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Equilibration of Real Financial Markets: Theory and Experimental Evidence

(Previously entitled *"Testing CAPM in Real Markets: Implications from Experiments")*

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Abstract

The theory and the data in this paper challenge the view that there is no structure in prices and allocations when markets are off equilibrium. Starting from the observation that price taking usually applies only to small orders, a theory of equilibration is derived based on the assumption that orders are optimal only locally. Prices adjust in the direction of the order imbalance. In the context of mean-variance preferences, the theory predicts that a security's price will correlate with excess demands in other securities, and the sign of this correlation is the same as that of the covariance of the final payoffs. In the short run, prices tend to a local equilibrium where the risk-aversion weighted endowment portfolio (RAWE) is mean-variance optimal. Relative to the market portfolio, RAWE overweighs securities that are held disproportionally by more risk averse agents; RAWE puts less weight on securities that are held primarily by more risk tolerant agents. Throughout equilibration, portfolio separation is violated generically, and violations are more extreme when payoff covariances are positive. For a variety of patterns of initial allocations (including identical initial holdings), the equity premium is larger at the outset than at (CAPM) equilibrium. Experimental evidence confirms the predictions conclusively.

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1 Introduction

Competitive markets and *competitive equilibrium* are fictions. In competitive markets, agents take prices as given. Competitive equilibrium means that agents choose demands based on prices which are already set to clear markets at the chosen demands. Even if one buys the concept of competitive markets, competitive equilibrium may be questioned because agents cannot make correct conjectures about equilibrium prices if, as is typically assumed, agents observe nothing about other agents (preferences, beliefs, endowments). Nevertheless, competitive equilibrium has been the workhorse of the bulk of asset pricing theory.

Many theories have been suggested to determine whether competitive equilibrium is the natural resting point of competitive markets. The answer in the most prominent of these theories, Walrasian price adjustment, is negative: the *Debreu-Mantel-Sonnenschein Theorem* claims that aggregate excess demand is not subject to any restrictions, so markets are not guaranteed to converge to competitive equilibrium if, as posited in Walrasian price adjustment, prices merely adjust in proportion to aggregate excess demand.

Real-life financial markets are often cited as the prime example of competitive markets. These markets are mostly organized as a set of parallel, continuous double auctions, sometimes around an order book open to all participants. In this institution, agents may submit market or limit orders at any time. Market orders are immediately executed against the best standing order on the other side of the market; limit orders are executed instantaneously only if they cross standing orders on the other side of the market. Otherwise they are added to the book. Markets are generally not connected, in the sense that limit orders cannot be made dependent on events in other markets.

Typically in financial markets, the bid-ask spread, namely, the difference between the prices of the best sell and buy orders, is small. This feature lends credibility to the claim that real financial markets are examples of competitive markets. But these markets are generally shallow at the best quotes, i.e., the quotes are valid only for limited quantities. Consequently, *price taking may be a good characterization of real financial markets, but only for small orders.*

It is hard to determine whether real financial markets equilibrate. In the study of asset pricing in field mar-

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kets, equilibration is usually an auxiliary assumption that cannot independently be verified for lack of knowledge of preferences, beliefs and endowments of the traders. Because of (albeit limited) control of preferences, beliefs and endowments, laboratory studies of financial markets provide an opportunity to establish equilibration independently. Recently, laboratory studies have confirmed that financial markets indeed move towards competitive equilibrium. See Bossaerts and Plott (2004), Bossaerts, Plott and Zame (2004a). Convergence obtains despite the fact that price taking in the laboratory markets, just like in field markets, applies only to small orders.

In this paper, a *theory of equilibration* is advanced for markets where price-taking only applies to small orders. At its core is the assumption that *agents submit orders that are optimal only locally.* Optimality is conditional on the last transaction price. Subsequently, *prices adjust in proportion to order imbalance.* We describe the nature of the price adjustment. In the short run, markets tend towards a local equilibrium that can be described in simple terms. As orders are converted into trades, holdings evolve over time. Generic features of the evolution of the holdings emerge.

The proposed theory of equilibration is developed in the context of mean-variance preferences, but obviously applies to more general preferences as well. We stay within the context of mean-variance preferences, because empirical verification will be done in an experimental setting where mean-variance preferences will be induced through suitably nonlinear payoff schedules. Mean-variance preferences are also implicitly assumed in the popular linear pricing models in empirical finance. And they provide a good description of prices and allocations in financial markets experiments with small but significant levels of risk.

In fact, it was a striking characteristic of price adjustment in the latter experiments that prompted the theoretical development of this paper. The characteristic was originally reported in Asparouhova, Bossaerts and Plott (2003) and Asparouhova and Bossaerts (2004), but we will replicate it here as well. When projecting transaction price changes onto (globally optimal) aggregate excess demands, strong cross-security effects emerge: prices in one market adjust to aggregate excess demands in *all* other markets. The cross-security effects obtain despite the absence of any direct, mechanical relationship between markets (as mentioned before, orders cannot be made dependent on events in other markets). The cross-security effects at times are so strong that they offset the positive relationship between a security's transaction price change and its own global excess demand. In other words, prices could fall even if a security was in excess demand, a rather puzzling observation in view of received wisdom.[1] The theory developed here explains cross-security effects.

The paper derives a number of additional implications about price and allocation dynamics which are tested in follow-up experiments. Unlike the earlier ones, the follow-up experiments do not involve risk. Instead, mean-variance preferences are induced by rewarding subjects according to a fixed, quadratic payoff schedule as a function of portfolio holdings. While mean-variance preferences appear to explain prices and (average) choices in experiments involving

[1] Arrow and Hahn (1971), p. 304, for example, argue that a process that mimics the invisible hand *must* have the property that the price of a good increases when it is in excess demand.

multiple risky securities – see Bossaerts and Plott (2004) and Bossaerts, Plott and Zame (2004a), theoretical equilibrium price levels cannot be computed unambiguously for lack of knowledge of individual subjects' levels of risk aversion. In contrast, when mean-variance preferences are directly induced through quadratic payoff functions, equilibrium price levels can be computed unambiguously. These computations are needed because some of the predictions of the proposed theory concern the level of off-equilibrium prices relative to equilibrium levels.

The payoff functions in the follow-up experiments consists of a linear and a quadratic part. In analogy with mean-variance preferences under risk, the coefficients in the linear part will be referred to as the *vector of mean payoffs.* The coefficients in the quadratic part will be referred to as the *payoff covariance matrix.* When payoffs are linear in a security's holdings, that security is referred to as a *riskfree security.* Otherwise, it will be referred to as a *risky security.* Of course, there is no risk in the follow-up experiments, and the references to risk are only made because of the analogy with standard portfolio theory.

From the point of view of general equilibrium theory, there is no difference between experiments where mean-variance preferences obtain through risk and those where mean-variance preferences are directly induced by means of quadratic payoff functions. Equilibrium prices and allocations in both cases are given by the Capital Asset Pricing Model (CAPM). We shall refer to the experiments involving risk as *CAPM experiments*, while those in which CAPM is induced through quadratic payoff functions will be denoted *Certainty-Equivalent CAPM experiments.* In the CAPM, equilibrium prices make the market portfolio mean-variance optimal, and equilibrium allocations exhibit portfolio separation. The latter means that all agents hold the same portfolio of risky securities, independent of risk aversion (in the CAPM experiments) or the numerical value of the coefficient of the quadratic part of the payoff function (in the Certainty-Equivalent CAPM experiments). A comparison of terminal prices and allocations in the two types of experiments confirms that they are indeed equivalent. (Which does not mean that the experiments support the theory uniformly; we shall discuss this later in the paper.)

The theory of equilibration proposed in this paper makes the following predictions.

First, it predicts that the *sign of the cross-security effects ought to be the same as that of the corresponding element of the covariance matrix in the payoff function.* If the covariance between the final payoffs of two securities is positive, then the cross-security effect between one security's excess demand and the other security's transaction price change is positive as well; otherwise it is negative.

Second, the theory *identifies a portfolio that is mean-variance optimal in local equilibrium.* That is, in the short run, prices always move in the direction that makes a specific portfolio mean-variance optimal. This portfolio, dubbed *RAWE*, for *risk-aversion-weighted endowment portfolio*, is the sum of investors' holdings weighted by relative risk aversion. Thus, holdings of more risk averse investors are weighted more heavily. RAWE and the market portfolio eventually coincide, which implies that CAPM pricing ultimately obtains. But because RAWE and the market portfolio are closely related, the latter may become approximately mean-variance optimal even when markets are still far off their (global) equilibrium. That is, the market portfolio may move towards the mean-variance frontier long before prices or holdings reach equilibrium levels.

Third, throughout equilibration, *violations of portfolio separation obtain generically*, even if all agents start with the same initial holdings. Violations are more extreme when diversification adds less to utility, i.e., when payoff covariances are positive. Eventually, CAPM allocations obtain, so portfolio separation holds. Nevertheless, if the adjustment process halts prematurely because further gains from trade are too small for agents to care, portfolio separation fails. At that point, holdings will deviate more from the equilibrium predictions when payoff covariances are positive.

Fourth, for a large variety of configurations of initial allocations, the *equity premium is larger at the initial local equilibrium than at the eventual global equilibrium.* The equity premium is the expected return on the market portfolio in excess of the return on the riskfree security. The equity premium translates into risk premia on individual securities through the covariances between their payoffs and the payoff on the market portfolio, i.e., through the betas. If a security's beta is positive, its risk premium will be bigger initially than at (CAPM) equilibrium. If a security's beta is negative, its risk premium will be smaller (and negative) initially.

The Certainty-Equivalent CAPM experiments provide convincing support for the four implications. Cross-security effects invariably change sign when payoff covariances do. RAWE (and the market portfolio) move to the mean-variance frontier long before markets reach equilibrium price levels and even if they never reach that point. Portfolio separation fails everywhere, and mean absolute deviations of individual final portfolio holdings from CAPM predictions are bigger when payoff covariances are positive. Finally, the equity premium is larger initially than at the end. The theory correctly predicts the relationship between initial allocations and the difference between the initial and final equity premia.

A final remark is in order before presenting the details. It may seem that agents in our theory are myopic, and hence, irrational, because they do not form expectations about potential future price changes. It should be considered, however, that agents *may not be able to form sensible expectations* for lack of information on other agents' preferences, beliefs and endowments. In addition, agents *can* trade small quantities at posted prices, and they *do so optimally.* That is, their actions must not be readily labeled as irrational.

The remainder of this paper is organized as follows. Section 2 discusses related literature. Section 3 develops the theory. Section 4 explains the experimental design. Section 5 presents the empirical results. Section 6 concludes.

2 Related Literature

Elements of the proposed theory of equilibration have been suggested elsewhere. Smale (1976) studied convergence of a price adjustment scheme that bears much resemblance to ours, although he was far less specific about price adjustments and he did not characterize local equilibrium. Importantly, Smale showed that such an equilibration process is guaranteed to converge to a Pareto optimal allocation for a wide variety of preferences as long as it does not halt prematurely. That is, the process exhibits the very stability that the Walrasian price adjustment scheme is deprived off because of the Debreu-Mantel-Sonnenschein Theorem.

In a working paper, Ledyard (1974) asked which direct mechanisms would guarantee convergence to Pareto optimal allocations in competitive situations. One of his suggestions is the very adjustment process that is proposed here.

Another related study is Saari and Simon (1978), who demonstrate that the Walrasian auctioneer would need the Jacobian of the excess demands in addition to the excess demands themselves in order for him to change prices in a way that ensures stability. Note that there is a close relationship between the Jacobian of excess demand and the Hessian of the utility function. In the case of mean-variance preferences, the Hessian is proportional to the covariance matrix. Now, the covariance matrix, and hence, the Hessian of utility or the Jacobian of excess demand, is crucial to our equilibration theory as well – cross-security effects are determined by covariances. That is, our equilibration process uses the information that Saari and Simon identify to be crucial for correct price adjustment.

A couple of experimental studies on equilibrium convergence in multi-security markets predate the present one, namely, Plott (2000) and Anderson, e.a. (2004). These deal with situations where equilibration is problematic, however. The approach here is different. We take markets that are known to converge to equilibrium, and we ask: how does it happen?

Finally, a companion study [Bossaerts, Plott and Zame (2004b)] demonstrates that the theory proposed here sheds light on a number of robust but previously unexplained off-equilibrium phenomena in well-known experiments on Walrasian equilibrium in a world with two goods.

3 Theory

Consider an economy with N agents, indexed $n = 1, ..., N$. There are three securities, referred to as securities A, B, and *Notes*. If agents n holds a vector x of units of A and B, and h units of the Notes, her utility is described by the following function:

$$u_n(h, x) = 100h + [x \cdot \mu] - \frac{b_n}{2}[x \cdot \Omega x]. \tag{1}$$

b_n is a positive scalar. If A and B are risky securities with expected payoff vector μ and covariance matrix Ω, and h is a riskfree security with payoff 100, then the above utility function is of the mean-variance type, and b_n would denote agents n's coefficient of risk aversion. Such an interpretation is not necessary: it may be that there is no risk at all, and that our agent has linear utility but is paid according to the quadratic schedule in (10). This will be the situation in the experiments to be introduced later. Or our agent may have nonlinear preferences over the securities, described by the utility function in (10). Nevertheless, we will refer to the coefficient vector μ as the vector of expected payoffs, to the coefficient matrix Ω as the covariance matrix (the off-diagonal elements will be called covariances), to the coefficient b_n as n's risk aversion, and to securities A and B as the risky securities.

There are markets in the three securities. Let p denote the vector of prices of securities A and B. The Notes are take to be the numeraire, and we set its price equal to 100.

The *Walrasian equilibrium* is derived as follows. Agents determine (globally) optimal demands subject to their budget constraint, taking prices as given. Agent n's vector of optimal demands for the risky securities A and B equals:

$$x_n^*(p) = \frac{1}{b_n}\Omega^{-1}(\mu - p) \tag{2}$$

The vector of optimal demands is proportional to $\Omega^{-1}(\mu - p)$, which is a vector that is common to all agents. That is, all agents demand the same portfolio of risky securities, up to a constant of proportionality. This is the aforementioned *portfolio separation* property. In equilibrium, the commonly demanded portfolio must of course equal the portfolio of supplies of A and B. The latter is referred to in the finance literature as the *market portfolio.* Consequently, the market portfolio must be a mean-variance optimal portfolio in equilibrium. This result is the prototype of asset pricing theory, the Capital Asset Pricing Model, or CAPM for short.

The explicit mathematical derivation of the CAPM proceeds as follows. Let x_n denote agent n's endowment of A and B. Define the the per-capita supply of risky securities, i.e., the market portfolio:

$$\bar{x}^N = \frac{1}{N}\sum_{n=1}^{N} x_n.$$

In equilibrium, aggregate demand must equal aggregate supply:

$$\frac{1}{N}\sum_{n=1}^{N} x_n^*(p) = \bar{x}^N.$$

Solving for p generates the equilibrium price:

$$p^* = \mu - B^N \Omega \bar{x}^N, \tag{3}$$

where B^N is the harmonic mean of the b_ns across the N agents,

$$B^N = \left(\frac{1}{N}\sum_{n=1}^{N}\frac{1}{b_n}\right)^{-1}.$$

Roll (1977) showed that whenever a portfolio z satisfies the following relationship for some (positive) scalar β,

$$p = \mu - \beta\Omega w, \tag{4}$$

then w is mean-variance optimal. That is, the portfolio has minimal payoff variance given its mean. Notice that this is exactly the form of the equilibrium pricing formula in (3), with $\bar{x}^N$ replacing w and B^N replacing β. Consequently, at equilibrium prices, the market portfolio is mean-variance optimal. As mentioned before, this is the essence of the CAPM.

Consider now the following *theory of equilibration.* It is meant to predict price and allocation dynamics in a continuous trading system that is competitive only for small quantities, like the one used in many financial markets, and in the experiments to be discussed soon. Constrained by the shallowness of markets, agents do not optimize globally, but only locally. That is, their orders maximize local gains in utility; they do not lead to a global maximum. This obviously amounts to a major departure from standard economic analysis. Our theory of equilibration will be build on an additional, uncontroversial proposition, namely, that order imbalance leads to price pressure; upward if there are more offers to buy (bids) than offers to sell (asks); negative otherwise.

Let p now denote the vector of prices of A and B at which agents can trade small quantities (as before, we set the price of the Notes equal to 100). The scalar h_n and the vector x_n denote agent n's current holdings of Notes and risky securities, respectively. Let L_n describe utility trade-offs along agent n's budget constraint:

$$L_n(x) = u_n((p/100) \cdot (x_n - x) + h_n, x) = 100[(p/100) \cdot (x_n - x) + h_n] + [x \cdot \mu] - \frac{b_n}{2}[x \cdot \Omega x].$$

As is well known, a function's gradient points into the direction of maximal local change, i.e., the gradient maximizes the directional derivative. Therefore, we assume that agent n's orders are the elements of the gradient of L_n:

$$z_n = \nabla L_n(x_n) = \mu - b_n \Omega x_n - p.$$

All the orders z_n, $n = 1, ..., N$, are sent to the marketplace, where they add up to a vector of order imbalances Z:

$$Z = \sum_{n=1}^{N} z_n = \sum_{n=1}^{N} (\mu - \Omega b_n x_n - p).$$

In general, Z is different from zero, so not all orders can be executed. As a result, there will be price changes (Δp), which we assume to be in proportion to the order imbalance:

$$\Delta p \sim Z = \sum_{n=1}^{N} (\mu - \Omega b_n x_n - p) \tag{5}$$

This amounts to a set of difference equations which describe the evolution of prices, conditional on holdings x_n.

Let us study these difference equations more closely, to determine whether they imply some easily verifiable predictions about the direction of price pressure. To accomplish this, let us re-express the equations in terms of global excess demands. In our setting, global excess demands equal global optimal demands minus holdings x_n. From (2), agent n's global excess demands equal:

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

Pre-multiplying with Ωb_n and re-ordering, one obtains:

$$\Omega b_n[x_n^*(p) - x_n] = \mu - \Omega b_n x_n - p.$$

The right-hand-side is the expression in parentheses in (5). After substitution, (5) therefore becomes:

$$\Delta p \sim \Omega \sum_{n=1}^{N} b_n[x_n^*(p) - x_n]. \tag{6}$$

We obtained our first major prediction.

Prediction 1 *Global excess demands translate into price pressure through the covariance matrix Ω. Among other things, the effect of the weighted sum of excess demands for one security onto the price of another security has the same sign as the corresponding covariance.*

Asparouhova, Bossaerts and Plott (2003) and Asparouhova and Bossaerts (2004) report results from projections of price changes onto aggregate (global) excess demand. Aggregation of individual excess demands was based on simple averaging. Prediction 1, however, refers to the sum of individual excess demands *weighted by risk aversion* [see (6)]. The simple average and the weighted sum of excess demands are sufficiently correlated, however, that the projection results turn out to be almost identical. If our theory of equilibration is true, then the interpretation of the results in Asparouhova, Bossaerts and Plott (2003) and Asparouhova and Bossaerts (2004) is that the significant cross-security effects emerge not because price changes and simple average excess demand are related in a fundamental way, but because the latter is highly correlated with the weighted sum of excess demands.

Next, let us determine where prices tend to in the short run. The *short run* is the time period during which some trade takes place (while prices adjust), but the total volume of transactions is insufficient to cause major shifts in the allocations of the majority of agents. In other words, holdings are essentially fixed. As a result, price adjustment is described by the difference equations in (5), with constant endowments x_n, $n = 1, ..., N$.

We are looking for the stationary point of the difference equations. Because they are first-order, linear equations, the stationary point always exists and will be approached exponentially. We will refer to the stationary point as the *local equilibrium*. Inspection of the difference equations reveals that it equals

$$p^o = \mu - \Omega \frac{1}{N} \sum_{n=1}^{N} b_n x_n. \tag{7}$$

Notice that this equation is of the same form as the one that characterizes mean-variance optimal portfolios, namely, (4). In particular, the two equations coincide for $\beta = 1$ and $w = (1/N)\sum_{n=1}^{N} b_n x_n$.[2] This implies that the portfolio $(1/N)\sum_{n=1}^{N} b_n x_n$ is mean-variance optimal at local equilibrium. This portfolio is the average holdings portfolio, where each agent's holdings are weighted by his or her risk aversion. The holdings of more risk averse agents (agents with higher b_n) are weighted more heavily, and *vice versa*. We will refer to this portfolio as the *risk-aversion weighted endowment portfolio*, or *RAWE* for short. We have obtained our second prediction.

Prediction 2 *In the short run, prices tend exponentially fast to a local equilibrium where RAWE (the risk-aversion weighted endowment portfolio) is mean-variance optimal.*

The RAWE and market portfolios are closely related. If allocations are independent of holdings, then the two coincide. Such is the case, for instance, if all agents hold the market portfolio, as in the CAPM equilibrium allocation. To the extent that the RAWE and market portfolios are related, Prediction 3 is relevant for the market portfolio as well. In particular, prices tend to levels that make the market portfolio close to mean-variance optimal. The market portfolio will be mean-variance optimal in the initial local equilibrium when all agents start out with the same holdings. The market portfolio may temporarily veer away from the mean-variance frontier, but it will eventually return, to reach CAPM equilibrium.

Our third prediction concerns changes in allocations. These occur when orders become transactions. Assuming that a fraction δ of an agent's orders are executed, her holdings change as follows:

$$\Delta x_n = \delta\left(\mu - \Omega b_n x_n - p\right).$$

Let us study what happens if the trades take place at local equilibrium prices (after all, this is the point at which all orders balance). Substituting p^o for p and using the formula (7), we obtain:

$$\Delta x_n = -\delta\Omega\left[b_n x_n - \frac{1}{N}\sum_{\nu=1}^{N} b_\nu x_\nu\right]. \tag{8}$$

In words: changes in endowments (Δx_n) are a linear transformation (defined by $\delta\Omega$) of the deviation between a subject's risk-aversion-weighted portfolio ($b_n x_n$) and the RAWE portfolio ($\frac{1}{N}\sum_{\nu=1}^{N} b_\nu x_\nu$).

It is interesting to study what such dynamics imply in the extreme case where all subjects start out with the market portfolio. In that case, the expression in square brackets in (8) simplifies:

$$\left[b_n x_n - \frac{1}{N}\sum_{\nu=1}^{N} b_\nu x_\nu\right] = \left(b_n - \frac{1}{N}\sum_{\nu=1}^{N} b_\nu\right)\frac{1}{N}\sum_{\nu=1}^{N} x_\nu = \left(b_n - \frac{1}{N}\sum_{\nu=1}^{N} b_\nu\right)\bar{x}^N.$$

[2] Alternatively, one could write

$$p^o = \mu - \left(\frac{1}{N}\sum_{n=1}^{N} b_n\right)\Omega\frac{1}{N}\sum_{n=1}^{N}\frac{b_n}{\frac{1}{N}\sum_{n=1}^{N} b_n}x_n.$$

In this case, $\beta = (1/N)\sum_{n=1}^{N} b_n$ and $w = (1/N)\sum_{n=1}^{N}[b_n/(1/N)\sum_{n=1}^{N} b_n]x_n$.

Hence,

$$\Delta x_n = -\delta \left(b_n - \frac{1}{N} \sum_{\nu=1}^{N} b_\nu \right) \Omega \bar{x}^N.$$

That is, changes in holdings are a linear transformation of the market portfolio. Except in the unlikely event that the market portfolio is an eigenvector of Ω, the new holdings will not be the market portfolio anymore. Agents trade away from the market portfolio, and consequently, they end up with holdings that *violate portfolio separation*.

The mathematical equations suggest in what direction portfolios change. Imagine that Ω is diagonal, the diagonal elements of Ω being the payoff variances. In that case, volume (the absolute value of the elements in Δx_n) will be highest for the high-variance securities. That is, most portfolio adjustments take place in the high-variance securities. The sign of the changes in an agent's holdings of risky securities depends on his risk aversion (b_n) relative to the average risk aversion ($\frac{1}{n} \sum_\nu b_\nu$). More risk averse agents sell risky securities (the entries of Δx_n are negative); less risk averse agents buy. Effectively, more risk averse agents unload risky securities, paying more attention to the most risky securities, because that way their local gain in utility is maximized. Likewise, less risk averse agents do what is locally optimal: increase risk exposure by buying the most risky securities first.

When Ω is non-diagonal, the sign of the off-diagonal elements interferes with the above dynamics. Intuitively, when the off-diagonal elements are negative, i.e., when the payoff covariances are negative, securities are natural hedges for each other, and the market portfolio provides diversification. Increasing one's risk exposure by buying mostly risky securities (or decreasing one's risk exposure by selling mostly risky securities) leads to a less diversified portfolio, i.e., to utility losses. Maximum local gains in utility are obtained by trading combinations of securities that are closer to the market portfolio. As a consequence, agents' portfolios of risky securities will remain closer to the market portfolio than if payoff covariances were zero (or positive, for that matter). That is, we expect to see less extreme violations of portfolio separation.

Eventually, equilibrium is reached, at which point portfolio separation will be restored. But agents must be willing to implement all trades necessary to attain equilibrium. At a certain point in the equilibration process, agents may not perceive enough gains to cover the effort it takes to trade. At that point, portfolio separation may still fails. The intuition behind this is simple. It is well known that gains from diversification are of second order. Agents first of all ensure that they hold the right mix of risky and riskfree securities. Once they acccomplish this, further rebalancing of their portfolio to fine-tune diversification may lead to utility gains, but if these are an order of magnitude smaller, they will be ignored.

We have obtained our third prediction

Prediction 3 *Throughout equilibration, violations of portfolio separation obtain generically. Violations are more extreme when covariances are positive.*

Finally, let us study the implication of our equilibration theory for the equity premium. As it turns out, while the market portfolio will be close to mean-variance efficient by virtue of its association with the RAWE portfolio, it may initially be priced very differently when compared to CAPM equilibrium predictions. In particular, the equity premium may be much higher than the equilibrium equity premium.

This is easiest to see when all agents start with the same endowments. In the initial local equilibrium, the market portfolio is *on* the mean-variance frontier, as mentioned before. The prices of the risky securities equal:

$$p^o = \mu - \Omega \frac{1}{N} \sum_{n=1}^{N} b_n x_n = \mu - \left(\frac{1}{N} \sum_{n=1}^{N} b_n \right) \Omega \frac{1}{N} \sum_{n=1}^{N} x_n = \mu - \left(\frac{1}{N} \sum_{n=1}^{N} b_n \right) \Omega \bar{x}^N.$$

At eventual (CAPM) equilibrium, the prices are different:

$$p^* = \mu - B^N \Omega \bar{x}^N$$

[see (3); B^N denotes the harmonic mean risk aversion]. Define the equity premium as the difference between the expected payoff on the market portfolio and its price (we ignore the riskfree rate because it is always zero by construction). From the above, the difference between the equity premium at the initial local equilibrium and that at the final CAPM equilibrium equals:

$$\bar{x}^N \cdot [(\mu - p^o) - (\mu - p^*)] = \left(\frac{1}{N} \sum_{n=1}^{N} b_n - B^N \right) \left(\bar{x}^N \cdot \Omega \bar{x}^N \right) > 0$$

because the harmonic mean is always smaller than the arithmetic mean (assume heterogeneity of risk aversion coefficients). That is, the equity premium is higher initially than when CAPM equilibrium is reached.

The equity premium is larger at the outset for other initial endowment patterns as well. Inspection of the pricing formulae reveals that this happens whenever

$$\bar{x}^N \cdot \Omega \left(\frac{1}{N} \sum_{n=1}^{N} b_n x_n - B^N \bar{x}^N \right) > 0. \tag{9}$$

The condition will be satisfied in the experiments. We conclude:

Prediction 4 *For a variety of patterns of initial allocations, the equity premium at the local equilibrium for initial allocations is larger than the equity premium at the final global (CAPM) equilibrium. The condition obtains, among others, when all agents start out with the same holdings.*

Let us now discuss experiments that are designed to test the four predictions.

4 Experiments

We proceed in two parts. First we describe the experimental setup. Next, we translate the predictions of the previous section into precise quantitative observations that we expect to obtain in the experiments.

4.1 Experimental Setup

Each experiment consists of a number of independent replications, referred to as *periods*, of the same situation. At the beginning of a period, subjects are endowed with a number of each of 3 securities. Like in the theory, these securities are referred to as A, B and *Notes*. Subjects are also endowed with cash, used in the trading, and perfectly substitutable for Notes. Markets in each of the securities are available, and subjects can submit orders and trade as they like, during a pre-set amount of time. The trading interface is a fully electronic (web-based) version of a continuous open order book system. After markets close, subjects are paid depending on their final holdings of the securities, minus a fixed, pre-determined loan payment. The payment is nonlinear in the holdings of A and B, and linear in the holding of Notes, as detailed below. After payment, securities are taken away and a new period starts. Subjects keep the payments accumulated over the periods.

In contrast to traditional experiments in economics, subjects are not present in a centralized laboratory equipped with computer terminals, but access the trading platform over the internet. Communication takes place by email, phone and announcements through the main experiment web page.[3] That is, the experiment takes place in cyberspace, as opposed to a single physical location. This allows for much larger experiments than usual (30 to 42 subjects instead of 8 to 12), as the number of participants is only limited by server and network capacity. The larger scale ensures that a trading environment is created that approximates the conditions of the theory: bid-ask spreads are reduced to a minimum (one tick), but they apply only to small quantities. That is, price-taking prevails, but only for small orders.

End-of-period payments are determined using payoff functions that are quadratic in the holdings of A and B and linear in the Notes. The chosen payoff function induces the mean-variance preferences of the theory in the previous section. Subject n, when holding h units of the Notes, C cash and the vector x of A and B receives a payoff

$$u_n(h, x) = C + 100h + [x \cdot \mu] - \frac{b_n}{2}[x \cdot \Omega x] - L_n, \tag{10}$$

where L_n denotes the loan payment. Note that only b_n and L_n are subject-dependent.

In the experiments,

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

[3]The interested reader can browse http://eeps3.caltech.edu/market-020528. This web site provides the instructions for a typical experiment (the 28 May 02 experiment), the trading interface, and the announcements. To log in as observer, use ID=1, password=a.

and

$$\Omega = \begin{bmatrix} 10000 & s3000 \\ s3000 & 1400 \end{bmatrix}.$$

The symbol s in front of an entry in the matrix Ω denotes the sign. That is, s is either $+$ or $-$. To generate strong confirmation of Prediction 1 (the sign of the correlation between price changes and excess demands depends on the sign of the corresponding payoff covariances), we change the sign s after four periods.

Subjects are assigned one of three levels for the parameter b_n, chosen in such a way as to generate similar pricing (equity premia) as in the earlier CAPM experiments reported in Asparouhova, Bossaerts and Plott (2003), and where significant cross-security effects were first documented. See Table 1 for details.

Each type also receives a different initial allocation of A and B (nobody receives any Notes to start with, i.e., Notes were in zero net supply). Subjects are not informed of each others' payment schedules or initial holdings, and whether these varied over the course of the experiment (they did not). This way, subjects with knowledge of general equilibrium theory could not possibly compute equilibrium prices. Therefore, subjects could not form reasonably credible expectations about where prices would tend to.

All accounting is done in terms of an artificial currency, the franc. At the end of the experiment, cumulative earnings are converted to dollars at a pre-announced exchange rate. On average, subjects make about \$45 for a three-hour experiment; the range of payments is \$0 to approximately \$150. These payments, however, inaccurately reflect the size of the incentives during trading. Explicit computations of the amounts of money subjects leave on the table because they did not fully optimize (and assuming that they can trade at end-of-period prices) reveal values over \$100 per subject/period in early periods. Some subjects are savvy enough to realize part of these potential gains, but most don't (which explains the substantial range of payouts across subjects). As more subjects realize that there is money to be made, their actions and the ensuing price changes cause these amounts invariably to drop to approximately \$2 in later periods. Subjects seem not to spend the extra effort needed to extract the last couple of dollars.[4]

4.2 Predictions

Armed with the numerical values of the parameters (allocations, payoff functions) in the experiments, let us translate the four predictions of our equilibration theory into specific numerical observations to be expected in the experiments.

Prediction 1 states, among other things, that the sign of the coefficients in projections of price changes onto excess demands is the same as that of the corresponding payoff covariance. In particular, we expect to observe a switch in the

[4]Since each hour consists of approximately three periods, this amounts to \$6 per hour, indicating that subjects need to be given incentives of at least as much in order to generate some evidence of optimizing behavior. The minimum incentive is likely to depend on the nature of the task, but little information on incentive sensitivity in other contexts seems to be publicably available. Detailed incentive calculations for the experiments at hand can be obtained from the author.

sign of the projection coefficients when the corresponding payoff covariances change halfway through the experiment.

To test Prediction 2, we study the evolution of the Sharpe ratio (expected excess return divided by volatility) of RAWE. We expect the Sharpe ratio to be close to maximal throughout the equilibration process, even when markets are still far off the levels predicted by CAPM equilibrium.

Proposition 3 can be verified by analyzing end-of-period holdings. We expect to observe violations of portfolio separation, in the form of significant mean absolute deviations of individual portfolios (weights on security A) from the market portfolio. In addition, we expect the mean absolute deviations to be larger when payoff covariances are positive.

To determine whether and by how much the beginning-of-period equity premium will be larger than the end-of-period one (Prediction 4), we evaluate (9) using the parametrization in the experiments. Assume an equal number of subjects of each type. (The actual numbers may be slightly different – see Table 1.) When the payoff covariance is positive, the theoretical difference in the equity premium equals:

$$\begin{aligned} & \bar{x}^N \cdot \Omega \left(\frac{1}{N} \sum_{n=1}^{N} b_n x_n - B^N \bar{x}^N \right) \\ = \;& (4,6) \cdot ((44,17) - (16,6)) \\ = \;& 178. \end{aligned}$$

When the payoff covariance is negative, the theoretical equity premium difference is as follows:

$$\begin{aligned} & \bar{x}^N \cdot \Omega \left(\frac{1}{N} \sum_{n=1}^{N} b_n x_n - B^N \bar{x}^N \right) \\ = \;& (4,6) \cdot ((4,2) - (6,-1)) \\ = \;& 10. \end{aligned}$$

In both cases, the equity premium is expected to be larger initially. But the discrepancy is far bigger when the covariance is positive.

5 Empirical Results

5.1 Transaction Prices

Figure 1 displays the evolution of prices of securities A (dashed line) and B (dash-dotted line). The prices of the Notes are not shown; these are invariably close to 100 francs, their no-arbitrage value. Each observation corresponds to a trade in one of the three securities. The prices of the non-trading securities is set equal to their previous trade prices.

Time (in seconds) is on the horizontal axis; Price (in francs) is on the vertical axis. Vertical lines separate periods. Horizontal lines indicate equilibrium prices of A (solid line) and B (dotted line). Note that their level changes after 4 periods, reflecting the change in the off-diagonal element of Ω, i.e., the payoff covariance.

The first observation to be made about Figure 1 is that transaction prices are almost invariably *below* equilibrium prices. It will be demonstrated shortly that this is related to Prediction 4, which states that the price of the market portfolio (a positively-weighted sum of the prices of A and B) will initially be below equilibrium levels. Figure 1 demonstrates that Prediction 4 applies throughout equilibration, and not just to beginning-of-period prices.

The covariance is negative in periods 1 through 4 in the first experiment (28 Nov 01) and positive in periods 5 through 8. The design is reversed in the other experiments: the covariance is positive in periods 1 through 4 and negative in periods 5 through 8.

With this in mind, a second observation can be made. Relative to equilibrium levels, prices generally start out lower in periods with positive covariance. Again, Prediction 4 is at work, as discussed later. It should also be remarked that prices generally do not come as close to equilibrium levels when the covariance is positive.

5.2 Prediction 1: Cross-Security Effects

Table 2 displays results from projections of changes in transaction prices of A and B onto the weighted sum of individual (global) excess demands (as mentioned before, the results are qualitatively the same when projecting onto the simple average of individual excess demands). The time series for each experiment are split in two; one sub-sample covers periods with positive covariance; the other covers periods with negative covariance. Only intra-period price changes are used. Estimates of slope coefficients of aggregate excess demands are bold-faced whenever they are significant at the 1% level. Tests are one-sided; they compare the null hypothesis that the coefficient is zero against the alternative that it is positive (in the case of the projection coefficient of a security's own aggregate excess demand) or has the same sign as the covariance (in the case of the projection coefficient of the other security's aggregate excess demand).

The regression R^2s are small, but the F tests reveal that significance is high. The first-order autocorrelation of the error term suggests little mis-specification (some are significantly negative, but one expects the data to generate a number of significant autocorrelations even if the null of no autocorrelation is right).

The support for Prediction 1 is strong. First, a security's aggregate excess demand has a significant impact on the price of the other security. This replicates the findings in Asparouhova, Bossaerts and Plott (2003), where cross-security effects were first documented, and Asparouhova and Bossaerts (2004), where cross-security effects are reported in a four-asset setting. Second, confirming Prediction 1, the signs of the cross-effects are almost always the same as that of the covariances (if they are not, the results are insignificant). In addition, the impact of a security's own aggregate excess demand is always positive, as expected. The estimation results are highly significant.

Table 2 thus confirms Prediction 1 in that the matrix of coefficients in projections of transaction price changes onto aggregate excess demands has the same structure as the covariance matrix. A closer inspection of the table suggests that this projection coefficient matrix not only reflects the signs of the corresponding elements of the covariance matrix, but also their relative magnitude. For instance, the slope coefficient of own excess demand in the projection of the price change of security A is generally the largest; the corresponding element in Ω, i.e., the variance of A, happens to be largest as well.

5.3 Prediction 2: Off-Equilibrium Mean-Variance Optimality Of The RAWE Portfolio

Prediction 2 states that prices in the short run will tend to make the RAWE portfolio mean-variance optimal. We verify this by recording the distance of the RAWE portfolio from the mean-variance efficient frontier. The distance is measured as the difference between the Sharpe ratio (at transaction prices) of the RAWE portfolio and the maximum possible Sharpe ratio. In an absolute sense, it is hard to know when this distance is "large." To obtain a relative sense of distance, we do the following. First, we normalize the distance by the maximum (observed) distance in an experiment. Hence, our distance measure will be between zero and one; it equals zero when the RAWE portfolio is mean-variance optimal; it equals one when the distance is maximal in the experiment at hand. Second, we compare the evolution of this distance with the difference of the value of the market portfolio evaluated at transaction prices and its value at CAPM equilibrium. We refer to the latter as the *distance from equilibrium pricing.* Again, we normalize this distance by the maximum observed in the experiment. The distance from equilibrium pricing is obviously zero if the value of the market portfolio equals that predicted by the CAPM.[5]

The normalization and the comparison with the distance from equilibrium pricing are insightful. Figure 2 displays the evolution of the distance of the RAWE portfolio from mean-variance optimality and that of the distance from equilibrium pricing. The contrast between the two distance measures is often pronounced. The RAWE portfolio almost invariably moves quickly to the mean-variance efficient frontier, confirming Prediction 2. Still, prices may be far from equilibrium. The latter is more pronounced in periods when the covariance is positive (periods 5-8 in experiment 28 Nov 01; periods 1-4 in the remaining experiments).

Figure 2 confirms Prediction 2 and therefore demonstrates that there is structure in the cross-section of prices even off-equilibrium. The speed with which the RAWE portfolio becomes mean-variance optimal confirms the hypothesis behind Prediction 2 that this is a short-run phenomenon – local equilibrium.

As mentioned earlier, the close relationship between the market portfolio and the RAWE portfolio suggests that, off equilibrium, even the market portfolio may be close to mean-variance optimal. While we do not report the results, the evolution of the distance of the market portfolio from mean-variance optimality is not much different from that

[5] Note that pricing at CAPM equilibrium levels is sufficient for the distance measure to be zero, but not necessary.

for the RAWE portfolio. The picture looks pretty much like Figure 2.

The evolution of the distance from equilibrium pricing generates the impression that markets have a tougher time equilibrating when the covariance is positive. This theme will re-appear when presenting the evidence on Prediction 4.

5.4 Prediction 3: End-Of-Period Portfolio Holdings

Figures 1 and 2 indicate that prices often fail to reach equilibrium levels by the end of a period. Because of this, Prediction 3 comes into play. It states that, if equilibration is not carried through all the way to the end, then end-of-period holdings will violate portfolio separation. Perhaps more importantly (in view of the fact that subjects' initial allocations violate portfolio separation anyway), the violations are expected to be larger when the covariance is positive.

The evidence in favor of Prediction 3 is conclusive. Table 3 not only shows that violations of portfolio separation are significant, but also that they are uniformly larger in periods when the covariance is positive. Violations of portfolio separation are measured as the mean absolute deviation between the weights on security A in individual portfolios and in the market portfolio. Straightforward computations of standard errors of the differences between the mean absolute deviations (not reported) lead one to conclude that the violations of portfolio separation are always significantly bigger in periods with positive covariance than in periods with negative covariance.

Notice also the remarkable similarity in the recorded mean absolute deviations across periods with the same covariance and across experiments.

5.5 Prediction 4: The Equity Premium

The choice of parameter values in the experiments implies that the difference between the initial equity premium and its equilibrium value is expected to be positive and largest when the covariance (off-diagonal element of Ω) is positive. The predictions may not apply, however, to the difference between the equity premium in the beginning and at the end of a period if prices fail to reach equilibrium (which is often the case in periods with positive covariance; see Figures 1 and 2).

Table 4 provides the evidence. Two observations can be made. First, equity premia are generally larger initially than either in equilibrium (numbers to the left of the slashes) or at the end of a period (numbers to the right of the slashes). Second, the differences are higher when the covariance is positive (bold-faced entries indicate significance at the 1% level using a one-sided test).

6 Conclusion

This paper presented a theory of dynamics of prices and allocations in markets where price taking is an appropriate behavioral assumption only for small orders. Experiments provided strong support for its predictions.

The theory was tested in a laboratory setting, where important parameters are known because they are directly controlled. Nevertheless, the theory has important qualitative and quantitative implications for empirical studies of field data as well. Specifically,

1. The cross-effects in the theory (Prediction 1) and the data imply that equilibration, and hence, short-term price behavior, cannot be studied in a single market in isolation. Partial equilibrium analysis may therefore be misleading. One may discover, for instance, that the prices of a security are not responsive to its excess demand because excess demand in other markets was ignored. A striking example of such a situation is discussed in Asparouhova and Bossaerts (2004).

2. Many doubt that markets are continuously in equilibrium. Neo-austrian economists, in fact, claim that markets never fully equilibrate [see Benink and Bossaerts (2001)]. Does this imply that markets defy formal analysis? More specifically, does this render futile thirty years of empirical work of linear asset pricing? The goal of this work has been to characterize the mean-variance efficient frontier in terms of a small number of spanning portfolios. The theory of this paper and the data strongly counter this pessimism. The theory identifies a mean-variance optimal portfolio throughout equilibration (Prediction 2) and the data confirm the prediction.

3. Many popular pricing models build on portfolio separation. These models need not be discredited because holdings in the field blatantly reject portfolio separation. The violations may be off-equilibrium effects. In this respect it would be interesting to determine whether one of our predictions (Prediction 3) is borne out in field data as well, namely, that violations of portfolio separation are related to benefits of diversification.

4. In the field, equity premia are often puzzlingly high. Our theory, however, predicts large off-equilibrium equity premia (Prediction 4) and the experimental results confirm the prediction. Therefore, to the extent that prices in field markets are recorded out of equilibrium, high equity premia may not be disturbing after all.

The theory developed in this paper identifies a portfolio that remains mean-variance optimal throughout equilibration (Prediction 2). This result can be used to model the cross-section of expected returns on risky securities. In particular, the model predicts that expected excess returns are proportional to betas defined with respect to the RAWE portfolio. The latter differs from the market portfolio in that it weighs more heavily securities held by more risk averse agents. A value effect emerges immediately if more risk averse agents hold value stock in larger proportions than more risk tolerant agents.

A final remark concerns stability. Smale (1976) proves that adjustment processes such as the one proposed in this paper are stable for a much larger set of preferences and endowments than the traditional Walrasian adjustment. Prices and allocations will not necessarily converge to the Walrasian equilibrium, however, but to a Pareto-optimal allocation.[6] The empirical success of our model suggests therefore that economists may want to study Pareto optimal points as the natural resting states of competitive markets, instead of focusing on Walrasian equilibrium.

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[6] The distinction is without consequence in the setting of the CAPM because there are no wealth effects.

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Table 1: Experimental Design Data.

Exp.[a]	Subject Cat. (#)[d]	b_n[b] ($\times 10^{-3}$)	Signup Reward (franc)	Endowments A	Endowments B	Endowments Notes	Cash (franc)	Loan Repayment[c] (franc)	Exchange Rate $/franc
28 Nov 01	14	2.30	125	2	8	0	400	2340	0.06
	14	0.28	125	8	2	0	400	2480	0.06
	14	0.15	125	2	8	0	400	2365	0.06
20 Mar 02	10	2.30	125	2	8	0	400	2320	0.06
	10	0.28	125	8	2	0	400	2470	0.06
	10	0.15	125	2	8	0	400	2370	0.06
24 Apr 02	14	2.30	125	2	8	0	400	2320	0.06
	13	0.28	125	8	2	0	400	2470	0.06
	13	0.15	125	2	8	0	400	2370	0.06
28 May 02	13	2.30	125	2	8	0	400	2320	0.06
	12	0.28	125	8	2	0	400	2470	0.06
	12	0.15	125	2	8	0	400	2370	0.06

[a]Date of experiment.
[b]Coefficient b_n in the payoff function (10).
[c]Coefficient L_n in the payoff function (10).
[d]Number per subject type.

Table 2: Projections Of Transaction Price Changes Onto Weighted Sum Of Excess Demands

Experiment	Periods	Sign[a]	Security	Coefficients[b]			R^2	F-statistic[c]	N^d	ρ^e
				Intercept	Excess Demand					
					A	B				
28 Nov 01	1-4	−	A	0.1	**20.7**	**-6.5**	0.05	27.0	1138	−0.12**
				(0.0)	(2.8)	(0.9)		(< .01)		
			B	-0.0	-1.4	**1.5**	0.06	33.6	1138	-0.06
				(0.0)	(1.8)	(0.6)		(< .01)		
	5-8	+	A	0.6	**20.0**	**5.4**	0.05	31.3	1224	−0.30**
				(0.1)	(2.8)	(0.9)		(< .01)		
			B	-0.1	0.5	**1.2**	0.05	30.3	1224	0.03
				(0.1)	(1.7)	(0.5)		(< .01)		
20 Mar 02	1-4	+	A	0.6	**18.8**	**5.4**	0.04	12.8	668	-0.02
				(0.1)	(3.7)	(1.1)		(< .01)		
			B	-0.5	-5.9	1.8	0.12	45.5	668	0.04
				(0.2)	(4.6)	(1.4)		(< .01)		
	5-8	−	A	-0.3	**32.1**	**-8.1**	0.06	16.6	491	-0.07
				(0.1)	(7.3)	(2.5)		(< .01)		
			B	-0.0	-7.0	**6.2**	0.16	48.1	491	0.08
				(0.1)	(5.0)	(1.7)		(< .01)		
24 Apr 02	1-4	+	A	1.3	**33.6**	**10.1**	0.07	26.5	745	−0.03
				(0.2)	(4.6)	(1.4)		(< .01)		
			B	-0.3	-2.2	0.5	0.07	25.9	745	0.06
				(0.1)	(3.0)	(0.9)		(< .01)		
	5-8	−	A	-0.3	**17.4**	**-5.2**	0.04	14.4	675	-0.04
				(0.1)	(5.2)	(1.9)		(< .01)		
			B	0.1	**-31.9**	**12.6**	0.14	52.6	675	-0.07
				(0.1)	(3.6)	(1.3)		(< .01)		
28 May 02	1-4	+	A	0.6	**18.8**	**4.9**	0.04	18.4	825	0.04
				(0.2)	(3.7)	(1.2)		(< .01)		
			B	-0.8	**10.5**	**6.9**	0.16	76.5	825	0.04
				(0.2)	(3.5)	(1.1)		(< .01)		
	5-8	−	A	-0.1	**9.0**	**-2.9**	0.02	4.3	563	−0.14**
				(0.1)	(3.1)	(1.1)		(0.01)		
			B	-0.1	**-9.3**	**4.6**	0.08	23.6	563	0.01
				(0.1)	(3.4)	(1.2)		(< .01)		

[a] Sign s of the off-diagonal element of the matrix Ω. The OLS coefficient matrix evidently inherits the structure (in particular, the sign s) of this matrix.

[b] OLS projections of transaction price changes onto (i) an intercept, (ii) the weighted sum excess demands for the two risky securities (A and B). Each individual excess demand is weighted by the coefficient risk aversion coefficient b_n. Time advances whenever one of the three assets trades. Boldfaced coefficients are significant at the 1% level using a one-sided test (effect of own excess demand is positive; cross-effect has the same sign as the corresponding covariance). Standard errors in parentheses.

[c] p-level in parentheses.

[d] Number of observations.

[e] Autocorrelation of the error term; * and ** indicate significance at the 5% and 1% level, respectively.

Table 3: Mean Absolute Deviations Of Individual Portfolio Weights From Market Portfolio Weights

Experiment	Periods	Sign[a]	Period			
			1 or 5	2 or 6	3 or 7	4 or 8
28 Nov 01	1-4	−	0.15[b]	0.14	0.12	0.12
			(0.02)[c]	(0.02)	(0.02)	(0.02)
	5-8	+	0.24	0.25	0.23	0.26
			(0.03)	(0.03)	(0.03)	(0.03)
20 Mar 02	1-4	+	0.24	0.26	0.24	0.25
			(0.03)	(0.03)	(0.03)	(0.03)
	5-8	−	0.13	0.11	0.13	0.11
			(0.02)	(0.02)	(0.03)	(0.02)
24 Apr 02	1-4	+	0.25	0.26	0.25	0.25
			(0.02)	(0.02)	(0.02)	(0.03)
	5-8	−	0.17	0.12	0.10	0.09
			(0.02)	(0.01)	(0.01)	(0.01)
28 May 02	1-4	+	0.24	0.27	0.22	0.22
			(0.03)	(0.02)	(0.02)	(0.03)
	5-8	−	0.17	0.15	0.10	0.10
			(0.02)	(0.02)	(0.02)	(0.02)

[a]Sign s of the off-diagonal element of the matrix Ω. The mean absolute deviation of individual portfolio weights from market portfolio weights is expected to be significantly larger when $s = +$.

[b]Average absolute difference between (i) the proportion individuals invest in security A relative to total franc investment in securities A and B, and (ii) the corresponding weight in the market portfolio; portfolio weights are computed on the basis of end-of-period prices and holdings.

[c]Standard error in parentheses.

Table 4: Initial Equity Premia *minus* Equilibrium Equity Premia and *minus* Final Equity Premia

Experiment	Periods	Sign[a]	Period			
			1 or 5	2 or 6	3 or 7	4 or 8
28 Nov 01	1-4	−	-45/-54[b]	37/27	16/-25	20/8
			(9/9)[c]	(2/2)	(2/2)	(2/2)
	5-8	+	35/3	97/87	71/7	47/34
			(20/18)	(4/3)	(3/26)	(2/2)
	5-8 *vs.* 1-4		**80/57**[d,e]	**60/61**	**55/32**	**27/26**
			(21/20)[f]	(4/4)	(3/7)	(3/3)
20 Mar 02	1-4	+	120/25	55/23	44/30	37/22
			(21/20)	(10/11)	(2/2)	(2/2)
	5-8	−	36/18	24/9	26/13	19/10
			(7/7)	(3/3)	(2/2)	(1/2)
	1-4 *vs.* 5-8		**84**/7[g]	**31**/14	**18/17**	**18/12**
			(22/22)	(10/12)	(3/3)	(2/2)
24 Apr 02	1-4	+	30/-61	99/69	59/11	62/11
			(14/11)	(4/6)	(1/3)	(1/1)
	5-8	−	86/49	51/38	23/6	25/7
			(5/7)	(10/9)	(3/5)	(2/3)
	1-4 *vs.* 5-8		-56/-110	**48/31**	**36**/5	**37**/4
			(15/13)	(10/11)	(4/5)	(2/3)
28 May 02	1-4	+	89/-33	99/35	76/29	75/19
			(19/19)	(11/10)	(1/2)	(2/2)
	5-8	−	108/69	46/31	46/22	37/8
			(5/7)	(1/2)	(3/3)	(1/2)
	1-4 *vs.* 5-8		-19/-102	**53**/4	**30/7**	**38/11**
			(20/20)	(11/11)	(3/3)	(3/3)

[a] Sign s of the off-diagonal element of the matrix Ω. The difference between the equity premium at the beginning of the period and the equilibrium or final equity premium is expected to be positive; it is expected to be significantly larger when $s = +$.

[b] Left number: average difference between (i) the equity premium at the beginning of the period, and (ii) the equilibrium equity premium; right number: average difference between (i) the equity premium at the beginning of the period, and (ii) the equity premium at the end of the period. Averages are taken over 20 transactions.

[c] Standard error in parentheses.

[d] Equity premium difference in period 5 (positive covariance) minus equity premium difference in period 1 (negative covariance).

[e] Boldface: significant at the 1% level (one-sided test).

[f] In parentheses: standard error of subtraction in previous row.

[g] Equity premium difference in period 1 (positive covariance) minus equity premium difference in period 5 (negative covariance).

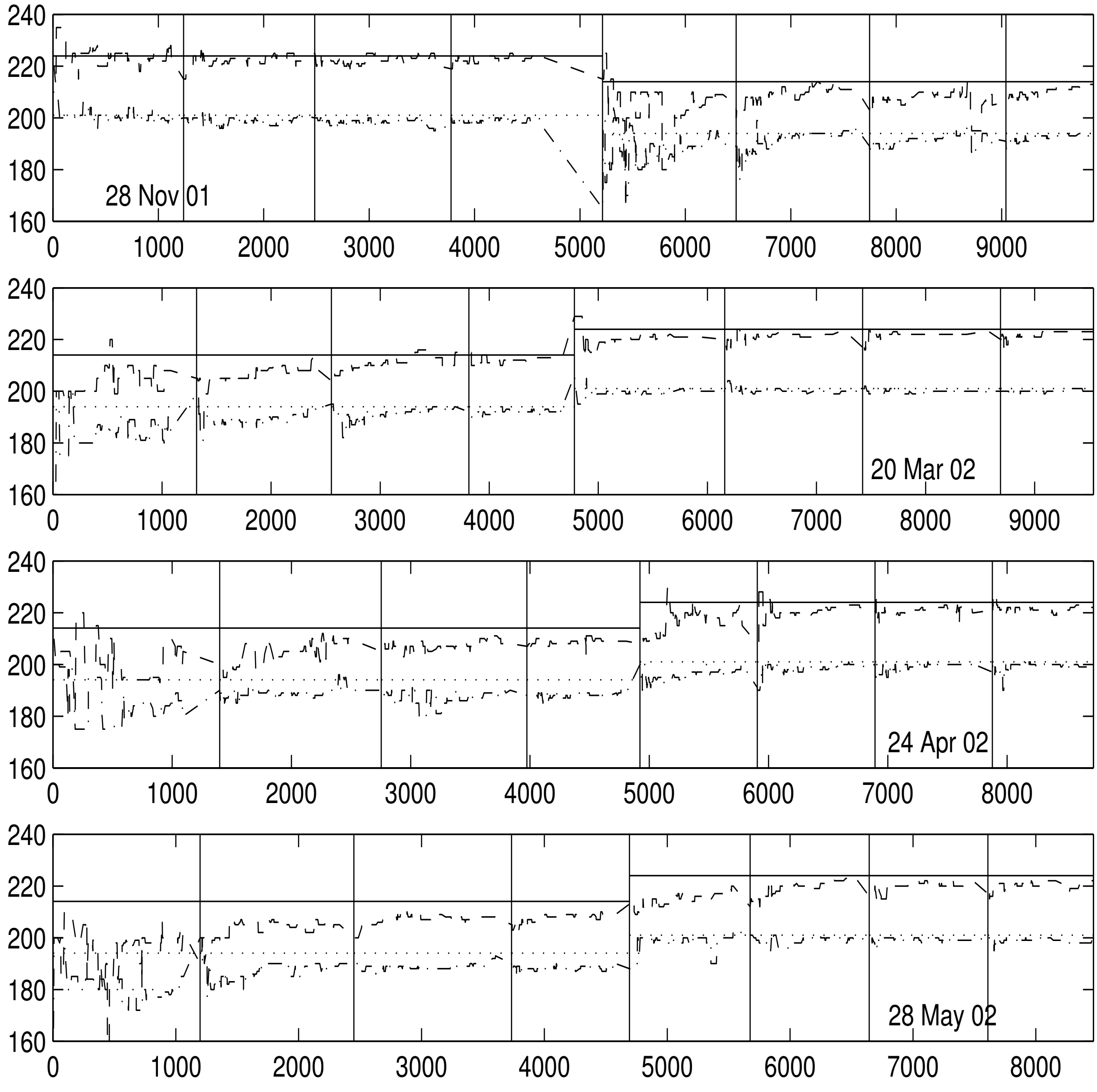

Figure 1: Evolution of transaction prices of securities A [dashed line] and B [dash-dotted line]. Horizontal lines indicate CAPM equilibrium price levels [A: solid line; B: dotted line]. Time (in seconds) on horizontal axis; prices (in francs) on vertical axis. Vertical lines delineate periods.

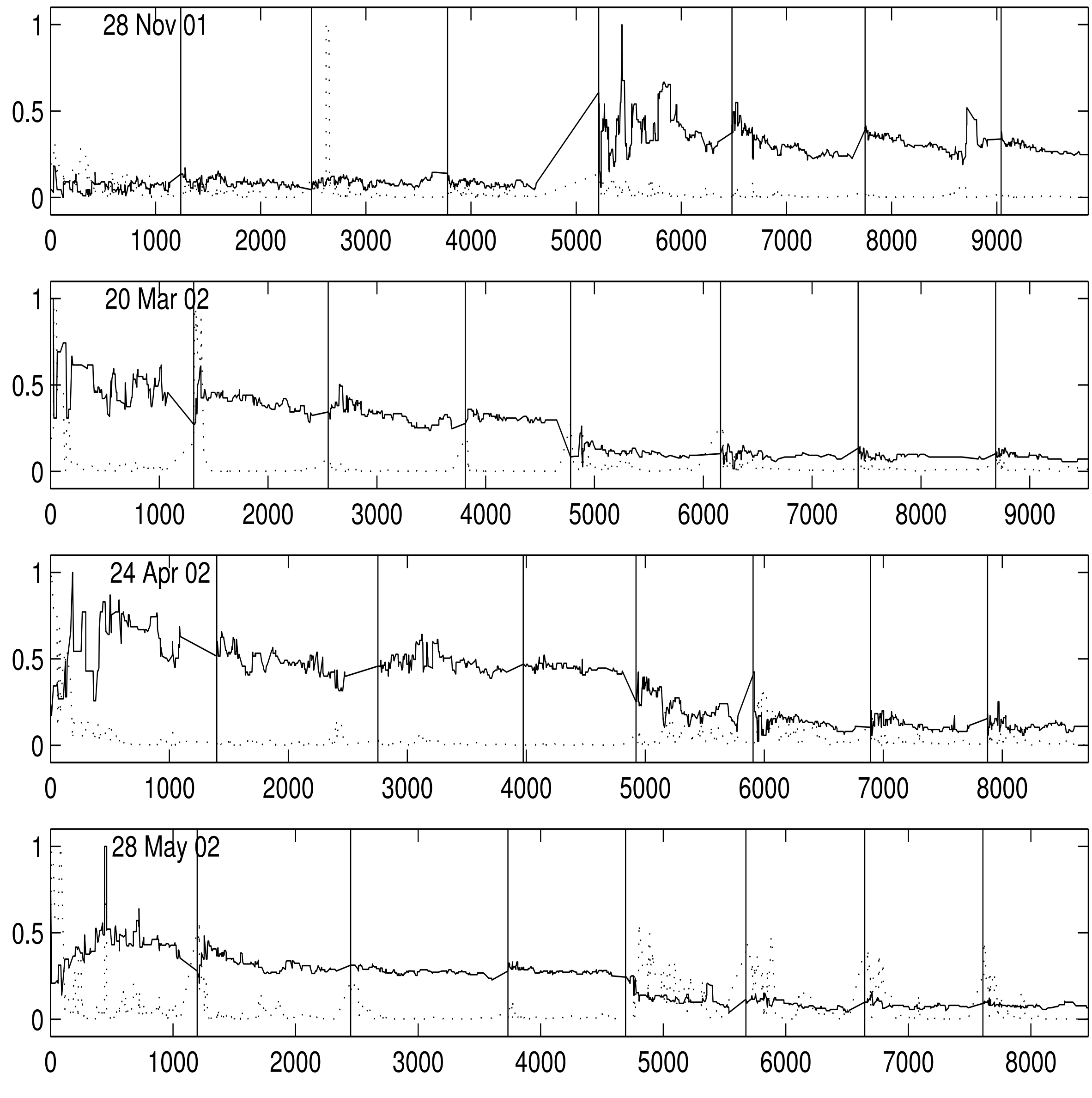

Figure 2: Evolution of (i) difference between value of market portfolio evaluated at market prices and at CAPM equilibrium prices [solid line]; (ii) difference between Sharpe ratio of the market portfolio and maximal Sharpe ratio at market prices [dotted line]. Differences are scaled so that maximum difference = 1. Time (in seconds) on horizontal axis; difference on vertical axis. Vertical lines delineate periods.