on the trading screen has four entries: a/b c/d (all equal to zero in the beginning of each period).

"a" is the number of units you sold at this market and price

"b" is the number of units sold by all sellers in this market and price

"c" is number of units currently offered by you in this market and price

"d" is the total number of units currently offered by all sellers in this market at that price.

If you are a seller and you submit a SELL OFFER for a given security at a given price, this means that you are willing to sell the security to anyone at that price. If no one accepts the offer (how offers are accepted is explained later in the text) it goes unfilled. Your unfilled offer remain on the trading screen until it is cancelled by you, is taken by a buyer, or the period is over.

If you are a seller, you may place sell offers for any number of units. The computer will automatically fill orders if possible. If you want to place an order, you have to click (in order to highlight it) on the cell indicating the market and the price you want to submit order at, and then click on the “submit offer” button. Each click on the “submit offer” button adds one more unit to the ones that are already offered at the market and the price indicated by the highlighted cell.

If you want to cancel a still unfilled offer, you have to click on the cell where you placed the offer and then click on the “Cancel Offer” button. Each click cancels one of your outstanding offers.

BUYERS:

Each cell on the trading screen consists of two numbers a/b (both equal to zero in the beginning of each period). “a” is the number of units bought by all buyers in this market and price, while “b” is the number of units currently offered in this market and price.

If you are a buyer, you will only be allowed to submit orders at those markets and prices for which there are already offers from the sellers (i.e., you can click on cells with posted offers only). If you attempt to submit a buy order for which there is no counter sell order, your order will be automatically cancelled and no one will see that you placed such an order. You are allowed to accept at most one buy order per period. When you decide which of the offers to accept, you have to click on that offer to highlight it and then hit the ”submit order” button. When the order is processed successfully, the market and the price cell is highlighted in red. You will not be able to cancel a once submitted order.

If there is more than one seller who offered a security at a given price, whenever a buy offer comes, one of the sellers is going to be chosen randomly and her security will be the one sold to the buyer. NOTICE: orders are not executed chronologically. A seller is chosen randomly each time there is more that one seller offering a given security at a given price. Thus, submitting many orders does not improve your chances of being chosen as long as you have at least one outstanding order.

Are there any questions?

Chapter 2

Dynamics in Markets with Adverse Selection

2.1 Introduction

This paper uses experiments to explore the dynamics of contract offers and acceptances in competitive markets with asymmetric information. The experiments are designed around the prototype of such markets, namely, Rothschild and Stiglitz' [1977] (RS) insurance markets. RS originally proposed a plausible notion of competitive equilibrium, which however opened up the possibility of nonexistence of equilibrium and, even if it exists, sub-optimality. Subsequent theoretical work[1] advanced other notions of equilibrium, based on different principles of equilibration, and restored generic equilibrium existence, if not optimality. It is an open question, however, what principles are at work in actual market dynamics. This is ultimately an empirical question, which this paper attempts to address. The different notions of equilibrium all have their own logic and some may be more persuasive theoretically than others, but it is ultimately the data that should determine which is more relevant.

In cases where the RS equilibrium exist, Asparouhova [2003] demonstrated that the RS insurance markets move towards equilibrium contract choices. The experiments in Asparouhova [2003] provide a unique testbed to discriminate between the key

[1] Only a short list of which is comprised by the papers of Wilson [1977], Miyazaki [1977], Spence [1978], Riley [1979], and the more recent ones by Dubey and Geanakoplos [2002] and A.B. Ania at al. [2002].

principles about equilibration dynamics that have been proposed in the literature to address the problem of equilibrium non-existence. These are: (i)insurers only consider offering contracts that are close to those already available in the marketplace;[2] (ii) pooling contracts are expected to be taken disproportionately by agents who have more to gain. In the original RS equilibrium, insurers expect different insuree types to take pooling contracts in the population proportion, and they consider offering any contract, not only "local" ones

It would be inappropriate to study these principles in a situation of nonexistence of RS equilibrium: while competing notions of equilibrium do make precise predictions about outcomes in such situations, it is not clear what should happen if the principles behind the RS equilibrium are correct. Observing that none of the competing equilibria come about, it would be presumptuous to conclude that therefore the RS principles are the correct ones. In cases where the RS equilibrium does exist (as in the experiments of Asparouhova [2003]), the eventual outcomes are the same under all notions of equilibrium; only the paths towards equilibrium differ substantially. Since equilibrium has been demonstrated to eventually obtain, these experiments provide a non-controversial setting in which to study dynamics of contract offerings.

The experimental setup can be briefly described as follows. A group of subjects[3] can each offer (through an open-book system) contracts that correspond to the RS insurance contracts. Subjects from another group can each accept any one from those contracts offered in the marketplace. Each participant from this second group has private information about his/her type. The proportion of the two possible types in the population, however, is public information. Each experimental session consists of ten to fifteen periods that are replications of the same situation. Periods are independent. In each period the market opens, and after a pre-announced length of time elapses, it closes. Offers and corresponding acceptances can be submitted at any time during open market. A participant's final earnings are the cumulative

[2]RS themselves advance the notion of *local* equilibrium as "a set of contracts such that there do not exist any contracts in the vicinity of the equilibrium contracts that will be chosen and make a positive profit."

[3]The subjects were undergraduate and graduate students from Caltech, UCLA, and Sofia University in Bulgaria.

earnings from all periods. Subjects earned on average \$35, with a minimum of \$0,[4] and a maximum of \$90 per experimental session lasting approximately two hours. The parameters in the experimental design are chosen so that the RS equilibrium exists. This paper presents the results from six such experiments.

In all experimental sessions, contract choices move towards the RS equilibrium pair of contracts. The process is not instantaneous, it takes time for the markets to discover equilibrium. Throughout this dynamic process, however, only about 10% of the contract recipients accept *dominated* offers: from the set of available offers, they choose ones that do not maximize their monetary payoffs. Undominated acceptances are necessary for testing the aforementioned principles of equilibration.

The conjecture that pooling contracts would be taken disproportionately by agents who have more to gain is not supported in the data analysis. Whenever pooling contracts are offered, they are taken by any of the two types agents in their proportion in the population independent of the magnitude of the marginal gains from trade. Also, when contract issuers compete in providing contracts, they *do not* always take local steps as suggested by several models (see next section). The hypothesis that they do so is strongly rejected by the data. Thus, this study suggest that the principles outlined in the seminal RS paper are borne out in the data. Different insuree types do take pooling contracts in their population proportions, and insurers do consider offering contracts globally.

The rest of the paper is organized as follows. The next section provides brief literature review along with a few motivational remarks. Section 2.3 goes through the theoretical overview. Section 2.4 explains the experimental setup, while section 2.5 describes the data. The results of the experiments are in section 2.6. Section 2.7 concludes.

[4]A bankruptcy rule is imposed in all experiments. If a participant's cumulative earnings remain negative for two periods in a row, he or she is excluded from further trading. Those with \$0 earnings are the bankrupted participants.

2.2 Brief Literature Review and Motivation

In general, to cope with the non-existence problem of RS equilibrium, other notions of equilibrium have been proposed; among them are the ones presented in Wilson [1977], Miyazaki [1977], Spence [1978], and Riley [1979]. Each adds a degree of sophistication on the beliefs that contract issuers hold: in Wilson's [1977] model it is the anticipation of immediate withdrawal of all unprofitable offers from the market that keeps insurance companies from offering equilibrium-destroying contracts. Miyazaki [1977] and Spence [1978] employ a similar anticipation concept that helps sustain equilibrium when multiple contracts can be offered. Riley's [1979] contract providers anticipate further entries in the market when they decide to offer a new contract. This anticipatory behavior supports the existence of equilibrium here as well. Interestingly, the above modifications of the RS equilibrium concept can be paralleled to the coalition-proofness "modification" used as a solution concept when the core of an economy is empty.

Dubey and Geanakoplos [2002] (DG) study markets with adverse selection characterized by generic existence of equilibrium. DG work in a general equilibrium framework where companies can offer contracts at market prices only. Equilibrium is supported by the self-sustaining beliefs of the agents in the economy. DG justify their using this particular notion of equilibrium by:

> Rothschild and Stiglitz might have argued that instead of thinking of the pools as strategic dummies, we could imagine that they were each run by some entrepreneur. ... We have in mind a competitive world with many small agents. If the little entrepreneur's gambit is to be successful, he must lure new reliable[5] households at κ^*, who were unwilling to contribute at κ_J. But it is the unreliable, already willing to contribute at κ_J, who will be even more eager to contribute at κ^*, and likely to get to him first. If so, his meagre wealth will certainly not be enough to stand guarantee for his exorbitant offer of κ^*, and he will suffer a disaster.

DG bring forward questions that may turn crucial for understanding the workings

[5] DG have reliable and unreliable households instead of high-risk and low-risk types of agents.

of markets with asymmetric information. When a contract is beneficial to several recipients, is it the case that the recipients with the highest gains from trade react among the first and take those contracts. The latter can be a problem, as pointed out by DG, if contract providers are wealth constrained and the first acceptances incur losses that exceed their wealth. Alternatively, imagine that pooling contracts (whose profits are conditional upon the two types accepting them in their population proportion) are not offered in quantities sufficient to cover the entire demand. In this case the high-risk types' swift reaction would result in ex-post aggregate acceptances of pooling contracts that do not reflect the two types' proportion in the population. Contract providers will find themselves not meeting their profit expectations if not incurring losses. In either case providers would eventually learn not to offer such contracts.

These questions are irrelevant in the original Rothschild-Stiglitz model. RS' contract providers are endowed with infinite wealth. They "specialize" in offering a single type of contract and are obliged to supply the entire market (populated with continuum of recipients) with it. Those conditions guarantee that if a pooling contract is offered (and the recipients are assumed rational), it would be taken by any of the types in their population proportion independent of the issuers' beliefs.

However, in reality contract providers are wealth constrained, offer multiple contracts and usually in quantities not sufficient to meet the entire demand for those contracts. This is the also the case in our experiments, thus all of the above questions remain pertinent within the experimental markets.

In order to prevent the indeterminacy of their model, DG introduce a refinement of market participants' beliefs regarding the profitability (rates of delivery of promised returns) of contracts were they to be offered in markets that are inactive in equilibrium.

This refinement touches on the issue of local versus global adjustments. The beliefs (regarding who is going to take it) accompanying each contract at its equilibrium price are required to be confirmed for small price deviations only. By requiring that beliefs regarding unopened markets be confirmed only for local price deviations, DG's study suggests that agents take small steps when competing against each other, around the prices that have already formed.

The issue of local adjustments arises more prominently in the model presented in A.B. Ania at al. [2002] (ATW). ATW provide an evolutionary version of the RS' equilibrium where the dynamics are built on imitation and experimentation.[6] Analogously to DG, ATW obtain the result that if the experimentation is confined to be only local, equilibrium always exists. In their interpretation the manager of an insurance company...

> ... might have an incentive to confine herself to local experiments. She might fear that the performance of a nonlocal experiment can differ too much from that of the contracts previously on the market, such that the failure of such an experiment would be disastrous for her evaluations.

While there is great intuitive and theoretical appeal, the empirical success of the above conjectures is yet to be proven. It is apparent that the existence of equilibrium and contract allocation results of the belief-based models can change dramatically if the assumed beliefs are not upheld. Same is valid about the issue of global vs. local adjustments that is studied here. Predictions of models of equilibration can differ substantially depending on the assumption they make about agents optimizing locally or globally. The relevance of those principles of dynamics goes well beyond the markets studied here.[7] Both components, beliefs and nature of adjustments, are necessary to determine which is the equilibrium (if any) that prevails in markets with adverse selection. Experiments provide an excellent venue for studying those problems and potentially for providing some guidance in the choice of appropriate equilibrium concept.

[6]Note that despite each providing a dynamic story to justify the use of a particular belief formation, all of the before-cited models are static.

[7]The tatonnement based models in the 60s and 70s assume that agents submit globally optimal net trades (for a survey on the topic see [9]), while more recent models like [4] and [5] rely on local optimization.

2.3 Theory Overview and Notation

We study markets for contracts under asymmetric information that takes the form of adverse selection. Although we adhere to contracts that correspond to the RS's insurance contracts, their exact interpretation is irrelevant for this study. The participants in our markets are providers (or issuers), and recipients of contracts. The providers can offer any contracts from an exogenously specified set S. They can also withdraw any of their outstanding contracts from the market. There are two types of potential recipients—high-risk, called H-type, and low-risk, called L-type. Recipients know their types while issuers only know the proportion λ of H types in the population. Each contract in the set S is defined by its four contingent payoffs, namely U^r_H, U^r_L, U^i_H, and U^i_L. U^r_H is the payoff to recipients of the H type, while U^r_L is the payoff to recipients of the L type. U^i_H is the payoff to the issuer when the contract recipient is of the H type. Similarly, U^i_L is issuer's payoff when the recipient is of the L type.[8] When a contract is offered on the market, it can be accepted by a recipient of either type if she finds it in her best interest to do so. Each acceptance is final, recipients cannot cancel their acceptances.

Time is discrete and advances with market activity. Contract offerings, acceptances, and withdrawals are what constitute activities in the market. Providers can offer and withdraw contracts one at a time. Recipients are allowed to accept at most one contract.

Given the nature of available contracts, the issuers have the opportunity to "screen" the potential receivers. This can be done by wisely choosing what contracts to offer, so that each contract lands in the hands of a receiver of a type upon which the issuer has calculated his ex-ante profits.

Rothschild and Stiglitz were the first to show that a competitive equilibrium in markets similar to the one described above might fail to exist.[9] Whenever it exists,

[8] As in RS we restrict those payoffs to be each functions of two parameters (α, β) corresponding to the coverage and the premium of the RS' insurance contracts. Thus $S \subset \mathbb{R}^2$. Moreover the payoffs for the recipients are required to satisfy the discrete single-crossing property (or strict increasing differences).

[9] RS' s model is static in nature. They take S to be isomorphic to $\mathbb{R}^2_+$. The main role of the

the RS equilibrium is comprised of a pair of contracts, each yielding zero profit for the providers and maximizing the recipients' payoffs subject to the incentive constraints.

An important feature that distinguishes the markets here from the original RS' markets is the dynamic setting. Such a setting is necessary to study the principles that take markets to equilibrium, or prevent them from ever reaching one.

The following notation although somewhat cumbersome, is necessary to define the hypotheses informally spelled out in the previous sections.

Definition 2.3.1. $S_M(t)$ is the set of all contracts offered in the marketplace after the activity at time t has taken place.

$S_M(t)$ belongs to the *multiset* of S.[10] If the activity at time t is an offering of a contract, then $S_M(t)$ is equal to $S_M(t-1)$ with the newly offered contract added to it. Similarly, if the activity is a withdrawal or acceptance of a contract, $S_M(t)$ is equal to $S_M(t-1)$ minus the contract withdrawn or accepted at time t.

Definition 2.3.2. $s(t)$ denotes a contract that is offered, accepted or withdrawn at time t; $s(t) \in S$

In the present case the contract space is given by 345 contracts, labelled as follows.

$$S = \begin{bmatrix} A1 & B1 & C1 & \cdots & N1 & O1 \\ A2 & B2 & C2 & \cdots & N2 & O2 \\ A3 & B3 & C3 & \cdots & N3 & O3 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ A23 & B23 & C23 & \cdots & N23 & O23 \end{bmatrix}. \tag{2.1}$$

If a contract, say $C5$, is offered, accepted or withdrawn at some time t, then $s(t) = C5$.

Definition 2.3.3. $U(\cdot)$ is a vector function from S to $\mathbb{R}^4$; $U(\cdot) = (U_H^r(\cdot), U_L^r(\cdot), U_H^i(\cdot), U_L^i(\cdot))$.

contract issuers in their model is to stand ready to offer a contract if a profitable opportunity arises. Thus, the equilibrium consists of a set of contracts s.t. when contract recipients choose contracts to maximize their payoff the following hold: (i) no contract in the equilibrium set makes negative expected profits; and (ii) there is no contract outside the equilibrium set that, if offered, will make a nonnegative profit.

[10]The multiset of the set S is the collection of all subsets of S where repetition of elements of S is also allowed.

For example, in the experimental setup $U(C5) = (50, 45, -16, 29)$.

Definition 2.3.4. $S^*_x(t)$, $x \in \{H, L\}$, is the set of contracts from $S_M(t)$ that give the x-type recipients the highest payoff, i.e. for all $s^* \in S^*_x(t)$, $U^r_x(s^*) = \max_{s \in S_M(t)} U^r_x(s)$.

An acceptance of a contract is called *undominated* if the recipient has chosen a contract that gives her the highest payoff from all the contracts in S_M. In other words, if a contract s is an undominated acceptance at time t by a recipient of type x then it must be the case that $s \in S^*_x(t-1)$. Note that choosing undominated contracts allows for myopia. The condition is weaker than imposing full rationality which would require that recipients optimally choose the timing of the acceptance as well. This minimal degree of rationality is needed to test the principles of equilibration as described in section 2.2. If recipients choose dominated contracts, accept orders at random, or follow some other rule, the theory must be adapted to this behavior accordingly. This motivates the first hypothesis.

Hypothesis 2.3.5. Recipients accept undominated offers.

If recipients accept only undominated offers then one expects the issuers to offer "relevant" contracts as defined below.

Definition 2.3.6. A contract s that is offered at time t is called *relevant* if $s \in S^*_H(t) \cup S^*_L(t)$.

Thus, a contract is *relevant* if it is among the contracts that provide the highest payoffs for at least one of the types. All contracts that are not relevant are called *irrelevant*. It is costless to the issuers to offer irrelevant contracts that provide them high payoffs hoping that recipients will err and take some of them. This is the second hypothesis.

Hypothesis 2.3.7. If some of the acceptances are dominated, issuers will offer contracts that are not relevant in addition to the relevant ones.

Definition 2.3.8. A contract s that is accepted at time t is called a *pooling* contract if $s \in S^*_H(t-1) \cap S^*_L(t-1)$, and $U^i_x(s) \geq \max_{s \in S^*_x(t-1)} U^i_x(s)$, $x \in \{H, L\}$.

The first condition is that a *pooling* contract must provide the highest payoff to both types. The second requires the payoff to the issuer be the highest among marketed contracts that provide payoffs to the recipients equal to their payoffs from the pooling contract. This excludes contracts such as the RS equilibrium one, designed for the L-type recipients and providing the highest payoff to both types, from being qualified as pooling. This is because the H-types are indifferent between the contract designed for them and the one designed for the L types. However, the contract designed for L also provides lower payoff to the issuers compared the the H-contract, when taken by an H-type recipient. Thus, the L-contract satisfies the first condition in the definition but not the second. Exclusion of such contracts in the definition of *pooling* contracts is necessary to avoid biases in the estimation of the relative frequency with which such contracts are taken by the two types of recipients. A *marginal* gain for an x-type recipient from a pooling contract s is equal to the difference between the pooling contract's payoff and the payoff of the contract that was the best available to the x-type before the pooling contract was offered. The next hypothesis can be now stated.

Hypothesis 2.3.9. Whenever pooling contracts are offered they are taken by the type with higher marginal gain in proportion that exceeds this type's proportion in the population.

The above hypothesis reflects the second of the two principles discussed in the previous section. We now turn to addressing the first one. We endow the contract space with the following metric:

Definition 2.3.10. The distance between two contracts s' and s'' in S_M, denoted $d(s', s'')$ is the city-block distance[11] between them in S.

Definition 2.3.11. Given the grid of contracts (2.1), a contract s' is a neighbor of contract s'' if $\max_{i=1,2} |s'_i - s''_i| = 1$.[12]

If $Z \subset S$ is a set of contracts, a contract s is in the neighborhood of Z if there exists a $z \in Z$ s.t. s and z are neighbors.

[11] In $\mathbb{R}^k$, the city-block distance is the Minkowski distance $d(x, y) = \sqrt[r]{\sum_k |x_i - y_i|^r}$, $x, y \in \mathbb{R}^k$ when $r = 1$. In S each contract is presented by its coordinates in the matrix (2.1). For example, the distance between $A1$ and $B4$ is equal to 3.

[12] For example the neighbors of contract $B2$ are contracts $A1$, $A2$, $A3$, $B1$, $B3$, $C1$, $C2$, and $C3$.

We express the idea that when a new contract is introduced, it is always similar to a contract already on the marketplace by the following hypothesis

Hypothesis 2.3.12. Each time a new contract is offered it is in the neighborhood of the contracts already on the marketplace.

We use data from financial market experiments to test the above hypotheses. Our experiments are characterized by a parameterization of the RS model in which the RS equilibrium exists.[13] The following section is devoted to describing the experimental setup and procedures.

2.4 Experimental Markets

A detailed description of the experimental markets can be found in [3]. We use the data from six experiments, conducted at Caltech, UCLA, and Sofia University in the period between May 2001–September 2002. Briefly, the experiments are organized as a sequence of ten to fourteen replications of the same situation. Each such replication is called a period. The number of participants in an experimental session ranges from 13 to 23. In the beginning of each session the participants are divided into two groups—contract providers (called sellers), and contract recipients (called buyers). The contract recipients are then further divided into two types—called "red" type, corresponding to the high-risk type in the model, and "blue" type, corresponding to the low-risk type in the model.[14] Next, instructions describing in detail the markets as well as the rules according to which contract are offered and accepted are read aloud to the participants. The type of a recipient remains private information throughout the experiment.[15] However, the proportion of H-type recipients, λ, is publicly announced. The contract issuers are presented with a set of contracts that they can choose from and offer to the recipients. The recipients can choose only one contract per period

[13]The parameterization is presented in [3].

[14]As usual the terms insurance contracts, high-risk, or low-risk recipients are not mentioned to the participants.

[15]In some of the experiments the type of a given recipient changed from period to period but the proportion of H-types remained the same in all periods.

from the contracts offered on the market. They are allowed to accept a contract at any time during a period. Recipients learn their payoff immediately after a successful acceptance. The issuers learn their payoff from each of their transactions in the end of each period. The contracts are organized in a table as the one presented in Figure 2.1. The contract space is a two-dimensional discrete grid, with the first coordinate denoted by a letter, while the second is a number.[16] Each contract specifies the four payoffs U_H^r, U_L^r, U_H^i, and U_L^i.[17] All payoffs are presented in a notional currency, called francs. For example, the contract $G8$ has $U_H^r = 102$, $U_L^r = 87$, $U_H^i = -52$, and $U_L^i = 46$. In the end of each experiment the earning of each participant are converted to dollars using an exchange rate announced privately to each participant in the beginning of the experiment. In all experiments the proportion of H-type recipients is such that RS equilibrium exist.[18] Three of the experiments are manual, while the other three are computerized.[19] Each experiment starts with a practice period, followed by the actual periods.[20]

[16]The letters are in alphabetical order from A to O, while the numbers are from 1 to 23, for a total of 345 contracts in S.

[17]U_H^i and U_L^i are in bold on the first row of every cell, while the corresponding U_H^r and U_L^r are below them in parentheses. Also, because the recipients need not know the payoffs of the issuers or the other type of recipients, they are presented with a very simplified version of the payoff table with their own payoff in each cell only.

[18]The equilibrium contract designed for the L-type recipients is $D4$, while for the H-type recipient (due to the discretization of the contract space) there are two possible contracts - $L16$ and $M18$ that can emerge in equilibrium.

[19]The experiment instructions are the same in both computerized and manual experiments except in the parts where it is explained how to submit and accept contract offers. In the computerized experiments all communication was realized through the internet. The trading screen was updated automatically after each offer or acceptance. In the manual experiments offers were submitted using open outcry system. All information was recorded on a blackboard and the updating was done manually by one of the experimenters. In all experiments contract providers were allowed to cancel any of their outstanding offers.

[20]Instructions and screens for the computerized experiments can be viewed a http://eeps4.caltech.edu/market-020603. To log on as a viewer use an identification number 1 and a password a.

2.5 Description of the Data

The data collected from each experimental session was in common format:[21] time stamp, action (offer, acceptance, or cancellation), contract name, and contract provider ID. If the action was an acceptance of a contract, the recipient ID, her type, as well as the payoffs to both parties in the transaction were recorded as well. Table 2.1 provides the numbers for each of the three market activities broken by types of experiments (manual vs. computerized). Inspection of the table reveals that computerizing of the experiments dramatically increases the number of the offerings and cancellations.

2.6 Results

In analyzing the data, we abstract from the problem of whether experimental markets reach equilibrium. That they actually do is reported in a companion paper [3].

The minimal rationality requirement on the recipients, namely that they do not choose dominated contracts, is tested first. The results from our experiments show that recipients seldom choose dominated contracts from the set of marketed contracts. Table 2.2 displays the *dominated* acceptances by types. The proportion of dominated acceptances is 0.08 in the manual experiments, 0.21 in the computerized, and 0.16 for the pooled data. If only the second half of each experiment is considered, then the numbers are 0.03, 0.08, and 0.07 respectively. Those findings provide support for Hypothesis 2.3.5. If there are any dominated acceptances they are almost entirely eliminated in the second half of the experiments. Therefore the acceptances in our markets pass the minimal degree of rationality needed for testing the remaining hypotheses.

It is possible that the higher proportion of dominated acceptances in the computerized experiments is caused by the enormous amount of offers that recipients have to process before making a decision on accepting one.[22] Interestingly, once providers

[21] The data files are available from the author upon request

[22] If recipients make more mistakes as the number of offers increases this would prompt issuers to offer even more irrelevant contract to "confuse" the recipients.

discover that recipients make small mistakes they can exploit this by offering irrelevant contracts as posed in Hypothesis 2.3.7. Table 2.3 presents the raw statistics for the offers from the manual and computerized experiments. Approximately only a third of the offers in each of the two sets of experiments are *relevant*. If some of those irrelevant offers were caused by confusion one should expect their proportion to decrease in the second half of the experiments. Those results are reported in Table 2.4. The proportion of relevant offers does increase in the computerized experiments but decreases in the manual. Thus despite the fact that in all experiments conversion to the equilibrium traded contracts is observed, the proportion of irrelevant offers overall does not decrease as the experimental sessions progress. The reasoning that it is costless for the providers to offer irrelevant contracts in hope to get mistaken recipients is one explanation. Another is that offering irrelevant contracts might serve an auxiliary purpose such as attracting the attention of the recipients into certain areas of contracts. Other possible explanations for this finding and/or confirmation of the above ones are left for further investigation.

Next we turn to testing Hypothesis 2.3.9. In our experimental markets we are able to verify what pooling contracts are offered and accepted in the marketplace, and also compute the marginal gains from such contracts for both types.[23] Table 2.5 displays the raw statistics for acceptances of pooling contracts in all six experiments.[24] The Pearson χ^2 test cannot reject the hypothesis that the frequency of H-type acceptances of pooling contracts coincides with λ (the table also shows the different values for λ in the six sessions). In order to test Hypothesis 2.3.9, the marginal gains from trade should be accounted for. We split the sample of pooling acceptances into two groups. The first consists of pooling contract acceptances when the high-risk types have higher marginal gains from taking the contract. In this subsample the Pearson χ^2 test again cannot reject the hypothesis that the frequency of H-type acceptances of pooling contracts coincides with λ. The same result obtains for the second subsample with

[23]Note that marginal gains are hard if not impossible to compute with field data for it requires knowledge of not only what contract was taken but also what the best possible alternative was before this contract was offered.

[24]All pooling contracts are presented in Table **??**.

acceptances for which the low-risk recipients have higher gains from trade.

The latter findings do not provide support for the conjecture that the DG-type beliefs are confirmed when pooling off-equilibrium contracts are actually offered.

Despite providing no empirical evidence for one of the possible beliefs that can keep issuers from offering pooling contracts, we are still faced with the question of whether issuers take only local steps in competing with one another. In other words, do contract providers compete by offering contracts that are "similar" to the ones that are already offered.

To test Hypothesis 2.3.12 we take the set of all offers (in chronological order). For each offer we compute the distance from the newly offered contract to the set of already marketed offers. Then we tabulate the distribution of the newly offered contracts whose distance to the set of marketed contracts is positive. Because neighbors of a given contract can be at distance 1 or 2 from this contract, we assign a value of 1.5 instead of 2 to the diagonal neighbors. The tabulated distributions of distances are presented in Table 2.6. In the upper portion of the table all nonzero distances are tabulated. More than a fifth of all newly introduced contracts are at distance 3 or larger, and at least 15 percent are at distance 4 or larger.

Very often the first couple of contracts introduced in the beginning of each period are somewhat around the two RS equilibrium contracts. Those initial offerings are therefore bound to be very far away from each other. In the bottom of Table 2.6 we present the results with the first three contracts with positive distance from the set of marketed contracts excluded from the sample. More than 15 percent of those offers are contracts that are at distance 3 or larger from the set of already marketed contracts. Hypothesis 2.3.12 is therefore rejected in the data. Thus the claim that agents make only local adjustments is not borne by the data. This suggest that equilibria based on a local adjustment assumption are not likely to be observed when dropping the assumption results in non-existence of equilibrium.

2.7 Conclusions

This paper uses experimental evidence to test several hypotheses about individual behavior in markets with adverse selection. The first main conjecture that is tested is that when pooling contracts are offered they are taken by the type of recipients with higher marginal gains in proportion that exceeds their proportion in the population. The data does not support the above hypothesis. We find that when a pooling contract is offered, it is taken by the two types of recipients in their proportion in the population independent of the gains from trade. The other significant finding is that agents do not take only local steps in introducing new contracts. Approximately a fifth of the time they make non-local moves. With abundance of experimental data the local adjustment hypothesis can be tested in other setting as well. This would provide further guidance in constructing theoretical models of market behavior. In markets with adverse selection, however, agents' behavior has little resemblance to what such local movement theories predict.

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Tables and Figures

Table 2.1: Experimental Market Activity

	Offers	Cancelations	Acceptances	All Activities
manual	1644	4	303	1951
computer	10024	525	561	11110
total	11668	529	864	13061

Table 2.2: Undominated Acceptances

	Undominated H	Undominated L	All Acceptances
manual	152	128	303
computer	257	185	561
totals	409	313	864

Table 2.3: Raw Statistics from All Experiments, All Periods

	All Offers	Relevant
manual	1644	676
computer	10024	2743
totals	11668	3419

Table 2.4: Raw Statistics from All Experiments, Second Half

	All Offers	Relevant
manual	808	295
computer	5689	1886
totals	6497	2181

Table 2.5: Purchases of Pooling Contracts

Date	Sample	Accepted by H	Accepted by L	λ
10625	All	7	4	5/9
	Higher Blue Gain	2	1	5/9
	Higher Red Gain	5	3	5/9
10817	All	1	0	6/11
	Higher Blue Gain			6/11
	Higher Red Gain	1	0	6/11
10818	All	10	11	6/11
	Higher Blue Gain	4	3	6/11
	Higher Red Gain	6	8	6/11
20603	All	12	13	8/15
	Higher Blue Gain	1	3	8/15
	Higher Red Gain	11	10	8/15
20718	All	17	15	9/14
	Higher Blue Gain	17	15	9/14
	Higher Red Gain			9/14
20919	All	4	12	9/17
	Higher Blue Gain	3	4	9/17
	Higher Red Gain	1	7	9/17

Table 2.6: Distribution of Nonzero Distances from All Experiments

Session	10%	20%	30%	40%	50%	60%	70%	80%	85%	90%	95%	100%	#[a]
					All Nonzero Distances								
010625	1	1.5	3	4	4	5.3	7	12.8	18	18.8	22	28	43
010817	1	1	1	1.5	1.5	3	3	5	6.15	7	13.1	25	149
010818	1	1	1.5	1.5	3	3	4	5	6	10.4	19	29	113
020603	1	1	1	1.5	1.5	3	3	4	4	7	15	25	250
020718	1	1	1	1	1.5	1.5	3	3	5	6.9	11.4	30	356
020919	1	1	1	1	1	1.5	1.5	3	4	6	11	25	387
					Trimmed Nonzero Distances[b]								
010625	1	1.5	1.5	1.5	3	4	4.6	5	5.5	6.2	6.85	7	13
010817	1	1	1	1	1.5	1.5	2	3	3	4.6	5.55	11	119
010818	1	1	1	1.5	1.5	3	3	4	5	5	5	8	83
020603	1	1	1	1.5	1.5	1.5	3	3	3.95	4	7.65	17	217
020718	1	1	1	1	1.5	1.5	1.5	3	3	4.5	6	23	320
020919	1	1	1	1	1	1	1.5	1.5	3	4	6	22	345

[a]Number of observations

[b]The first three nonzero distances from each period are removed from the sample.

Figure 2.1: The Payoff Table for the Sellers

	A		B		C		D		E		F		G		H		I		J		K		L		M		N		O	
1	-22	-4	-84	-49	-116	-71	-139	-88	-162	-104	-224	-149	-302	-204	-388	-266	-466	-321	-543	-377	-621	-432	-699	-488	-738	-516	-777	-543	-816	-571
	(41)	(47)	(99)	(131)	(127)	(170)	(147)	(199)	(166)	(227)	(216)	(297)	(272)	(377)	(326)	(455)	(369)	(516)	(406)	(568)	(436)	(612)	(461)	(647)	(470)	(661)	(479)	(672)	(485)	(682)
2	8	26	-54	-19	-86	-41	-109	-58	-132	-74	-194	-119	-272	-174	-358	-236	-436	-291	-513	-347	-591	-402	-669	-458	-708	-486	-747	-513	-786	-541
	(17)	(8)	(76)	(94)	(105)	(134)	(125)	(164)	(145)	(192)	(196)	(265)	(254)	(347)	(310)	(428)	(355)	(492)	(394)	(547)	(426)	(593)	(452)	(631)	(463)	(646)	(472)	(659)	(480)	(670)
3	38	56	-24	11	-56	-11	-79	-28	-102	-44	-164	-89	-242	-144	-328	-206	-406	-261	-483	-317	-561	-372	-639	-428	-678	-456	-717	-483	-756	-511
	(-9)	(-32)	(53)	(55)	(82)	(97)	(103)	(127)	(123)	(156)	(176)	(231)	(235)	(316)	(294)	(400)	(341)	(467)	(381)	(524)	(415)	(573)	(443)	(613)	(455)	(630)	(465)	(644)	(474)	(657)
4	68	86	6	41	-26	19	-49	2	-72	-14	-134	-59	-212	-114	-298	-176	-376	-231	-453	-287	-531	-342	-609	-398	-648	-426	-687	-453	-726	-481
	(-35)	(-74)	(28)	(15)	(58)	(58)	(80)	(89)	(101)	(119)	(155)	(196)	(216)	(284)	(277)	(370)	(325)	(440)	(368)	(500)	(404)	(552)	(434)	(594)	(446)	(612)	(457)	(628)	(467)	(642)
5	78	96	16	51	-16	29	-39	12	-62	-4	-124	-49	-202	-104	-288	-166	-366	-221	-443	-277	-521	-332	-599	-388	-638	-416	-677	-443	-716	-471
	(-43)	(-89)	(20)	(2)	(50)	(45)	(72)	(76)	(93)	(106)	(147)	(184)	(210)	(273)	(271)	(360)	(320)	(431)	(363)	(492)	(400)	(544)	(430)	(588)	(443)	(606)	(455)	(623)	(464)	(637)
6	108	126	46	81	14	59	-9	42	-32	26	-94	-19	-172	-74	-258	-136	-336	-191	-413	-247	-491	-302	-569	-358	-608	-386	-647	-413	-686	-441
	(-70)	(-133)	(-6)	(-40)	(25)	(4)	(48)	(36)	(70)	(67)	(125)	(147)	(190)	(238)	(253)	(329)	(304)	(402)	(349)	(466)	(387)	(521)	(420)	(567)	(433)	(587)	(446)	(604)	(456)	(620)
7	168	186	106	141	74	119	51	102	28	86	-34	41	-112	-14	-198	-76	-276	-131	-353	-187	-431	-242	-509	-298	-548	-326	-587	-353	-626	-381
	(-126)	(-225)	(-59)	(-128)	(-26)	(-82)	(-3)	(-48)	(-20)	(-15)	(79)	(68)	(147)	(165)	(214)	(262)	(269)	(340)	(318)	(409)	(360)	(470)	(396)	(521)	(412)	(544)	(426)	(564)	(439)	(582)
8	228	246	166	201	134	179	111	162	88	146	26	101	-52	46	-138	-16	-216	-71	-293	-127	-371	-182	-449	-238	-488	-266	-527	-293	-566	-321
	(-185)	(-323)	(-114)	(-222)	(-81)	(-174)	(-56)	(-138)	(-32)	(-104)	(30)	(-16)	(102)	(87)	(173)	(189)	(232)	(272)	(284)	(347)	(330)	(413)	(370)	(470)	(387)	(495)	(403)	(518)	(418)	(538)
9	288	306	226	261	194	239	171	222	148	206	86	161	8	106	-78	44	-156	-11	-233	-67	-311	-122	-389	-178	-428	-206	-467	-233	-506	-261
	(-247)	(-427)	(-173)	(-322)	(-138)	(-271)	(-112)	(-234)	(-87)	(-198)	(-22)	(-106)	(53)	(2)	(129)	(110)	(191)	(199)	(247)	(279)	(297)	(350)	(341)	(412)	(360)	(440)	(378)	(466)	(394)	(489)
10	348	366	286	321	254	299	231	282	208	266	146	221	68	166	-18	104	-96	49	-173	-7	-251	-62	-329	-118	-368	-146	-407	-173	-446	-201
	(-311)	(-536)	(-235)	(-427)	(-198)	(-374)	(-171)	(-336)	(-144)	(-298)	(-77)	(-201)	(2)	(-88)	(82)	(26)	(148)	(120)	(208)	(205)	(261)	(282)	(308)	(349)	(330)	(380)	(350)	(408)	(368)	(434)
11	468	486	406	441	374	419	351	402	328	386	266	341	188	286	102	224	24	169	-53	113	-131	58	-209	2	-248	-26	-287	-53	-326	-81
	(-449)	(-773)	(-367)	(-655)	(-327)	(-598)	(-298)	(-556)	(-269)	(-515)	(-195)	(-410)	(-109)	(-286)	(-21)	(-161)	(53)	(-56)	(120)	(40)	(181)	(127)	(236)	(206)	(261)	(241)	(284)	(275)	(306)	(306)
12	498	516	436	471	404	449	381	432	358	416	296	371	218	316	132	254	54	199	-23	143	-101	88	-179	32	-218	4	-257	-23	-296	-51
	(-485)	(-835)	(-401)	(-715)	(-361)	(-657)	(-331)	(-615)	(-302)	(-573)	(-227)	(-466)	(-138)	(-339)	(-48)	(-211)	(27)	(-103)	(96)	(-5)	(159)	(85)	(216)	(166)	(242)	(203)	(266)	(238)	(289)	(271)
13	528	546	466	501	434	479	411	462	388	446	326	401	248	346	162	284	84	229	7	173	-71	118	-149	62	-188	34	-227	7	-266	-21
	(-522)	(-900)	(-437)	(-777)	(-395)	(-718)	(-365)	(-675)	(-335)	(-632)	(-259)	(-523)	(-168)	(-394)	(-76)	(-262)	(1)	(-152)	(72)	(-51)	(136)	(42)	(195)	(125)	(222)	(164)	(247)	(200)	(271)	(234)
14	588	606	526	561	494	539	471	522	448	506	386	461	308	406	222	344	144	289	67	233	-11	178	-89	122	-128	94	-167	67	-206	39
	(-599)	(-1032)	(-510)	(-906)	(-467)	(-844)	(-436)	(-800)	(-405)	(-755)	(-325)	(-642)	(-231)	(-507)	(-135)	(-370)	(-54)	(-254)	(21)	(-148)	(89)	(-50)	(151)	(39)	(180)	(80)	(207)	(119)	(233)	(156)
15	648	666	586	621	554	599	531	582	508	566	446	521	368	466	282	404	204	349	127	293	49	238	-29	182	-68	154	-107	127	-146	99
	(-678)	(-1171)	(-586)	(-1040)	(-542)	(-976)	(-509)	(-930)	(-477)	(-884)	(-394)	(-766)	(-297)	(-627)	(-196)	(-483)	(-112)	(-362)	(-33)	(-250)	(39)	(-147)	(105)	(-53)	(135)	(-9)	(164)	(32)	(192)	(72)
16	678	696	616	651	584	629	561	612	538	596	476	551	398	496	312	434	234	379	157	323	79	268	1	212	-38	184	-77	157	-116	129
	(-718)	(-1242)	(-625)	(-1109)	(-580)	(-1045)	(-547)	(-997)	(-514)	(-951)	(-430)	(-830)	(-331)	(-688)	(-228)	(-542)	(-142)	(-419)	(-61)	(-304)	(13)	(-198)	(80)	(-101)	(112)	(-56)	(142)	(-13)	(170)	(27)
17	708	726	646	681	614	659	591	642	568	626	506	581	428	526	342	464	264	409	187	353	109	298	31	242	-8	214	-47	187	-86	159
	(-759)	(-1315)	(-665)	(-1180)	(-619)	(-1114)	(-585)	(-1066)	(-552)	(-1019)	(-467)	(-896)	(-365)	(-751)	(-261)	(-602)	(-172)	(-476)	(-90)	(-359)	(-14)	(-250)	(55)	(-151)	(88)	(-104)	(119)	(-60)	(148)	(-18)
18	718	736	656	691	624	669	601	652	578	636	516	591	438	536	352	474	274	419	197	363	119	308	41	252	2	224	-37	197	-76	169
	(-773)	(-1339)	(-678)	(-1203)	(-632)	(-1138)	(-598)	(-1089)	(-565)	(-1042)	(-479)	(-919)	(-377)	(-773)	(-272)	(-623)	(-183)	(-496)	(-100)	(-377)	(-23)	(-268)	(47)	(-168)	(80)	(-121)	(111)	(-76)	(141)	(-34)
19	728	746	666	701	634	679	611	662	588	646	526	601	448	546	362	484	284	429	207	373	129	318	51	262	12	234	-27	207	-66	179
	(-787)	(-1364)	(-692)	(-1227)	(-645)	(-1161)	(-611)	(-1113)	(-578)	(-1065)	(-491)	(-941)	(-389)	(-794)	(-283)	(-643)	(-193)	(-515)	(-110)	(-396)	(-33)	(-286)	(38)	(-185)	(71)	(-137)	(103)	(-92)	(133)	(-49)
20	748	766	686	721	654	699	631	682	608	666	546	621	468	566	382	504	304	449	227	393	149	338	71	282	32	254	-7	227	-46	199
	(-816)	(-1414)	(-719)	(-1276)	(-672)	(-1209)	(-638)	(-1160)	(-604)	(-1112)	(-516)	(-986)	(-412)	(-838)	(-305)	(-685)	(-214)	(-555)	(-130)	(-434)	(-51)	(-322)	(21)	(-219)	(55)	(-171)	(87)	(-125)	(117)	(-81)
21	778	796	716	751	684	729	661	712	638	696	576	651	498	596	412	534	334	479	257	423	179	368	101	312	62	284	23	257	-16	229
	(-859)	(-1490)	(-760)	(-1350)	(-713)	(-1282)	(-678)	(-1232)	(-643)	(-1183)	(-554)	(-1056)	(-449)	(-904)	(-339)	(-748)	(-247)	(-616)	(-160)	(-492)	(-80)	(-378)	(-6)	(-272)	(29)	(-222)	(62)	(-175)	(93)	(-130)
22	808	826	746	781	714	759	691	742	668	726	606	681	528	626	442	564	364	509	287	453	209	398	131	342	92	314	53	287	14	259
	(-902)	(-1568)	(-803)	(-1425)	(-754)	(-1356)	(-719)	(-1306)	(-684)	(-1256)	(-593)	(-1126)	(-486)	(-972)	(-374)	(-814)	(-280)	(-678)	(-191)	(-552)	(-109)	(-435)	(-33)	(-326)	(2)	(-276)	(36)	(-227)	(69)	(-180)
23	868	886	806	841	774	819	751	802	728	786	666	741	588	686	502	624	424	569	347	513	269	458	191	402	152	374	113	347	74	319
	(-992)	(-1727)	(-889)	(-1581)	(-839)	(-1509)	(-803)	(-1457)	(-767)	(-1405)	(-673)	(-1272)	(-562)	(-1113)	(-446)	(-948)	(-348)	(-807)	(-256)	(-676)	(-170)	(-553)	(-90)	(-439)	(-53)	(-386)	(-17)	(-335)	(17)	(-285)

Chapter 3

Modelling Price Pressure

3.1 Introduction

Economists have generally focused on the equilibrium implications of their models, leaving little time to consider how markets attain equilibrium. This focus is motivated by the claim that prices change in the direction of excess demand. If excess demand is positive (there is more demand than supply), prices tend to increase. Conversely, if excess demand is negative (supply outstrips demand), then prices tend to decrease. As a result, price adjustment only stops at the point where excess demand equals zero—the equilibrium.[1]

Evidence is presented here, however, that markets do not necessarily adjust as suggested in economic theory. We study the outcomes in financial markets experiments where up to 70 (human) subjects traded 4 securities for real money. One of the securities was risk-free, and the other three were risky. Prices of none of the risky securities react significantly to their excess demand, contrary to the presumption in economic theory. The lack of reaction of a security's price to its excess demand is caused by the presence of excess demand in other securities. Evidently, prices in

[1]The claim that, if prices adjust in the direction of excess demand, then equilibrium will be reached, does not hold for all preferences that are theoretically imaginable. It is easy to construct counterexamples (see, e.g., [12]). The counterexamples exploit the fact that no general shape restrictions exist for excess demand as a function of prices (this fundamental result is known as the Debreu-Mantel-Sonnenschein Theorem). It is an empirical (and open) question, however, whether preferences that generate weird excess demand, and hence, non-convergence, occur naturally. If not, then the counterexamples are a mere theoretical curiosity, and hence, of no further consequence.

one market react to excess demand in other markets, even if there is no direct link between markets.[2] Such cross-effects are not only surprising; economists generally consider them to be contrary to intuition, because it may imply that the price of a good falls when it is in excess demand.[3]

The cross-security effects were first discovered in experimental markets with three securities (two risky; one risk-free); see [2]. This paper demonstrates that the effects are replicable. In addition, the four-security environment reveals rich patterns in the signs and magnitudes of the covariances between a security's price changes and other securities' excess demands, which [2] could not detect, because they investigated experiments with only two risky securities.

The cross-security effects are all the more puzzling because prices and allocations in the experiments are otherwise well behaved. Demand and supply can be modelled in a way that has become standard in finance, namely, by assuming that subjects trade off expected payoff against risk as measured by variance. The moderate level of risk in the experiment justifies subjects' tendency to ignore higher-order moments (e.g., skewness). Substantial evidence has by now been collected that prices – and allocations, *modulo* a random error term—in experimental settings indeed tend to those predicted by equilibrium theory based on mean-variance preferences, namely, the Capital Asset Pricing Model (CAPM).[4] This model has the advantage that the exact trade-off that individual subjects make between expected return and risk (i.e., their risk aversion) need not be known to determine whether prices and allocations satisfy equilibrium restrictions, or even to determine whether prices change in the direction of excess demand. That is, the findings in this paper do not depend on knowledge of this trade-off parameter.

We present a model of price pressure that could explain not only the presence of the cross-security effects, but also, as turns out, their signs and even magnitude. Regarding the latter, the experiments reveal a systematic relationship between the

[2] Order execution in one market is not contingent on events in other markets.

[3] In a influential text on equilibrium theory, [1], p. 304, it is argued that acceptable equilibration processes *must* have the property that the price of a good falls when the good is in excess supply.

[4] See [3, 5].

cross-security effects and the covariances of the final payoffs of the securities: if two securities have negatively correlated payoffs, then their prices tend to be negatively correlated with each other's excess demands (*vice versa* if the correlation is positive); moreover, the magnitude of the cross-security effects is related to that of the payoff covariances.

Ours is a model of price pressure. It describes the mechanics of price changes when agents encounter difficulties trading to what we will refer to as their *aspiration levels*. In this paper, we will take the aspiration level to be the optimal positions at last transaction prices. That is, aspiration levels equal present positions plus excess demands. These are also the aspiration levels in the classical Walrasian tatonnement. The ensuing price adjustment in the Walrasian model, however, is mechanical and fictitious, without any obvious relationship to actual processes in decentralized markets: a security's price changes in proportion to its excess demand. Here, we spell out how agents react when their orders (which are based on their aspiration levels) fail to get executed. We conjecture that agents scale back their aspiration levels proportionally. Marginal valuations are updated correspondingly, i.e., prices at which agents are willing to trade are revised. Mean order prices, and as a result, prices at which subsequent transactions are likely to occur, change.

Price pressure in our model is driven by local changes in marginal valuations, which in turn are dictated by the Hessian of agents' utility functions. In the case of mean-variance preferences, the Hessian is proportional to the covariance matrix of the final payoffs. When covariances are nonzero, not only does our model therefore predict the presence of cross-security effects, but also that these cross-security effects are related to the sign and even the magnitude of these covariances. The experimental data confirm this. Our model therefore enjoys additional empirical support from a quite surprising angle.

The scope of our model is limited. It only deals with the mechanics of the direction in which prices change given unattainable aspiration levels. That is, ours is a model of price pressure, and not of, e.g., equilibration. Nevertheless, it could be embedded in a model of equilibration. One possibility is the following. As aspiration levels are scaled back and marginal valuations change correspondingly, the average order price changes as well, to the point that agents may decide to cancel their orders altogether and re-submit new orders that reflect their excess demands at these revised average order prices. We will not explore the implications, but, in the conclusion, we speculate to what extent this extension of our model would guarantee stability.

Likewise, our model takes aspiration levels to be *globally* optimal demands given last transaction prices. One could define aspiration levels differently. For instance, in the models of [4, 6, 9, 14], aspiration levels are current allocations plus changes that are *locally* optimal given previous transaction prices. In the context of mean-variance preferences, however, the empirical implications (in particular, the link between cross-security effects and payoff covariances) can be shown to be the same qualitatively.

Our model is meant to capture price pressure in novel environments, where agents cannot plausibly have formed expectations about the equilibration path. We are thinking about situations where agents meet for the first time, or when their endowments have changed unpredictably and in ways unknown to others. They cannot guess how long price adjustment will last, or even whether markets have reached equilibrium. As a consequence, they cannot envisage the opportunities they may face when postponing trade. In essence, they are forced to act in a myopic way. As the trading environment is repeated, it is reasonable to expect that agents start forming rational expectations about the price discovery process. As a consequence, they will alter their strategies accordingly. An interesting approach to modelling the ensuing learning has recently been suggested in [7]. In this paper, we abstract from such learning.

The remainder of this paper is organized as follows. The next section describes the experiments. In Section 3.3, the excess demands are derived in the model that has proven to be useful in predicting final prices and holdings in the experiments, namely, the CAPM. Subsequently, we present empirical evidence of the extent to which prices in our experiments fail to change in the direction of excess demand because of cross-security effects. In Section 3.5 we develop a theory of price pressure that explains the observed cross-security effects. Further implications of the model, about the signs and magnitudes of the cross-security effects, are verified in Section 3.6. Section 3.7

concludes.

3.2 Description of the Experiments

The experiments[5] are organized as a sequence of several replications of the same situation. Each replication is referred to as a *period*. At the beginning of a period, (human) subjects are given a number of securities and cash. They have the opportunity to trade the securities for cash during a pre-set amount of time. After trading ends, a *state* is drawn randomly, on the basis of which each of the securities pays a *liquidating dividend*. Subjects keep the dividends (the amount depends on the number of each of the securities they hold), as well as their end-of-period cash holdings, minus a pre-fixed charge. The securities are taken away when a period is over. Then a new period starts, whereby subjects are given a fresh allocation, identical to that in the previous period. The accumulated earnings from previous periods are fully exposed to risk. That is, if in a given period a subject loses money, then the amount is subtracted from the total earnings in previous periods. If a subject's cumulative earnings remain negative for more than two periods in a row, he or she is excluded from further trading.[6]

There are four securities in the experiment. One security, which we label *Notes*, is risk-free and can be held in positive or negative amounts (i.e., can be sold short);[7] the other three securities *A, B, C* are risky and can only be held in non-negative amounts (i.e., cannot be sold short). Cash and Notes are perfect substitutes at the

[5]The three experiments discussed here were conducted between October 1999 and November 2000.

[6]This *bankruptcy rule* causes rational subjects to be more risk averse in earlier periods than they would be if the experiment had been organized as a single trading period. When bankrupting, subjects forego the opportunity of making money in subsequent periods. To avoid bankruptcy, subjects therefore should invest more cautiously in earlier periods. Subjects evidently understand this: the number of shortsale–constrained subjects increases with time. Hence, our bankruptcy rule makes it possible to study asset pricing (which relies on risk aversion) even if subjects are risk neutral. It is well known, however, that most subjects exhibit risk aversion beyond that induced by our bankruptcy rule, even at the levels of risk in our experiments. So, our bankruptcy rule is not necessary to study asset pricing in the laboratory. See [5] for details.

[7]When selling short a Note, the seller promises to pay the face value of the Note to the buyer when the Note expires. Effectively, the seller borrows the purchase price; the face value of the Note acts as the loan amount, inclusive of interest.

end of a period. However, because assets can only be traded for cash, cash also has a transactions value *during* a trading period, which often showed up as a discount in the price of the Notes relative to their payoff.

At the outset of a period, the state is unknown, but the true (objective) distribution of the states is public information. Between the opening and the closing of the market, no information about the state is revealed, and no credits are made to subjects' accounts. Nobody has privileged information about upcoming states. All this is common knowledge.

Periods are independent. Each subject is given the same endowment in successive periods, but is *not* informed of the endowments of others, whether endowments of others were the same in successive periods, of the total endowment,[8] or even of the number of subjects in a given experiment, for that matter. All accounting in the experiments is done in terms of a fictitious currency called *francs*, exchanged for U.S. dollars at the end of the experiment at a pre-announced exchange rate (4 U.S. cents per franc). The parameters for all experiments are given in Table 3.1.

There are four states W, X, Y, Z, on the basis of which liquidating dividends are determined. The state-dependent dividends of the securities (in francs) are recorded in Table 3.2. Cash is risk-free: one unit of cash is one franc in each state of nature. States were drawn equally likely and independently across periods. That is, the chance of any state occurring remained 1/4 throughout the experiment.

All communication took place over the internet.[9] Trading was organized through

[8]The total endowment of risky securities is referred to in the finance literature as the *market portfolio*. Special care was exerted not to provide information about the market portfolio, so that subjects could not readily deduce the nature of aggregate risk — lest they attempt to use a standard theoretical model to *predict* prices, rather than to take observed prices as given. Economic theory does not require that participants have any more information than is provided in the experiment. Indeed, much of the power of economic theory comes precisely from the fact that agents know *only* market prices and their own preferences and endowments.

[9]Instructions and screens for the experiments we discuss here can be viewed at http://eeps2.caltech.edu/market-991026/, http://eeps3.caltech.edu/market-001030/, and http://eeps3.caltech.edu/market-001106/ respectively. Use identification number:1 and password:a to login as a viewer. The reader will not have a payoff but will be able to see the forms used. If the reader wishes to interact with the software in a different context, visit http://eeps.caltech.edu and go to the experiment and then demo links. This exercise will provide the reader with some understanding of how the software works.

parallel, unconnected, continuous electronic open books.[10] This architecture is heavily used in purely electronic financial markets around the world (including the Paris, Tel Aviv and Toronto stock exchanges). Subjects were given clear instructions, which included descriptions of some portfolio strategies (but no suggestions as to which strategies were better). Most of the subjects had at least some sophistication in economics in general and with financial markets in particular. The subjects were drawn from the Caltech community of undergraduate and graduate students. The average payment was \$60, with a minimum of \$0 (those who went bankrupt) and a maximum of approximately \$150 for a three-hour experiment.

3.3 Modelling Excess Demands

It is documented elsewhere (see [3, 5]) that prices and allocations in experiments like the ones described in the previous section tend to reflect mean-variance preferences. That is, prices and allocations move in a direction that reveals a concern to optimally trade off expected payoff against risk (as measured by variance). In other words, subjects' behavior reflects optimization of the following *utility function*

$$U_n(x) = E(x) - \frac{b_n}{2}\mathrm{var}(x), \tag{3.1}$$

where x denotes the random variable representing one's final payoff, n is a subject index ($n = 1, ..., N$), and b_n is a subject-specific constant (reflecting the magnitude of risk aversion).

Therefore, a subject can be characterized by an endowment (h_n^0, z_n^0) of the Note and the (vector of) risky securities, and by the risk-aversion coefficient b_n. Write $D_j(s)$ for the end-of-period payoff on the j-th risky asset ($j = A, B, C$) in state $s \in S$, where $S = \{W, X, Y, Z\}$. Thus, when holding h_n units of the Notes and the

[10] The software that implements the system is called Marketscape.

vector z_n of risky securities, a subject will have random final payoff of

$$x_n = 100h_n + z_{n,A}D_A + z_{n,B}D_B + z_{n,C}D_C,$$

and will enjoy utility as given in (3.1).

The four states in our setup are equally likely. Let μ be the vector of expected payoffs of risky assets and $\Omega = [\mathrm{cov}\,(D_j, D_k)]$ be the covariance matrix. The state-dependent payoffs are displayed in Table 3.2. They imply the following mean payoff vector and covariance matrix:

$$\mu = \begin{bmatrix} 230 \\ 200 \\ 170 \end{bmatrix}, \tag{3.2}$$

$$\Omega = \begin{bmatrix} 28850 & 11575 & -7375 \\ 11575 & 7450 & -2225 \\ -7375 & -2225 & 2250 \end{bmatrix}. \tag{3.3}$$

Using μ and Ω, we can rewrite the utility function (3.1) in a more convenient form, directly as a function of the final holdings of risk-free and risky securities, (h_n, z_n):

$$U_n(h_n, z_n) = 100h_n + [z_n \cdot \mu] - \frac{b_n}{2}[z_n \cdot \Omega z_n]. \tag{3.4}$$

We normalize the price of the Notes to be 100.[11] Write p for the vector of prices of risky securities. Given prices p, the feasible investments, i.e., the budget set, consists of portfolios (h, z) that satisfy the following *budget constraint*:

$$100h_n + p \cdot z_n \leq 100h_n^0 + p \cdot z_n^0. \tag{3.5}$$

Assume that the budget constraint is binding at the optimum. The utility function

[11] At a price of 100, there is no arbitrage opportunity between cash and Notes.

can then be re-written as a function of holdings of risky securities only:

$$U_n(h_n^0 + p \cdot (z_n^0 - z_n),\ z_n) = h_n^0 + p \cdot z_n^0 + z_n \cdot (\mu - p) - \frac{b_n}{2} (z_n \cdot \Omega z_n) .$$

From the first-order conditions that characterize the optimum,[12] an investor's demand for risky securities given prices p is[13]

$$z_n(p) = \frac{1}{b_n} \Omega^{-1}(\mu - p).$$

The *excess demand* then equals

$$z_n(p) - z_n^0 = \frac{1}{b_n} \Omega^{-1}(\mu - p) - z_n^0. \tag{3.6}$$

Therefore, the *per-capita (aggregate) excess demand* vector is

$$z^e(p) = \frac{1}{N} \sum_{n=1}^{N} \left(z_n(p) - z_n^0 \right) .$$

The per-capita excess demand is equivalent to that of an agent with endowment equal to the per capita endowment and risk-aversion coefficient equal to the harmonic mean aversion coefficient $B = \left(\frac{1}{N} \sum_{n=1}^{N} \frac{1}{b_n} \right)^{-1}$.

Armed with the above expressions, we are now ready to verify whether price changes are proportional to aggregate excess demand, as postulated in the standard Walrasian equilibration model.

[12]The second-order conditions are satisfied because of strict concavity of the utility function.

[13]Note that demand is independent of wealth. In the original version of the Walrasian model, the tatonnement version, no trade takes place before prices settle. In extensions, referred to as non-tatonnement models, trade is allowed to take place, potentially generating wealth effects on the way towards equilibrium. Since demand is independent of wealth in our context, there will not be wealth effects, and hence, the distinction between tatonnement and non-tatonnement is without consequence (as far as the Walrasian model is concerned).

3.4 Walrasian Price Adjustment: Empirical Evidence

In the Walrasian model, prices change in the direction of own excess demand. The model is highly stylized. It certainly does not literally describe what is going on in continuous computerized double auctions such as the ones we use in the financial markets experiments. Nevertheless, the Walrasian model captures the essence of what economists often informally claim justifies equilibrium theory, namely, that prices are pushed in the direction of excess demand.[14] It also captures the intuition that if there are no direct links between different markets (e.g., through the ability to submit limit orders in one market that depend on prices in other markets), prices in one market cannot adjust to excess demand in another.

In a nutshell, the Walrasian model makes the following prediction.

Hypothesis W **:** *The price of a security adjusts in the direction of its own excess demand; excess demands in other securities have no influence.*

Figure 3.1 provides visual evidence that refutes the first part of Hypothesis W. It plots all intra-period transaction price changes in the first experiment (26 Oct 99) against own excess demand. There is no evidence of any relationship, let alone positive. When excess demand is negative (i.e., when there is excess supply), there is no more tendency for prices to decrease than when excess demand is positive (i.e., demand outstrips supply). The lack of correlation between price changes and excess demand is caused by significant cross-security effects that act as confounding factors. That is, the second part of Hypothesis W is also wrong, and is the reason why the first part fails. We now document this formally.

Let k denote transaction time, i.e., transactions are indexed $k = 1, 2, ...$ According to the Walrasian model,

$$p^k - p^{k-1} = \Lambda z^e(p^{k-1}),$$

where Λ is a diagonal matrix with positive constants. An empirically viable version of the Walrasian model must, however, take into account the inherent randomness

[14] As mentioned before, the property that prices adjust in the direction of excess demand cannot be a complete justification of equilibrium theory, because it does not guarantee equilibration.

of changes in prices. An error term has to be included and suitable restrictions have to be imposed on it. We propose the following stochastic difference equation for transaction price changes.

$$p^k - p^{k-1} = \Lambda z^e(p^{k-1}) + \epsilon_k, \tag{3.7}$$

where the noise ϵ_k is assumed to be mean zero and uncorrelated with past public information as well as with past excess demand.[15]

We test this model by projecting transaction price changes onto estimates of per-capita excess demand. Excess demand equals demand minus supply. Per capita *supply* varies hardly during an experiment, so for all practical purposes, it can be considered constant.[16] Per-capita *demand* can only be measured up to a constant of proportionality, namely, the harmonic mean risk aversion B, which is unknown. We borrow the estimate from [5] (which is based on end-of-period prices and portfolio choices), namely, $\hat{B} = 10^{-3}$.[17] Because supply does not change (for all practical purposes), the error in the estimation of B is absorbed in the intercept when projecting price changes onto (our estimates of) aggregate excess demands.[18]

Inspection of the projection results revealed that the error term was affected by heteroscedasticity. White's test to detect heteroscedasticity confirmed this. As a result, we report standard errors that have been adjusted using White's general correction for heteroscedasticity.

Table 3.3 displays the projection results. Unlike expected after the visual evidence

[15]It should be noted that past excess demand in general may not be public information, so our requiring that the error term be independent of past excess demand is rather *ad hoc*.

[16]Only bankruptcies may lead to changes in per-capita supplies.

[17]The same estimate is used to compute per-capita excess demands used in Figure 3.1.

[18]To see this, consider (3.7), and re-write it such that estimated aggregate excess demand shows up on the right hand side:

$$\begin{aligned} p^k - p^{k-1} &= \Lambda z^e(p^{k-1}) + \epsilon_k \\ &= \left(\frac{\hat{B}}{B} - 1\right) \Lambda \bar{z} + \frac{\hat{B}}{B} \Lambda \left(\hat{z}^e(p^{k-1})\right) + \epsilon_k, \end{aligned}$$

where $\hat{z}^e(p^{k-1}) = \hat{B}^{-1}\Omega^{-1}(\mu - p^{k-1}) - \bar{z}$, i.e. the aggregate excess demand when the actual harmonic mean aversion B is replaced with its estimate $\hat{B}$. An intercept emerges, equal to $\left(\frac{\hat{B}}{B} - 1\right)\Lambda\bar{z}$.

in Figure 3.1, prices *are positively correlated with excess demand.* In six cases, the correlation is significant (at p-level equal to 0.05). The origin of the apparent discrepancy between Figure 3.1 and Table 3.3 is obvious, however: contrary to the predictions of the Walrasian model, two-thirds of the cross-security effects are significantly different from zero. That is, excess demands in other securities operate as confounding factors in the relationship between a security's price changes and its own excess demand.

The results replicate and extend the findings in [2], who also report evidence of significant cross-security effects, in eight large-scale financial markets experiments involving two risky and one risk-free securities. Likewise, our results confirm the significant cross-security effects discovered in four experiments with three securities, whereby mean-variance preferences were induced not through uncertainty, but by paying subjects directly according to the schedule provided in (3.4). The latter results are reported in [4].

3.5 An Alternative Model of Price Pressure

The significant cross-security effects refute the price adjustment story in the Walrasian model. Perhaps this is not surprising. In our experiments, price adjustment is not facilitated by a benevolent auctioneer, unlike in the Walrasian model.[19] Price pressure emerges endogenously, through order submission.

In a double auction setting, it is more plausible that prices change because of changes in valuations induced by changes in expectations about executable trades. We present a model of price pressure that builds on this conjecture. Unlike the Walrasian model, ours predicts the very cross-security effects that are present in the data. It does more: it links the signs and even relative magnitudes of the cross-security effects to corresponding elements in the Hessian of the utility functions on which excess demands are based. When we return to the data, we confirm this additional implication. As such, our model appears to be built on solid empirical

[19]For a similar criticism, see, e.g., [8].

foundation.

To set the stage, we make two assumptions about individual behavior in a competitive, decentralized market setting.

1. In the short run, agents' actions are quantity-driven. Agents desire to trade particular quantities, to be referred to as *aspiration levels.* To the extent that agents sense that they will not be able to trade up to their aspiration levels, they scale back proportionally. However, agents with higher risk aversion are less eager to move away from their original aspiration levels than more risk tolerant agents.

2. The environment is *competitive*, taken to mean that agents only hurt themselves when they bid less than the expected utility upon execution of the trades. In the absence of asymmetric information, there is no winner's curse, so agents should not expect losses when bidding their marginal valuation. Hence, along with order quantities, agents submit prices that reflect the marginal valuation of their holdings conditional on eventually reaching aspiration levels.

Thus, price pressure in our model originates in changes in aspiration levels in response to lack of execution of orders.

We refrain from making assumptions about order quantities. They may be mechanically tied to the volume needed to move to aspiration levels (e.g., a fixed fraction), but need not. Order quantities can be large or small – the latter being more typical of the continuous markets in our experiments. In contrast, order prices are determined by the aspiration levels that agents eventually expect to attain. If order size is small, then many orders may generally have to be executed before attaining one's aspiration point. Still, as long as the aspiration point does not change, marginal valuations, and hence, order prices will remain the same for all these orders. Therefore, our theory is one of (order) prices, not of quantities.[20]

[20] When weighted with the inverse of the limit order quantities, the average order prices are correlated with aggregate excess demands. See [2] for evidence. Therefore, it appears that limit order quantities are disproportionately higher on the ask side when there is aggregate excess demand, and disproportionately lower on the bid side when there is aggregate excess supply. Again, cross-security

Agents submit limit orders. There is no role in our model for market orders. A richer version of our theory ought to distinguish between market and limit orders, in order to generate a full theory of the evolution of transaction prices.[21] We merely focus on the mean limit order price and how it changes as aspiration levels change. The expected price at which the next transaction occurs will, however, be related to the mean order price. Therefore, our model indirectly makes predictions about changes in transaction prices.

Although other choices are possible, we take the initial aspiration level to be the optimal investment point at prevailing prices. The latter are prices at which agents expect to be able to trade. For simplicity, we take these to be the prices at which transactions last occurred. As in the Walrasian model, therefore, aspiration levels are determined by (globally optimal) excess demands at past prices. A different choice would lead to a different model. For instance, in [4, 6, 9, 14], aspiration levels are determined by *locally* optimal movements.

As mentioned above, once they experience delays in execution of orders, agents scale back their aspiration levels, and revise order prices correspondingly (and, if desired, order quantities as well). It is clear that a market where agents merely shrink their aspiration levels towards their present holdings may never equilibrate. But the revision of aspiration levels generates corresponding revisions in order prices. As a result, the mean order price, and hence, the price at which transactions can be expected to occur, changes. At one point, many agents will perceive their marginal valuations at (revised) aspiration levels to be way different from the mean order price. These agents may wish to revise their aspiration levels based on the new prevailing prices rather than continuing to mechanically scale back their aspiration levels. We assume that this occurs after each transaction.

Again, our theory is silent about the origin of transactions, for it does not distinguish between limit and market orders. Our theory merely predicts at which prices transaction

effects complicate this picture. But this evidence suggests that limit order quantities are not simply a fraction of (individual) excess demands. At the same time, the documented regularity indicates that order quantities are not random. The regularity could inspire new theoretical developments.

[21] Transactions occur when a market order is sent in (or equivalently, a limit buy order with limit price above the best ask or a limit sell order with a limit price below the best bid).

can be expected. Transactions may not take place on average at precisely the mean order prices. That is, there may be a bias in the mean order prices in predicting the next transaction prices. Econometrically, we will be able to accommodate any such bias.

Let us now discuss the mathematical details. We model price adjustment in continuous time. This allows us to characterize local price adjustment in terms of differential equations. Let t denote (calendar) time,[22] and the differential dt an infinitesimal change in time. As before, we concentrate on the price dynamics in the markets for the risky securities only, because we take Notes as the numeraire.

We need the following notation, some of which we already used in the discrete time setup of section 3.3.

$z_n(t)$	–	Investor n's current holdings (vector), or endowment at time t
$z_n^e(p)$	–	Investor n's individual excess demand vector, a function of the price vector p
$\tilde{z}_n(t)$	–	Investor n's order at time t
$p_n(t)$	–	The price vector that n submits along with his order at time t
$\nabla U_n(z)$	–	$\dfrac{\partial U_n(z)}{\partial z}$, the gradient of U_n
$H_n(z)$	–	$\dfrac{\partial \nabla U_n(z)}{\partial z}$, the Hessian of U_n, namely, the negative of $b_n\Omega$

At some point t^0, a transaction has taken place. The transaction price becomes the new reference price p^0 on which basis agents update their aspiration levels. The adjusted aspiration levels are determined by optimal positions at the new reference price. So, agent n needs to trade $\tilde{z}_n(t^0) = z_n^e(p^0)$ in order to reach his or her aspiration level. Agents then submit a batch of (new) orders that move them into the direction of their aspiration levels. Order prices are set equal to the marginal valuations conditional on reaching the aspiration levels. Obviously, the marginal valuations will be the same for all agents, and equal to the reference price. That is, orders are submitted at a price $p_n(t^0) = \nabla U_n(z_n(t^0) + \tilde{z}_n(t^0)) = p^0$.

[22]The index t is reserved for calendar time, while k indexes transactions.

In general, markets will not clear, i.e., investors' orders cannot all be filled simultaneously. They would if, e.g., p^0 happens to be the equilibrium price and order quantities are a fixed fraction of excess demands. Order imbalance makes agents nervous about the possibility of eventually reaching their aspiration levels. Agents react by scaling back their aspiration levels proportionally. The quantities they need to trade change accordingly:

$$d\tilde{z}_n = -\frac{\lambda}{b_n} z_n^e(p^0)dt, \tag{3.8}$$

where $\lambda > 0$. Note that agents with higher risk aversion (higher b_n) are assumed to scale back less. Agents update order prices (if not order quantities), to reflect changes in their marginal valuation as a result of changes in aspiration levels. Therefore, agent n revises order prices as follows:

$$\begin{aligned} dp_n &= H_n(u(z_n(t^0) + \tilde{z}_n(t^0)))d\tilde{z}_n \\ &= \lambda b_n \Omega \frac{1}{b_n} z_n^e(p^0)dt \\ &= \lambda \Omega z_n^e(p^0)dt. \end{aligned}$$

As a consequence, the mean order price vector p, and hence, the prices at which transactions can be expected, changes as follows:

$$\begin{aligned} dp &= \frac{1}{N}\sum_{n=1}^{N} dp_n \\ &= \lambda\Omega \frac{1}{N}\sum_{n=1}^{N} z_n^e(p^0)dt. \\ &= \lambda\Omega z^e(p^0)dt \end{aligned} \tag{3.9}$$

We assume that agents continue to revise orders until the next trade takes place, at time t^1. The transaction is expected to occur at the mean order price $p(t^1)$ (although we allow for a bias – to be discussed shortly). At this point, agents have a new common reference price p^1, and they revise their aspiration levels and their orders accordingly. Unless the market clears instantaneously, a new round of order adjustment ensues.

The transaction at t^1 is expected to occur at the mean order price $p(t^1)$. To accommodate potential biases, we assume that the transaction price p^1 is related to $p(t^1)$ as follows:

$$p^1 = \alpha + p(t^1) + \epsilon_1,$$

where ϵ_1 is mean-zero white noise. A discrete approximation of Equation (3.9) implies that $p(t^1)$ is related to p^0 as follows:

$$p(t^1) - p^0 = \lambda \Omega z^e(p^0)(t^1 - t^0).$$

Consequently, the change in the vector of transaction prices equals:

$$p^1 - p^0 = \alpha + \lambda \Omega z^e(p^0)(t^1 - t^0) + \epsilon_1.$$

Generalizing this for transactions at points t^k ($k = 1, 2, ...$), and assuming that transactions occur at regular intervals in time (which we scale to be equal to 1), we obtain the following stochastic difference equation:

$$p^k - p^{k-1} = \alpha + \lambda \Omega z^e(p^{k-1}) + \epsilon_k. \tag{3.10}$$

This is a system of differential equations that determines the drift in prices. That is, (3.9) provides a model of price pressure. The drift in prices is given by $\lambda \Omega z^e(p^0)$. Like the Walrasian model, the form of the drift implies that prices react positively to own excess demand. However, it also implies that the price of an asset reacts to the excess demands in markets for other assets as well. This is precisely what happened in the experiments. Consequently, our model explains the observed cross-security effects.

Our model generates an additional implication. (3.9) predicts that the drift in the price of one security depends on the excess demand of other securities through the corresponding covariances in final payoffs. That is, *cross-effects are proportional to the covariances between the assets involved.* This is a surprising finding that we confront with the data in the next section.

The intuition behind our theory is conveyed in Figure 3.2. As explained in the caption, marginal valuations are determined by the curvature of the indifference curves. This means that changes in marginal valuations are determined by the Hessian of the utility function, which is proportional here to the covariance matrix. Therefore, as aspiration levels change, marginal valuations change as dictated variances and covariances. Changes in marginal valuations ultimately translate into changes in order prices in a competitive market.

It deserves emphasis that, unlike in the empirical version of the Walrasian model [see Equation (3.7)], the error term in (3.10) is structural. It is not simply inserted for econometric convenience, but reflects the fact that transaction prices are random draws from a distribution indexed by the mean order prices.

3.6 The Data Revisited

The testable implications of the model presented in the previous section can be summarized as follows. The change in the price of each asset reacts to the excess demands of (possibly) all assets. The relation between one asset's price and another asset's excess demand is positive (negative) if and only if the covariance between the two assets is positive (negative). This gives the first testable hypothesis:

Hypothesis A **:** *The signs of the slope coefficients in the projection of price changes onto excess demands coincide with the signs of the corresponding elements in the covariance matrix* Ω.

Our model, however, implies an even stronger relation between the matrix of slope coefficients and the covariance matrix Ω, namely, that one is proportional to the other with strictly positive coefficient of proportionality. This gives rise to the second hypothesis:

Hypothesis B **:** *The matrix of slope coefficients is proportional to* Ω *with some positive constant of proportionality* κ.

To test Hypothesis A, we re-examine the estimation results reported in Table 3.3.

In only one out of eighteen instances does the sign of an off-diagonal slope coefficient not match that of its counterpart in the covariance matrix. Moreover, all nine significant cross-security effects bear signs coinciding with those of the corresponding element in Ω. These results provide very *strong support for Hypothesis A*, and therefore for our model of price pressure.

Next we turn to testing the proportionality between the slope coefficient matrix and Ω, Hypothesis B. Let l denote the row vector formed by concatenating the three rows of the matrix of slope coefficients in the projection of the vector of price changes onto the vector of excess demands. We use Wald's statistic to test the linear restriction $Rl' = 0$, where

$$R = \begin{pmatrix} \omega_{12} & -\omega_{11} & 0 & \dots & 0 \\ \omega_{13} & 0 & -\omega_{11} & \dots & 0 \\ \omega_{21} & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \omega_{33} & 0 & 0 & \dots & -\omega_{11} \end{pmatrix}.$$

The above linear restriction is equivalent to Hypothesis B but without imposing positivity on κ.

The Wald statistics are reported in Table 3.4. In two of three experiments, *Hypothesis B cannot be rejected.* It is rejected at the 5% level in the first experiment, however. Only 29 subjects participated in this experiment as opposed to 68 and 69 in the other two, so that the discrepancy may be due to differences in market thickness.

With our Wald statistic, no restriction is imposed on the sign of the constant of proportionality. According to Hypothesis B, it should be positive ($\kappa > 0$). To ascertain whether it is, we estimate the restricted model where the slope coefficient matrix is proportional to Ω and test whether the constant of proportionality is positive.[23] The t-statistics for the three experiments are 3.22, 3.67, and 4.77, respectively, thus providing further confirmation of Hypothesis B.

[23] We implement this by regressing the vector of price changes (resulting from concatenating each of the three price-change vectors) on a constant, dummy variables for the individual securities, and the excess demands multiplied by the corresponding elements of the covariance matrix.

3.7 Conclusion

Data from large-scale market experiments with four securities reject the simple price adjustment story in the Walrasian model because of significant cross-security effects: price changes correlate not only with own excess demand but with excess demands of other securities as well. This extends the findings of [2] and [4].

In this paper, we study a model of price pressure that enriches the basic Walrasian model, replacing its mechanical price adjustment rule with a model of price changes that better reflects the realities of competitive, decentralized markets. The agents in our model in the short run scale back their aspiration points in response to delays in execution, and change order prices accordingly, to reflect corresponding changes in their marginal valuations.

Our model of price pressure implies the very cross-security effects present in the data. In addition, it predicts the sign and relative magnitude of the cross-effects. Basically, as agents scale back their aspiration points, their marginal valuations change. The Hessian of the utility functions dictates how marginal valuations change. In the context of mean-variance preferences, the Hessian is proportional to the covariance matrix of final payoffs. This means that covariances provide the natural linkage between marginal valuation changes in one security and adjustments of desired quantities in another. Since changes in marginal valuations are revealed in changes in order prices, the pattern of covariances in payoffs show up in the way prices drift as a response to excess demands. The experimental data confirm the hypothesized link between cross-security effects and the structure of the covariance matrix.

Although our model fits the data well, we leave many questions unanswered. Foremost, ours is a model of local price pressure, and not of equilibration. It is meant simply as a more compelling and empirically relevant story of changes in prices given excess demands than the mechanistic adjustment in the original Walrasian model. Still, it could be embedded in the standard Walrasian model, replacing the Walrasian auctioneer, thus creating a model of equilibration. Its stability properties may be very different from those of the standard Walrasian model, however. This is because the link between excess demands and price changes is provided by the Hessian of the utility function. The latter conveys crucial information about derivatives of the excess demand function. As a consequence, price adjustment in our model reflects the very information that [11] proves to be needed for generic stability of equilibration mechanisms. In other words, replacing the standard, mechanistic price adjustment rule with our model of price pressure in the Walrasian equilibration model may generate the very stability that is needed to persuasively claim that general equilibrium is the natural state to which competitive markets tend. We leave this conjecture for future work.

In our model, we take aspiration points (desired portfolio holdings) to be globally optimal positions given past transaction prices. Alternatives can be imagined, such as aspiration points based on locally optimal movements. See, e.g., [4, 6, 9, 14]. In these papers, orders are proportional to locally optimal excess demands. But, as in the Walrasian model, price changes are mechanical: prices change in the direction of the net order flow. If we were to embed our model of price pressure into a model with aspiration points based on locally optimal movements, we would generate a completer model of price adjustment. Preliminary investigation of the implications of such an approach demonstrates, however, that the empirical implications of a model based on locally optimal aspiration points makes qualitatively similar predictions as one based on globally optimal aspiration points. This is because locally optimal movements are proportional to globally optimal movements, at least in the context of mean-variance preferences. More general preferences need to be contemplated in order to generate discriminatory power. We are working on such extensions at present.

Finally, we ought to mention yet another approach to establishing that price changes and excess demands are linked through the Hessian, namely, the global Newton procedure suggested in [13]. Our main objection to this model is, however, that it is devoid of economic meaning, being suggested by numerical analysis rather than conjectured economic forces.

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Tables and Figures

Table 3.1: Parameters in the Experimental Design

Experiment	Subject Category (Number)	Signup Reward (franc)	Endowments A	B	C	Notes	Cash (franc)	Loan Repayment (franc)	Exchange Rate $/franc
26 Oct 99	13	0	4	0	5	0	400	2075	0.04
	16	0	0	6	5	0	400	2350	0.04
30 Oct 00	46	0	4	0	5	0	400	2075	0.04
	22	0	0	6	5	0	400	2350	0.04
6 Nov 00	47	0	4	0	5	0	400	2075	0.04
	23	0	0	6	5	0	400	2350	0.04

Table 3.2: Payoff Matrix

State	W	X	Y	Z
Security A	30	190	500	200
Security B	100	270	300	130
Security C	200	210	90	180
Note	100	100	100	100

Table 3.3: OLS Projections of Transactions Price Changes onto Excess Demands

Experiment	Security	Coefficients[a] Intercept	Excess Demand[c] A	Excess Demand[c] B	Excess Demand[c] C	R^2	F-statistic[b]
991026	A	3.767	1.918	0.838	-0.473	0.024	5.89
		(1.814)*	(0.898)*	(0.408)*	(0.220)*		
	B	1.784	0.639	0.425	-0.123	0.031	7.64
		(0.997)	(0.480)	(0.232)	(0.115)		
	C	-2.039	-0.914	-0.467	0.214	0.019	4.51
		(0.878)*	(0.406)*	(0.204)*	(0.096)*		
001030	A	2.556	2.933	1.085	-0.775	0.062	21.63
		(0.788)*	(0.921)*	(0.357)*	(0.240)*		
	B	0.466	0.026	0.115	0.020	0.020	6.70
		(0.249)	(0.239)	(0.091)	(0.065)		
	C	-0.336	-0.223	-0.032	0.076	0.008	2.75
		(0.763)	(0.746)	(0.300)	(0.192)		
001106	A	0.687	0.492	0.205	-0.122	0.012	6.22
		(0.416)	(0.198)*	(0.091)*	(0.049)*		
	B	0.692	0.174	0.168	-0.018	0.019	10.11
		(0.37)	(0.143)	(0.083)*	(0.032)		
	C	-1.031	-0.376	-0.152	0.100	0.009	4.84
		(0.282)*	(0.110)*	(0.051)*	(0.028)*		

[a]OLS projections of intra-period transaction price changes onto (i) an intercept, (ii) the estimated excess demands for the three risky securities (A, B, and C). Standard (White) errors in parentheses.

[b]p-level in parentheses.

[c]Estimated on the basis of subjects' final holdings and last transaction prices.

Table 3.4: Wald's Test of Proportionality between Matrix of Slope Coefficients and Covariance Matrix

Experiment	Wald's Statistic	p-value
991026	17.691	0.0237
001030	9.581	0.2957
001106	10.744	0.2166

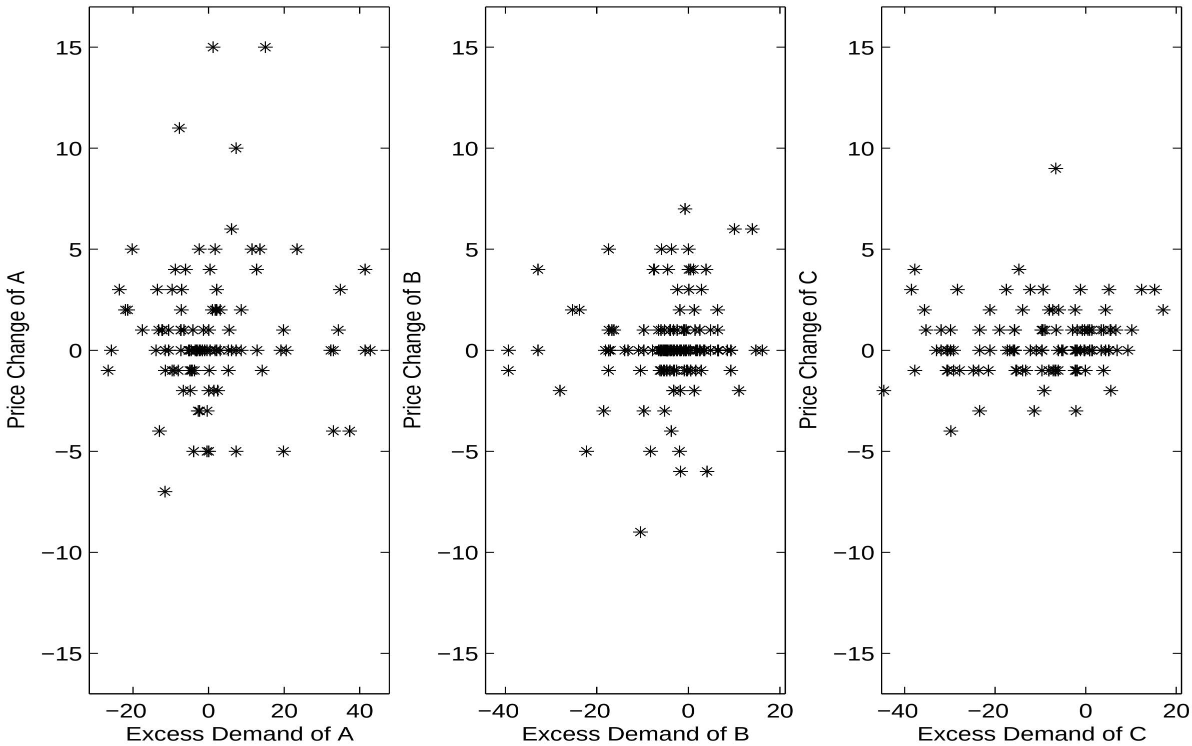

Figure 3.1: Plots of transaction price changes of A (left panel), B (middle panel) and C (right panel) as a function of excess demand.

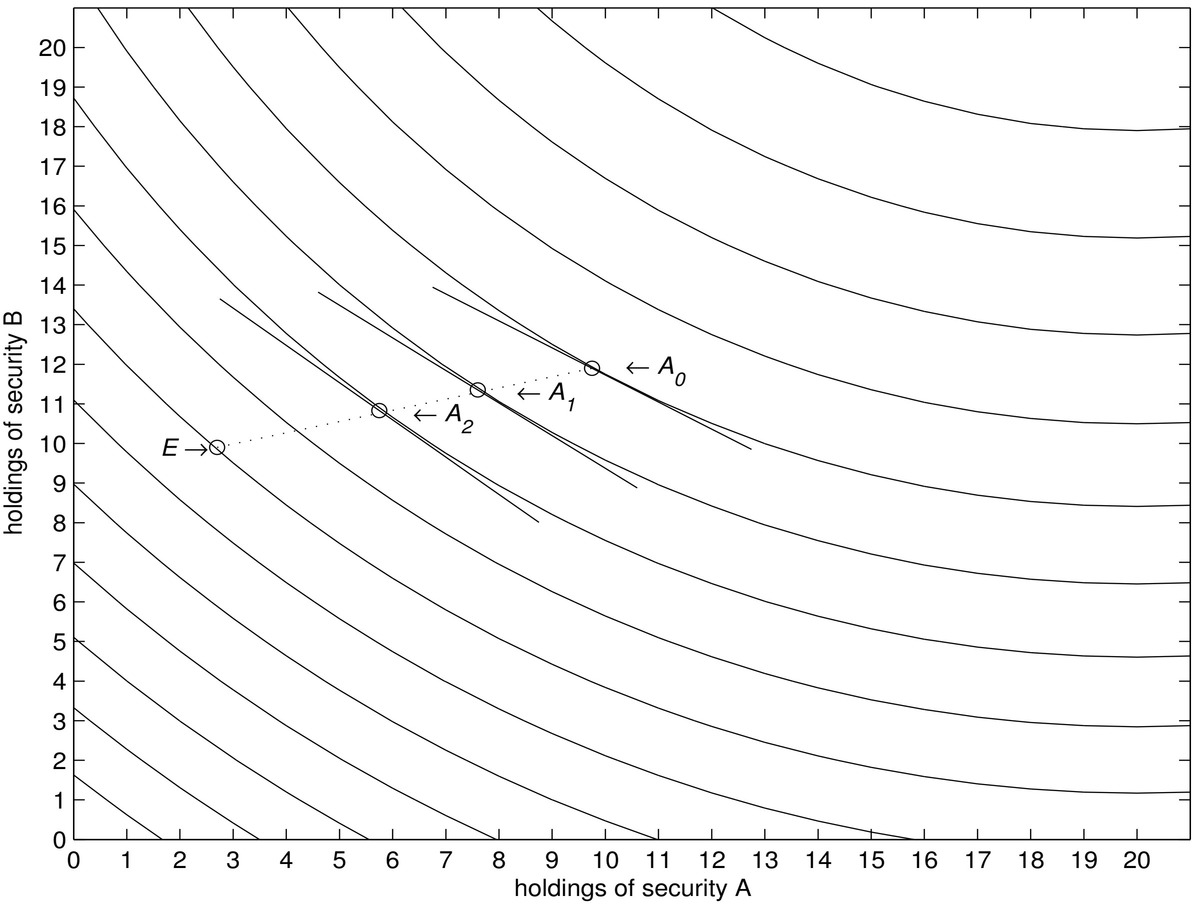

Figure 3.2: Mechanics of price pressure. Consider a situation where there are three securities, two risky (called A and B) and one risk-free (called Notes). In A-B space, an agent has endowment point E. S/he wishes to trade up to an aspiration point, say A_0. (The reader cannot verify that the budget constraint is satisfied, because the Notes dimension is not displayed.) We take the aspiration point to be the optimal position at relative prices given by the slope of the line tangent to the indifference curve. As the agent experiences delay in execution of the orders s/he submitted to implement the move from E to A_0, s/he scales back her aspiration point, to A_1. At the revised aspiration point, her marginal valuation for B has increased relative to that of A. This will translate into an increase in the relative price of B s/he is submitting along with her orders, and hence, potential transaction prices. The new marginal valuations are given by the slope of the tangent to the indifference curve at A_1. If execution is delayed further, the agent scales back her aspiration level even more, to A_2. Marginal valuations, and hence, order (and potential transaction) prices change correspondingly. The Hessian of the utility function prescribes how marginal valuations change locally. In the case of mean-variance preferences, the Hessian is proportional to the covariance of the final payoffs. Because revisions of marginal valuations induce changes in order prices, and hence, prices at which transactions will take place, changes in the latter are therefore ultimately determined by the structure of the covariance matrix. This is born out in the experimental data.