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# The Federal Reserve's Portfolio and its Effect on Interest Rates

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**Abstract**

We explore the historical composition of the Federal Reserve's Treasury portfolio and its effect on Treasury yields. Using data from 1985 to 2016, we show that the divergence of the composition of the Federal Reserve's portfolio from overall Treasury securities outstanding is associated with a statistically significant effect on interest rates. In aggregate, when the Federal Reserve's portfolio has shorter maturity than overall Treasury debt outstanding, measures of the term premium are higher at all horizons; likewise, when the Federal Reserve's portfolio has longer maturity, term premiums are lower. In addition, at the individual security level, differences in Federal Reserve holdings from overall Treasury debt outstanding are correlated with measures of pricing errors and liquidity premiums. We discuss the mechanism for this effect, which could include elements of preferred-habitat theory as well as the fiscal theory of the price level.

JEL classification: E42, E52, N12, O23.
Keywords: Federal Reserve, Treasury securities, SOMA portfolio, portfolio composition.

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# 1 Introduction

Does the Federal Reserve's securities portfolio affect interest rates? This question is at the heart of discussions surrounding the Federal Reserve's recent asset purchases in response to the financial crisis and ensuing recession. However, this question extends further back in history, and influenced the Federal Reserve's portfolio strategies adopted over the past 70 years. For example, under the 1960s Operation Twist, shorter-dated securities were sold and longer-dated securities were purchased with the goal of lowering longer-term interest rates. Moreover, in contrast with the Federal Reserve's recent asset purchase policy, for many years, the Federal Reserve aimed to *minimize* the effect of its asset holdings on broader interest rates. In particular, in the late 1990s and early 2000s, the Federal Reserve pursued a policy under which it obtained securities in proportion to Treasury debt issuance.[1] In an environment of declining Treasury debt, this strategy was viewed as having little influence on yields more generally. In addition, there have been other periods in the Federal Reserve's history in which the strategy of portfolio holdings was intended, as a first order effect, to support market liquidity—that is, the Federal Reserve explicitly pursued a portfolio that had a substantial amount of bills, which were generally more liquid securities.

In perfect markets, the Federal Reserve's portfolio should have little effect on interest rates. However, some theoretical models, such as Modigliani and Sutch [1966] or Vayanos and Vila [2009], point to preferred-habitat investor behavior that can give rise to possible changes in interest rates as a result of changes in quantities of securities. Moreover, results using the fiscal theory of the price level as in Cochrane [2014] suggest that changes in the maturity structure of government debt can have effects on interest rates and inflation. In addition, a number of recent empirical papers such as Hamilton and Wu [2012], Krishnamurthy and Vissing-Jorgensen [2011], Gagnon et al. [2011], D'Amico and King [2013] and Laubach and Williams [2015] illustrate the effects of Federal Reserve asset purchases, while others discuss the interest rate effects of Treasury debt outstanding, including Krishnamurthy and Vissing-

[1] Refer to Federal Open Market Committee (1992, 1996, and 2000).

Jorgensen [2012] and Greenwood and Vayanos [2014]. Still, other papers leave little room for a debt composition or quanitity channel for effects of changes in the Federal Reserve's portfolio on interest rates, and instead rely on the signalling or other channels for these effects, as in Bauer and Rudebusch [2014].

Against this backdrop, this paper takes a broad look at the Federal Reserve's domestic System Open Market Account (SOMA) portfolio over time. The composition and size of the Federal Reserve's balance sheet has shifted through its history, as have the goals of and the constraints on the portfolio. We use these facts and objectives to explore more generally the ability of the Federal Reserve's portfolio to affect interest rates. First, we document the major historical shifts in the size and composition of the portfolio over time. We discuss the various objectives of the Federal Reserve's portfolio since the Treasury-Federal Reserve Accord ("the Accord") and provide some comparisons with the international experience.

Second, we focus on the composition of the portfolio for the past 30 years. Specifically, we construct summary measures of the portfolio that attempt to quantify the Federal Reserve's attainment of different portfolio objectives. These measures are constructed relative to the universe of Treasury debt outstanding. We measure market neutrality using an index that summarizes the distance between the maturity distribution of the SOMA portfolio and the maturity distribution of overall Treasury securities outstanding. We measure liquidity similarly, and add a weight in both the SOMA distribution and the Treasury distribution that favors securities with shorter times to maturity. We construct a third measure that weights the distributions of Treasury and SOMA by the amount of "10-year equivalents," or the dollar amount of 10-year securities that would imply the equivalent dollar duration as the holdings themselves. Importantly, none of these measures can be satisfied simultaneously as, for any given balance sheet size, market neutrality requires that portfolio holdings be distributed across many securities, whereas liquidity is achieved by concentrating those holdings in securities with the shortest time to maturity; duration is reflected in holding securities with longer times to maturity. With these metrics, we then evaluate how the current portfolio may evolve when the normalization of the size of the balance sheet is under way. We assume that the portfolio sheds assets through redemptions of maturing securities, and we present illustrative paths to rebuilding the portfolio to bring it back toward a more balanced and liquid portfolio over time.

Finally, we examine how the characteristics of the portfolio influence yields on Treasury securities. We illustrate that differences between the Federal Reserve's portfolio composition and overall Treasury debt outstanding has the ability to affect interest rates. This empirical observation aligns with Cochrane [2014], who highlights that the maturity structure of privately-held debt determines interest rates. In many ways, the spirit of this exercise aligns with Li and Wei [2012], who estimate a term structure model of interest rates that relies on the private (not Federal Reserve) holdings of securities. However, the exercise is most closely related to Kuttner [2006], and shares similarities with Cochrane and Piazzesi [2005] and Ludvigson and Ng [2009] in illustrating factors that explain the term structure of interest rates outside of the expectations hypothesis. At the individual security or "CUSIP" level, we find, consistent with D'Amico and King [2013], that pricing errors on specific securities or "CUSIPs" have been correlated with Federal Reserve holdings of those CUSIPs relative to the total amounts outstanding; specifically, the more the Federal Reserve's holdings of securities deviate from a market neutral portfolio, the greater the pricing error. This result suggests that, in returning the portfolio to a more neutral and liquid portfolio, the Federal Reserve may be reducing its influence on individual security prices.

At the heart of our analysis is a hypothesis recognizing that the Treasury generally chooses the quantities of debt to issue at each maturity, for any given size of the deficit. By choosing this maturity structure, the Treasury implicitly determines the shape of the yield curve. The Federal Reserve can also affect the term structure, should its portfolio differ from that of the Treasury universe overall. The mechanism for this difference could be either a preferred-habitat channel, in which the Federal Reserve's purchases affects the investment decisions of investors by creating shortages and surpluses of selected securities, as in Vayanos and Vila

[2009] or Modigliani and Sutch [1966], or it could relate to the fiscal theory of the price level, in that an unexpected change in the maturity structure of debt outstanding has the ability to affect inflation, and by extension interest rates. Moreover, the size of the portfolio relative to the Treasury's portfolio, may also be an important determinant of yields. We investigate these ideas and find evidence that the Federal Reserve's portfolio does have a noticeable effect on yields, both in aggregate and at the CUSIP level.

# 2 Background

## 2.1 A short history of the Federal Reserve's balance sheet

Debate about the composition of the Federal Reserve's portfolio has waxed and waned since the formal separation of monetary policy from fiscal policy in 1951, which on some level allowed the Federal Reserve to pursue portfolio decisions independent from the Treasury. Initially, the Federal Reserve limited most of its purchases to Treasury bills to emphasize the separation of Federal Reserve portfolio policy from Treasury debt-management policy, leading to a prolonged debate on the appropriateness of a "bills only" or "bills preferably" portfolio. Despite their given emphasis, Treasury bills only represented a small portion of the portfolio through the mid-1960s due to legacy holdings and periodic purchases of longer-dated securities. Moreover, criticism of the bills only goal, summarized in Luckett [1960], led to a broadening of SOMA purchases to cover Treasury issuance of all maturities.

Even with the formal separation of Treasury debt management from Federal Reserve policy following the Accord, Federal Reserve portfolio strategy was still somewhat influenced by Treasury debt management decisions. One coordination episode was "Operation Twist," which occurred in 1961. Under this program, the Federal Reserve purchased longer-term government-guaranteed debt. In addition, the Federal Reserve pledged (that is, provided forward guidance) that it would keep short-term interest rates low for some time. At the same time, the Treasury agreed to keep issuance limited to shorter-term debt. Taken together, these actions were expected to place downward pressure on longer-term interest rates, which then would provide stimulus to the macroeconomy.[2] There were also other episodes in which Federal Reserve portfolio decisions were made with consideration of Treasury policies. In particular, the Federal Reserve followed an "even keel" policy, which aided the Treasury by maintaining rates at a constant level around times of Treasury auctions.[3]

The relative stability of portfolio composition and balance of purchases from the 1960s through the mid-2000s reduced both policy and academic debate about the Federal Reserve's portfolio. By 1970, Treasury bills represented 40 percent of all holdings of Treasury securities, a proportion that remained relatively stable until the early 1980s when a renewed focus on bill purchases raised the proportion of Treasury bills to 50 percent. From that point through the start of the financial crisis, the share of bills in the SOMA portfolio ranged from 36 to 54 percent.

That said, there are a few distinct occasions on which the Federal Open Market Committee (also known as the "FOMC" or "Committee" hereafter) discussed the composition of the portfolio. The collapse of Continental Illinois National Bank in 1984 precipitated the extension of a relatively large discount window loan. This event highlighted the need to maintain a liquid portfolio to offset potential unexpected Federal Reserve asset expansions. As such, the Federal Reserve began to shift its portfolio composition to gradually increase the liquidity of the portfolio through additional purchases of bill and short-dated Treasury coupon securities. By 1992, the maturity liquidity of the SOMA had grown substantially and the Federal Reserve began to maintain the average maturity of the SOMA at a steady level while retaining the established liquidity levels. On the other hand, in the early 1990s, there was some pressure from the Treasury for the Federal Reserve to extend the SOMA portfolio maturity. In particular, longer-term interest rates were at higher levels than desired by the Treasury, and the FOMC debated whether to buy securities in some of those sectors in order to push down interest rates and produce a more market-neutral portfolio.

[2]Refer to Swanson [2011].
[3]Refer to Meltzer [2009], vol. 2, p.49 and following.

The decline in Treasury debt outstanding in the late 1990s, marked by a rapid reduction in the stock of Treasury bills, led to a reduced emphasis on holding short-dated Treasury securities, as well as a policy debate regarding the desirability of alternative compositions of the SOMA portfolio.[4] In the late 1990s and early 2000s, the federal government ran budget surpluses; as a result, there had been a decline in Treasury debt outstanding. At that time, the FOMC "endorsed a proposal for a study of the issues associated with the System's asset allocation in light of declining Treasury debt."[5] Two goals of the portfolio were implicitly noted in the minutes of the FOMC meeting in which this study was discussed. The first was "a preference to distribute the demand for collateral as broadly as possible in order to minimize the impact on spread relationships in the financing market." The second was "the desirability of maintaining a liquid bill portfolio." Along these lines, the Federal Reserve did have a history of capping holdings of any one Treasury issue: For many years, the limit was 35 percent of any one CUSIP.

On the eve of the financial crisis, a policy of broad-based purchases was in place. The actions of the Federal Reserve at the start of the financial crisis highlighted the value of a portfolio of short-dated securities. The Federal Reserve allowed roughly $300 billion in shorter-dated Treasury securities to roll off the portfolio or sold the remaining balance. To that end, the Federal Reserve was able to constrain the growth in reserve balances at the early stages of the crisis, while simultaneously providing liquidity through term auction facility (TAF) credit and other operations. Moreover, by allowing the securities to roll off or selling them, the market possessed collateral that could be highly desirable during times of stress.

After the acute stages of the financial crisis, marked by the lowering of the policy rate to the effective zero lower bound, the economy still needed more economic stimulus. One of the tools that the Federal Reserve used to provide that stimulus was large-scale asset purchases. In adopting this policy, the Federal Reserve deliberately stepped away from

[4] Refer to Kohn [2002].

[5] Refer to Federal Open Market Committee [2000].

its neutral and liquid portfolio, and purchased securities to lower longer-term interest rates. Most estimates have suggested that this action achieved its goal, although some debate remains about the exact channel through which this was achieved. One of the channels discussed is the "portfolio balance" channel, as motivated by the segmented markets model in Vayanos and Vila [2009]. Under this hypothesis, the central bank can lower longer-term interest rates by purchasing longer-dated assets, thereby removing interest rate or "duration" risk from the market. Indeed, as in Bernanke [2013] and Gagnon et al. [2011], this channel was viewed as one plausible channel through which asset purchases operated. During the expansion of the size of the balance sheet, the SOMA CUSIP limit was revised upward to 70 percent of any Treasury issue outstanding.

## 2.2 Literature review

Central bank portfolios have been studied in a few contexts. One discussion focuses on potential risks to central bank independence from the fiscal authority as a result of its asset and liability composition. Broaddus and Goodfriend [2001] raise the issue of the appropriate composition of central bank assets. They argue that the Federal Reserve should hold only Treasury debt; otherwise, purchases of other assets could be viewed as credit policy, which, in their view, should be undertaken only by the fiscal authority. They and others also discuss the role of financial losses and possible designs of central bank loss sharing agreements to ensure continued central bank credibility in achieving its goals, and the related issue of the importance of central banks' capital position.[6] Of course, these issues are not new; central bank solvency has also been examined within a historical context of the central bank acquiring non-performing assets, as in Quinn and Roberds [Forthcoming].

Another strand of the literature focuses on the central bank balance sheet as a supplemental tool to the policy rate in affecting macroeconomic outcomes. In many advanced economy central banks, the main policy instrument is a target rate for a short-term money

[6] Refer to Archer and Moser-Boehm [2013], Cukierman [2011], and Stella and Lonnberg [2008].

market rate. While this is a reasonable operating target under most circumstances, if the policy rate reaches its effective lower bound – at one point thought to be zero, but in a few jurisdictions apparently lower than that – it may be difficult to implement the appropriate rate desired for the extant macroeconomic conditions. In the U.S. case, as discussed by Clouse [2000], Bernanke et al. [2004], and others, the Federal Reserve can use asset purchases to affect macroeconomic conditions. This strategy was taken by the Federal Reserve during the recent financial crisis, when it embarked on four asset purchase programs after the target range for the federal funds rate had been lowered to its effective lower bound of 0 to 25 basis points.

Against the backdrop, there has been a longstanding literature that surged more recently linking the duration of central bank holdings of securities to effects on yields, primarily through the term premium. Early literature used the 1960's "Operation Twist" as a motivating episode; in particular, Modigliani and Sutch [1966] study the ability of the supply of securities to affect bond prices. While those authors found little effect, Swanson [2011] found a larger effect using modern econometric techniques. Kuttner [2006] evaluates a pricing equation in the spirit of Cochrane and Piazzesi [2005]. In that model, excess holding returns on Treasury securities are viewed as a function of a few principal components of forward rates. In addition, Kuttner uses the share of SOMA holdings with greater than five years remaining maturity as an explanatory variable in the regression. Empirical studies such as Li and Wei [2012] illustrate that private supply does influence yields, and Laubach and Williams [2015] shows that these supply effects then have an impact on real activity. The recent asset purchases also generated a large event-study based literature including Krishnamurthy and Vissing-Jorgensen [2011] and Gagnon et al. [2011] that documented the effects of asset purchases on various bond yields. On a more micro level, D'Amico and King [2013] and Pasquariello et al. [2014] show that SOMA holdings and purchases of individual securities can affect pricing errors for those instruments. Andres et al. [2004] discuss the ability of the central bank to affect longer-term yields in a DSGE framework; in particular, they illustrate that there can be supply effects on longer-term yields such that movements in these yields are independent from deviations stemming from expectations of short-term interest rates.

Another approach to modeling the effect of central bank portfolios on the term structure of interest rates finds its roots in the fiscal theory of the price level, as in Cochrane [2001], Cochrane [2014], Stein [2012] and Leeper and Leith [2017]. In this exposition, central banks can affect the term structure of interest rates by changing the composition of its portfolio relative to that which was expected by investors. Cochrane [2014] makes the observation that:

$$\frac{B_{t-1}}{P_t} = \sum_{j=0}^{\infty} \beta^j E_t \left[ s_{t+j} + \frac{M_{t+j} - M_{t+j-1}}{P_{t+j}} \right] \tag{1}$$

where $B_{t-1}$ is government debt, $P_t$ is the price level, $s_t$ is the tax surplus received at time $t$, and $\frac{M_{t+j}-M_{t+j-1}}{P_t}$ is seigniorage.

Put simply, government debt, must equal the present discounted value of surpluses, plus seigniorage. Cochrane illustrates that a key element in this price level equation is the maturity structure of government debt. With a little rearranging, Leeper and Leith [2017] show that the maturity distribution of debt outstanding determines prices, that is,

$$\Lambda_t(t+k) \equiv \frac{B_t(t+k) - B_{t-1}(t+k)}{B_{t+k-1}(t+k)} \tag{2}$$

where the numerator is newly issued debt at time $t$ maturing at time $t+k$, and the denominator is all debt outstanding in period $t+k-1$ maturing in period $t+k$.

As Campbell and Leith show, this last expression can be iterated forward to capture the entire term structure. But one important thing to note is how the share of debt at a particular maturity point might differ from that which is expected. One way this might happen is by the central bank altering its holdings so that it shifts the distribution of private debt holdings. And, if this shift was contrary to what was expected, rates might change as a result. In this paper, one could interpret greater differences between the SOMA distribution and the overall Treasury distribution as these surprises, which then should have some effect on interest rates.

That said, many studies find that, theoretically, the central bank's portfolio composition can have little effect on rates, and by extension, macroeconomic outcomes. For example, Benigno and Nistico [2015] note that, depending on the loss sharing agreement between the Treasury and the central bank, the effect of the central bank taking on interest rate risk should be negligible. And, without frictions, there should be no real effect of central bank holdings on interest rates of any kind. The results in this paper should be viewed within a context of these competing views regarding the potential effects of central bank holdings of securities on interest rates.

# 3 Measuring the Federal Reserve's portfolio characteristics

Our analysis highlights aspects of the Federal Reserve's portfolio: market neutrality, market liquidity, and duration absorption. We define market neutrality relative to the outstanding stock of Treasury securities based on the premise that a market neutral stance by a central bank would mean that its holdings of securities would not affect the relative value of any particular security. Our definition of liquidity is based on the maturity of the securities, with shorter-term securities favored over longer-term ones. Finally, our definition in terms of duration neutrality is similar to that of market neutrality, but weighted instead by the ten-year equivalents of each individual security, in a way that favors longer-term securities. Duration and amounts outstanding are derived from data from the Center for Research on Security Prices (CRSP) accessed via Wharton Research Data Service (WRDS) as well as the yields in Gurkaynak et al. [2007] and Federal Reserve holdings data are from the Federal

Reserve Bank of New York.[7]

## 3.1 Market neutral portfolio

A policy of market neutrality can be interpreted as an effort to minimize the effect of Federal Reserve purchases and holdings on market functioning and prices, letting the supply of securities issued by the Treasury and private sector demand for these securities drive relative market prices. Formally, we define market neutrality as Federal Reserve holdings having the same maturity structure as the total stock of Treasury debt outstanding. In constructing a measure of market neutrality, we evaluate the distance between the share of each outstanding Treasury security in SOMA versus the share of each Treasury security of total marketable debt outstanding. Let $x_{it}$ be the par amount of each Treasury security held by SOMA, where $i = 1, ..., I$ indexes the securities outstanding and $t = 1, ..., T$ indexes date $t$. Let

$$s_{it} = \frac{x_{it}}{\sum\limits_i x_{it}} \tag{3}$$

be the share of CUSIP $i$ of SOMA Treasury holdings on date $t$. Furthermore, let $S_t$ be the vector of shares $s_{it}$ of SOMA holdings for each Treasury security (CUSIP) $i$, at date $t$. We can define a similar share for total Treasury debt outstanding as

$$g_{it} = \frac{y_{it}}{\sum\limits_i y_{it}} \tag{4}$$

where $y_{it}$ is the total amount of Treasury debt outstanding for CUSIP i. Let $G_t$ be the vector of shares $g_{it}$ of total marketable Treasury debt outstanding at date $t$. So, for any date $t$, $\sum_i s_{it} = 1$ and $\sum_i g_{it} = 1$.

[7] For holdings, refer to https://www.newyorkfed.org/markets/soma/sysopen_accholdings.html.

In what follows, we use a Hellinger distance metric, defined as:[8]

$$N_t = 1 - \left( \sum_i \sqrt{s_{it} g_{it}} \right). \tag{5}$$

For reference, this measure will equal zero if the shares in the Federal Reserve's portfolio exactly equal the shares of marketable Treasury debt outstanding. In terms of how to read this metric, "lower" numbers are more neutral than "higher" numbers; zero would be perfectly neutral. The Hellinger distance is insensitive to the number of CUSIPs, although by construction, it is likely that the distributions are "closer" as the number of CUSIPs increases.[9]

In figure 1, we compare neutrality portfolio targets with the actual Federal Reserve holdings at the maximum and minimum points in the neutrality metric between 1985 and 2016. [10] As shown in the left hand panel of Figure 1, the portfolio was closest to neutral in October 2002, which occurred when the Treasury's issuance of long-term debt was relatively low and so the penalty from a SOMA portfolio weighted somewhat more to shorter-dated securities was not as severe. In particular, as shown by the blue bars, the SOMA portfolio was slightly overweight in holdings of securities with the shortest maturities and underweight in securities at longer-maturities relative to the total market composition. The portfolio remained relatively neutral until the onset of the financial crisis. By the end of 2012, however, the SOMA portfolio was much less neutral. This non-neutrality was a direct consequence of the maturity extension program that was conducted from September 2011 through December 2012, under which the Federal Reserve sold securities with less than 3 years remaining maturity and purchased securities with an average duration in excess of 10 years.[11] The effect of this is clearly shown in the right panel of figure 1, with scant holdings of securities with remaining maturity of less than three years and high shares of securities with remaining

[8]By definition, a distance metric is such that for any $x, y, z$, $d(x, y) \geq 0; d(x, y) = 0 \Rightarrow x = y; d(x, y) = d(y, x); d(x, z) \leq d(x, z) + d(y, z)$.

[9]A Euclidean distance metric would explicitly have this property.

[10] We calculate this measure for all $t$=1,...,$T$, where our sample is monthly data from 1985:Q4 to 2016:Q4.

[11]Refer to https://www.federalreserve.gov/monetarypolicy/maturityextensionprogram.htm.

maturity of six years or more.

### 3.2 Liquidity portfolio

Liquidity is often defined as the ability to transact quickly without a significant change in the price of an asset. Measurements of liquidity can take many forms: these include bid-ask spreads, trade sizes, and market size. In the Treasury market, bills are often thought to be the most liquid; the most recently issued ("on-the run") securities or securities with shorter remaining maturity are also viewed as relatively liquid.[12]

There are some other considerations within the context of the central bank. In particular, liquidity can mean the ability of the central bank to provide monetary base instruments quickly in a turbulent market situation. [13] However, a central bank may need to "sterilize," or offset these operations should there be little desire to increase the level of the monetary base in aggregate. Importantly, another way a central bank could provide liquidity is by offering safe assets in a flight-to-quality episode. Specifically, when uncertainty is high, many investors do not want to hold credit risk or duration risk. Taken together, a central bank could both offset an increase in the monetary base while at the same time providing safe assets to private investors by selling short-dated Treasury securities. For those who argue that a central bank should be prepared to provide liquidity at any time, and particularly during crises, a portfolio composed of Treasury bills may be ideal.[14]

In the definition that follows, we focus on maturity liquidity as a desirable property of a central bank portfolio. This definition has its drawbacks – notably that it ignores the on-the-run market for recently issued long-dated Treasury securities – but it directs attention to Treasury securities with short maturities, that is, the securities with the least duration risk and, thus, the most sought-after securities in periods of high uncertainty in financial markets.

[12] Refer to Fleming [2003], and Amihud and Mendelson [1991].

[13] Refer to Nikolaou [2009].

[14] That said, there are episodes in the Federal Reserve's past when a leaning towards bills was independent of these liquidity considerations. For example, the "bills-only" policy was in part used to strengthen the separation between the Federal Reserve and the Treasury in the period following the adoption of the Accord.

Against this backdrop, we define a liquid portfolio as one with a relatively high proportion of short-dated securites. We construct share weights that are inversely related to the security's maturity in years, $W(x_{it})$. We choose this formulation because it places high weight on short-term securities, though other functional forms could be used with similar results. Formally, we define the liquidity share of security $i$ at time $t$ with par amount $x_{it}$ as:

$$l_{it} = \frac{x_{it} e^{-W(x_{it})}}{\sum_i x_{it} e^{-W(x_{it})}} \tag{6}$$

We relate actual holdings to the liquidity-based portfolio using the same distance metric that we constructed for market neutrality. We construct an analogous liquidity measure for the Treasury universe,

$$h_{it} = \frac{y_{it} e^{-W(y_{it})}}{\sum_i y_{it} e^{-W(y_{it})}} \tag{7}$$

Similar to market neutrality, we define the liquidity penalty of Federal Reserve holdings of an individual security in terms of its deviation from the liquidity of the Treasury market for the Hellinger distance measure,

$$Q_t = 1 - \left( \sum_i \sqrt{l_{it} h_{it}} \right). \tag{8}$$

That is, we want to measure liquidity relative to what is available to the Federal Reserve as holdings. If the Federal Reserve's portfolio is relatively more liquid than what is held by private investors, then it could potentially be a source of liquid securities in a crisis. An absolutely more liquid portfolio – without reference to Treasury debt outstanding more generally – may also be important, but the relative position may have different implications as well. A value near zero for $Q_t$ means the portfolio shares were the same as the liquidity-weighted Treasury universe of outstanding debt, while larger values indicate the degree of deviation.

In figure 2, we compare the liquidity portfolio target with the actual SOMA holdings at the dates on which we find the maximum and minimum differences between the portfolio and the liquidity metric. As shown to the left, in 2002, prior to the financial crisis, the SOMA portfolio was relatively more liquid, reflecting efforts since 2000 to shorten the average maturity of the portfolio. Given the Federal Reserve's efforts over the past few years to stimulate the economy through the purchases of long-dated Treasury securities, however, the portfolio became much less liquid. The right hand panel of figure 2 shows that the SOMA portfolio is currently biased towards longer-dated, less liquid securities, and is quite different from the target liquidity-based portfolio.

## 3.3 Duration absorption

In addition to the market neutrality goals established by the FOMC at various points in time, the Committee has also discussed the influence of SOMA portfolio holdings in terms of the total amount of duration removed from the market.[15] Simply defined, duration is the time-weighted average of discounted cash flows.[16] Another formulation, however, illustrates that duration reflects the sensitivity of bond prices to interest rates.[17] As such, by the Federal Reserve buying securities, particularly longer-dated ones, the Federal Reserve is assuming interest rate risk that would otherwise be borne by market participants. By doing so, the Federal Reserve increases the price on the securities it purchases, thereby pushing down longer-term interest rates and encouraging investors to switch to holding other securities through a portfolio balance effect. The aim of including this measure in our analysis is to give an idea as to whether the Federal Reserve, by holding a portfolio that is significantly different from the Treasury's in terms of duration, has the ability to affect longer-term interest rates.

To this end, we define our duration absorption metric in terms of the shares of 10-year equivalents of the security, or the amount of 10-year notes that would produce the same amount of dollar duration as the par value of the holdings. Specifically, let $t(x_{it})$ be the 10-

[15] Refer to Bernanke [2012].
[16] This formulation is known as Macaulay duration.
[17] This formulation is known as modified duration.

year equivalents amount of SOMA holdings of security $x_{it}$. For a 10-year Treasury security, $t(x_{it}) = x_{it}$. For securities with more than 10 years remaining maturity, $t(x_{it}) > x_{it}$, and for securities with less, $t(x_{it}) < x_{it}$. The yield used in the calculation of the 10-year duration is from Gurkaynak et al. [2007].

Similar to our market neutrality distance measure, we have

$$u_{it} = \frac{t(x_{it})}{\sum_i t(x_{it})} \tag{9}$$

$$p_{it} = \frac{t(y_{it})}{\sum_i t(y_{it})} \tag{10}$$

as well as

$$D_t = 1 - \left( \sum_i \sqrt{u_{it} p_{it}} \right) \tag{11}$$

Again, $D_t = 0$ implies that the distribution of 10-year equivalents in the Federal Reserve's portfolio is the same as that of the Treasury's portfolio. The duration weighting implies that distances between the distributions are magnified at longer maturities relative to shorter ones, suggesting a predilection towards removing duration from private investors.

In figure 3, we explore the minimum and maximum duration absorption relative to Treasury debt outstanding between 1985 and 2016. The portfolio was closest to the Treasury's duration in February 2001, a little before the time when the portfolio was close to its market neutral and market liquid minimum distance. Overall, this result suggests that the portfolio was headed toward a a market neutral position and that the goals of the portfolio may not have been particularly tilted towards duration absorption. The portfolio absorbed the greatest amount of duration around the time when it was relatively far from a market neutral or liquid portfolio, as shown in the right panel of figure 3. Again, this was a direct consequence of the maturity extension program, which had the effect of increasing the duration of the portfolio substantially over a two-year period.

### 3.4 Robustness checks: Other measures

For robustness, we include two other measures commonly used in the statistical literature. The first is a cosine similarity measure, which calculates the angle or disagreement between the distribution in SOMA and the overall Treasury distribution. The formula for this measure is:

$$\cos_t = \frac{\sum_{i=1}^{I} s_{it} g_{it}}{\sqrt{\sum_{i=1}^{n} s_{it}^2} \sqrt{\sum_{i=1}^{n} g_{it}^2}} \tag{12}$$

However, this measure is not a distance metric per se, and so the results should be interpreted accordingly.

The second distance measure we use is the Kullback-Leibler divergence. This measures the amount of information contained in the Treasury distribution that can be used to forecast the SOMA distribution. Again, this is not a distance metric. Furthermore, if SOMA does not hold a particular security, then the measure is set to zero for that security, as no information from the Treasury distribution is needed to forecast the SOMA distribution. The formula for this measure is:

$$KL_t = \sum_{i=1}^{I} s_{it} \ln \frac{s_{it}}{g_{it}} \tag{13}$$

Importantly, all measures specifically account for the distribution of securities held in the SOMA portfolio, and not just the aggregate amount of liquidity or duration absorption provided by the portfolio. In this way, the analysis here provides a measure of the "preferred habitat" channel of the Federal Reserve's balance sheet, consistent with the discussion in Modigliani and Sutch [1967] rather than the aggregate "duration" channel or "signaling" channel, as discussed in Krishnamurthy and Vissing-Jorgensen [2011] or Bauer and Rudebusch [2014], although the weighting in the $D_t$ metric does shed some light on the duration channel. And, these metrics can also shed light on some aspects of interest rate determination through the fiscal theory of the price level.

Summary statistics of our measures are presented in table 1. All measures shift considerably from the pre-crisis to the post-crisis sample, reflecting the substantial change in the Federal Reserve's portfolio. The scale of the shift differs according to the particular weights on each of the measures, with $Q_t$ and $KL_t$ jumping the most. A few notable points in time are displayed in the last few rows of the table: 2006, before the crisis; 2009, after the runoff of the bills portfolio but before the Treasury purchases; and 2014, after the completion of the purchases. These individual dates illustrate the stark changes in the portfolio in a short amount of time, with the distance by nearly all of these measures more than doubling.

## 3.5 Metrics over time

We now explore the evolution of the metrics in relation to FOMC communications on portfolio composition. As shown in figure 4, from 1985 through the mid-1990s, the portfolio most closely tracked a liquidity objective; market neutrality and duration neutrality were somewhat less present. This is consistent with Meulendyke's 1998 assessment of FOMC documents from the period, as well as the discussion in the 1992 and 1996 FOMC meeting minutes. From 1995 to 2000, the portfolio performed relatively worse on its liquidity objective, while at the same time, the market neutrality and duration neutrality measure improved. These portfolio changes, however, were the result of large compositional changes taking place in the Treasury market (refer to Garbade [2007]) rather than a stated shift in portfolio preferences. In particular, as discussed above, fiscal surpluses over this period led to a rapid decline in Treasury issuance. The lack of new supply of Treasury securities led to concerns that SOMA holdings could be disruptive to normal market functioning. The concerns were two-fold: SOMA holdings and therefore rollovers of Treasury bills were becoming a large part of overall bill issuance and declines in Treasury issuance of longer-dated securities were large enough for market participants to question the viability of traditional benchmark securities, defined as those with maturities of 5, 10 and 30 years.

As discussed above, SOMA had self-imposed limits on holdings of no more than 35 percent of a single security. When bill issuance fell quickly in 1997, SOMA responded by purchasing securities with longer maturities. As a result, the market neutrality of the portfolio improved but the liquidity declined. In 2000, the Federal Reserve announced its intentions to bias purchases towards shorter-dated securities.[18] This announcement represented an explicit shift towards a liquidity oriented portfolio. Two sentences from the announcement highlight the conflicts in the policy objectives at the time: "The Federal Reserve has attempted to maintain a short average maturity of the SOMA portfolio of Treasury securities"; and a few sentences later: "The FRBNY will no longer seek to spread purchases for the SOMA so that they result in roughly equal percentage holdings of Treasury coupon securities evenly across the maturity spectrum." Initially, the change in 2000 was not sufficient to stop the decline in liquidity or the improvement in market neutrality (shown in purple in figure 4). Fiscal deficits began to rise in 2001 and the Treasury responded by increasing the sizes of existing securities. In terms of our metrics, the larger issuance sizes of existing securities made SOMA holdings, relative to new issuance, less liquid. Prior to the increase in the number of securities issued by the Treasury (beginning in 2002), however, SOMA purchases of the small stock of older outstanding securities actually improved the market neutrality metric. By 2003, the Treasury's issuance calendar stabilized and the bias towards short-dated securities in SOMA began to be seen in the metrics shown in figure 4. At the onset of the financial crisis, Treasury bills held in the portfolio were sold or allowed to mature. The purchases that followed were biased towards longer-dated securities, leading to a sharp decline in both the market neutrality and liquidity of the portfolio, as well as increasing the amount of duration absorption. Market and duration neutrality and liquidity significantly worsened through the maturity extension program, announced in September 2011, which involved selling short-dated Treasury securities and purchasing longer-dated Treasury securities. With the phasing out of additional purchases in 2014, the portfolio became notably more liquid, as the average maturity of the portfolio declined. Market neutrality also improved, although the duration neutrality metric appears to tick up towards the end of the sample, likely reflecting the

[18] Refer to Federal Reserve Bank of New York [2000].

relative distribution of shorter-dated Treasury issuance vis à vis the Fed's continued elevated holdings of longer-duration securities.

# 4 Evolution of the portfolio

Our metrics can illustrate the future evolution of the portfolio. For this exercise, we assume that the portfolio will be reduced in terms of its size, primarily through redemptions, as part of the policy normalization process. How will this roll off of securities affect measures of neutrality and liquidity for the portfolio? How would securities purchases evolve if the Federal Reserve aimed towards neutrality and liquidity considerations in the future?

Using some assumptions and current communications from the Federal Reserve, we project the path of the portfolio neutrality and liquidity metrics from 2015:Q1 to 2025:Q4.[19] Included in these assumptions are the growth of total outstanding Treasury marketable debt, currency growth, Federal Reserve capital growth, and the path of interest rates as reported in the 2014 Federal Reserve Bank of New York Domestic Open Market Operations Annual Report.[20]

From the previous analysis we know that the current SOMA portfolio is very different from its historical norm in terms of the neutral and liquidity metrics developed herein. Concretely, figure 5 illustrates where the portfolio is today (blue bars) compared with the hypothetical target portfolio based on for market neutrality (red bars) by maturity bucket, as of 2015:Q1. As shown by the blue bars, the SOMA portfolio has very few securities with remaining maturities of less than two years, which makes it deviate from both its neutrality and liquidity targets in these shorter-dated maturities. Also, the portfolio is overweight holdings in the 4 to 9 year maturity range compared with both measures.

Communication from Federal Reserve officials, such as the Policy Normalization Principles and Plans, have suggested that redemptions of maturing securities would be a first step in

[19] The assumed evolution of the portfolio from 2015:Q1 to 2015:Q4 is identical to the actual.
[20] Refer to https://www.newyorkfed.org/medialibrary/media/markets/omo/omo2014-pdf.pdf.

normalizing the size of the portfolio.[21] For our analysis, we take SOMA holdings as of 2014:Q4 and simulate the securities rolling off the portfolio as they mature. Treasury holdings do not begin to decline until 2017. This decline continues until 2021:Q3, when Treasury holdings must increase to support growth of currency, capital, and other liabilities. At that juncture, we consider three rules for purchasing Treasury securities:

1. Purchases are directed towards securities that are furthest from their target holdings along the market neutrality dimension, that is, securities in which SOMA holdings are furthest from the proportion of the security outstanding;

2. Purchases are directed towards securities furthest from their target liquidity holdings; and

3. Purchases are directed towards securities that are furthest from an equally weighted neutrality and liquidity target portfolio.

Figure 6 shows the performance of the three rules over the course of the projection. From 2016:Q1 to 2021:Q3 securities are rolling off the portfolio as they mature and no Treasury securities are purchased. As the Treasury is issuing securities over this period but the Federal Reserve is not purchasing any of these securities, the SOMA portfolio moves further away from a perfectly neutral portfolio. With respect to the liquidity metric, initially there is improvement in liquidity as securities approach redemption. As those securities mature, however, the remaining securities are still relatively long-dated so the liquidity of the portfolio worsens until purchases resumes. Once securities purchases begin the portfolio becomes more neutral and more liquid (short-dated securities with no initial holdings in SOMA are purchased first). Looking across the three purchase paths, we see that any of these paths improve both metrics over the entire projection period. This phenomenon implies that even if there are disagreements over the importance of the two characteristics of the SOMA portfolio, any purchase plan will initially move SOMA to being more neutral and more liquid

[21] Refer to http://www.federalreserve.gov/newsevents/press/monetary/20140917c.htm.

than it is prior to when purchases start. Under the methodology that minimizes the sum of the targets, the portfolio returns to its pre-crisis distance from both objectives by the end of 2025.

Figure 7 depicts SOMA holdings at the end of the projection for the equally weighted purchase path. Not surprisingly, actual SOMA holdings lie between the neutral target and the liquid target.

# 5 Empirical results: Aggregate

We now investigate how the SOMA portfolio composition affects prices of Treasury securities. First, we ask whether our metrics are significantly correlated with the excess return on various tenors of securities. Evidence at the aggregate portfolio level (for example, Kuttner [2006] and Li and Wei [2012]) suggests that SOMA holdings of securities significantly affect the term premium embedded in Treasury yields at various tenors.

## 5.1 Aggregate analysis

As a first step, we ask whether our measures are correlated with excess returns on Treasury securities. The theoretical background for this hypothesis extends back to Modigliani and Sutch [1966], who investigated the existence of supply effects in the Treasury market within the context of the Operation Twist portfolio policy of the 1960s.

Our approach is most similar to that of Kuttner [2006], although there are a few key differences. One key difference between this analysis and the Kuttner analysis is that we use a measure of the distance of the entire SOMA portfolio from the Treasury portfolio using a number of different distance criteria. In this way, we take account of the difference between the distribution of SOMA securities and total securities outstanding, and not just the share of longer-dated securities held in SOMA.

Furthermore, our econometric approach controls for the possible endogeneity of the distance metrics. Specifically, the distance between the Federal Reserve's portfolio and the Treasury's portfolio may in fact depend on the term premium, if the Federal Reserve purchased assets in order to affect the term premium as little as possible (as in the pre-crisis period) or to change the term premium (as in the post-crisis period). Indeed, as discussed by Meaning and Zhu [2012] and D'Amico and King [2013], the Federal Reserve would routinely aim to purchase those securities that appeared "cheap" according to their pricing calculations. In this way, and to the extent that some securities would be more likely to exhibit this kind of cheapness, and be correlated with the current level of the term premium, the values of our neutrality metric could be endogenous to the level of the term premium at the time. In addition, our metrics implicitly assume that the Treasury does not change its issuance strategy with contemporaneous changes in the term premium, which may or may not be related to shifts in the Federal Reserve's portfolio. If the Treasury did this, our metric could be correlated with the error term, and lead to biased estimates.

Many papers investigate the effect of private holdings of Treasury debt on interest rates using model-based measures of the term premium. In order to make our results comparable to the literature, we perform a regression of the Adrian-Crump-Moench (ACM) term premium, discussed in Adrian et al. [2013], on our different metrics at the 2 through 10 year tenors. Our specification is

$$T_t^{(n)} = \alpha^{(n)} + \beta^{(n)} M_t + \epsilon_t^{(n)}, n = 2, ..., 10 \tag{14}$$

where $T_t^{(n)}$ is the term premium at tenor $n$ at time $t$, $M_t \in \left\{ N_t, Q_t, D_t, \cos_t, KL_t, \frac{privateTYE}{GDP}, \right\}$ is our measure of interest, and $\{\alpha, \beta\}$ are coefficients to be estimated. We run regressions separately for each measure, including only the measure and a constant as explanatory variables.

To control for possible endogeneity, we use two-stage least squares. For our instruments, and similar to Krishnamurthy and Vissing-Jorgensen [2012], we use the ratio of total Treasury debt outstanding to nominal GDP, as well as the square and the cube of this measure, as instruments. Total Treasury debt outstanding is a function of the deficit; arguably, the decisions regarding the deficit are predetermined from the perspective of the econometric analysis and therefore uncorrelated with unobserved factors affecting the term premium. In addition, it could be the case that the deficit is largely independent (although not completely so) from the maturity structure of the debt. As such, it could control from any endogeneity that may result from including any of our balance sheet metrics as a control variable. We also use the number of CUSIPs as an instrument. As discussed in section 3, our measures depend in part on the number of CUSIPs. And moreover, it is likely that the number of CUSIPs is independent of unobserved factors affecting the term premium. Standard errors are adjusted for potential autocorrelation and heteroskedasticity.

Tables 2 and 3 present the results. Across tenors, the results suggest that $N_t, Q_t$ and $D_t$ are significantly positively correlated with the term premium in the pre-crisis period, and significantly negatively correlated in the post-crisis period, implying that the difference between the maturity structure of the SOMA portfolio and overall Treasury debt outstanding was in such a way so as to put upward and downward pressure on rates, respectively. These correlations are significant at nearly all tenors, and tend to creep up in magnitude as the tenor increases. The coefficients on $N_t$ suggest that at the 10-year remaining maturity point, for every 1 percentage point increase in the distance between the SOMA portfolio and the Treasury portfolio, the term premium increases by 16 basis points pre-crisis and decreases by 10 basis points post-crisis. The magnitudes of the coefficients $Q_t$ and $D_t$ most notable for tenors starting at roughly 5 or 6 years and continuing to our 10 year maturity point. For tenors 2 through 5, the pre-crisis coefficients on each of our measures insignificant, while the post-crisis tenors have significant coefficients. For tenors 6-10, the coefficients on the market neutrality terms are statistically significant in the pre-crisis sample, but not in the post-crisis sample. However, for the measures that are weighted for liquidity or duration, both can be significant, and some are positive for the post-crisis sample. Within each specification, magnitudes of coefficients tend to be fairly constant for tenors greater than 5 years. Our robustness measures, Kullback-Leibler and cosine similarity, suggest similar results to those found using the distance metrics.

The patterns of these results are most evident from the coefficients on the market neutrality terms. The coefficients suggest that for every 1 percentage point increase in the distance between the SOMA portfolio and the Treasury portfolio, the term premium 10 year remaining maturity point falls by 15 basis points pre-crisis. These coefficients are somewhat lower in magnitude than those reported in Kuttner [2006] for the share of longer-dated securities in the portfolio; however, these coefficients may also be a little more realistic, as discussed by Sack [2006].

We can use our measures to get a sense of how much the change in the composition of the Federal Reserve's portfolio may have affected interest rates. Using the point-in-time values of the distance measures in table 1, the market neutrality metric increased by 0.14 from immediately before the Treasury purchases started, to right after they were completed. A back-of-the envelope calculation suggests that the asset purchases reduced the term premium by about 135 basis points at the 10-year point. Comparing this calculation to the studies cited in Bonis et al. [2017], our methodology arrives at an estimate comfortably within the range of other studies for the effect of the Federal Reserve's portfolio on interest rates.

Preferred-habitat models suggest that private 10-year equivalents over nominal GDP could be a significant predictor of the term premium. To compare our results to these models, the bottom lines of the table display results from a specification using private ten-year equivalents over nominal GDP as a control variable. These specifications uses the same instrumental variables as those for the distance measures. The results suggest that private 10-year equivalents over nominal GDP significantly predict the term premium in the pre-crisis period, across a range of tenors; the coefficients are generally positive. However, coefficients in the post-crisis period are generally insignificant.

A battery of econometric tests are shown in the lines beneath the coefficient estimates of interest. First, we test whether the metric is endogenous. Specifically, we perform a Hausman robust regression-based test for endogeneity that controls for heteroskedasticity and autocorrelated errors. The F-statistics ($F_{endog}$) and the p-values ($p_{endog}$) reported in the tables suggest that the metric is endogenous at most tenors in the pre-crisis sample, while it is endogenous only at longer tenors in the post-crisis sample. Given that the point estimates are still consistent even if an instrumental variables approach is used (although may not be efficient), we elect to use the same specification across tenors, even though not strictly necessary.

Second, we test whether we have weak instruments. If the instruments are weak, then the endogeneity would not be adequately controlled for and our estimates would be biased. Heteroskedasticity-adjusted F-statistics ($F_{firststage}$) and p-values ($p_{firststage}$) reported in the table suggest that our instruments are sufficiently strong. One exception are the F-statistics associated with tests for private ten-year equivalents in the post-crisis period. The first-stage F-tests suggest that the instruments used in the post-crisis sample could be considered weak by Stock et al. [2002], as the F-statistic, while indicating a valid regression, is less than 10.

And finally, the number of instruments exceed the number of endogenous variables. As such, we can use a Wooldridge score test to see if our over-identifying restrictions are valid. As indicated by the scores ($score_{overid}$) and p-values ($p_{overid}$) we cannot reject the hypothesis that the instruments are independent from the specified model's residuals.

# 6 Extensions and robustness checks

## 6.1 Excess return forecasting regressions

There are many ways to calculate a term premium. In order to explore how robust our results are to this choice, we first investigate simple excess return forecasting regressions of the form

$$rx_{t+1}^{(n)} = \alpha_0^{(n)} + \beta_1^{(n)} M_t + \epsilon_{t+1}^{(n)}, n = 2, ..., 10 \quad (15)$$

where $M_t \in \left\{N_t, Q_t, D_t, \cos_t, KL_t, \frac{privateTYE}{GDP}\right\}$ is our measure of interest. We run regressions separately for each measure, including only the measure and a constant as explanatory variables.[22] We use the Gurkaynak et al. [2007] yields, which allows us to evaluate a larger portion of the term structure than using the Fama-Bliss yields; analysis in Cochrane and Piazzesi [2008] and Sack [2006] suggest the results are similar. Separately, because our estimating equation involves factors constructed with overlapping data, we report Newey-West standard errors evaluated with 11 lags, appropriate for our annual returns calculated from monthly data.[23]

As Cochrane and Piazzesi [2008] and Swanson [2007] explain, the forward recursive expectation of the excess return is one representation of the term premium. We construct the dependent variable using the smoothed yields in Gurkaynak et al. [2007] so that we can explore the behavior of excess log holding period returns across maturities; we use those with 2 to 10 years remaining.

Compared to the term premium regressions shown above, the signs on the metric coefficients tend to be positive in the pre-crisis sample, and negative in the post-crisis sample. This change in result for the pre-crisis sample could simply reflect the nature of the measures; that is, the term premium can be interpreted as the excess returns iterated forward and summed over a horizon. In both cases, the statistical significance suggests that the distance of the Federal Reserve's portfolio from the Treasury's portfolio can have a significant effect on interest rates.

Again, we include the more-familiar private 10-year equivalents over GDP results for comparison purposes. The coefficient on this measure is usualy negative and and significant in the pre-crisis sample. There are a couple of instances at shorter tenors when the private 10-year equivalents over GDP are associated with higher excess returns in the post-crisis sample; overall, however, the coefficients tend to be insignificant.

[22] Results are robust to using other factors that determine the yield curve, such as the first three principal components of yields and the Cochrane-Piazzesi forward factor.

[23] Evaluating with 18 lags as in Cochrane and Piazzesi [2005] does not affect the statistical significance of the results.

## 6.2 Signed distance

By construction, our metrics measure the overall distance of the SOMA portfolio from Treasury debt outstanding, and do not account for whether the the direction – that is, whether $s_{it} \geq g_{it}$ or $s_{it} < g_{it}$. It is possible that the distance in one direction or another has a more significant effect on measures of the term premium.[24] In order to investigate this issue, for each of the distance measures discussed above, we construct two new distance measures, one conditional on $s_{it} \geq g_{it}$ and the other conditional on $s_{it} < g_{it}$. For example, we construct our "positive" market neutrality measure using

$$s_{it}^{pos} = \frac{x_{it}}{\sum\limits_{i|s_{it} \geq g_{it}} x_{it}} \text{ if } s_{it} \geq g_{it} \tag{16}$$

$$= 0 \text{ otherwise;} \tag{17}$$

$$g_{it}^{pos} = \frac{y_{it}}{\sum\limits_{i|s_{it} \geq g_{it}} y_{it}} \text{ if } s_{it} \geq g_{it} \tag{18}$$

$$= 0 \text{ otherwise;} \tag{19}$$

and

$$N_t^{pos} = 1 - \left( \sum_{i|s_{it} \geq g_{it}} \sqrt{s_{it}^{pos} g_{it}^{pos}} \right). \tag{20}$$

Negative distance metrics are constructed analogously.

Figure 8 plot positive and negative distance measures for the market neutrality metric. As is evident from the figure, distances are generally larger when the Federal Reserve's share is smaller than the overall Treasury share, reflecting in part the relatively large distances

[24] Thanks to Arvind Krishnamurthy for this suggestion.

generated when securities are not held in the SOMA portfolio. Consistent with this, these positive and negative measures very much reflect the maturity distribution of the securities in the portfolio. As explained in section 3, pre-crisis, the Fed's portfolio was more heavily weighted towards shorter-dated securities relative to total Treasury securities outstanding, while post-crisis, the Fed's portfolio leaned towards longer-dated securities. Looking at this a little more closely, as shown in table 6, pre-crisis, the median maturity of securities for which the relative share in SOMA share is higher than the relative share in the Treasury universe is a little over one year, versus the nearly four year median maturity of securities for which the relative share overall is higher than that in SOMA. The converse is true in the post-crisis period: the median maturity for the relatively higher SOMA shares is around five-and-a-half years, while for relatively lower SOMA shares, the median maturity is about two years.

The maturity aspect of these patterns are reflected in term premium regression results. As shown in table 7, the longer maturity of securities in private hands pushes up the term premium in the pre-crisis sample, as evidenced by the statistically significant coefficient on the positive market neutrality term for tenors 2 through 10 of the term premium. Likewise, the negative coefficient on the negative market neutrality term post-crisis is consistent with relatively shorter-term securities in private agents' portfolios. That is, because private agents hold shorter securities relative to the Treasury, or conversely, the SOMA portfolio holds longer securities than the Treasury, the correlations with the distance measures tend to reflect this. These results further support the observation that the Federal Reserve's portfolio affects interest rates by altering the maturity distribution of securities in private agents' hands.

# 7 Empirical analysis: Panel data

We now ask whether our metrics, on a CUSIP level, are significantly correlated with the pricing error for a particular CUSIP with respect to an off-the-run yield curve calculated with a Svensson specification as in Gurkaynak et al. [2007]. Our approach is consistent with D'Amico and King [2013], who show portfolio balance effects to be significant at the security level. With that in mind, we consider how deviations of the SOMA portfolio from a market-neutral portfolio or a liquidity target portfolio are related to CUSIP-level pricing errors and bid-asked spreads.

We use a panel regression framework for this analysis. Our dataset consists of end-of-month data on each security issued by the U.S. Treasury from 1985Q4 to 2016Q4 for a total of 84,015 observations. The data are necessarily an unbalanced panel, as securities differ by tenor and many of the securities present at the beginning of the sample mature over the sample period and many more were issued during the sample period. A security is observed for at a minimum of one quarter for Treasury bills originally issued as 13-week bills and for almost the entire sample period for 30-year bonds issued near the beginning of the sample period. On average, a security is included in the analysis for 29 months but the sample period for individual securities varies widely. In addition, the distribution of CUSIPS by original security type differs greatly, with most issues concentrated in bills and notes, and comparatively fewer bonds.

## 7.1 Pricing errors

We turn first to evaluating individual security pricing errors. The pricing error is the difference between the price of a Treasury security recorded in the CRSP dataset and the price derived from an off-the-run zero coupon Treasury curve in Gurkaynak et al. [2007]. We test for a correlation between pricing errors for individual securities and SOMA holdings of a security as a share of outstanding, our market neutrality metric. Our dependent variable is the CRSP end-of-day implied zero-coupon market prices on the last trading day of each month minus the zero-coupon yield curves from the same days to calculate theoretical pricing errors for each outstanding Treasury security, $\alpha_{it}$. Our independent variable of interest is the CUSIP-level neutrality measure, $n_{it}$, defined in section 3.1. Table 9 displays summary statistics of these variables.

On average, pricing errors tend to be slightly negative, suggesting the theoretical price is a little higher than the actual price. That said, the actual price can be quite a bit higher in some instances, usually in longer-dated securities. Larger fitting errors tend to indicate that there are specific demands for a particular security beyond what would be theoretically predicted. If those specific demands are correlated with SOMA holdings of that security, then there is some indication that there may be pricing effects of the Fed's holdings, and indicate some ability of the Fed to affect longer-term interest rates.

With these two measures in mind, we evaluate the following specification:

$$\alpha_{it} = \sum_{j=1}^{J} \beta_{-j}\alpha_{i,t-j} + \delta_1 V_t + \delta_2 S_t + \delta_3 C_t + \sum_{k=0}^{K} \gamma_{-j} n_{i,t-j} + \epsilon_{it} \tag{21}$$

where $\alpha_{it}$ is the security pricing error. $V_t$, $S_t$ and $C_t$ are the measures of the level, slope and curvature of the yield curve, which help control for time effects. $n_{it}$ is defined as

$$n_{it} = s_{it} - g_{it} \tag{22}$$

where $s_{it}$ and $g_{it}$ are as defined in equations 3 and 4.

We evaluate our specification over two sample periods. As in the aggregate results, the overall sample runs from 1985 to 2016. However, there is a significant structural break in the panel analysis and as a result, we evaluate the pre-crisis period and post-crisis period separately, using the same time periods as the aggregate analysis. In addition, we tailor the number of lags of $\alpha_{it}$ and $n_{it}$ to include based on a battery of specification tests.

Our estimation technique controls for a few potential specification problems. First, as reviewed above, the Federal Reserve took steps at various points in time to ensure (or not) market neutrality or liquidity of the portfolio. In addition, the Federal Reserve's purchase algorithm in part relies on market prices at the time. Potentially, if there is a (favorable) mispricing of a security from the Federal Reserve's point of view, the Desk would be more likely to purchase that security. Indeed, Swanson [2011] cites this as a reason why evaluating the effects of Federal Reserve holdings at a quarterly frequency instead of as an event study may be problematic. Taken together, these considerations suggest that it is possible that $n_{it}$ is endogenous. Second, time-invariant fixed effects of particular securities may be correlated with some of the explanatory variables. This fixed effect is potentially part of the error term,

$$\epsilon_{i,t} = \mu_i + \nu_{i,t} \tag{23}$$

As such, our coefficients could be biased unless we control for this adequately. And third, because we observe persistence in the dependent variable, the error terms are likely serially correlated, resulting in downward biased standard errors.

As a result, because this is an unbalanced panel specification with persistence in the dependent variable, we use an Arellano-Bond-type estimator with instrumental variables, where the instruments are the lagged levels and the lagged differences in the dependent variable. For our pre-crisis panel results, we use $\alpha_{i,t-6}, ..., \alpha_{i,t-9}$ to instrument for the lagged dependent variable terms and $n_{i,t-4}, ..., n_{i,t-6}$ as instruments for the market neutrality terms. For our post-crisis panel results, we use $\alpha_{i,t-8}, ..., \alpha_{i,t-11}$ and $n_{i,t-4}, ..., n_{i,t-6}$. And finally, to control for the constructed nature of the principal components regressors within a panel data context, we report robust standard errors to control for the possible understatement of standard errors otherwise.

Our results are shown in table 10. To start, pricing errors at the security level are fairly persistent, and lagged effects are statistically significant for at least a few months after an initial shock. For the pre-crisis sample, as indicated by the sum of neutrality coefficients line in the table, a 1 percentage point increase in the neutrality metric suggests the pricing error increases by 3.4 cents on the dollar. In other words, the Fed's purchases tends to increase the actual price of the security relative to the theoretical price. Post-crisis, the net effect of pricing errors is close to zero, although in the initial period, the effect of the purchases is to narrow the pricing error considerably. Of note, in order to get a one standard deviation change in the pricing error, the neutrality would need to shift by a large amount. Against that backdrop, therefore, the overall effect is modest; on a historical basis, actions to build up SOMA did not have large effects on market pricing.

## 7.2 Bid-asked spreads

In our second exercise, we investigate the correlation of the liquidity term with the bid-asked spread on the security. As shown in table 9, the average bid-ask spread is small, roughly 6/100 of a cent (6 basis points on the dollar). The specification is similar to that used for the pricing error, although we adjust the number of lags appropriately, and is as follows:

$$\omega_{it} = \sum_{j=1}^{J} \beta_{-j}\omega_{i,t-j} + \delta_1 V_t + \delta_2 S_t + \delta_3 C_t + \sum_{k=0}^{K} \gamma_{-j} q_{i,t-j} + \epsilon_{it} \tag{24}$$

As reported in table 10, similar to the market neutrality results, we see significant effects of individual securities holdings on measures of market liquidity. In particular, our coefficients suggest that pre-crisis, holdings consistent with a more liquid portfolio were associated with a higher bid-asked spread. The sum of the liquidity coefficients suggests that this effect was roughly 22 basis points on the dollar. Post-crisis, this effect changed in sign, and also fell in magnitude. An increase in the liquidity metric suggests a narrowing of the bid-asked spread of 5 basis points on the dollar.

Why would SOMA holdings of individual securities affect either the pricing error or the bid-asked spread? While there could be a number of mechanisms for this effect, other researchers have also uncovered similar results, as in Pasquariello et al. [2014]. More broadly, D'Amico and King [2013] finds significant effects of the Fed's asset purchases on the prices of individual securities. Moreover, the historical record suggests that some Federal Reserve officials observed a modest effect of SOMA purchases on pricing and liquidity. In particular, Peter Sternlight, the former SOMA manager made the following observation at the March 31, 1992 FOMC meeting:

> I believe that our occasional purchases outside the short-term area add some liquidity to the intermediate and longer markets, and perhaps contribute modestly to rates in those sectors being a little lower than they might be absent our participation.

The results presented above are largely consistent with the anecdotal observation made nearly 25 years ago.

# 8 Conclusion

Through quantification of the SOMA portfolio, we show which characteristic has dominated SOMA portfolio composition in the past and that recent policies have led to a portfolio that is neither market neutral or very liquid by historical standards. Going forward, we show that the portfolio is likely to move away from both characteristics in the coming years. Moreover, we show empirically that the composition of the portfolio is correlated with a measure of the term premium as well as pricing errors and bid-asked spreads on individual securities. In this way, we illustrate both on an aggregate and on a micro level that securities held by the Federal Reserve affect prices for Treasury securities, which in turn, have an effect on the macroeconomy.

The simple interpretations of the concepts that have shaped the Federal Reserve's balance sheet over time show how the composition of the balance sheet has reflected the debate between efforts to develop a market-neutral portfolio and efforts to maintain a liquidity-based portfolio, and then to pursue a duration absorbing portfolio. While most theoretical literature would suggest that the ability of the Federal Reserve's securities holdings to have permanent effects on the term structure of interest rates is limited, the empirical evidence suggests that the composition of the portfolio can significantly affect prices of Treasury securities.

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Table 1: Measures summary statistics

| | $N_t$ | $Q_t$ | $D_t$ | $\frac{privateTYE}{GDP}_t$ | $KL_t$ | $\cos_t$ |
|---|---|---|---|---|---|---|
| | | | | All | | |
| Mean | 0.11 | 0.16 | 0.08 | 0.06 | 0.34 | 0.20 |
| Std. Dev. | 0.09 | 0.22 | 0.05 | 0.02 | 0.22 | 0.10 |
| Min | 0.01 | 0.00 | 0.01 | 0.02 | 0.05 | 0.03 |
| Max | 0.35 | 0.83 | 0.22 | 0.09 | 0.95 | 0.42 |
| Obs | 374 | | | | | |
| | | | | Pre-crisis | | |
| Mean | 0.06 | 0.04 | 0.07 | 0.06 | 0.22 | 0.14 |
| Std. Dev. | 0.03 | 0.03 | 0.05 | 0.02 | 0.11 | 0.06 |
| Min | 0.01 | 0.00 | 0.01 | 0.03 | 0.05 | 0.03 |
| Max | 0.12 | 0.20 | 0.17 | 0.09 | 0.41 | 0.26 |
| Obs | 270 | | | | | |
| | | | | Post-crisis | | |
| Mean | 0.23 | 0.48 | 0.12 | 0.04 | 0.63 | 0.34 |
| Std. Dev. | 0.07 | 0.19 | 0.05 | 0.01 | 0.17 | 0.04 |
| Min | 0.13 | 0.27 | 0.04 | 0.02 | 0.35 | 0.22 |
| Max | 0.35 | 0.83 | 0.22 | 0.06 | 0.95 | 0.42 |
| Obs | 104 | | | | | |
| | | | | Values as-of | | |
| Feb. 28, 2006 | 0.04 | 0.02 | 0.04 | 0.04 | 0.14 | 0.09 |
| Feb. 29, 2009 | 0.13 | 0.32 | 0.05 | 0.03 | 0.35 | 0.22 |
| Nov. 30, 2014 | 0.27 | 0.65 | 0.14 | 0.03 | 0.73 | 0.34 |

# Table 2: Term premium and the SOMA portfolio

| | 2 | | | 3 | | | 4 | | | 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis |
| $N_t$ | -3.097** | 7.705** | -4.757** | -3.488** | 8.967** | -5.753** | -3.751** | 9.784** | -6.699** | -4.000** | 10.44** | -7.646** |
| | (0.657) | (2.367) | (0.752) | (0.815) | (3.230) | (0.992) | (0.959) | (3.893) | (1.217) | (1.085) | (4.388) | (1.411) |
| Constant | 0.826** | 0.168 | 1.151** | 1.065** | 0.301 | 1.531** | 1.269** | 0.432 | 1.905** | 1.455** | 0.555 | 2.269** |
| | (0.120) | (0.166) | (0.161) | (0.151) | (0.232) | (0.222) | (0.175) | (0.281) | (0.274) | (0.195) | (0.318) | (0.314) |
| $F_{endog}$ | 9.44 | 0.37 | 14.26 | 9.38 | 0.85 | 6.27 | 9.8 | 1.15 | 4.23 | 10.59 | 1.3 | 3.85 |
| $p_{endog}$ | 0 | 0.54 | 0 | 0 | 0.36 | 0.01 | 0 | 0.28 | 0.04 | 0 | 0.26 | 0.05 |
| $F_{first}$ | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 |
| $p_{first}$ | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 |
| $score_{overid}$ | 3.73 | 2.32 | 3.18 | 3.51 | 2.46 | 2.64 | 3.35 | 2.35 | 2.47 | 3.25 | 2.21 | 2.39 |
| $p_{overid}$ | 0.29 | 0.51 | 0.37 | 0.32 | 0.48 | 0.45 | 0.34 | 0.5 | 0.48 | 0.35 | 0.53 | 0.49 |
| $Q_t$ | -1.426** | 11.96** | -1.745** | -1.614** | 14.05** | -2.151** | -1.736** | 15.41** | -2.516** | -1.844** | 16.46** | -2.863** |
| | (0.284) | (4.122) | (0.449) | (0.354) | (5.675) | (0.579) | (0.416) | (6.872) | (0.700) | (0.469) | (7.768) | (0.810) |
| Constant | 0.717** | 0.218 | 0.904** | 0.943** | 0.355 | 1.251** | 1.138** | 0.488 | 1.585** | 1.314** | 0.613** | 1.898** |
| | (0.0877) | (0.164) | (0.185) | (0.113) | (0.227) | (0.245) | (0.132) | (0.275) | (0.297) | (0.146) | (0.311) | (0.341) |
| $F_{endog}$ | 11.19 | 13.58 | 21.58 | 10.13 | 10.23 | 18.23 | 9.97 | 8.47 | 16.9 | 10.39 | 7.57 | 16.7 |
| $p_{endog}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 |
| $F_{first}$ | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 |
| $p_{first}$ | 0.03 | 0 | 0 | 0.03 | 0 | 0 | 0.03 | 0 | 0 | 0.03 | 0 | 0 |
| $score_{overid}$ | 3.86 | 0.76 | 3.38 | 3.58 | 0.95 | 3.12 | 3.37 | 1.11 | 3.02 | 3.25 | 1.2 | 2.97 |
| $p_{overid}$ | 0.28 | 0.86 | 0.34 | 0.31 | 0.81 | 0.37 | 0.34 | 0.77 | 0.39 | 0.35 | 0.75 | 0.4 |
| $D_t$ | -2.923 | 5.646** | -6.220** | -3.275 | 6.476** | -7.350** | -3.593 | 7.019** | -8.517** | -3.954 | 7.478** | -9.771** |
| | (1.602) | (1.749) | (0.671) | (1.909) | (2.305) | (0.855) | (2.168) | (2.740) | (1.027) | (2.395) | (3.072) | (1.163) |
| Constant | 0.723** | 0.282** | 0.789** | 0.946** | 0.440** | 1.073** | 1.147** | 0.587** | 1.367** | 1.335** | 0.720** | 1.660** |
| | (0.130) | (0.130) | (0.0886) | (0.163) | (0.179) | (0.131) | (0.190) | (0.217) | (0.164) | (0.212) | (0.245) | (0.187) |
| $F_{endog}$ | 12.93 | 0.08 | 20.91 | 15.73 | 0.7 | 7.05 | 16.94 | 1.22 | 3.66 | 17.41 | 1.5 | 3.05 |
| $p_{endog}$ | 0 | 0.78 | 0 | 0 | 0.4 | 0.01 | 0 | 0.27 | 0.06 | 0 | 0.22 | 0.08 |
| $F_{first}$ | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 |
| $p_{first}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $score_{overid}$ | 3.03 | 2.93 | 4.02 | 2.95 | 2.86 | 3.28 | 2.88 | 2.63 | 2.82 | 2.82 | 2.42 | 2.63 |
| $p_{overid}$ | 0.39 | 0.4 | 0.26 | 0.4 | 0.41 | 0.35 | 0.41 | 0.45 | 0.42 | 0.42 | 0.49 | 0.45 |
| $KL_t$ | -1.037** | 2.175** | -1.861** | -1.160** | 2.554** | -2.261** | -1.244** | 2.798** | -2.636** | -1.326** | 2.989** | -3.008** |
| | (0.284) | (0.644) | (0.273) | (0.348) | (0.890) | (0.357) | (0.405) | (1.079) | (0.438) | (0.455) | (1.220) | (0.508) |
| Constant | 0.839** | 0.165 | 1.239** | 1.076** | 0.293 | 1.644** | 1.280** | 0.421 | 2.039** | 1.466** | 0.542 | 2.421** |
| | (0.136) | (0.162) | (0.158) | (0.170) | (0.227) | (0.218) | (0.196) | (0.277) | (0.269) | (0.218) | (0.313) | (0.309) |
| $F_{endog}$ | 6.79 | 1.98 | 10.8 | 6.59 | 2.77 | 4.12 | 6.79 | 3.16 | 2.43 | 7.28 | 3.32 | 2.09 |
| $p_{endog}$ | 0.01 | 0.16 | 0 | 0.01 | 0.1 | 0.05 | 0.01 | 0.08 | 0.12 | 0.01 | 0.07 | 0.15 |
| $F_{first}$ | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 |
| $p_{first}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $score_{overid}$ | 3.95 | 2.03 | 2.7 | 3.74 | 2.23 | 2.37 | 3.57 | 2.18 | 2.26 | 3.48 | 2.05 | 2.25 |
| $p_{overid}$ | 0.27 | 0.57 | 0.44 | 0.29 | 0.53 | 0.5 | 0.31 | 0.54 | 0.52 | 0.32 | 0.56 | 0.52 |
| $\cos_t$ | -1.803** | 3.662** | -5.638** | -1.975** | 4.319** | -6.769** | -2.082** | 4.744** | -7.839** | -2.195 | 5.073** | -8.918** |
| | (0.752) | (1.149) | (1.180) | (0.919) | (1.587) | (1.500) | (1.059) | (1.923) | (1.869) | (1.178) | (2.174) | (2.227) |
| Constant | 0.841** | 0.138 | 1.968** | 1.070** | 0.259 | 2.502** | 1.267** | 0.381 | 3.022** | 1.448** | 0.499 | 3.533** |
| | (0.171) | (0.174) | (0.394) | (0.212) | (0.244) | (0.511) | (0.244) | (0.297) | (0.637) | (0.271) | (0.336) | (0.758) |
| $F_{endog}$ | 1.46 | 0.62 | 2.24 | 1.23 | 0.69 | 0.48 | 1.25 | 0.69 | 0.11 | 1.42 | 0.68 | 0.04 |
| $p_{endog}$ | 0.23 | 0.43 | 0.14 | 0.27 | 0.41 | 0.49 | 0.26 | 0.41 | 0.74 | 0.23 | 0.41 | 0.84 |
| $F_{first}$ | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 |
| $p_{first}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $score_{overid}$ | 4.12 | 1.93 | 2.52 | 4.09 | 2.08 | 3.41 | 4 | 2.07 | 3.61 | 3.91 | 2 | 3.51 |
| $p_{overid}$ | 0.25 | 0.59 | 0.47 | 0.25 | 0.56 | 0.33 | 0.26 | 0.56 | 0.31 | 0.27 | 0.57 | 0.32 |
| $\frac{privateTYE}{GDP}$ | 15.16** | 10.88** | -3.716 | 17.69** | 13.01** | -0.368 | 19.24** | 14.38** | 1.115 | 20.42** | 15.40** | 0.887 |
| | (3.109) | (2.791) | (20.91) | (4.091) | (3.979) | (27.27) | (4.859) | (4.905) | (32.65) | (5.446) | (5.593) | (37.28) |
| Constant | -0.359 | -0.0182 | 0.214 | -0.304 | 0.0627 | 0.229 | -0.216 | 0.161 | 0.326 | -0.123 | 0.262 | 0.481 |
| | (0.197) | (0.185) | (0.844) | (0.256) | (0.265) | (1.102) | (0.302) | (0.327) | (1.321) | (0.337) | (0.373) | (1.510) |
| $F_{endog}$ | 0.71 | 21.51 | 0.59 | 1.01 | 18.52 | 0.62 | 1.09 | 16.14 | 0.68 | 1.05 | 14.54 | 0.74 |
| $p_{endog}$ | 0.4 | 0 | 0.44 | 0.32 | 0 | 0.43 | 0.3 | 0 | 0.41 | 0.31 | 0 | 0.39 |
| $F_{first}$ | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 |
| $p_{first}$ | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 |
| $score_{overid}$ | 1.59 | 1.13 | 1.05 | 1.32 | 1.25 | 0.94 | 1.4 | 1.31 | 0.89 | 1.47 | 1.29 | 0.88 |
| $p_{overid}$ | 0.66 | 0.77 | 0.79 | 0.72 | 0.74 | 0.82 | 0.71 | 0.73 | 0.83 | 0.69 | 0.73 | 0.83 |
| Observations | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 |

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Portfolio measures are instrumented with marketable debt over GDP, (marketable debt over GDP)$^2$, (marketable debt over GDP)$^3$ and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

## Table 3: Term premium and the SOMA portfolio

| | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis |
| $N_t$ | -3.087** | 13.57** | -7.226** | -3.241** | 14.33** | -7.944** | -3.410** | 15.03** | -8.596** | -3.588** | 15.69** | -9.180** | -3.771** | 16.33** | -9.699** |
| | (1.148) | (3.901) | (1.426) | (1.238) | (4.111) | (1.559) | (1.317) | (4.271) | (1.676) | (1.385) | (4.395) | (1.780) | (1.446) | (4.492) | (1.873) |
| Constant | 1.497** | 0.510 | 2.302** | 1.643** | 0.599 | 2.578** | 1.778** | 0.679** | 2.822** | 1.900** | 0.749** | 3.036** | 2.012** | 0.811** | 3.221** |
| | (0.193) | (0.298) | (0.330) | (0.204) | (0.315) | (0.355) | (0.214) | (0.327) | (0.377) | (0.222) | (0.337) | (0.395) | (0.229) | (0.344) | (0.411) |
| $F_{endog}$ | 11.53 | 1.36 | 4.04 | 12.49 | 1.36 | 4.46 | 13.39 | 1.32 | 4.97 | 14.19 | 1.27 | 5.48 | 14.9 | 1.2 | 5.98 |
| $p_{endog}$ | 0 | 0.25 | 0.05 | 0 | 0.25 | 0.04 | 0 | 0.25 | 0.03 | 0 | 0.26 | 0.02 | 0 | 0.27 | 0.02 |
| $F_{first}$ | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 | 3.95 | 25.07 | 11.51 |
| $p_{first}$ | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 |
| $score_{overid}$ | 3.19 | 2.08 | 2.35 | 3.14 | 1.96 | 2.33 | 3.09 | 1.87 | 2.33 | 3.05 | 1.79 | 2.33 | 3.02 | 1.72 | 2.34 |
| $p_{overid}$ | 0.36 | 0.56 | 0.5 | 0.37 | 0.58 | 0.51 | 0.38 | 0.6 | 0.51 | 0.38 | 0.62 | 0.51 | 0.39 | 0.63 | 0.51 |
| $Q_t$ | -1.955** | 17.40** | -3.188** | -2.070** | 18.31** | -3.486** | -2.187** | 19.23** | -3.754** | -2.304** | 20.14** | -3.994** | -2.421** | 21.07** | -4.206** |
| | (0.516) | (8.443) | (0.907) | (0.558) | (8.961) | (0.994) | (0.595) | (9.367) | (1.070) | (0.628) | (9.691) | (1.137) | (0.658) | (9.951) | (1.197) |
| Constant | 1.475** | 0.728** | 2.185** | 1.623** | 0.831** | 2.440** | 1.758** | 0.922** | 2.665** | 1.880** | 1.001** | 2.860** | 1.990** | 1.069** | 3.029** |
| $F_{endog}$ | 11.08 | 7.14 | 16.95 | 11.88 | 6.97 | 17.32 | 12.69 | 6.99 | 17.71 | 13.48 | 7.13 | 18.05 | 14.24 | 7.37 | 18.33 |
| $p_{endog}$ | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 |
| $F_{first}$ | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 | 3.01 | 19.28 | 10.24 |
| $p_{first}$ | 0.03 | 0 | 0 | 0.03 | 0 | 0 | 0.03 | 0 | 0 | 0.03 | 0 | 0 | 0.03 | 0 | 0 |
| $score_{overid}$ | 3.18 | 1.24 | 2.93 | 3.13 | 1.26 | 2.91 | 3.09 | 1.26 | 2.89 | 3.05 | 1.25 | 2.89 | 3.02 | 1.24 | 2.88 |
| $p_{overid}$ | 0.37 | 0.74 | 0.4 | 0.37 | 0.74 | 0.41 | 0.38 | 0.74 | 0.41 | 0.38 | 0.74 | 0.41 | 0.39 | 0.74 | 0.41 |
| $D_t$ | -4.342 | 7.925** | -11.04** | -4.734 | 8.382** | -12.25** | -5.110 | 8.854** | -13.37** | -5.463 | 9.337** | -14.38** | -5.789 | 9.827** | -15.29** |
| | (2.596) | (3.324) | (1.268) | (2.777) | (3.517) | (1.353) | (2.942) | (3.667) | (1.427) | (3.092) | (3.784) | (1.493) | (3.232) | (3.876) | (1.552) |
| Constant | 1.510** | 0.840** | 1.937** | 1.670** | 0.946** | 2.191** | 1.816** | 1.039** | 2.417** | 1.948** | 1.120** | 2.615** | 2.065** | 1.189** | 2.787** |
| $F_{endog}$ | 17.62 | 1.6 | 3.25 | 17.73 | 1.6 | 3.78 | 17.76 | 1.53 | 4.48 | 17.75 | 1.43 | 5.23 | 17.69 | 1.31 | 5.98 |
| $p_{endog}$ | 0 | 0.21 | 0.07 | 0 | 0.21 | 0.05 | 0 | 0.22 | 0.04 | 0 | 0.23 | 0.02 | 0 | 0.25 | 0.02 |
| $F_{first}$ | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 | 11.49 | 11.48 | 24.66 |
| $p_{first}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $score_{overid}$ | 2.77 | 2.27 | 2.57 | 2.72 | 2.15 | 2.57 | 2.66 | 2.06 | 2.59 | 2.61 | 1.99 | 2.61 | 2.57 | 1.93 | 2.62 |
| $p_{overid}$ | 0.43 | 0.52 | 0.46 | 0.44 | 0.54 | 0.46 | 0.45 | 0.56 | 0.46 | 0.46 | 0.57 | 0.46 | 0.46 | 0.59 | 0.45 |
| $KL_t$ | -1.414** | 3.160** | -3.366** | -1.506** | 3.325** | -3.699** | -1.600** | 3.488** | -4.003** | -1.694** | 3.653** | -4.276** | -1.786** | 3.817** | -4.518** |
| | (0.498) | (1.324) | (0.569) | (0.536) | (1.403) | (0.621) | (0.570) | (1.464) | (0.667) | (0.600) | (1.510) | (0.708) | (0.628) | (1.547) | (0.743) |
| Constant | 1.640** | 0.653 | 2.776** | 1.800** | 0.752** | 3.099** | 1.948** | 0.839** | 3.386** | 2.083** | 0.915** | 3.639** | 2.205** | 0.979** | 3.858** |
| | (0.236) | (0.340) | (0.341) | (0.251) | (0.360) | (0.368) | (0.264) | (0.375) | (0.390) | (0.276) | (0.387) | (0.409) | (0.286) | (0.396) | (0.425) |
| $F_{endog}$ | 7.89 | 3.37 | 2.18 | 8.53 | 3.37 | 2.45 | 9.14 | 3.33 | 2.79 | 9.69 | 3.27 | 3.15 | 10.16 | 3.2 | 3.49 |
| $p_{endog}$ | 0.01 | 0.07 | 0.14 | 0 | 0.07 | 0.12 | 0 | 0.07 | 0.1 | 0 | 0.07 | 0.08 | 0 | 0.07 | 0.06 |
| $F_{first}$ | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 | 11.17 | 37.48 | 5.61 |
| $p_{first}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $score_{overid}$ | 3.41 | 1.92 | 2.29 | 3.36 | 1.81 | 2.35 | 3.31 | 1.71 | 2.41 | 3.27 | 1.62 | 2.47 | 3.23 | 1.55 | 2.53 |
| $p_{overid}$ | 0.33 | 0.59 | 0.51 | 0.34 | 0.61 | 0.5 | 0.35 | 0.64 | 0.49 | 0.35 | 0.65 | 0.48 | 0.36 | 0.67 | 0.47 |
| $\cos_t$ | -2.327 | 5.364** | -9.972** | -2.473 | 5.643** | -10.97** | -2.629 | 5.919** | -11.88** | -2.789 | 6.195** | -12.71** | -2.950 | 6.471** | -13.45** |
| | (1.280) | (2.362) | (2.554) | (1.370) | (2.505) | (2.849) | (1.451) | (2.616) | (3.110) | (1.523) | (2.702) | (3.342) | (1.588) | (2.770) | (3.547) |
| Constant | 1.617** | 0.607 | 4.019** | 1.775** | 0.704 | 4.467** | 1.921** | 0.789 | 4.871** | 2.056** | 0.863** | 5.231** | 2.179** | 0.926** | 5.549** |
| | (0.292) | (0.365) | (0.867) | (0.311) | (0.387) | (0.964) | (0.327) | (0.403) | (1.050) | (0.342) | (0.416) | (1.126) | (0.355) | (0.426) | (1.192) |
| $F_{endog}$ | 1.65 | 0.67 | 0.04 | 1.91 | 0.66 | 0.05 | 2.17 | 0.6 | 6 0.08 | 2.42 | 0.67 | 0.11 | 2.64 | 0.68 | 0.15 |
| $p_{endog}$ | 0.2 | 0.41 | 0.84 | 0.17 | 0.42 | 0.82 | 0.14 | 0.42 | 0.78 | 0.12 | 0.41 | 0.74 | 0.11 | 0.41 | 0.7 |
| $F_{first}$ | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 | 13.52 | 98.83 | 17.39 |
| $p_{first}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $score_{overid}$ | 3.82 | 1.92 | 3.3 | 3.73 | 1.84 | 3.08 | 3.66 | 1.76 | 2.88 | 3.59 | 1.7 | 2.7 | 3.53 | 1.65 | 2.56 |
| $p_{overid}$ | 0.28 | 0.59 | 0.35 | 0.29 | 0.61 | 0.38 | 0.3 | 0.62 | 0.41 | 0.31 | 0.64 | 0.44 | 0.32 | 0.65 | 0.46 |
| $\frac{privateTYE}{GDP}_t$ | 21.47** | 16.25** | -0.419 | 22.49** | 17.03** | -2.292 | 23.51** | 17.78** | -4.406 | 24.54** | 18.51** | -6.576 | 25.58** | 19.23** | -8.700 |
| | (5.895) | (6.099) | (41.29) | (6.246) | (6.475) | (44.77) | (6.526) | (6.755) | (47.80) | (6.754) | (6.966) | (50.46) | (6.942) | (7.124) | (52.78) |
| Constant | -0.0377 | 0.358 | 0.664 | 0.0346 | 0.446 | 0.853 | 0.0933 | 0.524 | 1.034 | 0.139 | 0.591 | 1.203 | 0.173 | 0.648 | 1.356 |
| | (0.364) | (0.406) | (1.673) | (0.386) | (0.431) | (1.816) | (0.404) | (0.449) | (1.939) | (0.419) | (0.462) | (2.048) | (0.431) | (0.472) | (2.142) |
| $F_{endog}$ | 0.97 | 13.48 | 0.8 | 0.87 | 12.75 | 0.85 | 0.78 | 12.24 | 0.9 | 0.7 | 11.88 | 0.95 | 0.63 | 11.64 | 0.99 |
| $p_{endog}$ | 0.33 | 0 | 0.37 | 0.35 | 0 | 0.36 | 0.38 | 0 | 0.34 | 0.4 | 0 | 0.33 | 0.43 | 0 | 0.32 |
| $F_{first}$ | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 | 84.38 | 43.47 | 4.17 |
| $p_{first}$ | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 | 0 | 0 | 0.01 |
| $score_{overid}$ | 1.5 | 1.24 | 0.9 | 1.5 | 1.18 | 0.92 | 1.48 | 1.13 | 0.94 | 1.45 | 1.08 | 0.96 | 1.41 | 1.03 | 0.97 |
| $p_{overid}$ | 0.68 | 0.74 | 0.83 | 0.68 | 0.76 | 0.82 | 0.69 | 0.77 | 0.82 | 0.69 | 0.78 | 0.81 | 0.7 | 0.79 | 0.81 |

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Measures are instrumented with marketable debt over GDP, (marketable debt over GDP)$^2$, (marketable debt over GDP)$^3$ and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

# Table 4: Excess return forecasting regressions and the SOMA portfolio

| | 2 | | | 3 | | | 4 | | | 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis |
| $N_t$ | 3.059$^{**}$ | -3.939 | -2.782 | 4.948$^{**}$ | -6.934 | -7.744$^{**}$ | 5.935$^{**}$ | -8.777 | -10.72$^{**}$ | 6.680$^{**}$ | -10.08 | -12.09$^{**}$ |
| | (1.015) | (2.999) | (1.975) | (1.734) | (4.850) | (3.202) | (2.516) | (5.781) | (4.618) | (3.121) | (6.245) | (5.794) |
| Constant | 0.180 | 0.489$^{**}$ | 1.869$^{**}$ | 0.324 | 0.836$^{**}$ | 3.847$^{**}$ | 0.419 | 1.058$^{**}$ | 4.982$^{**}$ | 0.473 | 1.215$^{**}$ | 5.584$^{**}$ |
| | (0.149) | (0.232) | (0.420) | (0.237) | (0.372) | (0.780) | (0.295) | (0.438) | (1.150) | (0.331) | (0.464) | (1.439) |
| $Q_t$ | 1.361$^{**}$ | -4.916 | -0.910 | 2.234$^{**}$ | -9.012 | -2.875$^{**}$ | 2.690$^{**}$ | -11.68 | -4.128$^{**}$ | 3.022$^{**}$ | -13.68 | -4.745$^{**}$ |
| | (0.306) | (5.137) | (0.789) | (0.659) | (8.336) | (1.319) | (1.025) | (9.913) | (1.863) | (1.293) | (10.67) | (2.317) |
| Constant | 0.294$^{**}$ | 0.420 | 1.686$^{**}$ | 0.502$^{**}$ | 0.728 | 3.503$^{**}$ | 0.631$^{**}$ | 0.930$^{**}$ | 4.579$^{**}$ | 0.712$^{**}$ | 1.077$^{**}$ | 5.172$^{**}$ |
| | (0.0990) | (0.241) | (0.352) | (0.163) | (0.390) | (0.659) | (0.199) | (0.460) | (0.965) | (0.220) | (0.490) | (1.207) |
| $D_t$ | 1.454 | -2.961 | -5.467$^{**}$ | 1.308 | -5.186 | -9.439$^{**}$ | 1.165 | -6.593 | -10.59 | 1.264 | -7.646 | -10.43 |
| | (2.787) | (2.318) | (2.039) | (4.393) | (3.766) | (4.599) | (5.430) | (4.519) | (6.565) | (6.149) | (4.928) | (7.865) |
| Constant | 0.389 | 0.436$^{**}$ | 1.829$^{**}$ | 0.740 | 0.741$^{**}$ | 3.119$^{**}$ | 0.949 | 0.938$^{**}$ | 3.710$^{**}$ | 1.073 | 1.082$^{**}$ | 3.987$^{**}$ |
| | (0.247) | (0.192) | (0.260) | (0.411) | (0.309) | (0.658) | (0.502) | (0.366) | (0.959) | (0.554) | (0.390) | (1.164) |
| $KL_t$ | 1.069$^{**}$ | -1.093 | -1.115 | 1.753$^{**}$ | -1.928 | -2.849$^{**}$ | 2.117$^{**}$ | -2.432 | -3.872 | 2.392$^{**}$ | -2.772 | -4.313 |
| | (0.417) | (0.843) | (0.757) | (0.694) | (1.366) | (1.365) | (0.976) | (1.631) | (1.996) | (1.195) | (1.763) | (2.480) |
| Constant | 0.152 | 0.487$^{**}$ | 1.935$^{**}$ | 0.269 | 0.832$^{**}$ | 3.873$^{**}$ | 0.350 | 1.050$^{**}$ | 4.974$^{**}$ | 0.392 | 1.202$^{**}$ | 5.541$^{**}$ |
| | (0.175) | (0.235) | (0.442) | (0.277) | (0.378) | (0.932) | (0.343) | (0.445) | (1.377) | (0.387) | (0.472) | (1.698) |
| $\cos_t$ | 2.309$^{**}$ | -1.651 | -1.489 | 4.104$^{**}$ | -2.966 | -7.502 | 5.100$^{**}$ | -3.778 | -12.58 | 5.821$^{**}$ | -4.343 | -15.29 |
| | (1.012) | (1.454) | (2.426) | (1.764) | (2.357) | (5.618) | (2.438) | (2.808) | (10.08) | (2.935) | (3.027) | (13.20) |
| Constant | 0.0600 | 0.474 | 1.744$^{**}$ | 0.0587 | 0.817$^{**}$ | 4.622$^{**}$ | 0.0673 | 1.036$^{**}$ | 6.791$^{**}$ | 0.0617 | 1.190$^{**}$ | 7.990 |
| | (0.219) | (0.254) | (0.798) | (0.360) | (0.409) | (1.945) | (0.459) | (0.483) | (3.463) | (0.526) | (0.512) | (4.517) |
| $\frac{privateTYE}{GDP}_t$ | -12.02$^{**}$ | -5.415 | 11.98 | -19.86$^{**}$ | -9.566 | 58.75 | -23.82$^{**}$ | -11.93 | 81.35$^{**}$ | -26.38$^{**}$ | -13.33 | 95.45$^{**}$ |
| | (4.947) | (4.256) | (32.61) | (7.971) | (6.972) | (40.89) | (9.932) | (8.390) | (41.37) | (11.29) | (9.133) | (39.23) |
| Constant | 1.177$^{**}$ | 0.576 | 0.755 | 1.958$^{**}$ | 0.990$^{**}$ | -0.290 | 2.380$^{**}$ | 1.241$^{**}$ | -0.746 | 2.656$^{**}$ | 1.403$^{**}$ | -1.028 |
| | (0.341) | (0.310) | (1.306) | (0.556) | (0.504) | (1.586) | (0.698) | (0.598) | (1.588) | (0.796) | (0.640) | (1.518) |
| Observations | 362 | 269 | 93 | 362 | 269 | 93 | 362 | 269 | 93 | 362 | 269 | 93 |

Heteroskedastic-autocorrelation robust standard errors in parentheses. $^{**}$ significant at the 5 percent level.
Measures are instrumented with marketable debt over GDP, (marketable debt over GDP)$^2$, (marketable debt over GDP)$^3$ and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

# Table 5: Excess return forecasting regressions and the SOMA portfolio

| | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis |
| $N_t$ | 37.38** | -63.55** | 4.228 | 12.43** | -14.44** | 5.296 | 12.43** | -14.47** | 5.257 | 12.45** | -14.49** | 5.230 | 12.46** | -14.51** | 5.216 |
| | (5.454) | (6.646) | (9.196) | (1.544) | (3.092) | (2.713) | (1.551) | (3.111) | (2.734) | (1.558) | (3.131) | (2.754) | (1.565) | (3.151) | (2.775) |
| Constant | -11.02** | -5.457** | -1.306 | -2.018** | -0.512** | 0.113 | -2.016** | -0.508** | 0.128 | -2.013** | -0.504** | 0.139 | -2.012** | -0.501** | 0.148 |
| | (0.849) | (0.473) | (2.637) | (0.236) | (0.237) | (0.661) | (0.236) | (0.238) | (0.667) | (0.237) | (0.239) | (0.672) | (0.237) | (0.241) | (0.677) |
| $Q_t$ | 16.60** | -99.69** | 1.393 | 5.311** | -23.36** | 1.969** | 5.315** | -23.40** | 1.953** | 5.320** | -23.43** | 1.943** | 5.326** | -23.45** | 1.936** |
| | (2.544) | (13.79) | (3.206) | (0.533) | (4.643) | (0.807) | (0.536) | (4.671) | (0.816) | (0.539) | (4.702) | (0.825) | (0.542) | (4.732) | (0.833) |
| Constant | -9.632** | -5.834** | -1.034 | -1.526** | -0.572** | 0.346 | -1.523** | -0.568** | 0.360 | -1.521** | -0.565** | 0.371 | -1.519** | -0.562** | 0.379 |
| | (0.517) | (0.671) | (2.141) | (0.125) | (0.219) | (0.487) | (0.126) | (0.220) | (0.491) | (0.126) | (0.221) | (0.496) | (0.126) | (0.222) | (0.500) |
| $D_t$ | 18.03 | -49.11** | 10.73 | 8.764 | -11.36** | 6.659 | 8.752 | -11.39** | 6.630 | 8.747 | -11.41** | 6.615 | 8.749 | -11.44** | 6.614 |
| | (19.00) | (8.264) | (13.78) | (6.142) | (3.019) | (5.643) | (6.152) | (3.032) | (5.655) | (6.162) | (3.045) | (5.669) | (6.173) | (3.058) | (5.685) |
| Constant | -8.493** | -6.231** | -1.504 | -1.390** | -0.675** | 0.589 | -1.385** | -0.670** | 0.598 | -1.382** | -0.666** | 0.605 | -1.379** | -0.663** | 0.610 |
| | (1.317) | (0.547) | (1.932) | (0.415) | (0.236) | (0.575) | (0.417) | (0.237) | (0.578) | (0.418) | (0.238) | (0.580) | (0.418) | (0.239) | (0.582) |
| $KL_t$ | 12.96** | -17.27** | 2.940 | 4.390** | -3.869** | 2.395** | 4.393** | -3.875** | 2.381** | 4.398** | -3.880** | 2.372** | 4.403** | -3.883** | 2.368** |
| | (2.381) | (1.752) | (3.685) | (0.712) | (0.833) | (1.050) | (0.715) | (0.839) | (1.058) | (0.717) | (0.845) | (1.067) | (0.719) | (0.851) | (1.075) |
| Constant | -11.33** | -5.586** | -2.176 | -2.150** | -0.554** | -0.181 | -2.148** | -0.550** | -0.167 | -2.146** | -0.547** | -0.156 | -2.145** | -0.544** | -0.148 |
| | (1.026) | (0.460) | (2.787) | (0.302) | (0.230) | (0.684) | (0.303) | (0.231) | (0.690) | (0.303) | (0.232) | (0.696) | (0.304) | (0.234) | (0.701) |
| $\cos_t$ | 27.43** | -29.16** | 17.94 | 9.299** | -6.632** | 14.25** | 9.311** | -6.642** | 14.20** | 9.325** | -6.649** | 14.17** | 9.340** | -6.655** | 14.16** |
| | (6.977) | (2.877) | (19.56) | (2.054) | (1.332) | (4.895) | (2.058) | (1.342) | (4.950) | (2.062) | (1.351) | (5.003) | (2.066) | (1.362) | (5.051) |
| Constant | -12.34** | -5.359** | -6.364 | -2.492** | -0.489** | -3.471** | -2.491** | -0.485** | -3.448** | -2.490** | -0.482** | -3.432** | -2.490** | -0.479** | -3.422** |
| | (1.502) | (0.486) | (6.977) | (0.450) | (0.229) | (1.665) | (0.451) | (0.231) | (1.684) | (0.452) | (0.232) | (1.701) | (0.453) | (0.234) | (1.717) |
| $\frac{privateTYE}{GDP}_t$ | -146.3** | -78.72** | 202.8 | -39.32** | -16.89** | 95.89 | -39.35** | -16.90** | 96.27 | -39.38** | -16.90** | 96.61 | -39.41** | -16.89** | 96.90 |
| | (28.25) | (11.17) | (166.4) | (9.190) | (4.574) | (58.64) | (9.203) | (4.605) | (58.62) | (9.219) | (4.637) | (58.65) | (9.237) | (4.668) | (58.71) |
| Constant | 1.120 | -4.601** | -8.650 | 1.493** | -0.379 | -2.620 | 1.498** | -0.376 | -2.630 | 1.503** | -0.373 | -2.638 | 1.508** | -0.372 | -2.645 |
| | (2.048) | (0.723) | (6.945) | (0.675) | (0.320) | (2.398) | (0.676) | (0.322) | (2.398) | (0.677) | (0.324) | (2.399) | (0.678) | (0.326) | (2.402) |
| Observations | 362 | 269 | 93 | 362 | 269 | 93 | 362 | 269 | 93 | 362 | 269 | 93 | 362 | 269 | 93 |

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Measures are instrumented with marketable debt over GDP, (marketable debt over GDP)$^2$, (marketable debt over GDP)$^3$ and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

Table 6: Maturity of securities (in years)

| | Median | Mean | Share of observations |
|---|---|---|---|
| Pre-crisis, $s_{it} \geq g_{it}$ | 1.08 | 3.44 | 0.37 |
| Pre-crisis, $s_{it} < g_{it}$ | 3.88 | 7.34 | 0.63 |
| Post-crisis, $s_{it} \geq g_{it}$ | 5.09 | 7.84 | 0.58 |
| Post-crisis, $s_{it} < g_{it}$ | 2.33 | 4.60 | 0.42 |

Table 7: Term premium and positive/negative distance measures

| | 2 | | | 3 | | | 4 | | | 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis |
| $N_t^+$ | -20.15 | 56.58** | 38.74 | -20.64 | 66.54** | 45.64 | -20.79 | 73.06** | 52.60 | -21.48 | 78.19** | 60.02 |
| | (18.59) | (17.74) | (63.33) | (23.12) | (24.56) | (78.83) | (26.78) | (29.89) | (93.67) | (29.77) | (33.89) | (108.0) |
| Constant | 0.675** | 0.247 | -0.501 | 0.875** | 0.388** | -0.450 | 1.052** | 0.523** | -0.393 | 1.217** | 0.650** | -0.355 |
| | (0.170) | (0.138) | (0.940) | (0.216) | (0.195) | (1.163) | (0.253) | (0.239) | (1.380) | (0.283) | (0.271) | (1.591) |
| $N_t^-$ | -2.075** | 5.464 | -2.387** | -2.358** | 5.563 | -2.871** | -2.548** | 5.638 | -3.338** | -2.721** | 5.875 | -3.812** |
| | (0.343) | (3.095) | (0.447) | (0.434) | (3.726) | (0.590) | (0.517) | (4.229) | (0.721) | (0.589) | (4.637) | (0.834) |
| Constant | 0.754** | 0.411** | 0.885** | 0.985** | 0.619** | 1.203** | 1.185** | 0.798** | 1.522** | 1.366** | 0.952** | 1.832** |
| | (0.0931) | (0.153) | (0.151) | (0.120) | (0.193) | (0.206) | (0.140) | (0.223) | (0.252) | (0.156) | (0.246) | (0.288) |
| Observations | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 |

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Measures are instrumented with marketable debt over GDP, (marketable debt over GDP)$^2$, (marketable debt over GDP)$^3$ and the number of CUSIPS.
The instrument set passes first-stage instrument tests.



Table 8: Term premium and positive/negative distance measures

| | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis | all | pre-crisis | post-crisis |
| $N_t^+$ | -22.72 | 82.82** | 67.39 | -24.34 | 87.32** | 74.25 | -26.18 | 91.82** | 80.36 | -28.13 | 96.36** | 85.65 | -30.13 | 100.9** | 90.12 |
| | (32.27) | (36.91) | (121.4) | (34.41) | (39.20) | (133.7) | (36.28) | (40.96) | (144.9) | (37.93) | (42.34) | (154.8) | (39.41) | (43.43) | (163.7) |
| Constant | 1.372** | 0.766** | -0.333 | 1.516** | 0.870** | -0.320 | 1.649** | 0.961** | -0.314 | 1.771** | 1.041** | -0.311 | 1.881** | 1.110** | -0.310 |
| | (0.306) | (0.296) | (1.792) | (0.326) | (0.314) | (1.978) | (0.342) | (0.328) | (2.146) | (0.357) | (0.339) | (2.297) | (0.369) | (0.347) | (2.431) |
| $N_t^-$ | -2.896** | 6.278 | -4.276** | -3.074** | 6.808 | -4.711** | -3.253** | 7.427 | -5.109** | -3.431** | 8.104 | -5.467** | -3.606** | 8.818 | -5.786** |
| | (0.651) | (4.966) | (0.930) | (0.704) | (5.236) | (1.013) | (0.752) | (5.458) | (1.086) | (0.794) | (5.644) | (1.150) | (0.832) | (5.801) | (1.205) |
| Constant | 1.532** | 1.083** | 2.121** | 1.684** | 1.195** | 2.383** | 1.823** | 1.292** | 2.615** | 1.949** | 1.375** | 2.818** | 2.063** | 1.445** | 2.994** |
| | (0.168) | (0.265) | (0.316) | (0.179) | (0.279) | (0.339) | (0.187) | (0.291) | (0.358) | (0.195) | (0.300) | (0.375) | (0.201) | (0.308) | (0.389) |
| Observations | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 | 372 | 269 | 103 |

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Measures are instrumented with marketable debt over GDP, (marketable debt over GDP)$^2$, (marketable debt over GDP)$^3$ and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

Table 9: Summary Statistics

| | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Pricing Error ($\alpha_{it}$) | -0.34 | 2.27 | -35.43 | 34.20 |
| Market Neutrality Metric ($n_{it}$) | 0.0 | 0.004 | -0.02 | 0.03 |
| Bid-Ask Spread | 0.064 | 0.0911 | 0.0 | 1.0 |
| Liquidity Metric ($q_{it}$) | 0.0 | 0.006 | -0.058 | 0.092 |

Figure 1: Maturity distributions at minimum (October 2002) and maximum (December 2012) distance of SOMA from market neutrality

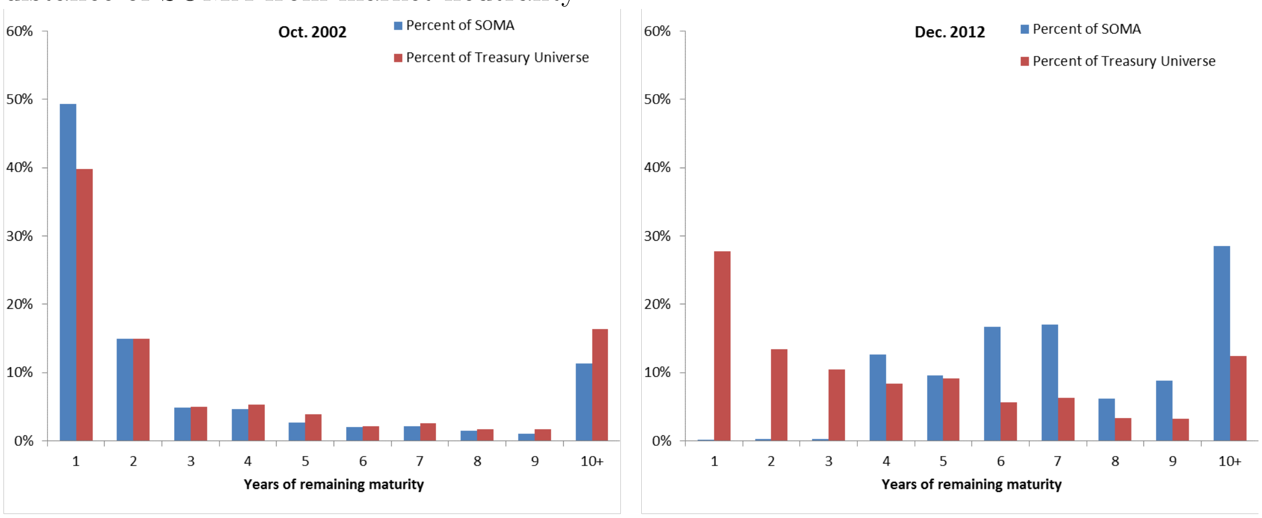

Figure 2: Minimum (October 2002) and maximum (December 2012) distance of portfolio from liquidity target

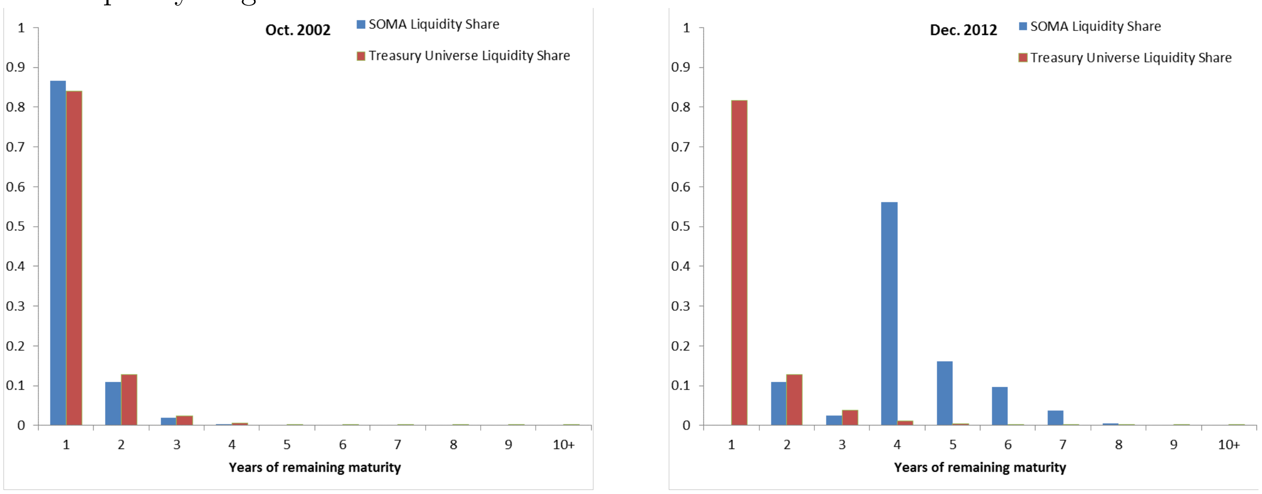


Figure 3: Minimum (February 2001) and maximum (December 2012) distance of portfolio from duration neutrality

Table 10: CUSIP-level effects of SOMA on prices and bid-asked spreads

| | Pricing error | | Bid-asked spread | |
|---|---|---|---|---|
| | pre | post | pre | post |
| Lag(1) | 0.583** | 0.726** | 0.437** | 0.188** |
| | (0.0280) | (0.00697) | (0.0477) | (0.0349) |
| Lag(2) | -0.318** | -0.623** | 0.184** | 0.207** |
| | (0.0156) | (0.0138) | (0.0420) | (0.0314) |
| Lag(3) | 0.281** | 0.513** | 0.0516 | 0.0616** |
| | (0.0283) | (0.0145) | (0.0303) | (0.0130) |
| Lag(4) | | -0.261** | 0.218** | |
| | | (0.0133) | (0.0734) | |
| Lag(5) | | 0.0676** | | |
| | | (0.00545) | | |
| $n_{it}$ | 237.7** | -438.6** | | |
| | (30.40) | (73.98) | | |
| $n_{i,t-1}$ | 176.6** | 287.3** | | |
| | (19.54) | (76.72) | | |
| $n_{i,t-2}$ | -72.63** | -135.4** | | |
| | (13.01) | (37.81) | | |
| $n_{i,t-3}$ | | 25.85 | | |
| | | (55.74) | | |
| $n_{i,t-4}$ | | 281.4** | | |
| | | (41.24) | | |
| $q_{it}$ | | | 0.227** | -0.0556** |
| | | | (0.0602) | (0.0264) |
| $q_{i,t-1}$ | | | -0.00560 | -0.0288 |
| | | | (0.0462) | (0.0345) |
| Level | 0.288** | 0.357** | -1.94** | 0.0203 |
| | (0.0168) | (0.0195) | (0.677) | (0.0509) |
| Slope | 1.499** | 0.610** | -0.00326** | 0.0784 |
| | (0.120) | (0.0424) | (0.00153) | (0.173) |
| Curvature | -1.126** | 2.236** | -0.0219 | -1.69** |
| | (0.397) | (0.186) | (0.0145) | (0.548) |
| Factor | -0.0379** | 0.114** | -0.0809 | -0.0995 |
| | (0.0049) | (0.013) | (0.054) | (0.084) |
| Constant | 0.698** | -1.939** | 0.00906** | 0.0214** |
| | (0.146) | (0.212) | (0.00211) | (0.00163) |
| Observations | 48,958 | 23,878 | 46,988 | 25,583 |

Standard errors in parentheses.
** $p < 0.05$

Figure 4: Evolution of Metrics

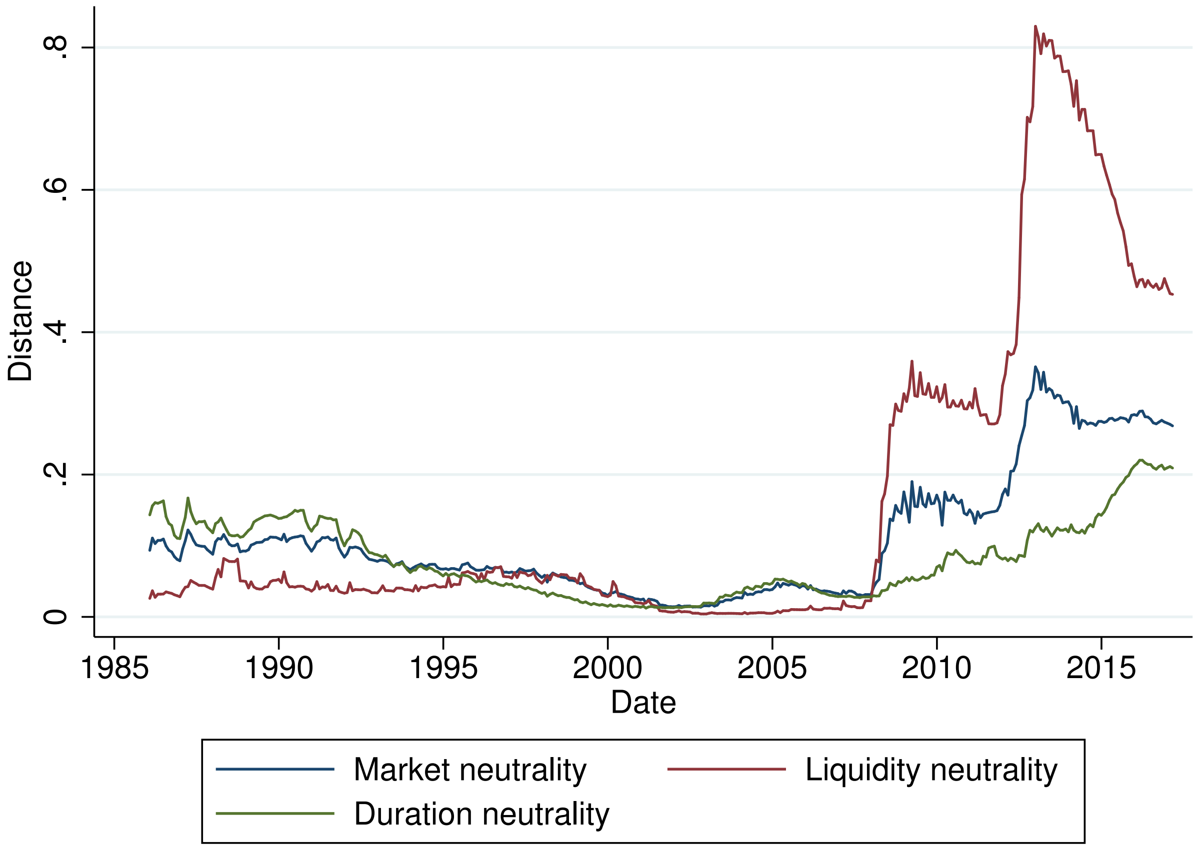


Figure 5: Securities relative to targets, by maturity (beginning of projection)

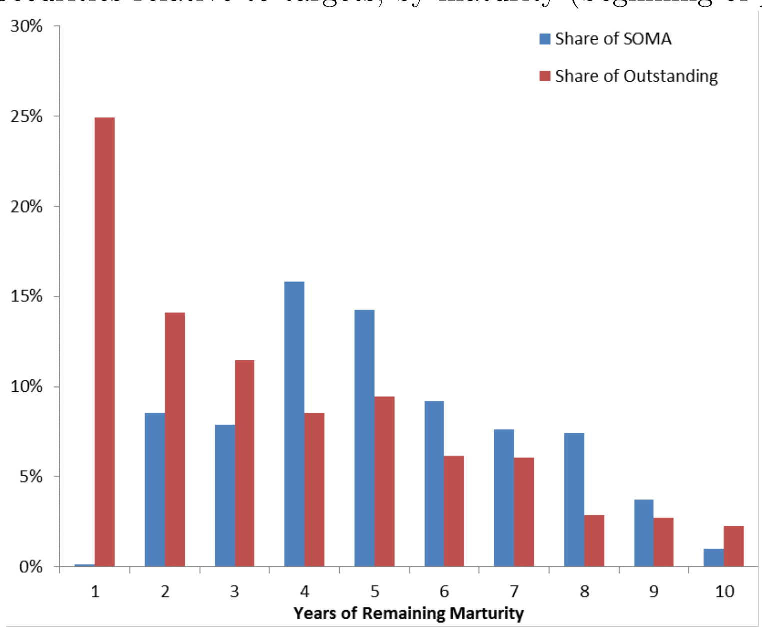

Figure 6: Market and Liquidity Measures

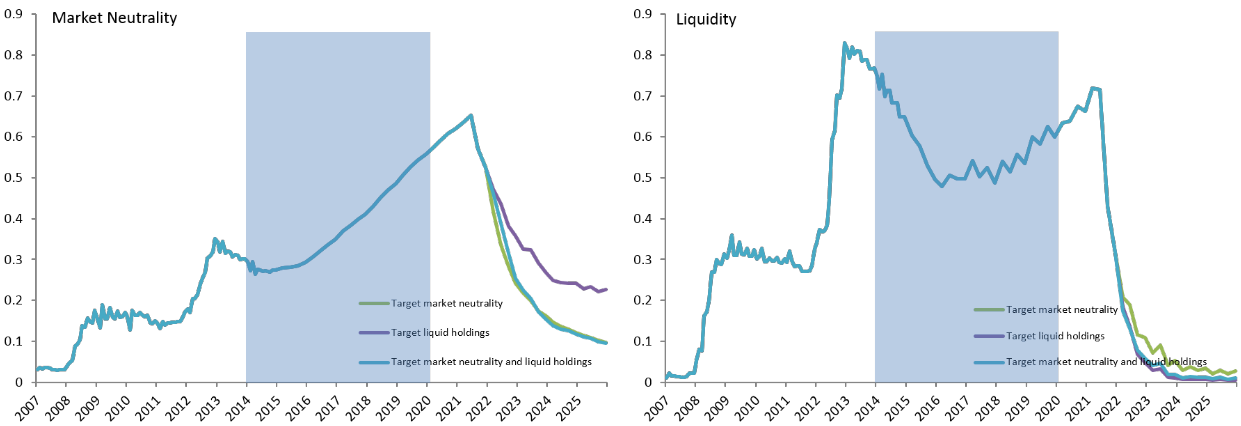


Figure 7: Securities Relative to Targets, by maturity (end of projection)

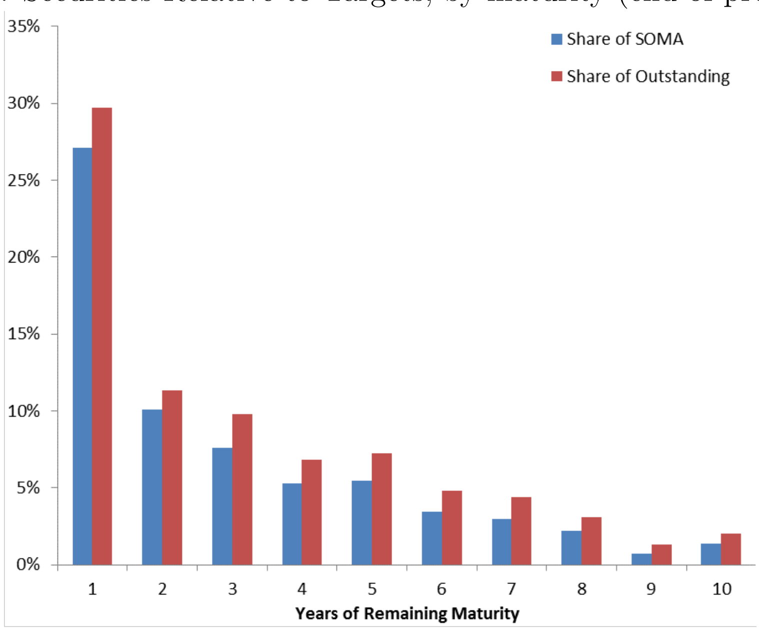

Figure 8: Market neutrality: SOMA relative to overall