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## Funding liquidity risk and the cross-section of stock returns

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Funding Liquidity Risk and the Cross-Section of Stock Returns

Tobias Adrian  
Erkko Etula

Staff Report no. 464  
July 2010

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## **Funding Liquidity Risk and the Cross-Section of Stock Returns**

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JEL classification: G1, G12, G21

### **Abstract**

We derive equilibrium pricing implications from an intertemporal capital asset pricing model where the tightness of financial intermediaries' funding constraints enters the pricing kernel. We test the resulting factor model in the cross-section of stock returns. Our empirical results show that stocks that hedge against adverse shocks to funding liquidity earn lower average returns. The pricing performance of our three-factor model is surprisingly strong across specifications and test assets, including portfolios sorted by industry, size, book-to-market, momentum, and long-term reversal. Funding liquidity can thus account for well-known asset pricing anomalies.

Key words: cross-sectional asset pricing, funding liquidity risk, ICAPM

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## 1. Introduction

Leveraged financial institutions intermediate the allocation of funds from savers to borrowers. We refer to financial institutions' funding liquidity as their ease of borrowing. Times of abundant funding liquidity are characterized by compressed risk premia. Shocks to funding liquidity thus capture shifts in the investment opportunity set. By implication, investors require higher compensation for holding assets that co-move strongly with funding liquidity shocks. Hence, such assets are expected to earn higher average returns.

In this paper, we show that funding liquidity risk constitutes an important risk factor for the cross-section of stock returns. In the first part of the paper, we formalize our definition of funding liquidity by constructing an intertemporal capital asset pricing model (ICAPM, see Merton, 1973) with two types of investors, active and passive. Active investors are leveraged financial intermediaries subject to borrowing constraints related to the Value at Risk (VaR) of their balance sheet. The model shows that these funding constraints link economy-wide expectations of investment opportunities directly to the portfolio choice of active investors. Specifically, a decrease in funding liquidity forces a decrease in their financial leverage. Thus, the behavior of active investors reflects economy-wide funding conditions, and by implication, economy-wide expectations of future investment opportunities. Most importantly, our model identifies three new state variables linked to the aggregate balance sheet components of active and passive investors. Since these state variables are observable, we can test the predictions of the model directly in the data.

The second part of the paper tests our theory in the cross-section of stock returns. We use the universe of security brokers-dealers as a representation of the active

investors, building on the work of Adrian and Shin (2010) who document that broker-dealers manage their balance sheets in an unusually aggressive way to take advantage of changes in funding conditions. We show that our funding liquidity model explains expected returns across a wide variety of equity cross-sections that have been problematic for existing asset pricing models: in addition to pricing the cross-section of 30 industry portfolios, our three-factor funding liquidity model rivals existing portfolio-based factor models that have been tailored to price the cross-sections of 25 size and book-to-market sorted portfolios, 25 size and momentum portfolios, and 25 size and long-term reversal portfolios. We regard these results as strong support for our insight that the portfolio choice of active forward-looking investors provides a window to expectations of future economic conditions.

### **1.1. Related Literature**

In developing and testing our funding liquidity model, we build on three broad strands of research. The first strand is comprised of the vast literature on intertemporal asset pricing. The idea that long-term investors care about shocks to investment opportunities originates in the ICAPM of Merton (1969, 1971, 1973). Kim and Omberg (1996) provide closed form solutions to a particular case of Merton's dynamic portfolio allocation behavior. Campbell (1993) solves a discrete-time empirical version of the ICAPM with a stochastic market premium, writing the solution in the form of a multifactor model. Campbell (1996) tests this model on industry portfolios, but finds little improvement over the CAPM. Other empirical studies of the ICAPM include Li (1997), Hodrick, Ng, and Sengmueller (1999), Lynch (1999), Brennan, Wang, and Xia (2002, 2003), Guo (2002), Chen (2002), Ng (2004), Ang, Hodrick, Xing, Zhang (2006, 2009), Adrian and Rosenberg (2008), and Bali and Engle (2009).

The second, emerging strand of literature investigates the impact of balance sheet constraints on aggregate asset prices. Early examples of papers that study the aggregate implications of balance sheet constraints include Aiyagari and Gertler (1999), Basak and Croitoru (2000), Gromb and Vayanos (2002), and Caballero and Krishnamurthy (2004). The approach taken in this paper is closely related to the endogenous amplification mechanisms via the margin spiral of Brunnermeier and Pedersen (2009) where margin constraints are time-varying and can serve to amplify market fluctuations through changes in risk-bearing capacity. The studies most relevant to ours are the investigation of foreign exchange markets of Adrian, Etula and Shin (2009) and of commodity markets by Etula (2009). Both papers introduce risk-based balance sheet constraints in a two-agent CAPM, generating time-varying effective risk aversion that can be expressed in terms of observable state variables. Danielsson, Shin and Zigrand (2009) endogenize risk and effective risk aversion simultaneously by solving for the equilibrium stochastic volatility function in a setting with value-at-risk constraints on financial intermediaries. The empirical study of Muir (2010) uses the growth of broker-dealer leverage to investigate average returns on size and book-to-market, industry, and momentum sorted portfolios. Since broker-dealer leverage is the inverse of one of the three state variables identified by our theory, his findings are consistent with our results.

The third strand of literature that relates to our paper is comprised of the numerous competing explanations for the size and value effects (Fama and French, 1993), the momentum effect (Jegadeesh and Titman, 1993, 2001; Rouwenhorst, 1998, 1999; Chui, Titman, and Wei, 2000), and the long-term and short-term reversal effects (DeBondt and Thaler, 1985, 1987; Chopra, Lakonishok and Ritter, 1992). It is well known that the Arbitrage Pricing Theory (APT) of Ross (1976) allows any pervasive source

of common variation to be a priced risk factor. Fama and French (1993) follow the APT insight and describe the average returns on portfolios sorted by size and value using a three-factor specification, which complements the market model with a size factor and a value factor. However, since the APT is silent about the determinants of factor risk prices, a model such as that of Fama and French cannot explain why the risk premia associated with certain factors are positive or negative. The same caveat applies to other APT-motivated factor models constructed to explain asset pricing anomalies, including the momentum factor of Carhart (1997) and the long-term reversal factor.

The failures of standard asset pricing models can also be interpreted in behavioral terms by arguing that the size, value, momentum and long-term reversal effects are due to mispricing. Lakonishok, Shleifer, and Vishny (1994), for example, suggest that investors irrationally extrapolate past earnings growth and thereby overvalue companies that have performed well in the past. DeBondt and Thaler (1985, 1987), Barberis, Shleifer and Vishny (1998), Daniel, Hirshleifer, and Subrahmanyam (1998), Hong and Stein (1999), and Hong, Lim and Stein (2000) suggest that both momentum and long-term reversal are the results of mispricing.

In this paper, we seek to avoid these alternative explanations. The theoretical motivation of our paper combines insights from the first two strands of literature to develop a version of Merton's ICAPM based on the first-order conditions of two rational investors, a long-horizon investor who is risk neutral but subject to a balance sheet risk constraint, and a myopic investor with constant relative risk aversion. The purpose of our empirical section is to investigate the extent to which deviations from the CAPM's cross-sectional predictions can be rationalized by intertemporal hedging considerations that are relevant for long-term investors.

The rest of the paper is organized as follows. Section 2 formalizes our hypothesis within an intertemporal asset pricing framework. Section 3 describes the data. Section 4 tests the theoretical predictions in the cross-section of stock returns. Section 5 concludes.

## 2. Theoretical Framework

We begin by working out a two-agent intertemporal asset pricing framework, which shows how liquidity enters the economy's pricing kernel. We derive an expression for equilibrium returns in terms of observable state variables.

### 2.1. Active Investors

Consider a leveraged financial institution ( $A$ ) such as a security broker-dealer that invests in risky assets. Denote by  $Y_i^A$  the number of asset  $i$  in the dealer's portfolio. The price of the risky asset  $i$  is  $P_i$ . The value of the portfolio is thus  $\sum_i P_i Y_i^A$ . The funding comes from two sources: equity capital  $w^A$ , and debt with price  $P_D$  and quantity  $Y_D^A$ . It follows that the dealer's balance sheet identity is:

$$\sum_i P_i Y_i^A = P_D Y_D^A + w^A. \quad (2.1)$$

We can take the derivative of (2.1) to obtain the dynamic budget constraint. Assuming that funding is riskless at rate  $r_D$ , defining portfolio weights  $y_i^A \equiv \frac{P_i Y_i^A}{w^A}$  and the excess asset returns  $dR_i = \frac{dP_i}{P_i} - r_D dt$ , we obtain:<sup>1</sup>

$$\frac{dw^A}{w^A} = \sum_i y_i^A dR_i + r_D dt.$$

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<sup>1</sup>Note that our analytical framework can accommodate risky funding at the cost of some added complexity.



We assume that excess returns (henceforth, we refer to excess returns simply as returns) evolve according to:

$$dR_i = \mu_i(x) dt + \sigma_i dZ_i \quad (2.2)$$

$$dx = \mu_x(x) dt + \sigma_x dZ_x \quad (2.3)$$

where  $\mu_i(x)$  is the conditional mean of asset return  $i$ , and  $\sigma_i$  is its conditional volatility.  $Z_i$  and  $Z_x$  are Brownian Motions, with correlations  $\rho^{ij} = \langle dZ_i, dZ_j \rangle$  and  $\rho^{ix_k} = \langle dZ_i, dZ_{x_k} \rangle$ . The conditional means of the state variables  $x$  are assumed to be affine so that  $\mu_x(x) = k(\bar{x} - x)$ .

We assume that dealers are risk neutral and maximize expected portfolio returns subject to a balance sheet constraint related to their Value-at-Risk (VaR), in the manner examined in another context by Danielsson, Shin and Zigrand (2009).<sup>2</sup> The investment problem is:

$$\begin{aligned} J^A(t, w^A, x) &= \max_{\{y_i^A\}_i} E_t [e^{-\delta T} w^A(T)] \\ \text{subject to} &: \\ (1) &: \kappa \langle dw^A \rangle^{\frac{1}{2}} \leq w^A \\ (2) &: \frac{dw^A}{w^A} = \Sigma_i y_i^A dR_i + r_D dt \end{aligned}$$

The quadratic variation of the wealth is  $\langle dw^A \rangle$ . The first constraint is interpreted as a restriction on the VaR, which is a policy function  $\kappa$  times the instantaneous volatility of returns on equity. Due to risk neutrality, the VaR constraint binds with equality. It follows that the Hamilton-Jacobi-Bellman equation is:

$$0 = \max_{\{y^A\}_i} \frac{E_t [dJ^A]}{dt} - \phi \left( \left\langle \frac{dw^A}{w^A} \right\rangle^{\frac{1}{2}} - \frac{1}{\kappa} \right) \quad (2.4)$$

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<sup>2</sup>Adrian and Shin (2008a) provide a microeconomic foundation for the Value-at-Risk constraint.

where  $\phi$  is the Lagrange multiplier on the risk management constraint. The solution to (2.4) can be summarized as:

**Proposition 1 (Portfolio Choice of Active Investors).** *Active investors choose:*

$$y^A = \frac{1}{\tilde{\phi}} (\sigma\sigma')^{-1} (\mu + \sigma\sigma'_x f_x), \quad (2.5)$$

where  $f_x = w^A J_{wx}^A / J^A$  and  $\tilde{\phi} = \kappa\phi / J^A$  is the scaled Lagrange multiplier given by:

$$\tilde{\phi} = \kappa \sqrt{(\mu + \sigma\sigma'_x f_x)' (\sigma\sigma')^{-1} (\mu + \sigma\sigma'_x f_x)}. \quad (2.6)$$

**Proof.** See Appendix A1.1. ■

From (2.5), we see that the asset demands of the active investors are identical to the standard ICAPM choices, but where the risk-aversion parameter is the scaled Lagrange multiplier  $\tilde{\phi}$  associated with the risk constraint. Even though the active investor is risk-neutral, it behaves as if it were risk-averse. In other words, the risk-aversion of the active investor fluctuates with shifts in funding conditions. As the risk constraint binds more strongly,  $\tilde{\phi}$  increases and leverage must be reduced. Note that  $\tilde{\phi}$  is proportional to the generalized Sharpe ratio (adjusted for hedging costs) for the set of risky securities traded in the market as a whole. In order to express  $\tilde{\phi}$  in terms of observable state variables, we will proceed by solving for the equilibrium.

## 2.2. Equilibrium Pricing

To close the model, we assume that there is a second, passive ( $P$ ) group of investors that are nonfinancial corporations or households with constant relative risk aversion  $\gamma$ .

For expositional simplicity, we assume that their demands are myopic:<sup>3</sup>

$$y^P = \frac{1}{\gamma} (\sigma\sigma')^{-1} \mu. \quad (2.7)$$

Market clearing implies:

$$y^A \frac{w^A}{w^A + w^P} + y^P \frac{w^P}{w^A + w^P} = s, \quad (2.8)$$

where  $s$  is a value-weighted aggregate supply of assets. It follows that the equilibrium expected returns can be written in the usual ICAPM form.

**Proposition 2 (Equilibrium Returns).** *The expected excess returns are given by:*

$$\begin{aligned} \mu &= \sigma\sigma'_M \Gamma - \sigma\sigma'_x F_x. \\ &= \text{Cov}_t(dR, dR_M) \Gamma - \text{Cov}_t(dR, dx) F_x, \end{aligned} \quad (2.9)$$

where  $dR_M = s'dR$  is the value-weighted market return,  $\Gamma = \frac{w^P + w^A}{w^P/\gamma + w^A/\tilde{\phi}}$  is the wealth-weighted effective risk aversion and  $F_x = \frac{w^A/\tilde{\phi}}{w^P/\gamma + w^A/\tilde{\phi}} f_x$  is a vector of prices of risk corresponding to the state variables  $x$ .

**Proof.** See Appendix A1.2. ■

We can now solve for the equilibrium prices of risk  $\Gamma$  and  $F_x$ , and for the scaled Lagrange multiplier  $\tilde{\phi}$  in terms of observable variables. Plugging (2.9) into the two investors' first order conditions gives:

$$y^A = \frac{\Gamma}{\tilde{\phi}} s - \frac{1}{\tilde{\phi}} (\sigma\sigma')^{-1} \sigma\sigma'_x (F_x - f_x), \quad (2.10)$$

$$y^P = \frac{\Gamma}{\gamma} s - \frac{1}{\gamma} (\sigma\sigma')^{-1} \sigma\sigma'_x F_x. \quad (2.11)$$

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<sup>3</sup>Allowing for intertemporal asset choice of passive investors is straightforward. However, there is little value added to justify the cost of additional complexity in the equilibrium expressions.

Defining the financial leverage of active investors and passive investors as  $lev^A = \sum_i y_i^A$  and  $lev^P = \sum_i y_i^P$ , and normalizing  $\sum_i s_i = 1$ , we can use the market clearing condition (2.8) along with (2.10) and (2.11) to obtain:

**Proposition 3 (Equilibrium  $\Gamma$ ,  $F_x$ , and  $\tilde{\phi}$ ).**

$$\Gamma = \gamma \left[ 1 + \frac{w^A}{w^P} \left( 1 - lev^A \frac{\left(1 + \frac{w^A}{w^P}\right) \gamma}{\left(1 + \frac{w^A}{w^P}\right) \gamma + Q_x f_x} \right) \right] \quad (2.12)$$

$$F_x = \frac{\frac{w^A}{w^P} lev^A}{1 + \frac{w^A}{w^P} + Q_x f_x / \gamma} f_x \quad (2.13)$$

$$\tilde{\phi} = (\gamma + Q_x f_x) \frac{1}{lev^A} + \gamma \frac{w^A}{w^P} \frac{1}{lev^A} - \gamma \frac{w^A}{w^P}, \quad (2.14)$$

where we have defined the constant  $Q_x = \mathbf{1}' (\sigma \sigma')^{-1} \sigma \sigma'_x$ .

**Proof.** See Appendix A1.3. ■

To gain intuition in (2.12) – (2.14), note that if both investors are myopic, the solutions reduce to

$$\Gamma = \gamma \left[ 1 + \frac{w^A}{w^P} (1 - lev^A) \right]; F_x = 0; \tilde{\phi} = \frac{\Gamma}{lev^A}.$$

That is, the effective risk aversion of the economy,  $\Gamma$ , decreases in the leverage of the active investors. The greater the wealth share of active investors, the greater the impact of their leverage on  $\Gamma$ .

### 2.3. State Variables

By inspection of (2.12) – (2.14), we nominate the following three state variables:<sup>4</sup>

$$x_1 = \frac{1}{lev^A}, \quad (2.15)$$

$$x_2 = \frac{w^A}{w^P} \frac{1}{lev^A}, \quad (2.16)$$

$$x_3 = \frac{w^A}{w^P}. \quad (2.17)$$

It follows that:

$$\Gamma = \gamma \left[ 1 + x_3 \left( 1 - \frac{1}{x_1} \frac{(1 + x_3) \gamma}{(1 + x_3) \gamma + Q_x f_x} \right) \right], \quad (2.18)$$

$$\begin{pmatrix} F_{x_1}(x) \\ F_{x_2}(x) \\ F_{x_3}(x) \end{pmatrix} = \frac{1}{x_1} \frac{x_3}{1 + x_3 + Q_x f_x / \gamma} \begin{pmatrix} f_{x_1} \\ f_{x_2} \\ f_{x_3} \end{pmatrix}, \quad (2.19)$$

$$\tilde{\phi}(x) = (\gamma + Q_x f_x) x_1 + \gamma x_2 - \gamma x_3. \quad (2.20)$$

Note that we can use (2.20) to solve for the value function of active investors. We delegate this solution to Appendix A1.4.

The economic content of our state variables can be understood in terms of time-varying economic conditions, which generate fluctuations in the capital ratio of active investors and the wealth of active investors relative to passive investors. An improvement in funding conditions is associated with an increase in asset values, which allows active investors to increase their leverage via greater borrowing from passive investors. We emphasize that our simple model does not allow us to identify the *causes* of fluctuations in economic conditions (e.g. productivity innovations). But by identifying the

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<sup>4</sup>In order to solve the asset pricing model analytically, we need  $\tilde{\phi}$  to be an affine function of the state variables. Thus, in principle, the model could be solved with two state variables,  $\frac{1}{lev^A}$  and  $\frac{w^A}{w^P} \left( \frac{1}{lev^A} - 1 \right)$ . However, it turns out that the latter variable is trending suspiciously within our empirical estimation sample; given our empirical focus, we thereby decompose it into  $\frac{w^A}{w^P} \frac{1}{lev^A}$  and  $\frac{w^A}{w^P}$ .

relevant state variables that *react* to such revisions in expectations of future investment opportunities, the model does allow us to measure how broader economic conditions vary over time. In this way the information content of our observable state variables can be expected to provide a forward-looking window to the state of the macroeconomy.

## 2.4. Cross-Sectional Predictions

We are now ready to express the equilibrium returns (2.9) in terms of observable state variables. Using (2.18) – (2.20), we obtain:

$$\mu = \sigma\sigma'_M\Gamma(x) - \sigma\sigma'_x F_x(x),$$

or equivalently in discrete time:

$$E_t r_{t+1}^i = Cov_t(r_{t+1}^i, r_{t+1}^M) \Gamma(x_t) - Cov_t(r_{t+1}^i, x_{t+1}) F_x(x_t), \quad (2.21)$$

with  $x_t = [x_t^1, x_t^2, x_t^3]'$  given by (2.15) – (2.17).

In order to test (2.21) in the cross-section of asset returns, we assume constant conditional second moments and take unconditional expectations to obtain:

$$E r_{t+1}^i = \beta_{iM} \lambda_M + \beta'_{ix} \lambda_x \quad (2.22)$$

where  $\beta_{iM} = \frac{Cov(r_{t+1}^i, r_{t+1}^M)}{Var(r_{t+1}^M)}$  denotes the CAPM beta,  $\lambda_M = Var(r_{t+1}^M) \Gamma(x_t)$  denotes the price of market risk,  $\beta'_{ix} = \frac{Cov(r_{t+1}^i, x_{t+1} - E_t x_{t+1})}{Var(x_{t+1} - E_t x_{t+1})}$  denote the factor exposures associated with the risk premia  $\lambda_x = -Var(x_{t+1} - E_t x_{t+1}) F_x$ . The above specification can be estimated via the Fama-MacBeth (1973) two-step procedure. In the first step, we estimate  $\beta_{if}$  from the time-series regression:

$$r_{t+1}^i = a_i + \beta_{iM} r_{t+1}^M + \beta'_{ix} \tilde{x}_{t+1} + \epsilon_{t+1}^i, \quad \text{for } t = 1, \dots, T; \quad i = 1, \dots, N \quad (2.23)$$

In the second step we use the time-series betas  $\beta_{if}$  to estimate the factor risk premia  $\lambda_f$  via the cross-sectional regression:

$$Er_{t+1}^i = \alpha + \beta_{iM}\lambda_M + \beta'_{ix}\lambda_x + \xi^i, \quad \text{for } i = 1, \dots, N. \quad (2.24)$$

We are interested in testing the following predictions:

**Empirical Prediction 1.** Average cross-sectional excess returns are explained by exposures to systematic risk factors. That is,  $\alpha = 0$  in (2.24).

**Empirical Prediction 2.** The cross-sectional prices of risk are of theoretically expected signs and statistically different from zero. Specifically, we expect the prices of risk associated with the capital ratio of active investors,  $\frac{1}{lev^A}$ , and the scaled capital ratio of active investors,  $\frac{w^A}{w^P} \frac{1}{lev^A}$ , to be negative and significant. Intuitively, assets that hedge against adverse funding shocks should earn lower average returns. In Appendix A1.4., we show that under reasonable assumptions the prices of risk  $\lambda_{x_1}$  and  $\lambda_{x_2}$  are indeed negative. We also show that the price of risk associated with the active investor wealth ratio,  $\frac{w^A}{w^P}$ , is expected to be positive. Intuitively, assets that comove with positive surprises to the stock of arbitrage capital should earn higher average returns.

### 3. Data and Construction of State Variables

Our theoretical framework identifies three new potential risk factors for the pricing kernel. In this section, we construct proxies for these state variables using data on the aggregate balance sheets of securities broker-dealers (active investors) and the rest of the U.S. economy (passive investors).

We motivate our choice of broker-dealers as the class of active investors with the work of Adrian and Shin (2008a) who document that broker-dealers manage their balance sheets in an unusually aggressive way to take advantage of changes in funding

conditions. This behavior of broker-dealers results in high leverage in economic booms and low leverage in economic downturns. That is, broker-dealer leverage is *procyclical*.

Guided by our theoretical specification (2.15) – (2.17), we construct the following state variables (BD abbreviates "Broker-Dealer"):

$$x_t^1 = \frac{1}{lev_t^A} = \frac{Equity_t^{BD}}{Assets_t^{BD}} = CapitalRatio_t^{BD} \quad (3.1)$$

$$x_t^2 = \frac{w_t^A}{w_t^P} \frac{1}{lev_t^A} = \frac{Equity_t^{BD}}{Equity_t^{Non-BD}} CapitalRatio_t^{BD} \quad (3.2)$$

$$x_t^3 = \frac{w_t^A}{w_t^P} = \frac{Equity_t^{BD}}{Equity_t^{Non-BD}} \quad (3.3)$$

That is, our first state variable is simply the *capital ratio* (inverse of financial leverage) of broker-dealers. The second state variable is ratio of broker-dealer equity to non-broker-dealer equity, multiplied by the broker-dealer capital ratio, which we will henceforth call the *scaled capital ratio* to lighten notation. The third state variable is simply the ratio of broker-dealer equity to non-broker-dealer equity, or the *wealth ratio*. We construct quarterly series of these variables using data on the book values of total financial assets and total financial liabilities of broker-dealers and the rest of the U.S. economy as captured in the Federal Reserve Flow of Funds.<sup>5</sup>

While the Flow of Funds data begins in the first quarter of 1952, the data from the broker-dealer sector prior to 1969 seems highly suspicious. In particular, broker-dealer equity is *negative* over the period Q1/1952-Q4/1960 and extremely low for the most of 1960s, resulting in unreasonably low capital ratios. As a result, we begin our sample in the first quarter of 1969. The state variables are plotted in Figure 3.1. To test the unconditional model (2.22), we construct shocks  $\tilde{x}_{t+1}$  to the state variables as residuals from a VAR conditioned on information available at time  $t$ . We incorporate

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<sup>5</sup>Note that  $equity_t = (\text{total financial assets}_t - \text{total financial liabilities}_t)$ .



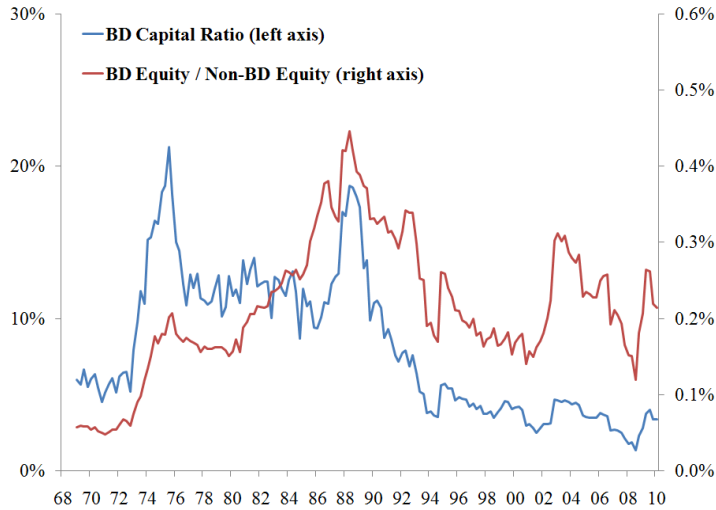


Figure 3.1: Funding Liquidity State Variables. We plot the broker-dealer capital ratio and the ratio of broker-dealer equity to non-broker-dealer equity, as reported in the Federal Reserve’s Flow of Funds Database.

a one-quarter announcement lag for the Flow of Funds variables.<sup>6</sup> We obtain all data on equity portfolios and risk factors from Kenneth French’s data library and cumulate these variables to quarterly frequency.<sup>7</sup>

## 4. Empirical Results

We conduct Fama-MacBeth two-pass regressions to investigate the performance of our funding liquidity model in the cross-section of stock returns. As test assets, we consider the following portfolios constructed to address well-known asset pricing puzzles: 30 industry portfolios, 25 size and book-to-market portfolios, 25 size and momentum portfolios, 25 size and short-term reversal portfolios, 25 size and long-term reversal portfolios.

<sup>6</sup>For instance, the conditional expectation at the end of March 2000 uses data from the most recent Flow of Funds release, which corresponds to December 1999.

<sup>7</sup>For instance, the quarterly market excess return is simply the three-month cumulative excess return on the market portfolio.

We compare the performance of our funding liquidity model to existing benchmark models in each cross-section of stock returns. Whenever a factor is a return, we include it also as a test asset. For instance, when pricing the portfolios sorted on size and book-to-market, we also include the Fama-French (1993) factors Market, SMB and HML as test assets. A good pricing model features an economically small and statistically insignificant average cross-sectional pricing error (“alpha”), statistically significant and stable cross-sectional prices of risk across different test assets and specifications, and high explanatory power as measured by the adjusted R-squared statistic. In order to correct the standard errors for the pre-estimation of betas we report t-statistics of Jagannathan and Wang (1998) in addition to the t-statistics of Fama and MacBeth (1973). Following these evaluation criteria and applying our model to a wide range of test assets, we seek to sidestep the criticism of traditional asset pricing tests of Lewellen, Nagel and Shanken (2010).

The sample considered in the main text is Q1/1969-Q4/2009. We display the results for the subsample that excludes the 2007-09 financial crisis in the Appendix.<sup>8</sup> The results for the pre-crisis subsample, Q1/1969-Q4/2006, are largely similar to the results for the full sample. The sole qualitative difference concerns the magnitude and statistical significance of the cross-sectional alphas implied by our funding liquidity models. Specifically, the alphas are generally small and statistically significant in the full sample but not for some specifications in the pre-crisis subsample. This suggests that the pre-crisis sample may underestimate the exposures of some test assets to systematic funding liquidity risk.

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<sup>8</sup>See Tables A1-A5.

## 4.1. Industry Portfolios

Table 1 displays our pricing results for the 30 industry portfolios. We begin with this cross-section as these simple portfolios have posed a challenge to existing asset pricing models. Column (i) confirms the well-known result that the CAPM cannot price this cross-section: there is no explanatory power, the cross-sectional alpha is 1.51% per quarter and highly statistically significant, and the price of risk of the single market factor is economically small and insignificant.

Columns (iii)-(v) report univariate pricing models with each of our funding liquidity variables. In contrast to the CAPM, our funding liquidity factors are able to explain between 21% and 49% of the cross-sectional variation in mean returns (as measured by the adjusted R-squared). Moreover, all of the cross-sectional alphas are substantially smaller than the CAPM alpha and statistically insignificant. The prices of risk of the broker-dealer capital ratio and the scaled capital ratio are negative, as expected. However, contrary to our theory's prediction, the price of risk associated with the broker-dealer wealth ratio is also negative. We will see that this surprising finding recurs in most of our empirical tests, and one can show that it is fairly robust to the addition of controls.<sup>9</sup> Since our goal is to find a pricing model that is both theoretically motivated and is able to explain cross-sectional returns consistently across different specifications, we will henceforth focus on our two other funding liquidity variables, broker-dealer capital ratio and the scaled capital ratio. We will exclude the broker-dealer wealth ratio also from our preferred multi-factor specifications.<sup>10</sup>

Moving on to the multifactor specifications, column (vi) displays the results from a model with our two funding liquidity factors, broker-dealer capital ratio and the

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<sup>9</sup>These additional tests can be obtained from the authors.

<sup>10</sup>Note that, due to colinearity, we may not put all three funding liquidity variables in a single specification.

scaled broker-dealer wealth ratio. This two-factor specification explains 49% of the cross-sectional variation with an alpha that at 0.80% is fairly small and statistically insignificant. The prices of risk of both funding liquidity factors remain negative and statistically significant. Adding the market factor to the specification (column (vii)) deteriorates the performance of the model slightly by increasing the alpha without contributing to the explanatory power.

We contrast the performance of our funding liquidity model to a popular multi-factor benchmark, the Fama-French three-factor model. The results in column (ii) show that the Fama-French model explains only 9% of the industry cross-section with a large, statistically significant alpha of 1.26%. Also, the prices of risk associated with the Market, SMB and HML factors are statistically insignificant. The specification in column (viii) combines our funding liquidity model with this benchmark to show that both the magnitude and the statistical significance of the funding liquidity factors are preserved when the Fama-French factors are included in the regression specification. The adjusted R-squared increases by a few percentage points to 53%.

#### **4.2. Size and Book-to-Market Portfolios**

Table 2 reports the pricing results for the 25 size and book-to-market sorted portfolios. Column (i) again confirms that the market factor alone is not capable of pricing this cross-section. In contrast, columns (iii)-(iv) show that the univariate specifications with broker-dealer capital ratio and the scaled capital ratio alone are able to explain 66% and 47% of the cross-sectional returns, respectively, with alphas that are small and statistically insignificant.

Columns (vi) and (vii) display the results for our two and three-factor funding liquidity models, which we compare to the 3-factor Fama-French benchmark in column

(ii). Not surprisingly, the Fama-French model—tailored to price this cross-section—produces a high adjusted R-squared of 67%. However, only the market and the HML factors have significant prices of risk and the intercept, while small at 0.13%, is nevertheless statistically different from zero. The performance of this well-known benchmark can be contrasted with that of our funding liquidity models. Quite surprisingly, our three-factor funding liquidity model prices as much as 62% of the cross-section with a small and statistically insignificant alpha of 0.20%. Both funding liquidity variables are negative and statistically significant.

Column (viii) shows that the magnitude and significance of our funding liquidity factors diminish somewhat as one combines the funding liquidity model with the benchmark. The additional explanatory power of the combined model is also limited to a few percentage points. These observations suggest that the information content of our funding liquidity variables overlaps somewhat with the information content of the portfolio-based Fama-French factors. The alpha of the combined specification is small at 0.03%, and is statistically insignificant.

### **4.3. Size and Momentum Portfolios**

Table 3 reports the pricing results for the 25 size and momentum sorted portfolios. The format follows that of Tables 1 and 2 but now the momentum factor of Carhart (1997) replaces the HML in the three-factor benchmark specification. Column (i) again confirms that the market model has no explanatory power for this cross-section. Columns (iii)-(iv) show that the univariate specifications with each of our two funding liquidity variables explain 72% and 73% of the cross-sectional returns with small and statistically insignificant alphas.

Column (ii) shows that the three-factor benchmark explains 76% of the cross-section

but produces a statistically significant alpha of 0.39%. In column (vii), we see that our three-factor funding liquidity model rivals the benchmark by explaining 79% of the cross-section with a statistically insignificant alpha of only  $-0.15\%$ . The prices of risk of the two funding liquidity variables are again negative and highly statistically significant.

Combining our funding liquidity model with the benchmark in column (viii) increases the explanatory power to 87% and further decreases the magnitude of the alpha. In this combined specification, the magnitude and the statistical significance of both funding liquidity factors decreases, suggesting that their information content overlaps somewhat with that of the momentum factor.

#### **4.4. Size and Long-Term Reversal Portfolios**

Table 4 displays the pricing results for the 25 size and long-term reversal sorted portfolios. The format again follows that of the previous tables but now the multifactor benchmark model comprises the market, the SMB and the long-term reversal factor. The qualitative results of the univariate specifications in columns (i) and (iii)-(iv) are similar to those of the previous tables. Column (ii) demonstrates that the multifactor benchmark specification explains 65% of the cross-sectional returns but the alpha of 0.31% is statistically significant. Column (vii) contrasts the benchmark's performance with our funding liquidity model, which explains 48% of the cross-section with a statistically insignificant alpha of 0.23%. The prices of risk of the funding liquidity factors are again negative and highly statistically significant.

Column (viii) shows that combining the funding liquidity model with the benchmark increases the explanatory power to 82% and decreases the alpha to  $-0.10\%$ . The prices of risk of both funding liquidity variables remain statistically significant.

#### 4.5. Size and Short-Term Reversal Portfolios

Our final portfolio is sorted by size and short-term reversal and the results are reported in Table 5. The benchmark model now consists of the Market, the SMB and the short-term reversal factors. Column (ii) demonstrates that the benchmark specification explains 65% of the cross-sectional returns with a statistically insignificant alpha of 0.22%. Columns (iii)-(iv) show that our funding liquidity factors do not have explanatory power for this cross-section; the prices of risk of both factors are positive and statistically insignificant. The inability of our funding liquidity model to explain short-term reversal may not be surprising as short-term reversals occur at intervals shorter than one quarter, which is our data frequency.

#### 4.6. Discussion of Pricing Results

The results in Tables 1-4 demonstrate that our two funding liquidity factors, broker-dealer capital ratio and the scaled capital ratio, do remarkably well in pricing four well-known asset pricing anomalies. A three-factor model that combines the two funding liquidity factors with the market exhibits consistently strong pricing performance across all four cross-sections of test assets, as judged by the explanatory power, the pricing error, and the economic magnitude and significance of the prices of risk. The performance of our model rivals and in some cases even exceeds that of the portfolio-based “benchmarks” that were specifically tailored to explain each anomaly.

To visualize the performance of our funding liquidity model, the four panels of Figure 4.1 plot the realized mean returns of the 30 industry portfolios, 25 size and book-to-market portfolios, 10 momentum portfolios, and 10 long-term reversal portfolios against the mean returns predicted by the CAPM, the Fama-French three-factor model, a 5-factor model that adds the momentum and short-term reversal factors, and our

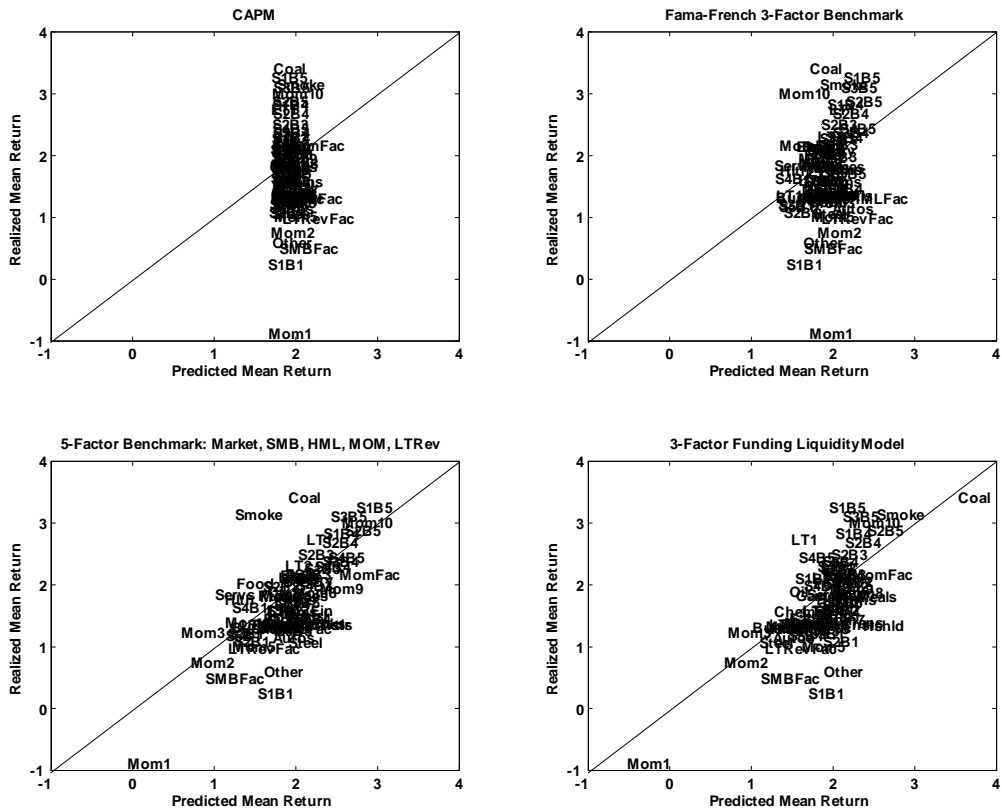


Figure 4.1: Realized vs. Predicted Mean Returns. We plot the realized mean excess returns of 75 portfolios (30 industry, 25 size and book-to-market, 10 momentum, 10 long-term reversal) and 5 factors (market, SMB, HML, momentum, long-term reversal) against the mean excess returns predicted by the CAPM, the Fama-French 3-factor benchmark, a 5-factor benchmark, and the 3-factor funding liquidity model. The sample period is Q1/1969-Q4/2009.



three-factor liquidity model. The plots demonstrate that the funding liquidity model does remarkably well pricing this large cross-section: the explanatory power of the funding liquidity model (adj.  $R^2 = 46\%$ ) easily beats the explanatory power of the Fama-French model (adj.  $R^2 = 6\%$ ) and even that of the tailored 5-factor model (adj.  $R^2 = 43\%$ ).

Yet, what we find most notable is that the prices of risk associated with our two funding liquidity variables are not only statistically significant across different sets of test assets, but their magnitudes are also relatively stable across all four cross-sections. In the three-factor funding liquidity model (column (vi) of Tables 1-4) the price of risk associated with shocks to broker-dealer capital ratio varies from  $-0.17\%$  per quarter (industries) to  $-0.29\%$  (size/long-term reversal) to  $-0.36\%$  (size/momentum) to  $-0.41\%$  (size/book-to-market). The price of risk of the scaled broker-dealer capital ratio varies from  $-0.23\%$  per quarter (industries) to  $-0.35\%$  (size/long-term reversal) to  $-0.42\%$  (size/book-to-market) to  $-0.46\%$  (size/momentum). These findings lend additional support to the broad-based performance of our funding liquidity model.

#### **4.7. Further Tests**

In order to better understand the commonality between our three-factor funding liquidity model and existing benchmarks, including both portfolio-based and macroeconomic models, we next examine how the factor prices of risk implied our funding liquidity model relate to the factor prices of risk implied by such benchmarks. Table 6 conducts this comparison for three benchmark specifications: the Fama-French-Carhart four factor model, the Lettau and Ludvigson (2001) conditional consumption CAPM model, and a three-factor macro model adapted from the specification of Chen, Roll and Ross

(1986).<sup>11</sup>

The results in the first panel demonstrate that the prices of risk of the broker-dealer capital ratio and the scaled capital ratio are both negatively correlated with the price of SMB risk and particularly with the price of HML risk. Both correlations are statistically significant. The correlations with the price of momentum risk are positive and significant, explaining in part why our funding liquidity factors are also able to account for the momentum anomaly.

In the second panel, we show that the prices of risk of our funding liquidity factors correlate positively with the price of risk associated with Lettau and Ludvigson's *cay* factor and negatively with the consumption growth interaction  $cay \times \Delta c$ . The latter suggests that adverse shocks to funding liquidity tend to coincide with adverse shocks to consumption growth.

Finally, the third panel shows that the prices of risk associated with shocks to the broker-dealer capital ratio and the scaled capital ratio are also highly negatively correlated with the compensation for shocks to industrial production and positively correlated with the compensation for inflation risk and confidence risk. Intuitively, the former suggest that adverse shocks to funding liquidity tend to coincide with lower-than-expected industrial production and higher unexpected inflation and default spreads.

Taken together, the economically meaningful and statistically significant correlations between the prices of risk of our funding liquidity factors and other common risk factors lend support to the view that our funding liquidity factors reflect economy-wide funding conditions, which in turn are linked to economy-wide expectations of future investment opportunities. It is in this light that we interpret the robust pricing

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<sup>11</sup>We thank Martin Lettau for making the factors used in Lettau and Ludvigson (2001) available on his website. All other macroeconomic data are obtained from Haver Analytics.

performance of our funding liquidity model across a wide range of test assets.

## 5. Conclusion

In this paper, we set out to investigate the extent to which well-known deviations from the CAPM's cross-sectional predictions can be rationalized by intertemporal hedging considerations relevant for long-term investors. Our cross-sectional asset pricing results suggest that Merton's (1973) ICAPM hedging demands linked to the funding liquidity of financial intermediaries may indeed provide a common explanation for many asset pricing puzzles. Specifically, we show that our three-factor funding liquidity model does remarkably well in pricing the cross-section of industry portfolios: it rivals the Fama-French model in the cross section of size and book-to-market sorted portfolios; it beats the benchmark tailored to explain the cross section of size and momentum sorted portfolios; and it does well compared to the benchmark in the cross-section of size and long-term reversal sorted portfolios.

Rooted in the theory of intertemporal asset pricing, our funding liquidity model offers a departure from the class of factor models motivated solely by the absence of arbitrage. Our new risk factors are identified by the first-order conditions of two rational investors, an active long-horizon investor subject to a balance sheet risk constraint and a passive myopic investor with constant relative risk aversion. While our representative active investors, security broker-dealers, have been studied extensively in the context of market making, the information content of aggregate broker-dealer balance sheets in pricing the cross section of stock returns is new. We regard our study as a first step in understanding the aggregate asset pricing implications of funding liquidity in the context of long-term portfolio choice. Our results lend support to the view that the portfolio choice of active forward-looking investors provides a window to economy-wide

expectations of future investment opportunities.

## A1. Appendix

### A1.1. Proof of Proposition 1 (Portfolio Choice of Active Investors)

We make the following guess for the value function (see Merton, 1973):

$$\begin{aligned} J^A(t, x, w^A) &= e^{f(t,x)} w^A \\ f(T, x) &= -\delta T, \end{aligned}$$

which implies

$$\frac{E_t [dJ^A]}{J^A dt} = f_t + f'_x \frac{E_t [dx]}{dt} + E_t \left[ \frac{dw^A}{w^A dt} \right] + \left\langle \frac{dw^A}{w^A} \frac{dx'}{dt} \right\rangle f_x + \frac{1}{2} \left( f_{xx} \frac{\langle dx' dx \rangle}{dt} + f'_x \frac{\langle dx' dx \rangle}{dt} f_x \right),$$

where partial derivatives are denoted by subscripts. The stacked first order conditions for portfolio choice are:

$$E_t [dR] + \langle dR dx' \rangle f_x = \frac{\phi}{J^A} \left\langle \frac{dw^A}{w^A} \right\rangle^{-\frac{1}{2}} \sigma \sigma' y^A.$$

Invoking the binding VaR constraint  $\left\langle \frac{dw^A}{w^A} \right\rangle^{\frac{1}{2}} = \frac{1}{\kappa}$  and defining  $\tilde{\phi} = \kappa \phi / J^A$ , one obtains:

$$E_t [dR] + \langle dR dx' \rangle f_x = \tilde{\phi} \sigma \sigma' y^A,$$

so that the portfolio choice is:

$$y^A = \frac{1}{\tilde{\phi}} (\sigma \sigma')^{-1} (\mu + \sigma \sigma'_x f_x).$$

By the VaR constraint,

$$\left\langle dw^A \right\rangle^{\frac{1}{2}} = w^A \sqrt{y^{A'} (\sigma \sigma') y^A} = \frac{w^A}{\tilde{\phi}} \sqrt{(\mu + \sigma \sigma'_x f_x)' (\sigma \sigma')^{-1} (\mu + \sigma \sigma'_x f_x)} = \frac{w^A}{\kappa},$$

which implies that the scaled Lagrange multiplier is given by:

$$\tilde{\phi} = \kappa \sqrt{(\mu + \sigma \sigma'_x f_x)' (\sigma \sigma')^{-1} (\mu + \sigma \sigma'_x f_x)}.$$

### A1.2. Proof of Proposition 2 (Equilibrium Returns)

Plugging the asset demands (2.5) and (2.7) of the two investor types in the market clearing condition gives:

$$\left(\frac{w^P}{\gamma} + \frac{w^A}{\tilde{\phi}}\right) (\sigma\sigma')^{-1} \mu + \left(\frac{w^A}{\tilde{\phi}}\right) (\sigma\sigma')^{-1} \sigma\sigma'_x f_x = (w^A + w^P) s,$$

or

$$\mu = \frac{\sigma\sigma' S}{w^P/\gamma + w^A/\tilde{\phi}} - \frac{w^A/\tilde{\phi}}{w^P/\gamma + w^A/\tilde{\phi}} \sigma\sigma'_x f_x. \quad (\text{A1.1})$$

Denote the covariance matrix of individual asset returns with the market portfolio by

$$\sigma\sigma'_M = (\sigma\sigma') s,$$

and the wealth-weighted risk aversion and the prices of risk of the state variables by

$$\begin{aligned} \Gamma &= \frac{w^P + w^A}{w^P/\gamma + w^A/\tilde{\phi}}, \\ F_x &= \frac{w^A/\tilde{\phi}}{w^P/\gamma + w^A/\tilde{\phi}} f_x, \end{aligned}$$

such that the expected returns (A1.1) can be written in the usual ICAPM form:

$$\begin{aligned} \mu &= \sigma\sigma'_M \Gamma - \sigma\sigma'_x F_x \\ &= \text{Cov}_t(dR, dR_M) \Gamma - \text{Cov}_t(dR, dx) F_x. \end{aligned}$$

### A1.3. Proof of Proposition 3 (Equilibrium $\Gamma$ , $F_x$ , and $\tilde{\phi}$ )

Defining  $lev^A = \sum_i y_i^A$ ,  $lev^P = \sum_i y_i^P$ , and normalizing  $\sum_i s_i = 1$ , we rewrite (2.8) as:

$$\frac{w^P + w^A}{w^P} - lev^A \frac{w^A}{w^P} = lev^P.$$

Using (2.11), it follows that:

$$\frac{w^P + w^A}{w^P} - lev^A \frac{w^A}{w^P} = \frac{\Gamma}{\gamma} - \frac{1}{\gamma} Q_x F_x,$$

where we have defined  $Q_x = \mathbf{1}' (\sigma \sigma')^{-1} \sigma \sigma'_x$ . We can rewrite the above as:

$$\begin{aligned} \Gamma &= \gamma \left( 1 + \frac{w^A}{w^P} (1 - lev^A) \right) + Q_x F_x \\ &= \gamma \left( 1 + \frac{w^A}{w^P} (1 - lev^A) \right) + Q_x \frac{w^A / \tilde{\phi}}{w^P / \gamma + w^A / \tilde{\phi}} f_x. \end{aligned}$$

On the other hand, we know that  $\Gamma = \frac{w^P + w^A}{w^P / \gamma + w^A / \tilde{\phi}}$ , which allows us to solve for  $\Gamma$  and  $\tilde{\phi}$ :

$$\begin{aligned} \Gamma &= \gamma \left[ 1 + \frac{w^A}{w^P} \left( 1 - lev^A \frac{\left( 1 + \frac{w^A}{w^P} \right) \gamma}{\left( 1 + \frac{w^A}{w^P} \right) \gamma + Q_x f_x} \right) \right], \\ \tilde{\phi} &= (\gamma + Q_x f_x) \frac{1}{lev^A} - \gamma \frac{w^A}{w^P} \left( 1 - \frac{1}{lev^A} \right). \end{aligned}$$

Since  $F_x = \frac{w^A / \tilde{\phi}}{w^P / \gamma + w^A / \tilde{\phi}} f_x$ , we use the latter to obtain:

$$F_x = \frac{\frac{w^A}{w^P} lev^A f_x}{1 + \frac{w^A}{w^P} + Q_x f_x / \gamma}. \quad (\text{A1.2})$$

#### A1.4. Solving for the Value Function of Active Investors

Plugging the optimal portfolio choice of active investors (2.5) back into the Hamilton-Jacobi-Bellman equation (2.4) gives:

$$\begin{aligned} 0 &= f_t + f'_x \mu_x + y^{A'} \mu + r^D + y^{A'} \langle dR dx' \rangle f_x + \frac{1}{2} (f_{xx} \sigma_x \sigma'_x + f'_x \sigma_x \sigma'_x f_x) \\ &= f_t + f'_x \mu_x + \frac{1}{\tilde{\phi}} (\mu + \sigma \sigma'_x f_x)' (\sigma \sigma')^{-1} (\mu + \sigma \sigma'_x f_x) + r^D + \frac{1}{2} (f_{xx} \sigma_x \sigma'_x + f'_x \sigma_x \sigma'_x f_x). \end{aligned}$$

Using the expression for  $\tilde{\phi}$  from (2.6), we obtain:

$$0 = f_t + f'_x \mu_x + \frac{\tilde{\phi}}{\kappa^2} + r^D + \frac{1}{2} (f_{xx} \sigma_x \sigma'_x + f'_x \sigma_x \sigma'_x f_x). \quad (\text{A1.3})$$

In order to solve the PDE in (A1.3), we make the simplifying assumption that all second moments are constant. Using the equilibrium expression (2.20) for the scaled Lagrange multiplier,

$$\tilde{\phi} = (\gamma + Q_x f_x) x_1 + \gamma x_2 - \gamma x_3, \quad (\text{A1.4})$$

the PDE becomes affine in  $x_1$ ,  $x_2$  and  $x_3$ . Hence, we make the following guess for the value function:

$$f(t, x) = A(T - t) + B_1(T - t)x_1 + B_2(T - t)x_2 + B_3(T - t)x_3,$$

which implies:

$$f_{x_1} = B_1(T - t), \quad f_{x_2} = B_2(T - t), \quad f_{x_3} = B_3(T - t),$$

$$f_{xx} = 0,$$

$$f_t = -A' - B_1'x_1 - B_2'x_2 - B_3'x_3.$$

Since  $\mu_x(x) = k(\bar{x} - x)$ , it follows that the PDE (A1.3) simplifies to:

$$\begin{aligned} A' + B_1'x_1 + B_2'x_2 + B_3'x_3 &= B_1k_1(\bar{x}_1 - x_1) + B_2k_2(\bar{x}_2 - x_2) + B_3k_3(\bar{x}_3 - x_3) \\ &+ r^D + \frac{\gamma + Q_{x_1}B_1 + Q_{x_2}B_2 + Q_{x_3}B_3}{\kappa^2}x_1 \\ &+ \frac{\gamma}{\kappa^2}x_2 - \frac{\gamma}{\kappa^2}x_3 + \frac{1}{2}(B_1^2\sigma_1^2 + B_2^2\sigma_2^2) \end{aligned}$$

with boundary conditions  $A(0) = \delta$  and  $B(0) = 0$ . Thus, the problem can be expressed as a system of four equations:



$$\begin{aligned}
A' &= -B_1 k_1 \bar{x}_1 - B_2 k_2 \bar{x}_2 + r^D + \frac{1}{2} (B_1^2 \sigma_1^2 + B_2^2 \sigma_2^2), \\
B'_1 &= -B_1 k_1 + \frac{\gamma + Q_{x_1} B_1 + Q_{x_2} B_2 + Q_{x_3} B_3}{\kappa^2}, \\
B'_2 &= -B_2 k_2 + \frac{\gamma}{\kappa^2}, \\
B'_3 &= -B_3 k_3 - \frac{\gamma}{\kappa^2},
\end{aligned}$$

all of which have straightforward analytical solutions.

**Steady State Value Function.** In steady states where the time derivatives are zero, we obtain:

$$f_{x_1} = \frac{\gamma + Q_{x_2} f_{x_2} + Q_{x_3} f_{x_3}}{\kappa^2 k_1 - Q_{x_1}}, \quad (\text{A1.5})$$

$$f_{x_2} = \frac{\gamma}{k_2 \kappa^2}, \quad (\text{A1.6})$$

$$f_{x_3} = -\frac{\gamma}{k_3 \kappa^2}. \quad (\text{A1.7})$$

Note that  $f_{x_2} > 0$  and  $f_{x_3} < 0$ . Recall also that  $Q_x = \mathbf{1}'(\sigma\sigma')^{-1}\sigma\sigma'_x$ ; in other words,  $Q_{x_1}, Q_{x_2}$  and  $Q_{x_3}$  are sums of OLS regression coefficients from time-series regressions of each state variable on the set of test assets. Estimated from quarterly data,  $Q_{x_1}, Q_{x_2}$  and  $Q_{x_3}$  are of similar magnitudes and lie between  $-0.05$  and  $-0.03$  (depending on the set of test assets), implying that the denominator of (A1.5) is positive. It follows that  $f_{x_1}$  is positive if:

$$\begin{aligned}
\gamma + Q_{x_2} f_{x_2} + Q_{x_3} f_{x_3} &> 0 \\
\Leftrightarrow \kappa^2 + \frac{Q_{x_2}}{k_2} - \frac{Q_{x_3}}{k_3} &> 0,
\end{aligned}$$

which holds if  $\kappa$  is sufficiently large. Note that  $\kappa$  increases in the tightness of capital regulations. For the sake of illustrations, say that active investors are required to stay

solvent 99% of the time, and that the distribution of equity returns is Gaussian. Then  $\kappa = 2.33$ , which implies  $\kappa^2 = 5.43$ . In addition,  $k_2$  and  $k_3$  are of similar magnitude, so  $\frac{Q_{x_2}}{k_2} - \frac{Q_{x_3}}{k_3}$  is close to zero, and hence  $\gamma + Q_{x_2}f_{x_2} + Q_{x_3}f_{x_3} > 0$ , which implies  $f_{x_1} > 0$ .

**Steady-State Prices of Risk.** The prices of risk  $F_x$  associated with the state variables are given by (A1.2) as:

$$\begin{pmatrix} F_{x_1} \\ F_{x_2} \\ F_{x_3} \end{pmatrix} = \frac{\frac{w^A}{w^P} lev^A}{1 + \frac{w^A}{w^P} + Q_x f_x / \gamma} \begin{pmatrix} f_{x_1} \\ f_{x_2} \\ f_{x_3} \end{pmatrix}.$$

Thus, the signs of  $F_x$  are the same as the signs of  $f_x$  if the common multiplier  $\frac{w^A}{w^P} lev^A / \left(1 + \frac{w^A}{w^P} + Q_x f_x / \gamma\right)$  is positive. Since the numerator of the expression is always positive, this condition holds if:

$$\gamma \left(1 + \frac{w^A}{w^P}\right) + Q_x f_x > 0.$$

A sufficient (but not necessary) condition is  $\gamma + Q_x f_x > 0$ , which is the same as requiring that the tightness of broker-dealer funding conditions  $\tilde{\phi}$  is positively related to inverse of broker-dealer leverage  $x_1$  (see equation (A1.4)). Thus, we may expect  $F_{x_1}, F_{x_2} > 0$  and  $F_{x_3} < 0$ , which implies that the expected factor risk premia are  $\lambda_{x_1}, \lambda_{x_2} < 0$  and  $\lambda_{x_3} > 0$ .

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## Tables

Table 1: Pricing the Cross-Section of 30 Industry Portfolios

We use Fama-MacBeth two-pass regressions to price the cross-section of 30 industry portfolios. The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2009.

	Benchmarks		Funding Liquidity Models					
	3-Factor		Capital	Scaled	Wealth	2-Factor	3-Factor	Combined
	CAPM	Benchmark	Ratio	Cap. Ratio	Ratio	Fund. Liq.	Fund. Liq.	
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)		
Constant	1.512 (4.190) (4.177)	1.257 (4.756) (4.741)	1.104 (1.534) (1.529)	0.841 (1.242) (1.238)	0.862 (1.354) (1.350)	0.800 (1.230) (1.226)	1.084 (3.154) (3.144)	1.001 (3.544) (3.533)
Capital Ratio			-0.137 (-1.605) (-1.600)			-0.178 (-2.068) (-2.061)	-0.173 (-2.021) (-2.014)	-0.152 (-1.772) (-1.766)
Scaled Cap. Ratio				-0.234 (-2.224) (-2.217)		-0.234 (-2.206) (-2.199)	-0.233 (-2.165) (-2.158)	-0.208 (-1.957) (-1.951)
Wealth Ratio					-0.178 (-1.984) (-1.978)			
Market	0.012 (0.139) (0.139)	0.054 (0.653) (0.651)					0.048 (0.543) (0.541)	0.066 (0.789) (0.787)
SMB		-0.110 (-1.169) (-1.165)						-0.051 (-0.534) (-0.532)
HML		0.013 (0.146) (0.146)						0.038 (0.405) (0.403)
R-Squared	0%	18%	24%	47%	51%	52%	54%	61%
Adj. R-Squared	-3%	9%	21%	46%	49%	49%	49%	53%

Table 2: Pricing the Cross-Section of 25 Size and Book-to-Market Portfolios

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and book-to-market sorted portfolios.

The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang

t-statistics in parentheses. The sample period is Q1/1969 - Q4/2009.

	Benchmarks		Funding Liquidity Models					Combined
	3-Factor		Capital	Scaled	Wealth	2-Factor	3-Factor	
	CAPM	Benchmark	Ratio	Cap. Ratio	Ratio	Fund. Liq.	Fund. Liq.	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Constant	1.615	0.125	-0.026	0.136	1.137	0.330	0.196	0.028
	(3.785)	(1.953)	(-0.045)	(0.466)	(3.645)	(1.537)	(1.499)	(0.495)
	(3.774)	(1.947)	(-0.045)	(0.465)	(3.634)	(1.532)	(1.494)	(0.494)
Capital Ratio			-0.450			-0.449	-0.411	-0.230
			(-4.438)			(-3.929)	(-4.215)	(-2.743)
			(-4.424)			(-3.917)	(-4.202)	(-2.734)
Scaled Cap. Ratio				-0.493		-0.485	-0.423	-0.254
				(-3.311)		(-3.134)	(-4.032)	(-2.709)
				(-3.301)		(-3.124)	(-4.020)	(-2.701)
Wealth Ratio					-0.177			
					(-1.093)			
					(-1.089)			
Market	0.031	0.137					0.125	0.135
	(0.337)	(1.723)					(1.464)	(1.702)
	(0.336)	(1.718)					(1.460)	(1.697)
SMB		0.081						0.095
		(1.014)						(1.201)
		(1.011)						(1.197)
HML		0.218						0.224
		(2.709)						(2.782)
		(2.701)						(2.774)
R-Squared	2%	71%	66%	47%	11%	64%	66%	76%
Adj. R-Squared	-2%	67%	65%	45%	7%	61%	62%	71%

Table 3: Pricing the Cross-Section of 25 Size and Momentum Portfolios

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and momentum sorted portfolios.

The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang

t-statistics in parentheses. The sample period is Q1/1969 - Q4/2009.

	Benchmarks		Funding Liquidity Models					
	3-Factor		Capital	Scaled	Wealth	2-Factor	3-Factor	Combined
	CAPM	Benchmark	Ratio	Cap. Ratio	Ratio	Fund. Liq.	Fund. Liq.	
(i)	(vii)	(ii)	(iii)	(iv)	(v)	(vi)	(viii)	
Constant	2.119 (4.391) (4.377)	0.388 (2.028) (2.022)	0.631 (0.636) (0.634)	0.642 (0.638) (0.636)	0.592 (0.580) (0.578)	0.651 (0.672) (0.670)	-0.148 (-0.947) (-0.944)	-0.019 (-0.203) (-0.202)
Capital Ratio			-0.354 (-3.548) (-3.537)			-0.318 (-3.194) (-3.184)	-0.361 (-5.185) (-5.169)	-0.151 (-2.004) (-1.998)
Scaled Cap. Ratio				-0.425 (-3.355) (-3.345)		-0.417 (-3.238) (-3.228)	-0.456 (-4.424) (-4.410)	-0.106 (-1.029) (-1.025)
Wealth Ratio					-0.368 (-3.231) (-3.221)			
Market	-0.036 (-0.351) (-0.350)	0.153 (1.890) (1.884)					0.222 (2.564) (2.556)	0.177 (2.226) (2.219)
SMB		0.125 (1.469) (1.464)						0.122 (1.421) (1.417)
Momentum		0.249 (3.082) (3.072)						0.261 (3.227) (3.217)
R-Squared	1%	79%	73%	74%	74%	76%	82%	91%
Adj. R-Squared	-2%	76%	72%	73%	73%	74%	79%	89%

Table 4: Pricing the Cross-Section of 25 Size and Long-Term Reversal Portfolios

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and long-term reversal sorted portfolios.

The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2009.

	Benchmarks		Funding Liquidity Models					
	CAPM (i)	3-Factor Benchmark (ii)	Capital Ratio (iii)	Scaled Cap. Ratio (iv)	Wealth Ratio (v)	2-Factor Fund. Liq. (vi)	3-Factor Fund. Liq. (vii)	Combined (viii)
Constant	0.846 (3.384) (3.374)	0.306 (2.094) (2.088)	1.041 (1.726) (1.721)	0.851 (1.474) (1.469)	0.960 (1.696) (1.691)	0.783 (1.395) (1.391)	0.226 (1.299) (1.295)	-0.093 (-1.000) (-0.997)
Capital Ratio			-0.269 (-2.921) (-2.912)			-0.323 (-3.690) (-3.678)	-0.285 (-3.348) (-3.337)	-0.223 (-3.598) (-3.587)
Scaled Cap. Ratio				-0.384 (-3.314) (-3.303)		-0.409 (-3.708) (-3.697)	-0.354 (-3.318) (-3.307)	-0.242 (-3.316) (-3.306)
Wealth Ratio					-0.290 (-3.155) (-3.146)			
Market	0.130 (1.510) (1.505)	0.162 (2.014) (2.008)					0.189 (2.303) (2.296)	0.178 (2.218) (2.211)
SMB		0.086 (1.018) (1.015)						0.132 (1.586) (1.581)
LT Reversal		0.170 (2.110) (2.103)						0.180 (2.243) (2.236)
R-Squared	31%	69%	28%	34%	32%	38%	53%	86%
Adj. R-Squared	28%	65%	25%	31%	29%	33%	48%	82%

Table 5: Pricing the Cross-Section of 25 Size and Short-Term Reversal Portfolios

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and short-term reversal sorted portfolios.

The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2009.

	Benchmarks		Funding Liquidity Models					
	CAPM	3-Factor Benchmark	Capital Ratio	Scaled Cap. Ratio	Wealth Ratio	2-Factor Fund. Liq.	3-Factor Fund. Liq.	Combined
	(i)	(vii)	(ii)	(iii)	(iv)	(v)	(vi)	(viii)
Constant	0.219 (1.155) (1.151)	0.222 (1.604) (1.600)	1.955 (2.479) (2.472)	2.142 (2.684) (2.676)	2.275 (2.990) (2.980)	2.343 (3.228) (3.217)	0.355 (2.147) (2.140)	-0.022 (-0.276) (-0.275)
Capital Ratio			0.063 (0.866) (0.863)			0.037 (0.481) (0.480)	0.102 (1.215) (1.211)	-0.087 (-1.292) (-1.288)
Scaled Cap. Ratio				0.139 (1.490) (1.485)		0.122 (1.153) (1.150)	0.286 (2.348) (2.341)	-0.017 (-0.193) (-0.192)
Wealth Ratio					0.146 (1.571) (1.566)			
Market	0.153 (1.735) (1.729)	0.134 (1.673) (1.668)					0.096 (1.127) (1.123)	0.149 (1.874) (1.868)
SMB		0.069 (0.824) (0.822)						0.058 (0.682) (0.680)
ST Reversal		0.301 (3.741) (3.729)						0.332 (4.106) (4.093)
R-Squared	22%	69%	2%	6%	7%	12%	63%	79%
Adj. R-Squared	19%	65%	-2%	2%	3%	4%	59%	74%

Table 6: Correlations of Cross-Sectional Prices of Risk

We investigate the correlations of the factor prices of risk implied by our three-factor funding liquidity model and three benchmark models, the Fama-French-Carhart model, the Lettau-Ludvigson CCAPM, and a Macro model adapted from the specification of Chen, Roll, and Ross (1986). The prices of risk are computed via Fama-MacBeth two-pass regressions applied to the cross-section of 25 size and book-to-market sorted portfolios. The table reports estimated correlation coefficients with t-statistics in parentheses. The sample period is Q1/1969 - Q4/2009.

	3-Factor Funding Liquidity Model		
	Market	Capital Ratio	Scaled Capital Ratio
Fama-French-Carhart Model			
Market	0.917 (73.00)	-0.040 (-0.51)	-0.047 (-0.59)
SMB	0.745 (21.17)	-0.146 (-1.89)	-0.187 (-2.45)
HML	-0.429 (-6.66)	-0.787 (-26.09)	-0.703 (-17.61)
Momentum	-0.329 (-4.66)	0.246 (3.32)	0.231 (3.08)
Lettau-Ludvigson CCAPM			
$cay$	0.069 (0.88)	0.193 (2.54)	0.136 (1.75)
$\Delta c$	0.703 (17.57)	0.047 (0.59)	0.018 (0.23)
$cay \times \Delta c$	-0.026 (-0.33)	-0.353 (-5.11)	-0.439 (-6.87)
Macro Model			
DEF	-0.206 (-2.72)	0.143 (1.85)	0.192 (2.52)
CPI	-0.503 (-8.52)	0.184 (2.41)	0.157 (2.03)
IP	-0.582 (-11.11)	-0.799 (-27.93)	-0.728 (-19.61)



Table A1: Pricing the Cross-Section of 30 Industry Portfolios (1969-2006)

We use Fama-MacBeth two-pass regressions to price the cross-section of 30 industry portfolios. The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2006.

	Benchmarks		Funding Liquidity Models					
	CAPM	3-Factor Benchmark	Capital Ratio	Scaled Cap. Ratio	Wealth Ratio	2-Factor Fund. Liq.	3-Factor Fund. Liq.	Combined
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Constant	1.563 (4.078) (4.064)	1.097 (3.907) (3.894)	0.883 (1.542) (1.537)	0.743 (1.457) (1.452)	1.081 (1.998) (1.992)	0.777 (1.478) (1.473)	0.987 (2.896) (2.886)	0.952 (3.355) (3.344)
Capital Ratio			-0.158 (-1.823) (-1.817)			-0.165 (-1.934) (-1.928)	-0.191 (-2.063) (-2.056)	-0.169 (-1.764) (-1.758)
Scaled Cap. Ratio				-0.182 (-1.892) (-1.886)		-0.183 (-1.960) (-1.953)	-0.217 (-2.080) (-2.073)	-0.195 (-1.813) (-1.807)
Wealth Ratio					-0.094 (-1.401) (-1.396)			
Market	0.023 (0.248) (0.248)	0.085 (0.964) (0.960)					0.074 (0.813) (0.810)	0.089 (1.015) (1.012)
SMB		-0.096 (-1.000) (-0.997)						-0.042 (-0.441) (-0.440)
HML		0.046 (0.475) (0.473)						0.035 (0.367) (0.366)
R-Squared	2%	26%	39%	48%	32%	48%	54%	60%
Adj. R-Squared	-2%	19%	37%	46%	30%	44%	49%	53%

Table A2: Pricing the Cross-Section of 25 Size and Book-to-Market Portfolios (1969-2006)

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and book-to-market sorted portfolios. The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2006.

	Benchmarks		Funding Liquidity Models					
	3-Factor		Capital	Scaled	Wealth	2-Factor	3-Factor	Combined
	CAPM	Benchmark	Ratio	Cap. Ratio	Ratio	Fund. Liq.	Fund. Liq.	
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	
Constant	1.907	0.109	0.015	0.596	1.687	0.330	0.367	0.141
	(4.422)	(1.959)	(0.073)	(3.155)	(4.261)	(4.033)	(4.230)	(2.540)
	(4.407)	(1.953)	(0.073)	(3.144)	(4.246)	(4.019)	(4.216)	(2.532)
Capital Ratio			-0.343			-0.383	-0.373	0.055
			(-3.203)			(-3.738)	(-3.167)	(0.568)
			(-3.192)			(-3.726)	(-3.157)	(0.566)
Scaled Cap. Ratio				-0.257		-0.340	-0.329	0.080
				(-1.768)		(-2.670)	(-2.511)	(0.770)
				(-1.762)		(-2.661)	(-2.503)	(0.767)
Wealth Ratio					-0.060			
					(-0.500)			
					(-0.498)			
Market	0.024	0.159					0.137	0.159
	(0.253)	(1.921)					(1.591)	(1.928)
	(0.252)	(1.915)					(1.585)	(1.921)
SMB		0.089						0.085
		(1.070)						(1.031)
		(1.066)						(1.027)
HML		0.233						0.229
		(2.791)						(2.749)
		(2.781)						(2.740)
R-Squared	1%	76%	48%	25%	3%	60%	57%	77%
Adj. R-Squared	-3%	73%	46%	22%	-1%	56%	52%	72%

Table A3: Pricing the Cross-Section of 25 Size and Momentum Portfolios (1969-2006)

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and momentum sorted portfolios. The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2006.

	Benchmarks		Funding Liquidity Models					
	CAPM	3-Factor Benchmark	Capital Ratio	Scaled Cap. Ratio	Wealth Ratio	2-Factor Fund. Liq.	3-Factor Fund. Liq.	Combined
	(i)	(vii)	(ii)	(iii)	(iv)	(v)	(vi)	(viii)
Constant	2.249 (5.215) (5.197)	0.483 (2.466) (2.457)	0.216 (0.531) (0.529)	0.081 (0.316) (0.315)	0.453 (3.164) (3.153)	0.290 (2.020) (2.013)	0.565 (3.454) (3.442)	0.083 (0.777) (0.774)
Capital Ratio			-0.299 (-3.369) (-3.358)			-0.336 (-3.770) (-3.758)	-0.586 (-5.126) (-5.109)	-0.064 (-0.792) (-0.789)
Scaled Cap. Ratio				-0.331 (-2.888) (-2.879)		-0.326 (-2.563) (-2.554)	-0.742 (-4.538) (-4.522)	0.062 (0.632) (0.630)
Wealth Ratio					-0.215 (-1.903) (-1.897)			
Market	-0.034 (-0.331) (-0.330)	0.173 (2.064) (2.057)					0.162 (1.822) (1.816)	0.188 (2.268) (2.261)
SMB		0.103 (1.181) (1.177)						0.092 (1.051) (1.048)
Momentum		0.327 (3.912) (3.899)						0.357 (4.262) (4.248)
R-Squared	1%	73%	21%	20%	12%	26%	45%	85%
Adj. R-Squared	-3%	69%	18%	17%	8%	21%	38%	82%

Table A4: Pricing the Cross-Section of 25 Size and Long-Term Reversal Portfolios (1969-2006)

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and long-term reversal sorted portfolios. The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2006.

	Benchmarks		Funding Liquidity Models					
	3-Factor		Capital	Scaled	Wealth	2-Factor	3-Factor	Combined
	CAPM	Benchmark	Ratio	Cap. Ratio	Ratio	Fund. Liq.	Fund. Liq.	
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)		
Constant	0.956 (3.777) (3.764)	0.352 (2.394) (2.386)	0.415 (1.554) (1.549)	0.234 (1.340) (1.336)	0.677 (2.403) (2.395)	0.144 (0.947) (0.944)	0.242 (1.499) (1.494)	-0.037 (-0.381) (-0.380)
Capital Ratio			-0.318 (-2.706) (-2.697)			-0.351 (-2.989) (-2.979)	-0.452 (-4.400) (-4.385)	-0.367 (-4.938) (-4.921)
Scaled Cap. Ratio				-0.359 (-2.774) (-2.765)		-0.389 (-2.954) (-2.945)	-0.513 (-4.307) (-4.292)	-0.384 (-4.870) (-4.853)
Wealth Ratio					-0.228 (-2.585) (-2.577)			
Market	0.144 (1.606) (1.601)	0.185 (2.213) (2.206)					0.205 (2.367) (2.359)	0.191 (2.277) (2.269)
SMB		0.094 (1.105) (1.102)						0.129 (1.509) (1.504)
LT Reversal		0.185 (2.208) (2.201)						0.190 (2.269) (2.261)
R-Squared	30%	68%	52%	57%	46%	63%	64%	89%
Adj. R-Squared	27%	65%	50%	56%	44%	60%	59%	87%

Table A5: Pricing the Cross-Section of 25 Size and Short-Term Reversal Portfolios (1969-2006)

We use Fama-MacBeth two-pass regressions to price the cross-section of 25 size and short-term reversal sorted portfolios. The table reports estimated coefficients in quarterly percentage points with Fama-MacBeth and Jagannathan-Wang t-statistics in parentheses. The sample period is Q1/1969 - Q4/2006.

	Single-Factor Models				Multi-Factor Models				
	CAPM	Capital Ratio	Scaled Cap. Ratio	Wealth Ratio	2-Factor Fund. Liq.	3-Factor Fund. Liq.	3-Factor Benchmark	Combined	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	
Constant	0.200 (1.034) (1.031)	0.215 (1.621) (1.615)		2.273 (3.511) (3.498)	2.447 (3.802) (3.789)	2.526 (4.079) (4.065)	2.389 (3.927) (3.914)	0.151 (0.836) (0.833)	-0.062 (-0.723) (-0.721)
Capital Ratio				0.058 (0.817) (0.814)			-0.036 (-0.517) (-0.515)	0.099 (1.365) (1.360)	-0.142 (-2.031) (-2.025)
Scaled Cap. Ratio					0.090 (1.203) (1.199)		0.035 (0.452) (0.451)	0.246 (2.905) (2.895)	-0.075 (-0.990) (-0.986)
Wealth Ratio					0.082 (1.343) (1.338)				
Market	0.181 (1.958) (1.952)	0.163 (1.965) (1.958)						0.152 (1.673) (1.668)	0.180 (2.180) (2.173)
SMB		0.063 (0.743) (0.741)							0.047 (0.555) (0.553)
ST Reversal		0.362 (4.332) (4.317)							0.398 (4.746) (4.730)
R-Squared	22%	74%		2%	4%	6%	10%	72%	84%
Adj. R-Squared	19%	71%		-2%	1%	2%	2%	69%	80%