The Economic Implications of Money Market Fund Capital Buffers

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Abstract. This paper develops an affine term structure for the valuation of money market funds. This valuation framework is then used to consider the economic implications of funds that are supported by a capital buffer. The main findings are twofold. First, relatively small capital buffers are capable of absorbing daily fluctuations between a fund's shadow price and its amortized cost. For example, a fund with a capital buffer of 60 basis points can absorb most day-to-day price risk. The ability to absorb large scale defaults, however, would require a significantly larger and more costly buffer. Second, because a buffer is designed to absorb credit risk, capital providers demand compensation for bearing this risk. The analysis shows that, after compensating capital buffer investors for absorbing credit risk, the returns available to money market fund shareholders are comparable to default free securities, which would significantly reduce the utility of the product to investors.

1 Introduction

U.S. money market funds are open-end investment management companies that are registered under the Investment Company Act of 1940. The principal regulation underlying money market funds is rule 2a-7 under the Investment Company Act, which was promulgated in 1983 and most recently amended in 2010.

A mutual fund chooses whether or not to comply with rule 2a-7. A fund that does so may represent itself as a money market fund, rather than, for example, an ultra-short-term bond fund. All other funds are prohibited from suggesting that they are money market funds. Under rule 2a-7, a money market fund must satisfy constraints on portfolio holdings related to liquidity, maturity, and portfolio composition, as well as satisfy a number of operational requirements.

Compliant funds also are permitted to use amortized cost accounting when valuing their portfolios rather than market-based valuations. Using amortized cost valuation allows a money market fund to value its assets at acquisition cost, adjusting for any premium or discount over the bond's life. A fund also must calculate its mark-to-market value on a per-share basis, which is commonly referred to as the "shadow price." The price per share of a money market fund share can be rounded to $1.00 provided the shadow price is within one half penny of $1.00.

The ability to price at a stable $1.00 is an important distinguishing feature of money market funds compared to other mutual funds. The essential difference can be viewed from the perspective of an investor that invests $1.00 in two identical funds. The first is a 2a-7 compliant money market fund; the second is an ultra-short bond fund that holds exactly the same portfolio of assets.[1] Shareholders in a money market fund typically reinvest dividends paid by the fund. Since share purchases and redemptions all occur at the fund's $1.00 stable share price (unless the fund breaks the buck), the representative investor then tracks performance by monitoring the number of shares they own, rather than changes in share price. By contrast, since an ultra-short bond fund is valued at its market-based value (analogous to a money market fund's shadow price), this same investor tracks performance by monitoring changes in the market-based price, holding the number of shares constant.

The opportunity for investors to sell assets at amortized cost provides

[1] Since the two portfolios are identical, the realized returns to investors also should be the same over a sufficiently long holding period. I discuss this distinction in greater detail in Section 5.

them with an embedded put option to sell assets for $1. That is, since redeeming shareholders settle at amortized cost, any capital losses or liquidity discounts are borne by the remaining investors rather than those redeeming their shares. This wealth transfer to liquidating from remaining shareholders creates an incentive to be the first to redeem shares when asset values drop.

Financial turmoil in 2007 and 2008 put money market funds under considerable pressure, which culminated the week of September 15, 2008 when Lehman Brothers Holdings Inc. (Lehman Brothers) declared bankruptcy. This event when coupled with concerns about American International Group, Inc (AIG) and other financial sector securities led to heavy redemptions from about a dozen money market funds that held, or were expected to be holding, these debt securities. The largest of these was the Reserve Fund, whose Primary Fund series held a $785 million position in commercial paper issued by Lehman Brothers. The capital loss associated with the failure of Lehman Brothers caused the Primary Fund to "break the buck." A fund is deemed to break the buck when the shadow price deviates from amortized cost by more than 0.50%.

During the week of September 15, 2008, investors withdrew approximately $300 billion from prime (taxable) money market funds, or 14 percent of all assets held in those funds. The heaviest redemptions generally came from institutional funds, which placed widespread pressure on fund share prices as credit markets became illiquid. A Study by the U.S. Securities and Exchange Commission's Division of Economic and Risk Analysis (DERA Study) documents that most of these assets were reinvested in institutional government funds. The DERA Study concludes that this behavior is consistent with a number of alternative explanations that include fights to quality, transparency, liquidity, and performance. It also discusses the possibility that redemption activity may have been partially caused by shareholders exercising the redemption put associated with stable dollar pricing.

The SEC's response to the market events of 2008 was to initially propose (June 2009) and later adopt (February 2010) amendments to Rule 2a-7. The amendments tightened the risk-limiting conditions of Rule 2a7 by, among other things, requiring funds to maintain a portion of their portfolios in instruments that can be readily converted to cash, reducing the maximum weighted average maturity of portfolio holdings, and improving the quality of portfolio securities. The specific portfolio constraints are:

- *Liquidity.* A money market fund must have daily liquidity of 10% and weekly liquidity of 30% of total assets under management. Daily liquid assets include cash, U.S. Treasury bills, and securities that mature in one day such as repurchase agreements. Weekly liquid assets generally include these same securities plus certain government agency securities and securities that mature in one week.

- *Maturity.* There are three maturity requirements: 1) individual securities can have a maximum maturity of 397 days, 2) the weighted average maturity (WAM) cannot exceed 60 days, and 3) the weighted average life (WAL) cannot exceed 120 days. The difference between WAM and WAL is that WAM can be calculated using interest reset dates for floating rate securities.

- *Portfolio Composition.* Portfolio composition constraints generally require funds to hold no more than 5% of any individual first tier asset. The maximum aggregate second tier concentration limit is 3.0%. A fund may not hold more than 0.5% of any second tier security with a maturity not to exceed 45 days. Illiquid securities can comprise at most 5.0% of portfolio assets. A security is deemed to be illiquid if it cannot be sold close to its fair value within seven business days.

The 2010 amendments to rule 2a-7 also include a number of operational requirements. These include reporting portfolio holdings to the Commission on a monthly basis and stress testing. In addition, the Commission broadened affiliates options to purchase fund assets and permitted a money market fund that has broken the buck, or is at imminent risk of breaking the buck, to suspend redemptions to allow for an orderly liquidation of fund assets. These amendments are designed to make money market funds more resilient to certain short-term market risks, and to provide greater protections for investors in the event that a money market fund is unable to maintain a stable price per share.

Against this backdrop, the U.S. Securities Exchange Commission is considering additional options to further reform the MMF industry to address potential problems associated with investor tendencies to redeem shares during periods of stress. Concerns about the effect of heavy redemptions on short-term funding markets have prompted the Financial Stability Oversight Council (FSOC) to recommend a number of regulatory alternatives in a report issued in November 2012, which include, among other items, a floating net asset value alternative and two capital buffer alternatives. The first capital buffer alternative recommends a stand-alone 3.0% buffer; the second recommends a 1.0% buffer plus a minimum balance at risk requirement.[2]

[2] See "Proposed Recommendations Regarding Money Market Mutual Fund Reform,"

In June 2013, the Commission proposed a rule that considers two separate reform options.[3] The first is the so-called floating net asset value option which requires funds to price securities at their market values but permits "basis point" rounding (round to $1.0000) at the portfolio level.[4] The second option recommends the use of liquidity fees and redemption gates once certain liquidity thresholds are breached.[5] Additionally, the proposal recommends enhanced diversification disclosures, and stress testing requirements, as well as reporting in Forms N-MFP and PF.

The release also considers the two capital buffer alternatives suggested by FSOC and concludes that they are too costly relative to the proposed alternatives. The purpose of this paper is to illustrate the economic effects of requiring a money market fund to be supported by a capital buffer. Specifically, I document the risk and return characteristics of MMFs associated with a capital buffer, assess the differences between market and amortized cost valuations, and characterize the economic implications of capital buffers.

The model treats a money market fund as a portfolio of fixed income securities that faces three distinct risks: 1) interest rate risk, 2) credit risk, and 3) liquidity risk. This paper specifically addresses the first two and abstracts from liquidity risk. The idea underlying my analysis is to understand how the current regulatory framework affects the broad risks that a fund faces.

Interest rate risk reflects the fact that changing market conditions cause interest rates to change. The primary economic factor that determines the level of interest rate risk is changing expectations about future inflation rates. At a fundamental level, all securities are subject to interest rate risk, including default-free U.S. Treasuries.

Money market funds also invest in securities that have credit risk. In addition to requiring compensation for expectations about future market

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Financial Stability Oversight Council (2012). McCabe, Cipriani, Holscher, and Martin (2012) discuss the efficacy of a minimum balance at risk feature.

[3]The proposed rule also considers the possibility of combining the two options that would work in tandem, but does not formally propose this as an alternative.

[4]The proposal also exempts Government and retail funds from the floating NAV requirement. A retail fund is identified as one that limits redemptions to $1 million per day for each shareholder.

[5]A liquidity fee of 2% would be imposed if a MMF's level of weekly liquid assets fell below 15%. The imposition is automatic unless the MMF board of directors determines it is not in the best interest of the fund or that a lower fee would be in the best interest of the fund. Once weekly assets fall below 15%, a fund may temporarily suspend redemptions. The rule also proposes to exempt Government and retail funds from fees and gates.

conditions, investors require an additional risk premium to compensate for the possibility that a specific borrower may default. Credit risk varies over time as the prospects for repayment change.

The third risk relates to the possibility that a fund may be forced to rapidly liquidate investments at discounts to fundamental value (or even fire-sale prices) to meet large-scale redemption requests. Since MMFs currently value their portfolio assets at amortized cost, fund investors transact at "prices" that, almost surely, reflect small deviations from market value. If a MMF must liquidate assets to satisfy redemption requests, the fund realizes capital gains and losses and returns become uncertain.

Section 2 describes the valuation of fixed income securities. Section 3 describes the econometric approach used to estimate the stochastic properties of interest rates and credit risk. It also describes the data used to perform these estimates and provides parameter estimates. Section 4 explains my valuation model. In Section 5, I provide Monte Carlo simulation evidence of how MMFs perform under the current regulatory baseline. Section 6 considers the economic implications of a capital buffer. Section 7 offers conclusions.

2 The Valuation of Fixed Income Securities

This section describes the valuation of fixed income securities. Initial work in this area by Vasicek (1977) was extended to default free-zero-coupon bonds by Cox, Ingersoll, and Ross (CIR, 1985), and generalized to multivariate affine diffusions (see, for example, Duffie and Kan (1996)).

I assume that state variables follow independent affine processes. Loosely speaking, an affine process is one for which the instantaneous drift vector and covariance matrix have affine dependence on the current state vector X_t. I adopt this modeling framework for three reasons: 1) it provides a fully-specified model of the term structure of interest rates, 2) it accommodates credit risk in a straight-forward manner, and 3) it has closed-form solutions.

The affine processes are assumed to be independent one-dimensional "CIR" diffusions, under which

$$dX_t = \kappa\left(\theta - X_t\right)dt + \sigma\sqrt{X_t}dB_t \tag{1}$$

where X_t is the instantaneous state variable, κ is the mean-reversion rate, θ is the long-run mean, σ is the standard deviation of the state variable, and

B_t is a standard Brownian motion process.[6] The long-run variance of X_t is

$$\lim_{t\to\infty} var\left(X_t\right) = \frac{\sigma^2\theta}{2\kappa}. \tag{2}$$

2.1 Valuation of Zero-Coupon Default-Free Bonds

To value a default-free zero coupon bond, I make a distinction between the "physical" ("P") and risk-neutral ("N") densities. The physical density is useful for characterizing actual price behavior, while the risk-neutral density allows me to value contingent claims. Based on the assumption that the spot interest rate follows a CIR process, the physical process for the instantaneous spot rate of interest r_t is defined as:

$$dr_t = \kappa_r\left(\theta_r - r_t\right)dt + \sigma_r\sqrt{r_t}dB_t^P \tag{3}$$

where dB_t^P is a standard Brownian motion under the physical density. In the absence of arbitrage opportunities, it can be shown that the price of any contingent claim can be valued under the corresponding risk-neutral density Q, i.e.,

$$dr_t = \hat{\kappa}_r\left(\hat{\theta}_r - r_t\right)dt + \sigma_r\sqrt{r_t}dB_t^Q. \tag{4}$$

where

$$\hat{\kappa}_r = \kappa_r + \eta_r$$
$$\hat{\theta}_r = \frac{\kappa_r\theta_r}{\kappa_r + \eta_r}$$

and η_r is the market price of risk associated with the default-free rate of interest. Using an application of Ito's lemma, CIR (1985) show that the local expected return equals

$$r_t + \eta_r r_t\frac{\partial b\left(t,T\right)}{\partial r}/b\left(t,T\right), \tag{5}$$

where $\eta_r r_t$ is the covariance of changes in the spot interest rate with changes in optimally invested wealth and $b\left(t,T\right)$ is the value of a zero-coupon bond at time t that pays \$1 at time T. The compensation for risk as measured by the risk premium in Eq. (5) will be positive if η_r is negative since $\frac{\partial b}{\partial r} < 0$.

The value of a zero-coupon bond that pays \$1 at maturity is

$$b\left(t,T\right) = E_t^Q\left[\exp\left(-\int_t^T r_z \mathrm{d}z\right)\right] = e^{\bar{\alpha}_r(\tau)+\bar{\beta}_r(\tau)r_t} \tag{6}$$

[6] The instantaneous state variable will never reach zero provided that $2\kappa\theta > \sigma^2$.

where $\bar{\alpha}(\tau)$ and $\bar{\beta}(\tau)$ are coefficients that only depend on $\tau = T - t$. The explicit solutions to $\bar{\alpha}(\tau)$ and $\bar{\beta}(\tau)$ are given below.

$$\bar{\beta}_r(\tau) = \frac{2(e^{\gamma_r \tau} - 1)}{(\gamma_r + \hat{\kappa_r})(e^{\gamma_r \tau} - 1) + 2\gamma_r}$$
$$\bar{\alpha}_r(\tau) = \frac{2\hat{\kappa}_r \hat{\theta}_r}{\sigma_r^2} log\left[\frac{2\gamma_r e^{(\hat{\kappa}_r + \gamma_r)\tau/2}}{(\gamma_r + \hat{\kappa_r})(e^{\gamma_r \tau} - 1) + 2\gamma_r}\right]$$
$$\gamma_r = \sqrt{\hat{\kappa}_r + 2\sigma_r^2}$$

2.2 Valuation of Zero-Coupon Bonds with Credit Risk

Next I describe the valuation of a risky zero-coupon bond that provides for a fractional recovery of the face value equal to ω. Introducing credit risk requires the specification of the "physical" intensity rate process. I assume that the instantaneous intensity rate also follows an independent CIR process,

$$d\lambda_t = \kappa_\lambda (\theta_\lambda - \lambda_t)\, dt + \sigma_\lambda \sqrt{\lambda_t} dB_t^P, \tag{7}$$

and has a risk-neutral specification defined in an analogous manner to Eq. (4). Under the intensity density, the time t conditional risk-neutral probability of survival to a future time T is

$$p(t, T) = E_t^Q \left[\exp\left(-\int_t^T \lambda_z \mathrm{d}z\right)\right] = e^{\bar{\alpha}_\lambda(\tau) + \bar{\beta}_\lambda(\tau)\lambda_t}. \tag{8}$$

Following Duffie and Singleton (2003), let $1_{[\tau > s]}$ take the value 1 if there has been no default prior to s where $\tau \in [t, s)$. They show that the price of a defaultable zero-coupon bond equals

$$d(t, T) = d_0(t, T) + \omega E_t^Q \left[\exp\left(-\int_t^\tau r_s ds\right) 1_{[\tau \leq T]}\right] \tag{9}$$

where

$$d_0(t, T) = E_t^Q \left[\exp\left(-\int_t^T r_s ds\right) 1_{[\tau > T]}\right]. \tag{10}$$

The first term in Eq. (9) is the value of the survival contingent payment and the second term is the present value of the recovered proceeds contingent on a default occurring prior to maturity. Lando (1988) has shown that $d_0(t, T)$

is valued as

$$\begin{aligned} d_0(t,T) &= E_t^Q\left[\exp\left(-\int_t^T (r_s+\lambda_s)\,ds\right)\right] \\ &= E_t^Q\left[\exp\left(-\int_t^T r_s ds\right)\right] E_t^Q\left[\exp\left(-\int_t^T \lambda_s ds\right)\right] \\ &= b(t,T)\,p(t,T) \end{aligned}$$

The second line follows because, by assumption, r_t and λ_t are uncorrelated; the third line simply reflects the definitions of $b(t,T)$ and $p(t,T)$.

The solution to the second term in Eq. (9) is

$$\omega E_t^Q\left[\exp\left(-\int_t^\tau r_s ds\right) 1_{[\tau\leq T]}\right] = \omega \int_t^T b(t,u)\,\pi^*(t,u)\,du \tag{11}$$

where

$$\pi^*(t,u) = -\frac{d}{du}p(t,u) = p(t,u)\,\lambda(u) \tag{12}$$

Although not available in closed-form, the solution to the integration in Eq. (11) is readily calculated numerically using recursive adaptive Simpson quadrature.

3 Estimation of the Stochastic Properties of Interest Rate and Credit Risk Processes

Parameter estimates of the default-free rate of interest and the intensity rate process are estimated with a Kalman filter.[7] This approach is particularly useful when, as is the case here, the underlying state variables are unobservable. The Kalman filter employs a recursive algorithm that exploits the theoretical affine relation between the physical and risk-neutral densities. This recursion allows me to infer the underlying state variables of interest along with the underlying parameters of the distributions.

Estimation begins by specifying a system of measurement and transition equations for the unobserved state variables under the assumption that it follows a CIR diffusion. The idea is to start with a series of observable bond yields that are measured with error, possibly due to differences in the bid and ask prices. Since these yields depend on the unobserved state

[7]Duffee (2002) and Duffee and Stanton (2012) demonstrate that the Kalman filter is a reasonable techniques when estimating one-factor square-root diffusions.

variables (e.g., the spot rate of interest), the Kalman filter separates the state variables from the "noise" using a recursive forecasting procedure.

The algorithm begins with a set of initial parameter values and an initial estimate of the accuracy of the initial parameters. Using these starting values, the value of the measurement equation is inferred. The linearity assumption underlying the Kalman filter permits the calculation of the conditional moments of the measurement equation. The algorithm then compares the predictions to the observed values. This allows me to update my inferences about the current value of the transition system. These updated values are then used to predict the subsequent values of the state variables. This procedure is repeated for each day in my sample period, which allows me to construct a time series of estimates of the underlying state variables. This implicitly creates a likelihood function, which can be treated as an objective function to estimate the parameters using maximum likelihood estimation.

3.1 Estimation of the Process for the Default-Free Rate of Interest

The data used to estimate the parameters that characterize the dynamics of the default-free rate of interest consist of a time series of $T \times M$ zero-coupon yields with

$$y_{t,m} = -\frac{\ln\left(P_{t,m}\right)}{\tau_{t,m}} \tag{13}$$

for $t = 1, \cdots, T$, $m = 1, \cdots, M$, and where $y_{t,m}$ is the yield on a zero-coupon bond with price $P_{t,m}$ and years to maturity $\tau_{t,m}$. I use yields from U.S. Treasury securities that have 30, 90, 120, 360, and 720-days to maturity. Prices are observed on a daily basis over the period January 4, 2000 through March 22, 2012.

3.1.1 The measurement equation

The measurement equation that links the observed yields to the theoretical yields (see Eq. (6)) is defined as follows:

$$y_{t,m} = -\frac{1}{\tau_m}\bar{\alpha}_r\left(\tau_m\right) - \frac{1}{\tau_m}\bar{\beta}_r\left(\tau_m\right) r_t + e_{t,m} \tag{14}$$

where the measurement error $e_{t,m}$ is assumed to be Normally distributed, i.e., $e_{t,m} \sim N\left(0, h_t^2\right)$. For each day t, this can be expressed as

$$y_t = A_t + B_t r_t + e_t \tag{15}$$

where y_t is $M \times 1$, e_t is $M \times 1$, $A_t = (\bar{\alpha}_r(\tau_1)/\tau_1, \cdots, \bar{\alpha}_r(\tau_M)/\tau_M)$, and $B_t = \left(\bar{\beta}_r(\tau_1)/\tau_1, \cdots, \bar{\beta}_r(\tau_M)/\tau_M\right)$, The measurement error vector is assumed to be Normally distributed such that $e \sim N(0, H)$ where e is the $T \times 1$ error vector that has covariance matrix H where

$$H = \begin{bmatrix} h_1^2 & 0 & \dots & 0 \\ 0 & h_2^2 & \dots & 0 \\ \vdots & \vdots & \ddots & \dots \\ 0 & 0 & \dots & h_T^2 \end{bmatrix}.$$

3.1.2 The transition equation

The transition equation characterizes the evolution of the state vector r_t over time. It also relies on the assumption that r_t is Normally distributed. Since, under a CIR process, r_t follows a non-central χ^2 distribution, this condition is violated.

Ball and Torous (1996) show that, over small time intervals, diffusions arising from stochastic differential equations behave like Brownian motion. As a result, the assumption that r_t can be approximated by a Normal distribution is sensible. For estimation purposes, I use the conditional mean and variance of r_t under the non-central χ^2 distribution as:

$$r_t \sim N\left(\mu(r_t), h_t^2\right) \tag{16}$$

where $\Delta t = \frac{1}{360}$ and

$$\begin{aligned} \mu(r_t) &= \theta_r\left(1 - e^{-\kappa_r \Delta t}\right) + e^{-\kappa_r \Delta t} r_{t-1} \\ h_t^2 &= \frac{\theta_r \sigma_r^2}{2\kappa_r}\left(1 - e^{-\kappa_r \Delta t}\right)^2 + \frac{\sigma_r^2}{\kappa_r}\left(e^{-\kappa_r \Delta t} - e^{-2\kappa_r \Delta t}\right). \end{aligned}$$

Based on this approximation, the transition equation is described as follows:

$$r_t = \mu(r_t) + \epsilon_t \tag{17}$$

where $\epsilon_t \sim N\left(0, h_t^2\right)$.

3.1.3 Sample Characteristics

Panel A of Table 1 depicts the summary statistics for U.S. Treasury yields over the sample period. The mean values range from 1.7451% for 30-day yields to 2.3674% for 720-day yields with corresponding medians of 1.21% to

2.04%. Figure 1 illustrates the U.S. Treasury yield curve from January 2000 through March 2012. As you look at the figure, the leading axis represents the evolution of yields over time, while moving from front to back depicts different maturities (shorter maturities are closest to the leading edge).

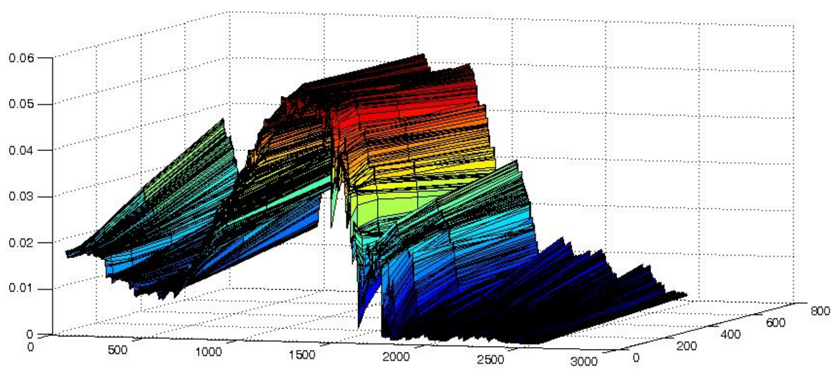


Figure 1: U.S. Treasury yield curve from January 2000 through March 2012.

3.1.4 Parameter Estimates

Panel A of Table 2 presents parameter estimates for the default-free rate of interest. The instantaneous spot rate of interest has an elastic force of 1.3894 that causes the spot-rate of interest r_t to revert to its long-run mean of 0.87%. The standard error for the estimate of κ_r indicates there is significant mean-reversion in the default-free rate of interest. The spot rate r_t has an annualized volatility of 8.07%. Based on Eq. (2) and the parameter estimates in Panel A of Table 2, the spot rate of interest has a long-term standard deviation equal to 0.00452.

To provide some indication of the speed at which the estimated mean-reversion parameter causes volatility to revert to the long-run mean θ_r, κ_r can be used to infer the spot interest rate's "half-life." The half-life is defined as the time required for the expected future spot interest rate to revert halfway to the long-run mean. The half-life is determined by finding the date, t_s, for which

$$E\left(r_{t_s}|r_t\right) = \frac{1}{2}\left(r_t + \theta_r\right) \tag{18}$$

Following Cox, Ingersoll, and Ross (1985), the estimate for the expected future spot interest rate is given by

$$E(r_{t_s}|r_t) = r_t e^{-\kappa_r(t_s - t)} + \theta_r \left(1 - e^{-\kappa_r(t_s - t)}\right) \tag{19}$$

Examination of Equations (18) and (19) indicates that the half-life is determined by setting $e^{-\kappa_r \tau}$ equal to one-half and solving for τ. Given that κ_r equals 1.3894, the expected time for an arbitrary spot rate of r_t to revert halfway to its long-run mean is 0.50 years.

The default-free rate of interest has a market price of risk equal to −0.3748. To provide some intuition for its economic importance, the associated risk premium can be estimated from Eq. (5), i.e., $\eta_r r_t \frac{\partial b}{\partial r}/b = r_t \hat{\beta}_r(\tau)$. Assuming the spot rate of interest rate equals its long-run mean of 0.87%, the annualized risk-premium associated with default-free bonds is 17.6 basis points.

3.2 Estimation of the Process for the Intensity Rate

The parameters for the intensity process are estimated in an analogous manner using 30, 90, and 120-day credit spreads. The credit spread is calculated as the difference between the maturity-matched yields for AA Financial Commercial Paper and U.S. Treasuries securities. Credit spreads are used to estimate the process for the spot intensity rate because they filter out contemporaneous information about the spot rate of interest.

3.2.1 Sample Characteristics

Panel B of Table 1 depicts the summary statistics for credit spreads over the sample period. Unlike the yields for Treasuries, the mean and median credit spreads are not monotonically increasing with maturity. Mean values range from 0.29% for 30-day spreads to 0.34% for 90-day spreads, about double their median values. These skewed results are an implication of including the 2007-2008 Financial Crisis in the estimation period (see Figure 2), which also accounts for the comparatively large standard deviations for the credit spreads of 0.45% to 0.46%. Because of this skewness, I use the mdeian values.

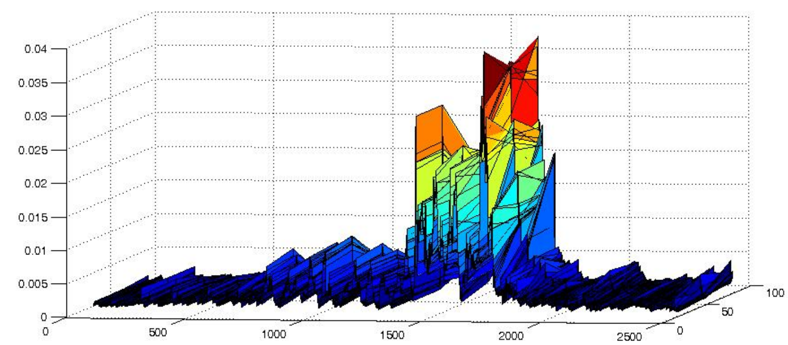


Figure 2: AA financial commercial paper credit spread curve from January 2000 through March 2012.

Figure 3 illustrates the credit spread curves in the post-Financial Crisis period (March 2009 through March 2012).

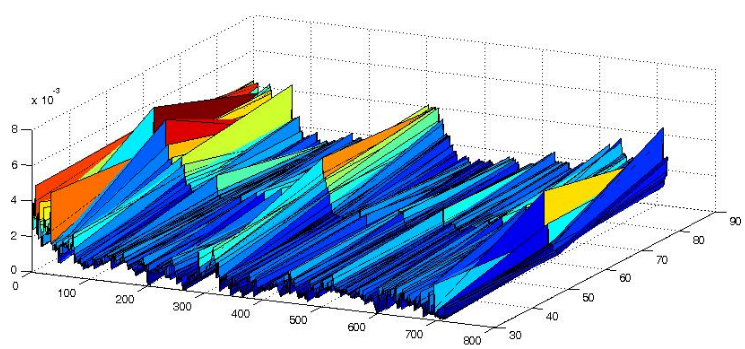


Figure 3: AA financial commercial paper credit spread curve from March 2009 through March 2012.

3.2.2 Parameter Estimates

Panel B of Table 2 indicates that the intensity rate process has a mean-reversion factor of 1.7632 that causes the spot intensity rate λ_t to revert to the long-run mean of 0.13%. The spot intensity rate λ_t has a volatility rate of 3.72%. Given that κ_λ equals 1.7632, the expected time for an arbitrary spot rate of λ_t to revert halfway to its long-run mean is 0.39 years.

The intensity rate has a market price of risk (η_λ) equal to -1.4454. This implies that the corresponding risk premium is 22 basis points when Eq. (5) is evaluated at its long-run mean of 0.13%.

4 Valuation of Money Market Funds

A MMF is a portfolio of fixed income securities. At time t, the shadow price of a fund is the market value of its assets

$$MMF_t = \sum_{s=t+1}^{T} \left(m\left(t,s\right)b\left(t,s\right) + n\left(t,s\right)d\left(t,s\right)\right) \tag{20}$$

where $m\left(t,s\right)$ is the number of units of default-free zero-coupon bonds $\left(b\left(t,s\right)\right)$ with maturity in s days and $n\left(t,s\right)$ is the number of units of risky zero-coupon bonds $\left(d\left(t,s\right)\right)$ with maturity in s days. The fund has an associated duration defined as:

$$D_t = \sum_{s=t+1}^{T} s \times \left(m\left(t,s\right)b\left(t,s\right) + n\left(t,s\right)d\left(t,s\right)\right)/MMF_t. \tag{21}$$

Each MMF has a specific risk-return profile that is determined by the duration of the portfolio and the mix of risky and default-free securities. I assume that I can approximate the investment strategy of a fund's advisor by selecting a target duration and the mix of risky and default-free securities. The idea is to build a parsimonious model that has the ability to capture the risk-return dynamics of the underlying portfolio.

The initial portfolio holdings at time 0 are established by choosing a target duration, D^*, and the proportion of default-free bonds, ϕ. This is tantamount to assuming that the fund manager adopts a particular style and maintains this investment philosophy over the fund's life. It ignores, for example, the possibility that a manager may endogenously respond to changing market conditions by adjusting the mix and duration of securities to mitigate certain exposures.

4.1 Initial Portfolio

To calibrate the initial state of the fund, I choose the number of maturities $\hat{T}$ so that the calculated duration matches the target duration. That is, choose $\hat{T}$ such that

$$\hat{T} = min\left\{\tau : \left|D^* - D_0\left(\tau\right)\right| = 0, \tau = 1, 2, \cdots, \infty\right\}, \tag{22}$$

subject to the constraints that the number of default-free and risky bonds reflect the proportion ϕ, i.e.,

$$m(t,s) = W\phi/\hat{T}, \forall s, 1, \cdots, \hat{T},$$
$$n(t,s) = W(1-\phi)/\hat{T}, \forall s, 1, \cdots, \hat{T},$$

and where W is a normalizing constant that sets the initial value of the fund to \$1.[8]

The time 0 value is

$$MMF_0 = \sum_{s=1}^{\hat{T}} W\hat{T}^{-1}\left(\phi b(t,s) + (1-\phi) d(t,s)\right) \tag{23}$$

and has duration

$$D_0 = \sum_{s=1}^{\hat{T}} sW\hat{T}^{-1}\left(\phi b(t,s) + (1-\phi) d(t,s)\right)/MMF_0. \tag{24}$$

Given $\hat{T}$, the normalizing constant W is calculated as:

$$W = D_0\left(\sum_{s=1}^{\hat{T}} \hat{T}^{-1}\left(\phi b(t,s) + (1-\phi) d(t,s)\right)\right)^{-1}. \tag{25}$$

4.2 Money Market Valuation at Time t

This section establishes a methodology for evaluating intertemporal changes in a fund's shadow price. Throughout the paper, I use the terms market value and shadow price interchangeably. I characterize changes in the value of a portfolio of fixed income securities by simulating the time series for both the default-free rate of interest and the process that characterizes defaults.

4.2.1 Monte Carlo simulation of CIR processes

An advantage of the affine structure is that the distribution of a CIR-type process over a given time period of length τ years is distributed as a non-central Chi-Square with $d = 4\kappa\theta/\sigma^2$ degrees of freedom and non-centrality

[8] The requirement that the number of default-free and risky bonds are the same for every maturity is without loss of generality. It simply provides a convenient way to calibrate the initial portfolio holdings.

parameter $\zeta(X_t, \tau)$ where

$$\zeta(X_t, \tau) = \frac{4\kappa e^{-\kappa\tau} X_t}{\sigma^2 (1 - e^{-\kappa\tau})}. \tag{26}$$

To simulate a time series for the spot interest rate and default intensities for days $t = 1, \cdots, \hat{T}$, I use the following algorithm:

- For day t, I estimate the instantaneous spot rate of interest, r_t by taking a draw from a non-central Chi-square distribution, $\chi^2_{nc}(d, \zeta(r_{t-1}, \tau))$.
- The day t spot interest rate is calculated as

$$r_t = \sigma_r^2 \left(1 - e^{-\kappa_r \tau}\right) \chi^2_{nc}(d_r, \zeta(r_{t-1}, \tau)) \tag{27}$$

- I next estimate the day t instantaneous intensity rate, λ_t by taking a draw from a non-central Chi-square distribution for the spot intensity rate process, $\chi^2_{nc}(d, \zeta(\lambda_{t-1}, \tau))$.
- The day t intensity rate is then calculated as

$$\lambda_t = \sigma_\lambda^2 \left(1 - e^{-\kappa_\lambda \tau}\right) \chi^2_{nc}(d_\lambda, \zeta(\lambda_{t-1}, \tau)) \tag{28}$$

- I assume that all bonds have a common intensity process λ_t and that defaults across different maturities are independent. To determine whether a bond with maturity s defaults on day t, I calculate the probability of default over day t using $p(t, t+1)$ from equation (7). I then take a draw from the implied binomial distribution to determine whether there has been a jump to default. If a default occurs, I assume that $I_t(s) = 1$ and the value of a risky zero-coupon bonds equals the recovery rate. If there is no default, $I_t(s) = 0$. I repeat this process for all maturities $s = 1, \cdots, \hat{T}$.[9]

[9] To facilitate the comparison of risk across portfolios with different durations, I normalize the number of bonds so that each portfolio holds the same number of bonds. For example, if a default-free 60-day duration portfolio is constructed with 120 bonds and a 90-day duration portfolio requires 180, the 60-day portfolio would be adjusted so that on each day it would hold three bonds and the 90-day portfolio would hold 2 bonds. This would result in each portfolio being identically concentrated, in that, each would hold exactly 360 bonds. In this manner, defaults, which are independent of maturity, occur with the same frequency across portfolios.

4.2.2 Portfolio decisions at time t

The next step is to design an algorithm for reinvesting proceeds from maturing bonds subject to two constraints: 1) maintain the target duration D^* and 2) reinvest the proceeds to maintain a constant proportion ϕ of default-free bonds to total bonds. Let X_t denote the cash flow generated by expiring bonds at time t. Since bonds are zero coupon, the holder receives the face value of $1 at maturity. This implies that $m(t-1,t)$ is the value of expiring default-free securities. Analogously, $n(t-1,t)$ is the value of risky zero coupon bonds conditional on no default and $n(t-1,t)\omega$ reflects the amount that is available after a default event. Taken together,

$$X_t = m(t-1,t) + n(t-1,t)\left((1-I_t(0)) + \omega I_t(0)\right). \tag{29}$$

The proceeds X_t are reinvested in zero-coupon bonds that have a maturity T^* where T^* is the maturity that sets the portfolio duration equal to the target duration D^*.[10] Since all bonds are zero-coupon and each bond's duration equals its maturity, I solve for the maturity date that results in the current duration that is closest to the target duration. This is estimated as

$$T^* = floor\left((D^* - CurDur)(MMF_t/X_t)\right) \tag{30}$$

where $CurDur$ is the duration of the portfolio *excluding* X_t, i.e.,

$$CurDur = \sum_{s=t}^{T-1} s \times \left(m(t-1,s)\,b(t,s+1) + n(t-1,s)\,d(t,s+1)\right)/MMF_t. \tag{31}$$

Having identified the maturity of the bonds that will achieve the target duration, the fund advisor allocates X_t between default-free and risky zero-coupon bonds as follows:

$$m(t,T^*) = \frac{\phi X_t}{(\phi b(t,T^*) + (1-\phi)\,d(t,T^*))}$$
$$n(t,T^*) = \frac{(1-\phi)X_t}{(\phi b(t,T^*) + (1-\phi)\,d(t,T^*))}$$

5 Time Series Properties of Money Market Funds

This section examines the time series properties of money market funds under the "baseline" as it currently exists under rule 2a-7. As I have noted

[10] As a practical matter, the duration of the portfolio can be reasonably approximated by reinvesting the proceeds in a zero-coupon bond that matures in $\hat{T}$.

above, the most important economic consequence of the 2010 amendments to rule 2a-7 is to constrain the risk taking opportunities of fund managers relative to the regulatory framework that preceded them..

I evaluate how different combinations of risky and default-free securities alter the risk-return characteristics of MMFs. At one extreme, I consider a portfolio that only holds risky securities that are designed to behave like securities with a AA bond rating and at the other, a portfolio that is equivalent to a Treasury bond portfolio. For simplicity, I refer to the extreme portfolios as "risky" ($\phi = 0.00$) and "default-free" ($\phi = 1.00$) throughout the remainder of the paper.

5.1 Monte Carlo simulation

The Monte Carlo simulation is based on the following parameters. The long-run rate assumptions for the spot interest and intensity rates respectively are 0.87% and 0.13% (see Table 2). I assume that the recovery rate for security defaults is 40%. This assumption reflects the typical recovery rate convention used to price credit default swaps when the underlying reference security is a senior debt obligation. Finally, the evaluation period is 360 days.

The analysis reports results for portfolios that have different combinations of default-free and risky securities where ϕ defines the proportion of default-free securities held in the MMF, i.e., $\phi = \{0.00, 0.25, 0.50, 0.75, 1.00\}$.

The simulation is based on the following algorithm:

1. The starting values for r_1 and λ_1 are set equal to their long-run means of 0.87% and 0.14%, respectively.

2. Based on the simulation parameters and initial values for the spot rates, solve for the number of maturities $\hat{T}$ that result in a portfolio duration of 60 (or 90) days (see Eq. (21)).

3. To create a single 360-day sample path, I draw $\hat{T}+360$ spot interest and intensity rate pairs $\{r_t, \lambda_t\}$ using the procedure described in Section 4.2.1. The first $\hat{T}$ days are used to calculate the initial portfolio; the next 360 days are used to evaluate the time-series behavior over the estimation period. The initial portfolio formation period of $\hat{T}$ days is required so that each security has a corresponding valuation based on amortized cost.

4. To facilitate the comparison of the shadow price to its amortized cost

(AC), I calculate AC for the *initial portfolio* using the following algorithm:

(a) For each day t, $t = 1, \cdots, \hat{T}$, calculate the values of $b(t, \hat{T})$ and $d(t, \hat{T})$ with $\hat{T}$ days to maturity using $\{r_t, \lambda_t\}$. Note that this holds the maturity for all bonds purchased on day t constant. This ensures that on day $\hat{T}$ (the last day of the initial portfolio formation period), I have initial prices for bonds with maturities ranging from 1 to $\hat{T}$ days.

(b) At day $\hat{T}$, the amortized cost $AC_{\hat{T}}$ is

$$AC_{\hat{T}} = \sum_{s=1}^{\hat{T}} m(\hat{T}, s) b(s, \hat{T}) e^{y_b(s,\hat{T})(\hat{T}-s)/360} + n(\hat{T}, s) d(s, \hat{T}) e^{y_d(s,\hat{T})(\hat{T}-s)/360}$$

where $y_b(t, \hat{T})$ and $y_d(t, \hat{T})$ denote the corresponding yields to maturity. These are calculated as $y_x(s, \hat{T}) = ln(x(s, \hat{T})^{-1})$. I assume that amortized cost accrues at each security's yield to maturity. This is an approximation to the approach specified in rule 2a-7, which requires straight-line amortization over the security's life.

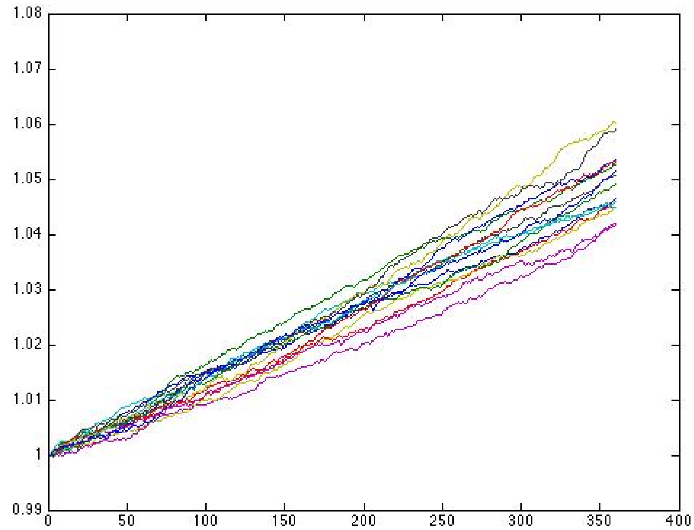
(c) For each day $t, t = \hat{T} + 1, \cdots, \hat{T} + 360$, the portfolio SP and AC are updated using $\{r_t, \lambda_t\}$.

(d) This is repeated for M sample paths ($M = 2,500$).

5.2 Buy-and-hold returns based on amortized cost

Currently, the U.S. money market fund industry is permitted to use amortized cost accounting to value portfolio securities. This implies that fund managers are allowed to price the fund at amortized cost even though the underlying portfolio fluctuates in value as market conditions change. Amortized cost is, loosely speaking, the accounting or book value of the security.

Figure 4 depicts a number of representative sample paths from a Monte Carlo simulation. Figure 4a is the market value of the fund under the assumptions described in 4.1; Figure 4b is the amortized cost of the MMF along the same simulation paths. These figures demonstrate that amortized cost is less volatile than the underlying shadow price.



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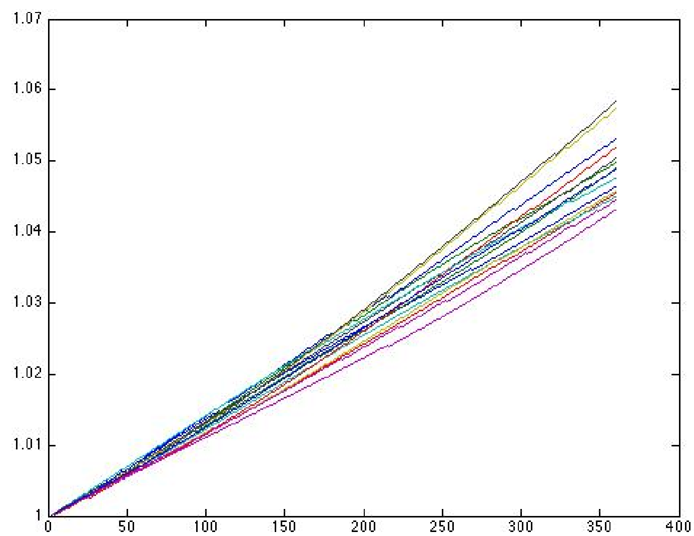
(a) Shadow Price



(b) Amortized Cost

Figure 4: Representative sample paths for a MMF that holds 75% risky securities over a 360-day period.

The main difference between tracking performance using amortized cost valuations and a fund's shadow price is how income accrues.[11] Amortized cost valuations reflect the ratable accrual of interest over the bond's life plus realized capital gains and losses. By contrast, the shadow price not only reflects accrued interest but also realized *and* unrealized capital gains and losses.

Figure 5 provides a more granular look at the differences between shadow prices and amortized cost along two representative sample paths assuming an investor follows a buy-and-hold strategy that reinvests all distributions.[12] It can be seen that deviations from amortized cost are mean reverting.

5.2.1 Statistics for buy-and-hold returns based on amortized cost

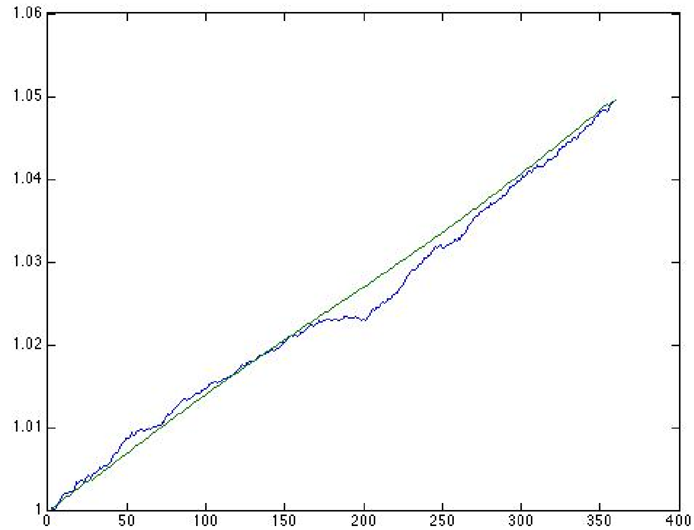
Amortized cost valuation smooths but does not eliminate the price fluctuations caused by changing market conditions. The intuition can be seen best by noting that, when default-free bonds are held to maturity, capital gains and losses net to zero. It then follows that, without default or sales at a loss, differences between the shadow price and amortized cost represent idiosyncratic risk - a type of risk that is not priced in equilibrium.

Table 3 presents summary statistics from the Monte Carlo simulation. Panels A and B respectively report statistics for buy-and-hold returns based on amortized cost and the shadow price. The analysis uses a 360 day investment horizon to evaluate the impact on portfolios with 60-day durations. The columns depict results for portfolios that range from being fully invested in risky securities ($\phi = 0.00$) to those fully invested in default-free securities ($\phi = 1.00$).

Panel A reports that amortized cost returns for 60-day duration portfolios range from 0.9410% to 0.9126%. The relatively small spread between risky and default-free securities (2.84 b.p.) suggests that, even the riskiest portfolio is not expected to be very volatile. The standard deviations of re-

[11] Money market funds either distribute or accumulate income. In the U.S., almost all funds distribute income. Funds that distribute income do so through either periodic (monthly) dividends or share reinvestments. Funds that accumulate income simply add their daily income to the daily share price. Accumulating funds also have tax advantages over distributing funds in some jurisdictions like Europe, but in the U.S. distribution is the tax-advantaged option. For example, by adding income to the daily share price rather than paying it out, (1) the fund shareholders' receipt of the income is postponed, and (2) the earned income is converted into capital gains, which might be taxed at a lower rate. Nearly all U.S. money market funds distribute income monthly.

[12] By definition, a buy-and-hold strategy abstracts from the possibility of modeling shareholder redemptions.



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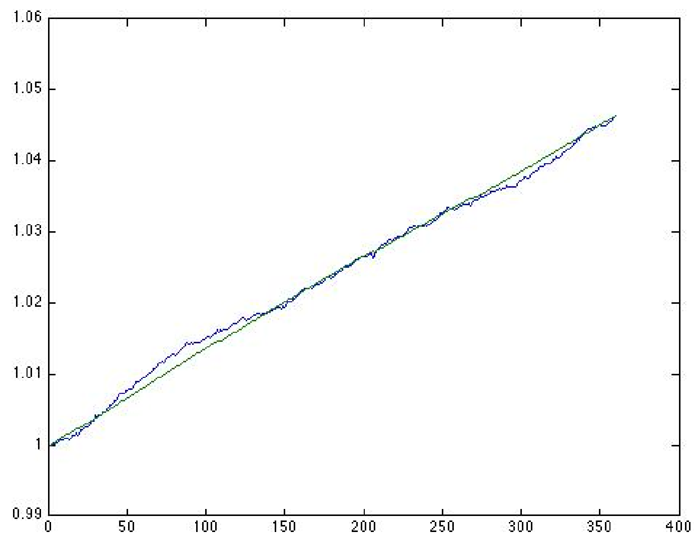
(a) Path 1



(b) Path 2

Figure 5: Monte Carlo simulation results for two representative paths of a MMF that holds 75% risky securities over a 360-day period.

turns across different portfolios confirm this conjecture. I find that standard deviations are economically small, ranging from 0.2701% to 0.2626%. As a point of reference, the mean yield on a 30-day Treasury security is 1.7451% with a standard deviation of 1.6991%, resulting in a mean-volatility ratio of 1.03. By contrast, the mean-volatility ratio for a portfolio of default-free securities from the Monte Carlo simulation is 3.92 (0.9126/0.2626) - almost four times higher. This is largely attributable to the mean-reverting nature of the processes that characterize interest rate and credit risk, as well as, the risk constraints imposed by rule 2a-7 on weighted average maturity.

5.2.2 Statistics for buy-and-hold returns based on shadow price

Panel B of Table 3 summarizes the time-series properties of 360-day buy-and-hold returns for the fund's shadow price. The mean shadow price (SP) returns range from 0.9180% to 0.9162% and have corresponding standard deviations ranging from 0.2822% to 0.2811%. To place these results into context, the long-run yield for the Treasury fund ($\phi = 1.00\%$) of 0.9162% is close to the estimated unconditional long-run physical mean of 0.87%. Also note that the mean returns based on amortized cost in Panel A are higher than the corresponding SP returns. This follows because amortized cost returns do not reflect security defaults.[13] I present unadjusted returns because they are the basis upon which shareholder returns under the capital buffer are determined.[14]

Taken together, the volatility rates for SP and AC returns suggest that there is relatively little times series variation in market values under the current regulatory baseline. For example, the SP mean/volatility ratio for the "risky" portfolio is 3.953 (0.9180/0.2322). The same ratio for AC returns is 3.484 (0.9410/0.2701). For purposes of interpretation, it should be noted that all of the simulation runs are initialized by assuming that the spot interest and intensity rates are seeded at their long-run means. Intuitively, this equivalent to starting the simulation runs in a period of "normal" market conditions.

[13]The median estimates of SP and AC returns are very close to one another. This is attributable to the low default rates for individual securities and the likelihood that the median price paths do not reflect a security default. If I adjust amortized cost returns for security defaults as would be the case under the current regulatory baseline, there is very little difference between SP and AC returns.

[14]For an analysis of amortized cost returns that reflect security defaults, see Tables 5 and 7 of the RSFI (2012), study.

5.2.3 Statistics for relative AC/SP valuation ratios

Table 4 presents summary statistics characterize the distribution of the ratio of amortized cost to shadow price across all 360 days. I make four observations. First, the mean and median are effectively 1.00 across all portfolios, indicating that, on average, the pricing is very similar across different valuation methodologies. Second, it is possible to "break the buck" - the maximum value across all portfolios is 1.0060. Third, a fund breaks the buck with low probability - the 99-percentile value for riskiest portfolio is 1.0027. Note also that a MMF that is fully invested in default-free securities never breaks the buck. Finally, none of the funds break the buck on the upside - all ratios exceed 0.9950.

5.2.4 First passage time statistics

One of the limitations of the statistics reported in Table 4 is that they evaluate the likelihood of "breaking the buck" on *any* given day. A more natural way to evaluate the impact of a fund breaking the buck is to consider whether it has done so at any time over a particular holding period. Table 5 directly addresses this point by providing additional information about the distribution of returns and volatility across different risk portfolios.

Panel A of Table 5 reports the mean first passage time until the difference between the shadow price and amortized cost falls below a particular threshold over a 360-day holding period for 60-day duration portfolios. Panel B reports the frequency that this spread falls below a particular threshold.

Panel A indicates that credit risk induces volatility. Here one sees that the mean first passage time until a MMF first has a shadow price that falls 5 basis points below amortized cost is 183.962 days. The first passage time also rises rapidly as the threshold increases. For example, the first passage time to a 10 b.p. threshold is is 308.801 days. The first passage time increases to 348.811 days for a 25 b.p. threshold.

Panel B reports the probability that a MMF hits specific thresholds at least one time prior to year end. The results indicate that the failure rate rapidly decreases as the size of the buffer increases. For example, the probability that a "risky" MMF will have its shadow price drop at least 5 b.p. below amortized cost sometime during the year is 71.520%. As a point of reference, a portfolio that only invests in default-free securities hits a 5 b.p. threshold 60.240% of the time.

An interesting aspect of of this analysis is the importance of credit risk. Note that there is virtually no chance that a fund holding default-free securities would experience a decline in shadow price relative to its amortized cost by an amount as small as 25 basis points. By contrast, there is 4.880% chance that a MMF with risky securities will experience a 25 b.p. decline. An alternative way to consider these findings is in terms of the complement - the survival rate. If a fund only hits the 25 b.p. threshold 4.880% of the time, the probability that a fund never experiences a loss of 25 b.p. relative to its amortized cost is 95.220%.

Consistent with Tables 3 and 4, Table 5 indicates that the 2010 amendments to rule 2a-7 do not eliminate the possibility of breaking the buck. For a portfolio that has 100% of its assets under management invested in securities that have credit risk, the mean time to breaking the buck is 359.653 days. If there was no chance that the fund would ever break the buck, the mean time would be 360 days. Panel B reports that the frequency a MMF breaks the buck is 0.240%.

6 Money Market Funds with a Capital Buffer

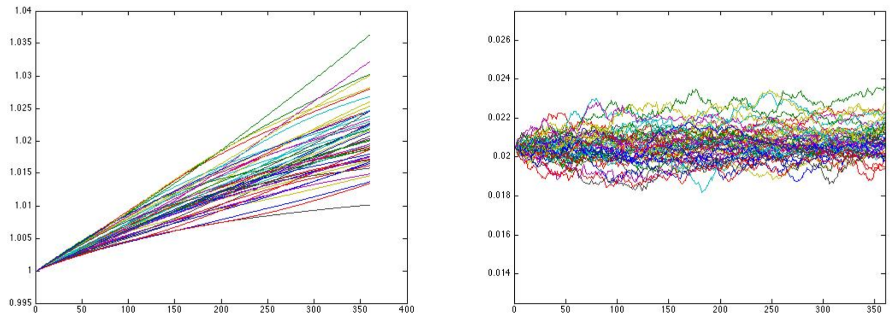
A capital buffer is an alternative approach for structuring a MMF. It is designed to decompose a traditional fund into two separate components - a capital buffer (B shares) and a stable value claim (A shares). The providers of the capital buffer, possibly the plan sponsor, absorb all gains and losses on the portfolio in excess of the amortized cost of the underlying assets in exchange for a capital charge that has a promised yield of y_B. The stable value claim provides investors with a payout that is equal to the amortized cost of the the underlying assets less the capital charge, provided the buffer remains solvent.

6.1 Valuation of the capital buffer

I assume that the initial capital buffer is funded at time 0 by investing B_0 in the same portfolio of assets as those in the MMF. By assuming that the buffer replicates the MMF portfolio, I preserve the risk-return characteristics of the original MMF, making it possible to compare different alternatives.[15] This implies that the total assets under management are $(1 + B_0)\,MMF_t$.

Since the capital buffer absorbs any gains or losses in excess of amortized

[15] Since the assets of shareholders and the provider of the capital buffer are co-mingled, the risk-return characteristics of the MMF reflect these combined risks. For example, if I assume that the buffer invests in default-free securities, it effects the overall risk-return trade off.



(a) A shares

(b) B shares

Figure 6: Monte Carlo simulation results for a MMF with a duration of 60.0 days and $\phi = 1.00\%$ and a capital buffer of 2.0%

cost of the fund assets, at the end of each day t, B shares investors have

$$B_t = max\left(0, (1 + B_0)\, MMF_t - AC_t + B_0\left(e^{y_B t/360} - 1\right)\right) \tag{32}$$

where B_t is the value of the capital buffer at day t, AC_t is the amortized cost of the fund assets on day t, and y_B is the promised yield on the capital buffer which continuously accrues over a 360 year.

The A shares at day t are valued as follows:

$$\begin{aligned} A_t &= min\left(AC_t - B_0\left(e^{y_B t/360} - 1\right), (1 + B_0)\, MMF_t\right) \\ &= (1 + B_0)\, MMF_t - B_t \end{aligned} \tag{33}$$

Eq. (33) simply reflects the identity that the sum of A_t and B_t must be equal to $(1 + B_0)\, MMF_t$. Figure 6 presents a look at the payoffs for A and B shares for fifteen representative sample paths based on 200 b.p. capital buffer. Figure 6(a) shows that the A shares essentially trade at their amortized cost net a charge for providing the buffer, while Figure 6(b) demonstrates that the B shares display considerable volatility relative to the size of the capital buffer - a direct implication of a 98% leverage ratio.

6.2 How a capital buffer functions

The capital buffer is designed to absorb the fluctuations in the value of the fund's underlying assets relative to their amortized cost. An interesting feature of the buffer is that it is expected to absorb the same amount of risk regardless of its size. That is, the deviations between amortized cost and market value are determined by the underlying portfolio assets and are, therefore, independent of buffer size. The size of the buffer does, however, determine how likely it is to fail and its inherent risk absorbing capacity. In equilibrium, capital buffer investors must earn an expected rate of return that compensates them for this risk. This implies that as one reduces the size of the capital buffer, the expected return must increase. While this is, of course, accurate, this intuition provides an incomplete picture of the underlying economics.

The best way to understand how a buffer investor is compensated is to consider a fund that is fully invested in default-free securities. By abstracting from defaults, I can focus on fluctuations between market value and amortized cost. Since these deviations are mean reverting and converge to the same value at maturity, the risk-return profiles for a security whose payoffs reflect current market values or one whose prices are based on amortized cost are very similar. In effect, the deviations that a capital buffer (for a default-free portfolio) is designed to absorb reflect idiosyncratic risk rather than systematic (or "market") risk.[16]

In this context, the buffer payoffs are analogous to an equity claim on the underlying assets. This explains why a buffer investor demands higher expected returns as the buffer becomes small, even if the underlying assets are default-free.[17] In effect, a buffer investor requires compensation for bearing the financial risk associated with the leverage implicit with specific buffer levels.

Assume now that the portfolio holds risky securities. The buffer is expected to not only absorb deviations due to changing interest rates and credit quality, but also losses associated with defaults. As a result, a buffer investor requires compensation for bearing both risks. In equilibrium, if shareholders do not bear credit risk, they will not be able to demand yields in excess of the default-free rate. To the extent that the buffer is of suffi-

[16]A small caveat is that a very small buffer would only remain solvent part of the time. For example, a 10 b.p. buffer would remain solvent 74.760% of the time (Panel B, Table 5, $\phi = 1.00$, 10 b.p.), 1- 25.240%). That is, as the capital buffer becomes small relative to the risk it is designed to absorb even a buffer that supports a portfolio ofdefault-free securities takes on "market" risk because not all large losses can be fully absorbed. It then follows that, if the capital buffer level is set sufficiently high so that the probability of failure approaches zero, buffer investors cannot demand additional compensation for bearing any of these price deviations because idiosyncratic risk is not priced in equilibrium.

[17]The underlying assets include the investments made by the fund advisor plus those that are used to fund the capital buffer.

cient size to absorb security defaults, MMFs are effectively converted into "synthetic" "Treasury" funds.

6.3 The promised yield demanded by providers of buffer capital and its expected cost to MMF shareholders

In equilibrium, the promised rate of return is estimated by finding the rate y_B that sets the present value of the future cash flows to B shareholders under the risk-neutral density equal to the initial capital contribution, i.e., $E^Q\left(\exp\left(-\int_t^\tau r_s ds\right) B_T(y_B)\right) = B_0$.

Table 6 presents an analysis of the promised yields for capital buffer levels ranging from 10 to 300 b.p. Panels A through E report results for portfolios where the proportion of default-free securities ranges from 0% to 100%. Since the results are comparable across all panels, I focus my discussion of the results on Panel A without loss of generality. The promised yield respectively ranges from 31.1408% to 1.2093%. The expected buffer cost (BC) is calculated as

$$BC = B_0 \times y_b \times (1 - FailureRate) \tag{34}$$

where the Failure Rate denotes the probability that the buffer fails at some point over the 360 day investment horizon (estimates are presented in Table 6). The expected per dollar buffer costs range from 2.8848 b.p. for a buffer of 10 b.p. to 3.6500 b.p. for buffers that exceed 70 b.p.s. Note that once this critical threshold is reached, the expected cost of the buffer remains constant. This result is best explained by examining Table 7, which presents the associated Failure Rates for different buffer levels ranging from 10 to 70 b.p. Here one can see that, as the probability of a buffer failure approaches zero, the expected cost of providing a buffer becomes constant. This finding is consistent with my observation that a buffer is designed to absorb the same risk regardless of size.

6.4 The cost of capital for stable value shareholders and the capital buffer

Given an estimate of y_B, I can then estimate the cost of capital for the A and B shares by calculating the discount rate that respectively sets the present values of the expected payoffs under the physical distribution equal to the respective market prices of the A and B shares, i.e., \$1.00 = $E^P(A_T(y_B))e^{-k_A T})$ and $B_0 = E^P(B_T(y_B))e^{-k_B T})$.

Since the results across Panels A through E of Table 6 are qualitatively similar, I use Panel A to describe a number of the salient features of my analysis. The first is that the stable value A shares, which have been structured to provide payoffs that replicate amortized cost net of a payment to the capital buffer to compensate for default risk, have a cost of capital (k_A) that is very similar to the cost of capital associated with a default-free security. Since I assume that the capital buffer contributes the same securities as those in the MMF, the overall cost of capital for the MMF plus the buffer is the same as the stand-alone MMF fund. The reason that the cost of capital for the capital buffer shares (k_B) is higher than the A shares is that they reflect a risk premium for absorbing default risk from the A shares.

Since the amount of default risk a capital buffer attempts to absorb is the same regardless of the size of the buffer, smaller buffers have higher costs of capital to reflect the higher leverage levels. Although the cost of capital k_B declines monotonically with buffer size, the Buffer Cost does not follow suit. This is because, small buffers, of say 10 b.p.s, fail at high enough rates that they do not insulate A shares from default and force them to absorb nontrivial levels of risk that may cause them to fail, even if the only hold default-free securities. As buffer levels increase to the point where the probability of a buffer failure approaches zero, the Buffer Cost does not change even though the promised yields and their associated costs of capital do. The standard deviation columns also demonstrate that the standard deviation of the realized returns to A shares is very stable across buffer levels. By contrast, the standard deviation of the returns to B shares are significantly higher. They also naturally decrease as the size of the capital buffer grows.

Panel E reports results for a portfolio of default-free securities. There are a number of results that warrant discussion. The first is that the cost of buffer capital exceeds the cost of capital for A shares by a significant amount for small buffer levels. For example, $k_B = 5.3127\%$ and $k_A = 0.9111\%$ for a 10 b.p. buffer. The second point is that, as the capital buffer increases in size, k_B approaches k_A. By contrast, k_B for portfolios of risky securities always reflects a premium for default risk ($k_B = 1.2268\% > k_A = 0.9080\%$ for a 300 b.p. buffer).

Table 7 provides summary statistics for buffer failure rates. It reports the expected time to first failure and the corresponding probability of a buffer failure. The analysis indicates that a fund could protect itself from failure for buffer levels greater than 60 basis points under the current regulatory baseline.

6.5 Concentration and Defaults

The results of my simulation analysis are determined, in part, by the portfolio construction algorithm. This algorithm calculates the number of zero-coupon bonds that are needed to achieve a target duration (see Section 4.1). For example, the simulation analysis used to create Table 9 is based on a portfolio with a 60-day duration. The algorithm determined that an equally-weighted portfolio requires 122 bonds with consecutive daily maturities ranging from 1 to 122 days.

The choice of portfolio weights is relevant because funds are permitted to hold concentrated positions of up to 5% in individual securities. Since the failure of a single concentrated position could result in significant investor losses, it is important, therefore, to better understand how concentration levels affect portfolio default rates.[18]

I evaluate the impact of portfolio diversification by comparing default "shocks" of the same economic magnitude. To do this, I calculate the number of bonds that would need to default on the same day to cause a loss of $X\%$. Under the maintained assumption that a portfolio is comprised of N equally-weighted securities, an $X\%$ default shock can be represented as the probability that no more than K bonds default on a given day where $X = floor\left(\frac{K}{N}\right)$. For the case of a 5% default, a portfolio comprised of 20 positions would only need one bond to default. By contrast, a well-diversified portfolio that holds 120 securities would require 6 securities to default on the same day.

The probability that **no more** than K bonds default on a given day t for a portfolio containing N bonds is computed as

$$\hat{p}_t(K) = \sum_{k=0}^{K} p_t(t, t+1)^{N-k} \left(1 - p_t(t, t+1)\right)^k \frac{N!}{(N-k)!k!} \tag{35}$$

where $p_t(t, t+1)$ is the probability of survival from time t to $t+1$. The one-day survival probability (see Equation (8)) equals:

$$p(t, t+1) = e^{\bar{\alpha}_\lambda(1) + \bar{\beta}_\lambda(1)\lambda_t}. \tag{36}$$

For calculation purposes,both $\bar{\alpha}_\lambda(1)$ and $\bar{\beta}_\lambda(1)$ are computed using the estimated parameters for the physical intensity process. The probability that **more** than K bonds default on any given day t over an investment horizon

[18] Note that such an event would cause the fund to break the buck if the recovery rate is less 90%.

of T days is

$$P_t(K) = 1 - E_t^P \left[\prod_{\tau=1}^{T} \hat{p}_\tau (K; \lambda_\tau) \right] \tag{37}$$

Using the simulated intensity rates, a Monte Carlo estimate of $P_t(K)$ is calculated as

$$\bar{P}_t(K) = 1 - \sum_{j=1}^{J} \prod_{\tau=1}^{T} \hat{p}_\tau (K; \lambda_{\tau j}) / J \tag{38}$$

where $\lambda_{\tau j}$ is the simulated intensity rate on date τ for simulation run j.

Table 8 reports the probability of experiencing **more** than K defaults on a given day at some point over a 360-day investment horizon for six different portfolio formation strategies. Portfolio $P1$ contains 20 securities and can be viewed as a maximally concentrated portfolio. In this portfolio, each security represents 5% of the fund's shadow price. The results for this portfolio represent an upper bound on default probabilities. Portfolios $P2$ through $P6$ represent funds that have progressively higher diversification levels. These portfolios are respectively comprised of 40, 60, 80, 100, and 120 securities. Portfolio $P6$ is of particular interest because it has approximately the same level of diversification as the portfolio that is used throughout this paper.

The first row of Table 8 indicates that the probability of more than one default is rather low and that the rate monotonically declines as portfolios become more diversified. The highlighted amounts in each column reflect the probability of experiencing a common 5% default shock on at least one day over the 360-day holding period. The highlighted amounts show that the probability of a 5% default shock ranges from 1.380084% to 0.000001%. The relatively high default rate for the maximally concentrated Portfolio $P1$ declines rapidly as portfolios become more diversified. For example, Portfolio $P2$ only has a 0.046205% chance of a 5% economic shock.

Paradoxically, the expected returns across portfolios $P1$ through $P6$ are very similar. This simply reflects the fact that less diversified have a relatively small number of large shocks, while the more diversified portfolios experience a relatively high number of small shocks. On net, since they are exposed to the same aggregate level of credit risk, they earn similar returns.

Since funds tend to hold a relatively small number of concentrated positions, the assumption that a fund holds twenty maximally concentrated positions is unrealistic. As a consequence, my estimate of the upper bound on default rates can be tightened considerably by basing these estimates on the empirical distribution of actual MMF holdings. Using monthly data provided to the U.S. Securities Commission on Form N-MFP submissions, Table 9 reports the number of MMFs that hold positions with economic exposure to the issuer's parent company that exceed specified thresholds over the period November 2010 through November 2012.[19]

Table 9 reports results for the 592 money market funds that submitted data to the SEC at some point during November 2010 to November 2012 period. Consider the column labeled 5%. This column provides the distribution of the average number of assets per fund with at least a 5% exposure level. The first row shows that 122 of the 529 funds never held a security over the 25 month estimation period that had at least a 5% exposure to a single parent. This implies that 76.9% of the funds actually had significant exposure to at least one issuer. The tenth row indicates that, on average, 7 funds held between 5 and 6 securities with at least a 5% exposure. One also can see that no fund maintained 5% exposure levels for more than 6 securities. That is, no money market funds reported maximally concentrated positions that exceeded 30.0% of the assets under management.

Based on this empirical distribution, I estimate the probability of an economic shock that results in a loss of X% of a fund's shadow price on any given day over a 360-day investment horizon. These estimates are based on portfolios that hold ten maximally concentrated positions and N equally-weighted positions where $N = 20$, 40, 60, 80, 100, and 120 securities. Given that no fund held more than 6 concentrated positions, this represents a conservative bias for measuring exposure to concentrated positions. One can then interpret the results of Table 9 as generating an empirically motivated least upper bound.

Table 10 reports my estimates of default probabilities for different economic shocks. Each row represents the probability of an economic shock that falls within the indicated range. For example, the first row represents the probability of an economic shock of between 0.0% and 2.5%. It is interesting to note that the probability of a 5.0% shock for the maximally concentrated portfolios $P1$ drops from 1.3801% (Table 8) to 0.0099%.

Taken as a whole, these results suggest that the assumptions underlying the portfolio formation algorithm do not materially affect the implications of my analysis. They do show that large losses are more likely if a fund has concentrated positions, but that the marginal increase in the probability of default is not economically significant.

[19]Since I am interested in examining default risk as it primarily relates to corporate issuers, the analysis excludes variable rate demand notes, other municipal debt, Treasury repurchase agreements, government repurchase agreements, asset backed commercial paper with a guarantee or demand feature, and public debt.

7 Conclusion

The topic of money market regulation is the subject of much debate. The objective of this paper is to illustrate the economic effects of requiring a money market fund to be supported by a capital buffer. To put my findings into context, it is important to understand that a capital buffer can be designed to satisfy different potential objectives.

One possible objective is to design a buffer so that it is able absorb day-to-day variations in market value relative to the amortized cost of the underlying portfolio assets. My examination of this design strategy demonstrates that a 60 basis point buffer would be sufficient to provide price stability under normal market conditions. Although a 60 basis point buffer is able to withstand most day-to-day price variation, it would most likely fail if a concentrated position, of say 5%, were to default.

A larger buffer could protect shareholders from losses related to defaults in concentrated positions, such as the one experienced by the Reserve Primary Fund following the Lehman Brothers bankruptcy. However, if complete loss absorption is the objective, a substantial buffer would be required. For example, a 3% buffer would accommodate all but extremely large losses. A limitation of a large buffer is that the cost of providing this protection would be borne at all times even though it is likely to be significantly depleted only rarely.

While a capital buffer would make a money market fund more resilient to deviations between the shadow price and amortized cost, it may be a costly mechanism from the perspective of the opportunity cost of capital. Those contributing to the buffer deploy valuable scarce resources that could be used elsewhere. Moreover, because the capital buffer absorbs fluctuations in the value of the portfolio, much of the yield of the fund will be diverted to funding the capital buffer, which, in turn, will reduce fund yield. Put another way, to the extent that the capital buffer absorbs default risk, those contributing to a capital buffer will demand a rate of return that compensates them for bearing this risk. Since, by construction, a capital buffer absorbs defaults until it is fully depleted, money market funds will allocate that portion of the returns associated with credit risk to capital buffer "investors" and only will be able to offer MMF shareholders returns that mimic those available for government securities. This effectively converts MMFs into "synthetic" Treasury funds.

My findings may have broader implications for capital formation. Many investors are attracted to money market funds because they provide stability but offer higher rates of return than government securities. Since these higher rates of return are intended to compensate for exposure to credit risk and to the extent that fund managers are unable to pass through enhanced yields to MMF shareholders, fund managers may be less willing to invest in risky securities such as commercial paper or short-term municipal securities, particularly if these securities increase the probability that a buffer is depleted. An inability to materially differentiate fund performance on the basis of yield would significantly reduce, but not necessarily eliminate, the utility of money market funds to investors.

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Table 1: Summary statistics for yields of U.S. treasuries, AA-rated financial commercial paper, and the credit spread between AA-rated financial commercial paper and maturity-matched U.S. Treasury yields over the period January 2000 through January 2012.

Maturity	Mean (%)	Median (%)	Standard Deviation (%)	Minimum (%)	Maximum (%)
Panel A. U.S. Treasury yields					
30-Day	1.7451	1.21	1.6991	-0.01	5.27
90-Day	1.8221	1.29	1.7245	0.00	5.19
120-Day	1.9610	1.54	1.7512	0.02	5.33
360-Day	2.0873	1.68	1.6782	0.08	5.30
720-Day	2.3674	2.04	1.5231	0.16	5.29
Panel B. AA-rated financial commercial paper					
30-Day	2.0398	1.54	1.8076	0.02	5.42
90-Day	2.0902	1.63	1.8059	0.05	5.38
120-Day	2.1453	1.68	1.8057	0.11	5.48
Panel C. Maturity-matched credit spread					
30-Day	0.2947	0.13	0.4353	-0.07	3.84
90-Day	0.3451	0.17	0.4626	-0.05	3.52
120-Day	0.3232	0.15	0.4579	-0.02	3.73

Table 2: Kalman filter estimates of the spot interest rate and intensity rate processes. Panel A reports the parameter estimates for the spot rate of interest process ; Panel B reports parameter estimates for the intensity rate process. The parameter estimates for the physical distribution and their associated standard errors are reported in columns (1) and (2). The corresponding t-statistic are reported in column (3). The risk-neutralized parameters implied by the physical distribution are reported in column (4).

Parameter	Physical Distribution Estimate	Standard Error	t-statistic	Risk-Neutral Distribution Estimate
Panel A. Parameter estimates for the spot interest rate process, r_t				
θ_r	0.0087	0.0047	1.8511	0.0119
κ_r	1.3894	0.1706	8.1442	1.0146
σ_r	0.0807	0.0123	6.5610	0.0807
η_r	-0.3748	0.1478	-2.5359	
Observations	3,066			
Panel B. Parameter estimates for the spot intensity rate process, λ_t				
θ_c	0.0013	5.76E-06	34.7331	0.0072
κ_c	1.7632	0.0572	30.8876	0.3178
σ_c	0.0372	0.0024	15.5367	0.0372
η_c	-1.4454	0.0409	-35.356	
Observations	3,066			

Table 3: Summary statistics for 360-day buy-and-hold returns for portfolios with 60-day durations based on a Monte Carlo simulation Panels A and B respectively report results for returns based on amortized cost (AC) and shadow price (SP). The simulation is based on 2,500 draws.

	Proportion of fund invested in default-free securities				
Description	0.00	0.25	0.50	0.75	1.00
Panel A. 360-day buy-and-hold AC returns for a fund with a 60-day duration					
Mean	0.9410	0.9290	0.9203	0.9149	0.9126
Standard Deviation	0.2701	0.2650	0.2631	0.2626	0.2626
Minimum	0.3489	0.3738	0.3862	0.3869	0.3874
1-percentile	0.4884	0.4884	0.4816	0.4730	0.4687
25-percentile	0.7424	0.7337	0.7283	0.7240	0.7206
Median	0.9039	0.8925	0.8830	0.8787	0.8765
75-percentile	1.0958	1.0809	1.0714	1.0648	1.0627
99-percentile	1.7411	1.7146	1.7055	1.7085	1.7073
Maximum	2.2935	2.2278	2.1828	2.1772	2.1716
Panel B. 360-day buy-and-hold SP returns for a fund with a 60-day duration					
Mean	0.9180	0.9176	0.9171	0.9167	0.9162
Standard Deviation	0.2822	0.2816	0.2813	0.2811	0.2811
Minimum	0.3248	0.3421	0.3454	0.3481	0.3508
1-percentile	0.4370	0.4398	0.4381	0.4407	0.4414
25-percentile	0.7171	0.7153	0.7167	0.7141	0.7143
Median	0.8797	0.8795	0.8794	0.8798	0.8797
75-percentile	1.0816	1.0794	1.0785	1.0780	1.0752
99-percentile	1.7727	1.7724	1.7747	1.7740	1.7739
Maximum	2.2902	2.2845	2.2789	2.2732	2.2676

Table 4: Summary statistics for the daily asset valuation ratio of AC to SP based on a Monte Carlo simulation. Panels A and B respectively report results for portfolios with durations of 60 and 90 days. The simulation is based on 2,500 draws.

	Proportion of fund invested in default-free securities				
Description	0.00	0.25	0.50	0.75	1.00
Panel A. 360-day AC to SP ratio for a fund with a 60-day duration					
Mean	1.0001	1.0001	1.0000	1.0000	1.0000
Standard Deviation	0.0007	0.0005	0.0004	0.0004	0.0004
Minimum	0.9979	0.9979	0.9979	0.9979	0.9979
1-percentile	0.9990	0.9990	0.9990	0.9990	0.9990
25-percentile	0.9998	0.9998	0.9998	0.9997	0.9997
Median	1.0000	1.0000	1.0000	1.0000	1.0000
75-percentile	1.0003	1.0003	1.0003	1.0002	1.0002
99-percentile	1.0027	1.0016	1.0010	1.0009	1.0008
Maximum	1.0060	1.0037	1.0022	1.0020	1.0020

Table 5: Analysis of the spreads between the shadow price and amortized cost. Panel A reports the first passage time to x-basis point thresholds, and Panel B reports the frequency that a money market fund falls below specific x-basis point thresholds. Portfolio duration is 60 days and the period of analysis is 360 days. The simulation is based on 2,500 draws.

	Proportion of fund invested in default-free securities				
Basis Points	0.00	0.25	0.50	0.75	1.00
Panel A. First passage time					
0.05	183.962	195.804	204.734	218.446	222.758
0.10	308.801	315.534	334.495	343.052	344.375
0.15	329.526	345.578	357.256	358.958	359.061
0.20	336.400	355.520	359.790	360.000	360.000
0.25	351.487	358.824	360.000	360.000	360.000
0.30	355.956	359.698	360.000	360.000	360.000
0.35	356.400	359.846	360.000	360.000	360.000
0.40	358.423	360.000	360.000	360.000	360.000
0.45	359.558	360.000	360.000	360.000	360.000
0.50	359.653	360.000	360.000	360.000	360.000
Panel B. Frequency that threshold is reached					
0.05	71.520	68.320	66.200	61.880	60.240
0.10	25.240	22.640	15.320	10.640	9.600
0.15	14.160	8.040	1.920	0.720	0.640
0.20	11.160	2.560	0.160	0.000	0.000
0.25	4.880	0.800	0.000	0.000	0.000
0.30	2.160	0.240	0.000	0.000	0.000
0.35	1.880	0.080	0.000	0.000	0.000
0.40	0.920	0.000	0.000	0.000	0.000
0.45	0.320	0.000	0.000	0.000	0.000
0.50	0.240	0.000	0.000	0.000	0.000

Table 6: Estimates of the promised yield to the capital buffer and summary statistics for the associated costs of capital to stable value shares, the capital buffer, and the underlying money market fund at different capital buffer levels and for different proportions of default-free and risky securities.

Panel A: $\phi = 0.00, k_{MMF} = 0.9180\%, \sigma_{MMF} = 0.2812\%$.						
Buffer	Promised	Buffer	Cost of Capital		Standard deviation	
Level (b.p.)	Yield (%)	Cost (b.p.)	A (%)	B (%)	A (%)	B (%)
10	31.1408	2.8848	0.9077	10.5160	0.2753	67.1790
20	18.3257	3.6122	0.9080	5.5465	0.2738	43.1400
30	11.4117	3.5699	0.9081	3.9721	0.2717	26.7174
40	8.7399	3.6445	0.9078	3.2878	0.2712	20.1006
50	7.0500	3.6464	0.9080	2.7800	0.2714	16.2830
60	5.9005	3.6454	0.9080	2.4591	0.2714	13.5991
70	5.0841	3.6509	0.9080	2.2451	0.2714	11.6657
80	4.4615	3.6500	0.9080	2.0781	0.2714	10.2189
90	3.9755	3.6500	0.9080	1.9491	0.2714	9.0937
100	3.5850	3.6500	0.9080	1.8459	0.2714	8.1936
200	1.8086	3.6500	0.9080	1.3816	0.2714	4.1456
300	1.2093	3.6500	0.9080	1.2268	0.2714	2.7991

Panel B: $\phi = 0.25, k_{MMF} = 0.9176\%, \sigma_{MMF} = 0.2816\%$						
Buffer	Promised	Buffer	Cost of Capital		Standard deviation	
Level (b.p.)	Yield (%)	Cost (b.p.)	A (%)	B (%)	A (%)	B (%)
10	28.6490	3.3174	0.9073	10.4935	0.2754	63.8390
20	13.4731	2.8846	0.9092	4.7098	0.2697	34.4628
30	8.6422	2.7080	0.9100	3.1962	0.2687	22.5764
40	6.4955	2.6844	0.9101	2.6005	0.2687	16.8597
50	5.2301	2.6846	0.9101	2.2659	0.2687	13.4972
60	4.3836	2.6887	0.9100	2.0478	0.2687	11.2645
70	3.7666	2.6869	0.9101	1.8837	0.2687	9.6698
80	3.3035	2.6869	0.9101	1.7628	0.2687	8.4740
90	2.9418	2.6869	0.9101	1.6688	0.2687	7.5440
100	2.6514	2.6869	0.9101	1.5936	0.2687	6.8001
110	2.4133	2.6869	0.9101	1.5321	0.2687	6.1916
120	2.2144	2.6869	0.9101	1.4808	0.2687	5.6846
130	2.0458	2.6869	0.9101	1.4375	0.2687	5.2556
140	1.9010	2.6869	0.9101	1.4003	0.2687	4.8880
150	1.7754	2.6869	0.9101	1.3680	0.2687	4.5695
160	1.6654	2.6869	0.9101	1.3398	0.2687	4.2908
170	1.5682	2.6869	0.9101	1.3150	0.2687	4.0450
180	1.4817	2.6869	0.9101	1.2928	0.2687	3.8266
190	1.4043	2.6869	0.9101	1.2730	0.2687	3.6312
200	1.3345	2.6869	0.9101	1.2552	0.2687	3.4554
210	1.2714	2.6869	0.9101	1.2391	0.2687	3.2964
220	1.2139	2.6869	0.9101	1.2245	0.2687	3.1519
230	1.1614	2.6869	0.9101	1.2111	0.2687	3.0200
240	1.1133	2.6869	0.9101	1.1988	0.2687	2.8991
250	1.0690	2.6869	0.9101	1.1876	0.2687	2.7879
260	1.0281	2.6869	0.9101	1.1771	0.2687	2.6854
270	0.9902	2.6869	0.9101	1.1675	0.2687	2.5904
280	0.9550	2.6869	0.9101	1.1585	0.2687	2.5023
290	0.9223	2.6869	0.9101	1.1502	0.2687	2.4203
300	0.8916	2.6869	0.9101	1.1424	0.2687	2.3437

Panel C: $\phi = 0.50, k_{MMF} = 0.9171\%, \sigma_{MMF} = 0.2813\%$						
Buffer	Promised	Buffer	Cost of Capital		Standard deviation	
Level (b.p.)	Yield (%)	Cost (b.p.)	A (%)	B (%)	A (%)	B (%)
10	25.4151	2.8937	0.9083	8.9973	0.2745	60.5203
20	9.0015	1.8838	0.9115	3.3513	0.2674	27.8496
30	5.8315	1.8015	0.9118	2.4503	0.2667	18.1373
40	4.3980	1.7985	0.9118	2.0626	0.2667	13.6143
50	3.5305	1.7968	0.9118	1.8300	0.2667	10.9149
60	2.9507	1.7968	0.9118	1.6777	0.2667	9.1155
70	2.5345	1.7968	0.9118	1.5690	0.2667	7.8304
80	2.2211	1.7968	0.9118	1.4874	0.2667	6.8667
90	1.9768	1.7968	0.9118	1.4239	0.2667	6.1173
100	1.7808	1.7968	0.9118	1.3732	0.2667	5.5179
110	1.6203	1.7968	0.9118	1.3317	0.2667	5.0275
120	1.4862	1.7968	0.9118	1.2971	0.2667	4.6190
130	1.3727	1.7968	0.9118	1.2678	0.2667	4.2735
140	1.2753	1.7968	0.9118	1.2427	0.2667	3.9774
150	1.1907	1.7968	0.9118	1.2209	0.2667	3.7208
160	1.1167	1.7968	0.9118	1.2019	0.2667	3.4964
170	1.0514	1.7968	0.9118	1.1851	0.2667	3.2985
180	0.9933	1.7968	0.9118	1.1702	0.2667	3.1226
190	0.9412	1.7968	0.9118	1.1568	0.2667	2.9652
200	0.8944	1.7968	0.9118	1.1448	0.2667	2.8237
210	0.8520	1.7968	0.9118	1.1339	0.2667	2.6957
220	0.8134	1.7968	0.9118	1.1240	0.2667	2.5794
230	0.7782	1.7968	0.9118	1.1150	0.2667	2.4733
240	0.7459	1.7968	0.9118	1.1067	0.2667	2.3760
250	0.7161	1.7968	0.9118	1.0991	0.2667	2.2866
260	0.6887	1.7968	0.9118	1.0921	0.2667	2.2040
270	0.6633	1.7968	0.9118	1.0856	0.2667	2.1277
280	0.6397	1.7968	0.9118	1.0795	0.2667	2.0568
290	0.6177	1.7968	0.9118	1.0739	0.2667	1.9908
300	0.5971	1.7968	0.9118	1.0686	0.2667	1.9293

Panel D: $\phi = 0.75, k_{MMF} = 0.9167\%, \sigma_{MMF} = 0.2811\%$						
Buffer	Promised	Buffer	Cost of Capital		Standard deviation	
Level (b.p.)	Yield (%)	Cost (b.p.)	A (%)	B (%)	A (%)	B (%)
10	19.3591	2.1360	0.9095	7.3041	0.2727	54.2648
20	4.5094	0.9225	0.9135	2.1503	0.2656	22.3251
30	2.9783	0.9069	0.9136	1.7059	0.2655	14.8578
40	2.2420	0.9069	0.9136	1.5084	0.2655	11.1774
50	1.7976	0.9069	0.9136	1.3899	0.2655	8.9694
60	1.5002	0.9069	0.9136	1.3109	0.2655	7.4976
70	1.2873	0.9069	0.9136	1.2545	0.2655	6.4465
80	1.1273	0.9069	0.9136	1.2122	0.2655	5.6584
90	1.0027	0.9069	0.9136	1.1792	0.2655	5.0456
100	0.9028	0.9069	0.9136	1.1529	0.2655	4.5554
110	0.8211	0.9069	0.9136	1.1314	0.2655	4.1545
120	0.7529	0.9069	0.9136	1.1134	0.2655	3.8205
130	0.6952	0.9069	0.9136	1.0982	0.2655	3.5380
140	0.6457	0.9069	0.9136	1.0852	0.2655	3.2960
150	0.6028	0.9069	0.9136	1.0739	0.2655	3.0863
160	0.5652	0.9069	0.9136	1.0640	0.2655	2.9029
170	0.5321	0.9069	0.9136	1.0553	0.2655	2.7411
180	0.5026	0.9069	0.9136	1.0476	0.2655	2.5974
190	0.4762	0.9069	0.9136	1.0407	0.2655	2.4689
200	0.4524	0.9069	0.9136	1.0344	0.2655	2.3532
210	0.4309	0.9069	0.9136	1.0288	0.2655	2.2487
220	0.4114	0.9069	0.9136	1.0236	0.2655	2.1537
230	0.3935	0.9069	0.9136	1.0190	0.2655	2.0670
240	0.3772	0.9069	0.9136	1.0147	0.2655	1.9876
250	0.3621	0.9069	0.9136	1.0107	0.2655	1.9146
260	0.3482	0.9069	0.9136	1.0071	0.2655	1.8473
270	0.3353	0.9069	0.9136	1.0037	0.2655	1.7849
280	0.3234	0.9069	0.9136	1.0006	0.2655	1.7271
290	0.3122	0.9069	0.9136	0.9976	0.2655	1.6733
300	0.3019	0.9069	0.9136	0.9949	0.2655	1.6231

Panel E: $\phi = 1.00, k_{MMF} = 0.9162\%, \sigma_{MMF} = 0.2811\%$						
Buffer	Promised	Buffer	Cost of Capital		Standard deviation	
Level (b.p.)	Yield (%)	Cost (b.p.)	A (%)	B (%)	A (%)	B (%)
10	11.0242	1.1655	0.9111	5.3127	0.2722	49.1956
20	0.1065	0.0213	0.9153	1.0221	0.2653	20.1061
30	0.0577	0.0173	0.9153	0.9732	0.2653	13.4526
40	0.0433	0.0173	0.9153	0.9588	0.2653	10.1263
50	0.0346	0.0173	0.9153	0.9501	0.2653	8.1308
60	0.0289	0.0173	0.9153	0.9444	0.2653	6.8007
70	0.0247	0.0173	0.9153	0.9402	0.2653	5.8508
80	0.0217	0.0173	0.9153	0.9371	0.2653	5.1385
90	0.0193	0.0173	0.9153	0.9347	0.2653	4.5847
100	0.0173	0.0173	0.9153	0.9328	0.2653	4.1418
110	0.0158	0.0173	0.9153	0.9312	0.2653	3.7796
120	0.0144	0.0173	0.9153	0.9299	0.2653	3.4778
130	0.0133	0.0173	0.9153	0.9288	0.2653	3.2225
140	0.0124	0.0173	0.9153	0.9279	0.2653	3.0039
150	0.0116	0.0173	0.9153	0.9270	0.2653	2.8144
160	0.0108	0.0173	0.9153	0.9263	0.2653	2.6487
170	0.0102	0.0173	0.9153	0.9257	0.2653	2.5026
180	0.0096	0.0173	0.9153	0.9251	0.2653	2.3728
190	0.0091	0.0173	0.9153	0.9246	0.2653	2.2567
200	0.0087	0.0173	0.9153	0.9241	0.2653	2.1523
210	0.0083	0.0173	0.9153	0.9237	0.2653	2.0579
220	0.0079	0.0173	0.9153	0.9234	0.2653	1.9721
230	0.0075	0.0173	0.9153	0.9230	0.2653	1.8938
240	0.0072	0.0173	0.9153	0.9227	0.2653	1.8221
250	0.0069	0.0173	0.9153	0.9224	0.2653	1.7562
260	0.0067	0.0173	0.9153	0.9221	0.2653	1.6954
270	0.0064	0.0173	0.9153	0.9219	0.2653	1.6392
280	0.0062	0.0173	0.9153	0.9217	0.2653	1.5870
290	0.0060	0.0173	0.9153	0.9215	0.2653	1.5384
300	0.0058	0.0173	0.9153	0.9213	0.2653	1.4931

Table 7: Estimates of the mean first passage time to a buffer failure and the proportion of times a capital buffer fails over a 360 day period the underlying money market fund at different capital buffer levels and for different proportions of default-free and risky securities. Duration = 60 days, the recovery rate = 40%, and the volatility levels are at their estimated values.

	$\phi = 0.00$		$\phi = 0.25$		$\phi = 0.50$		$\phi = 0.75$		$\phi = 1.00$	
Buffer (b.p.)	Time to Fail (Days)	Failure Rate (%)	Time to Fail (Days)	Failure Rate (%)	Time to Fail (Days)	Failure Rate (%)	Time to Fail (Days)	Failure Rate (%)	Time to Fail (Days)	Failure Rate (%)
5	214.24	52.600	222.93	50.600	229.46	49.080	235.40	47.480	244.09	44.760
10	313.39	20.120	317.27	18.680	324.81	16.080	338.93	11.480	344.30	8.680
15	327.18	14.120	334.16	11.440	349.83	5.320	357.53	1.440	358.66	0.800
20	335.64	10.440	351.80	4.120	357.84	1.320	359.90	0.120	360.00	0.000
25	352.08	3.800	357.04	1.760	359.81	0.200	360.00	0.000	360.00	0.000
30	356.92	1.840	358.87	0.640	359.96	0.040	360.00	0.000	360.00	0.000
35	357.46	1.600	359.81	0.200	360.00	0.000	360.00	0.000	360.00	0.000
40	359.18	0.480	359.93	0.080	360.00	0.000	360.00	0.000	360.00	0.000
45	359.75	0.240	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000
50	359.90	0.120	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000
55	359.99	0.040	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000
60	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000
65	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000
70	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000	360.00	0.000

Table 8: Probability that no more than K bonds default on the same day over a 360-day investment horizon for a equally-weighted portfolio containing N positions. Portfolios $P1$ through $P6$ respectively have equal-weighted positions of 20, 40, 60, 8-, 100, and 120 securities. The amounts that are highlighted with a **bold** font correspond to a default shock of 5.0%.

	Probability of K defaults on any given day					
Number Defaults K	Maximally Concentrated P1	P2	P3	P4	P5	Maximally Diversified P6
0	98.608224	97.260752	95.925538	94.494261	93.424563	92.058393
1	**1.380084**	2.692405	3.970167	5.312826	6.300212	7.540331
2	0.011617	**0.046205**	0.102168	0.187469	0.265884	0.385001
3	0.000075	0.000631	**0.002090**	0.005309	0.009060	0.015700
4	0.000000	0.000007	0.000037	**0.000131**	0.000273	0.000557
5	0.000000	0.000000	0.000001	0.000003	**0.000008**	0.000018
6	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000001**
7	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Table 9: Empirical distribution of the number of money market funds that hold positions with economic exposure to the issuer's parent company that exceed the indicated thresholds (0%. 1%, 3%, 5%, 7%, and 10%). Each column/row combination reports the number of funds that have the indicated number of security positions (row indicator) with an economic exposure at least as high as the threshold (column indicator). The information is derived from Form N-MFP over the period November 2010 through November 2012.

Average Number of Bonds per Fund	Economic shock threshold %					
	0%	1%	3%	5%	7%	10%
No exposure	529	529	529	529	529	529
(0.00, 0.25]	529	516	491	407	311	177
(0.25, 0.50]	529	507	468	331	183	90
(0.50, 0.75]	529	502	440	273	134	57
(0.75, 1.00]	529	488	415	232	106	38
(1, 2]	416	396	332	149	51	9
(2, 3]	362	348	266	75	14	5
(3, 4]	340	325	243	36	5	2
(4, 5]	327	301	227	16	2	1
(5, 6]	315	289	201	7	0	0
(6, 7]	309	270	177	0	0	0
(7, 8]	299	263	155	0	0	0
(8, 9]	291	258	137	0	0	0
(9, 10]	284	257	115	0	0	0
(10, 11]	276	253	93	0	0	0
(11, 12]	273	245	68	0	0	0
(12, 13]	263	241	49	0	0	0
(13, 14]	254	235	38	0	0	0
(14, 15]	251	232	24	0	0	0
(15, 16]	242	219	17	0	0	0
(16, 17]	237	208	10	0	0	0
(17, 18]	229	196	5	0	0	0
(18, 19]	223	185	4	0	0	0
(19, 20]	217	176	1	0	0	0
> 20	213	158	0	0	0	0

Table 10: Probability that a fund has a default that results in a loss of X% of its shadow price on any given day over a 360-day investment horizon for a portfolio comprised on ten maximally concentrated positions and N equally-weighted positions. Portfolios $P1$ through $P6$ respectively have concentrated positions in ten securities and equal-weighted positions of 20, 40, 60, 80, 100, and 120 securities. Portfolios $P1$ and $P6$ respectively represent the maximally concentrated and diversified portfolios.

	Probability of an economic shock of X%					
Economic Loss %	Maximally Concentrated P1	P2	P3	P4	P5	Maximally Diversified P6
[0.00, 2.50]	99.279770	99.306529	99.306056	99.301023	99.306085	99.305934
[2.50, 5.00)	0.707346	0.671845	0.663055	0.658437	0.645041	0.636419
[5.00, 7.50)	0.009943	0.018870	0.028159	0.037751	0.046113	0.054899
[7.50, 10.00)	0.002891	0.002672	0.002612	0.002630	0.002570	0.002522
[10.00, 12.50)	0.000040	0.000075	0.000111	0.000151	0.000184	0.000218
[12.50, 15.00)	0.000009	0.000008	0.000007	0.000008	0.000007	0.000007
[15.00, 17.50)	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001
[17.50, 20.00)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
$\geq$ 20.00	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000