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

Jeffrey Huther, Jane Ihrig, Elizabeth Klee, Alexander Boote and Richard Sambasivam*

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Abstract

We explore the Federal Reserve's portfolio composition over a 30-year period and its effect on Treasury yields. We examine the achievement of theoretical portfolio objectives used by the Federal Reserve, broadly defined as market neutrality, market liquidity, and interest rate risk ("duration") absorption. We construct measures for these objectives, investigates how these objectives were achieved over time by and then posits how the attainment of these objectives could evolve as the size of the portfolio normalizes in the future. We then discuss how, on an aggregate and CUSIP-level basis, these measures are correlated with prices on Treasury securities. Our results suggest that the further the Federal Reserve's portfolio is from the Treasury's portfolio on any of these measures, the larger the effect on the term premium and on the pricing of individual securities.

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 in history to the Operation Twist of the 1960s, and influenced the portfolio strategies pursued by the Federal Reserve for much of the thirty years before the financial crisis. Against this backdrop, this paper reviews the portfolio strategies of the Federal Reserve from 1980 to the present and provides econometric evidence that the portfolio composition can affect yields, both in aggregate and on specific securities.

Reviewing the objectives for the Federal Reserve's portfolio provides context on the importance of this question. To start, the recent expansion of the Federal Reserve's portfolio of securities was undertaken with the explicit goal of supporting economic growth.[1] A key idea underpinning the Federal Reserve's asset purchases is that a change in the securities holdings of the central bank generates a commensurate change in the securities holdings of private investors. In perfect markets, this shift in holdings should have little effect on interest rates. However, through a

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[1] Refer to Bernanke (2013b).

preferred-habitat or related channel, this shift could have effects on interest rates, which would then influence economic activity.[2] Evidence suggests that the Federal Reserve's asset purchases did have a measurable effect on longer-term interest rates.[3] As such, the central bank has the ability to influence the term structure of yields through its balance sheet holdings, as the Federal Reserve has recently done by purchasing and then holding longer-dated securities.

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.[4] 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. Most notably, this strategy was pursued during the "bills preferably" period of the portfolio from 1953 through 1960, but also was emphasized as an objective more recently, in the early to mid-1990s.[5] This portfolio liquidity allows the Federal Reserve's portfolio to transform rapidly during times of stress. Indeed, in the early stages of the financial crisis, the Federal Reserve provided liquidity to financial institutions through the Term Auction Facility and other programs, and simultaneously sold or allowed shorter-dated Treasury securities to mature to keep the level of reserve balances roughly steady.

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

[2] Refer to Vayanos, Vila (2009).
[3] Refer to Hamilton, Wu (2012) and Laubach, Williams (2015).
[4] Refer to Federal Open Market Committee (1992, 1996, and 2000).
[5] Refer to Federal Open Market Committee (1992).

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.[6] 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 perform two separate exercises. To start, leaning on the framework outlined in the Policy Normalization Principles and Plans, published in September 2014, we use the metrics to 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 market-neutral and liquidity characteristics of the portfolio influence yields on Treasury securities. Our main hypothesis is that while the levels and structure of holdings are key to understanding the influence of the Federal Reserve's portfolio on interest rates, the difference between the Federal Reserve's portfolio composition and that of the overall market matters as well. In many ways, the spirit of this exercise aligns with Li, Wei (2012), who estimate a term structure model of interest rates that relies on the private (not Federal Reserve) holdings of securities. The exercise is most closely related to Kuttner (2006), and shares similarities with Cochrane, Piazzesi (2005) and Ludvigson, Ng (2009) in illustrating factors that explain the term structure of interest rates outside of the expectations hypothesis. We find, consistent with D'Amico, 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, as a large holder of these securities, can also affect the term structure, should its portfolio differ from that of the Treasury universe overall. 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.

[6] Refer to Gagnon et al. (2011) for a discussion.

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.[7] There were also other episodes in which Federal Reserve portfolio decisions were made with consideration of Treasury policies. In particular, the FOMC followed an "even keel" policy, which aided the Treasury by maintaining rates at a constant level around times of Treasury auctions.[8]

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 in the past 30 years. 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

[7] Refer to Swanson (2011).

[8] Refer to Meltzer (2009), vol. 2, p.49 and following.

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.

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.[9] 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."[10] 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 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, 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 (2013a) and Gagnon et al. (2011), this channel was viewed as one plausible channel through which asset purchases operated. During

[9] Refer to Kohn (2002).

[10] Refer to Federal Open Market Committee (2000).

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 The international experience

2.2.1 Market neutrality in operating frameworks

Various central banks have followed, and occasionally abandoned, their own versions of market neutrality rules. The European Central Bank (ECB) faces a different financial market structure than does the Federal Reserve, and must align its balance sheet policies accordingly. Until recently, the ECB refrained from purchases of euro area government securities, largely due to political resistance. The ECB ultimately resorted to a purchase program that included sovereign debt in early 2015, purchasing sovereign bonds proportional to the size of its member countries. As of December 2016, the ECB held roughly €1.25 trillion in government securities and about €300 billion in other types of securities.

Market neutrality became more difficult for the Bank of Japan (BOJ) and the Bank of England to achieve over time. When the BOJ began purchasing securities in the 2000s, it imposed on itself the banknote rule, a ceiling on outright purchases of long-term Japanese government bonds equal to the amount of outstanding bank note issuance. By the end of this first round in 2006, the BOJ held about 50 trillion yen in government bonds, against 80 trillion in currency in circulation. As of October 2015, the BOJ held approximately 29 percent of Japanese government debt–as a result, there have been concerns about the drastic reduction in private holdings and whether the BOJ may need to expand its purchases to other asset classes. As of October 2015 the Bank of England's (BOE) Asset Purchase Facility held about 25 percent of the outstanding gilt (UK government bond) market, primarily in long maturities. However, rather than crowd out the private market, the BOE appears to be easing government funding pressure, as demand for gilts from the domestic private sector and from Asian markets has been low. Asian central bank balance sheets have also ballooned. For the central banks of China, Hong Kong, India, the Philippines, Singapore, Thailand, and other Asian countries, nearly 100 percent of the expansion in assets from 2002-11 were in foreign assets. Although this approach provides the banks with the ability to manage fluctuations in the exchange rate, it may lead to financial distortions. Cook, Yetman (2012) find that because central banks frequently sterilize their foreign exchange reserves on the asset side with bill issuance on the liability side, they reduce bank lending and investment. Although the foreign asset purchases themselves do not disrupt domestic financial markets, the corresponding issuance of central bank bills can crowd out holdings of other securities. Thus, how the assets are funded by the central bank can matter as much as the assets themselves.

2.2.2 Liquidity in operating frameworks

Central banks have also maintained a liquidity objective in the composition of the balance sheet. Euro area companies rely more on loans than bonds for funding, so the ECB has generally focused on lending facilities—the first phase of its response to the crisis was dominated by long-term refinancing operations (LTROs) rather than outright asset purchases. The BOJ, however, considers holding liquid securities essential to crisis remediation; in late 2015, the secondary market for Japanese Treasury bills shrank significantly as the BOJ added bills to its portfolio, moving liquid securities from the private market to the central bank's arsenal in case of a crisis, as well as further depressing interest rates. As a result of the BOJ's emphasis on a liquid portfolio, concerns about market functioning arose.

The drive of Asian central banks to accumulate foreign exchange reserves is due to the desire to provide liquidity in foreign currency to the market in times of crisis. Indeed, Cook, Yetman (2012) have documented findings that central banks with substantial foreign exchange reserves were better able to weather financial crises and avoid exchange-rate depreciations. While this is a clear benefit, this strategy carries costs particularly in terms of market neutrality and economic impact; the accumulation of reserves provides some safety but also could reduce economic growth.

2.3 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, 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.[11] 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, 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 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

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

premium. Early literature used the 1960's "Operation Twist" as a motivating episode; in particular, Modigliani, 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. Empirical studies such as Li, Wei (2012) illustrate that private supply does influence yields, and Laubach, 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, 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, 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.

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, 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 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) as well as the yields in Gurkaynak et al. (2007) and Federal Reserve holdings data are from the Federal Reserve Bank of New York.

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

$$s_{it} = \frac{x_{it}}{\sum_i x_{it}} \tag{1}$$

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

$$g_{it} = \frac{y_{it}}{\sum_i y_{it}} \tag{2}$$

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 $\sum_i g_{it} = 1$.

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

$$N_t = 1 - \left(\sum_i \sqrt{s_{it} g_{it}} \right). \tag{3}$$

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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.[13]

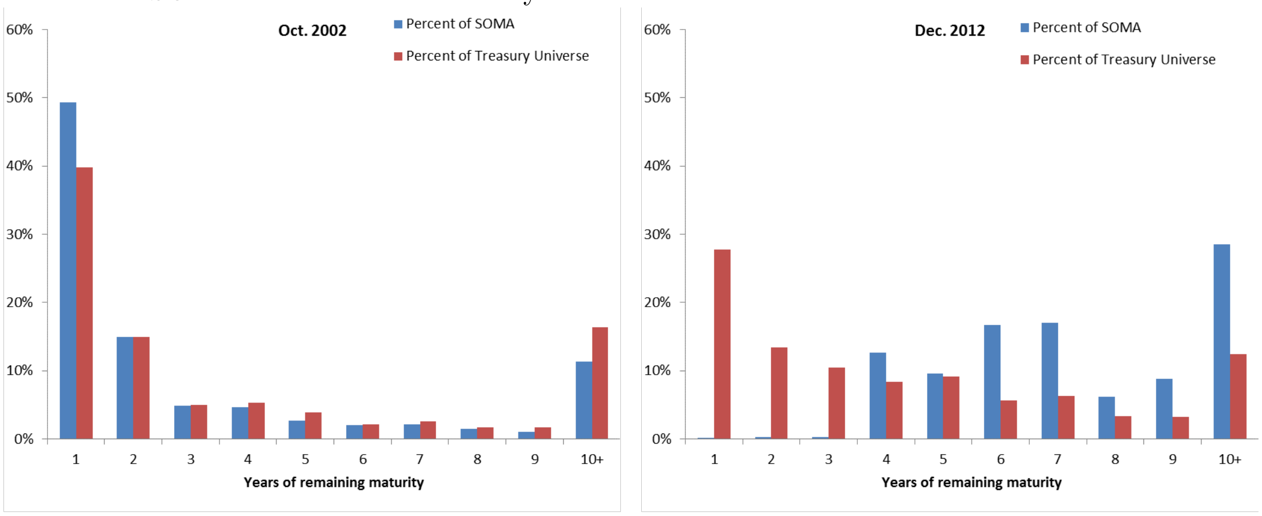
In figure 1, we compare neutrality portfolio targets with the actual Federal Reserve holdings at the maximum and minimum points in the neutrality metric between 1985 and 2014. [14] As shown in the left hand panel of Figure 1, the portfolio was closest to neutral in October 2002, which occurred when the 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

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

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

[14]We calculate this measure for all t=1,...,T, where our sample is monthly data from 1985:Q4 to 2014:Q4.

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



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.[15] 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 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.[16]

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. [17] 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

[15]Refer to https://www.federalreserve.gov/monetarypolicy/maturityextensionprogram.htm.
[16]Refer to Fleming (2003), and Amihud, Mendelson (1991).
[17]Refer to Nikolaou (2009).

time, and particularly during crises, a portfolio composed of Treasury bills may be ideal.[18]

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.

Against this backdrop, we define a liquid portfolio as one in which the share of a given Treasury security holding is inversely related to the exponent of its maturity in years, $M(x_{it})$. 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:

$$l_{it} = \frac{x_{it}e^{-M(x_{it})}}{\sum\limits_{i} x_{it}e^{-M(x_{it})}} \tag{4}$$

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,

$$h_{it} = \frac{y_{it}e^{-M(y_{it})}}{\sum_i y_{it}e^{-M(y_{it})}} \tag{5}$$

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,

$$Q_t = 1 - \left(\sum_i \sqrt{l_{it}h_{it}} \right). \tag{6}$$

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. Over the entire sample (1985:Q4 – 2014:Q4), the average value of the metric is 0.55, with the pre-crisis liquidity fluctuating little around an average value of 0.50 and then the metric increasing with quantitative easing measures since 2008. At the end of the sample, the liquidity metric is about 0.80, reflecting the large share of longer-dated securities in the portfolio resulting from the various large-scale asset purchase programs.

[18]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.

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.

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

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.[19] Simply defined, duration is the time-weighted average of discounted cash flows.[20] Another formulation, however, illustrates that duration reflects the sensitivity of bond prices to interest rates.[21] 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.

[19]Refer to Bernanke (2012).
[20]This formulation is known as Macaulay duration.
[21]This formulation is known as modified duration.

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-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

$$u_{it} = \frac{t(x_{it})}{\sum\limits_i t(x_{it})} \tag{7}$$

$$p_{it} = \frac{t(y_{it})}{\sum\limits_i t(y_{it})} \tag{8}$$

as well as

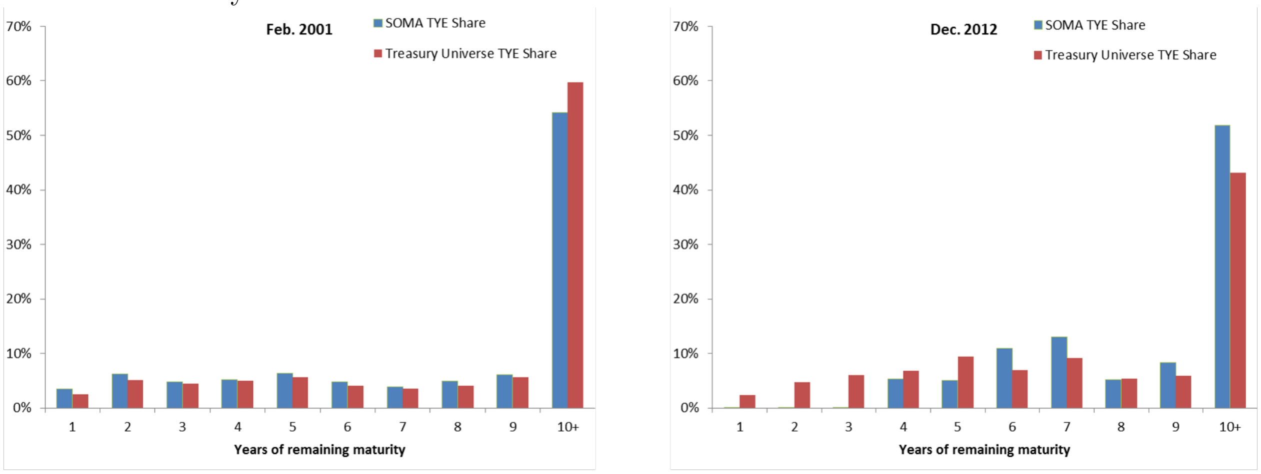
$$D_t = 1 - \left(\sum_i \sqrt{u_{it} p_{it}} \right) \tag{9}$$

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 2014. As above, we calculate this measure for all t=1,...,T, where our sample is monthly data from 1985:Q4 to 2014:Q4. As shown in figure 3, 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.

Importantly, all three 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 **?** rather than the aggregate "duration" channel or "signaling" channel, as discussed in Krishnamurthy, Vissing-Jorgensen (2011), although the weighting in the D_t metric does shed some light on the duration channel.

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



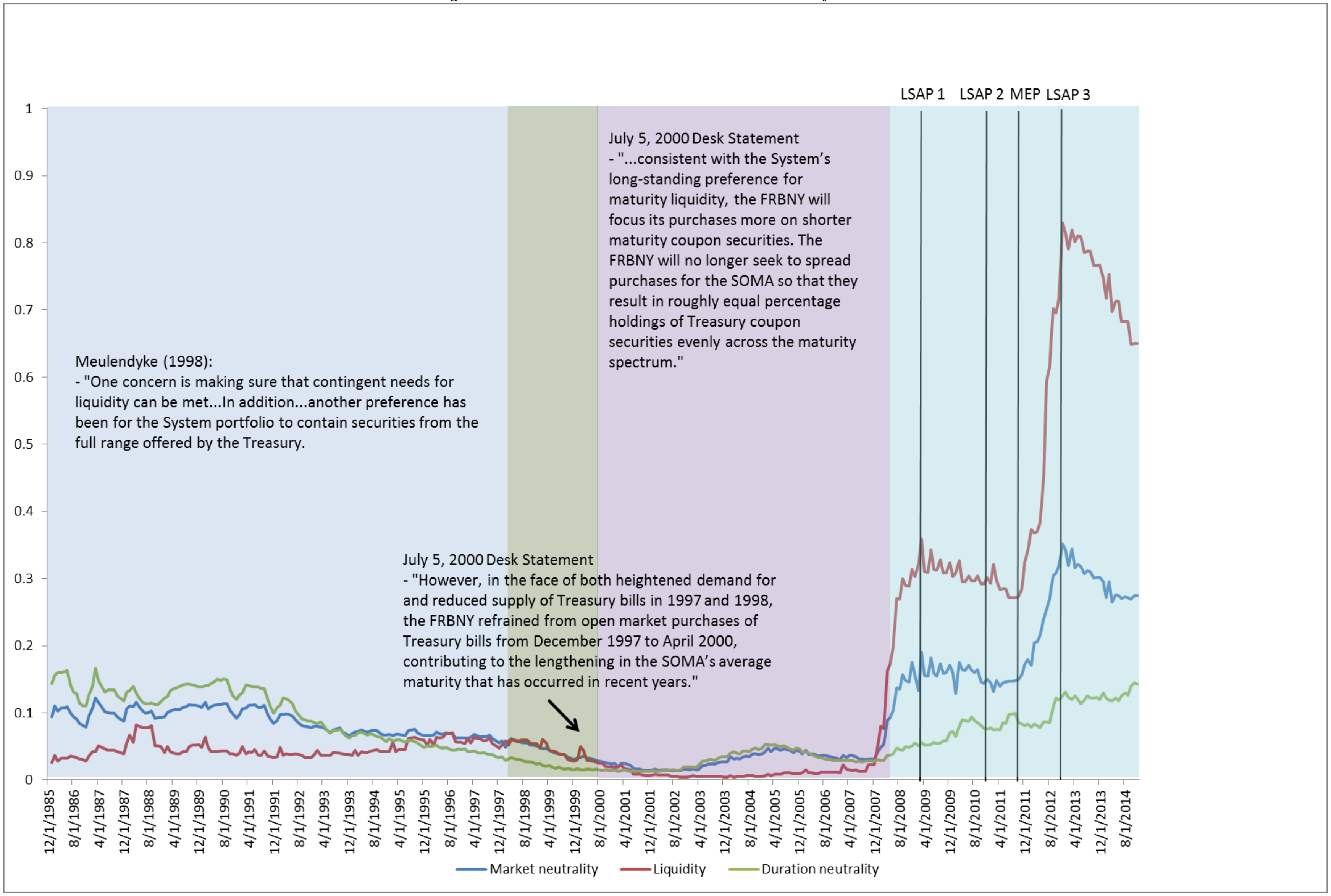
3.4 Metrics over time

We now look at 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, shown in green in figure 4, 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.[22] 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

[22] Refer to Federal Reserve Bank of New York (2000).

Figure 4: Evolution of Metrics and Policy Goals



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 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

We now use our metrics to examine 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.[23] 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.[24]

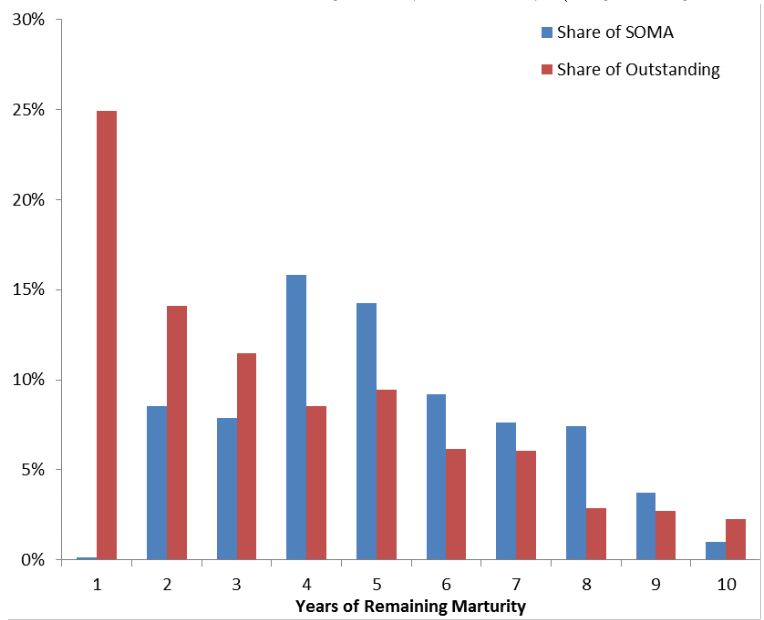
From the previous analysis we know that the current SOMA portfolio is very different from its historical norm in terms of the neutral and liquidity metrics developed herein. Concretely, figure 5 illustrates where the portfolio is today (blue bars) compared with the hypothetical target portfolio based on for market neutrality (red bars) and liquidity (green line) by maturity bucket, as of 2015:Q1. As shown by the blue bars, the SOMA portfolio has very few securities with remaining

[23] The assumed evolution of the portfolio from 2015:Q1 to 2015:Q4 is identical to the actual.

[24] Refer to https://www.newyorkfed.org/medialibrary/media/markets/omo/omo2014-pdf.pdf.

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 10 year maturity range compared with both measures.

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



Communication from Federal Reserve officials, such as the initial exit strategy principles articulated in June 2011 as well as the Policy Normalization Principles and Plans released in September 2014, have suggested that redemptions of maturing securities would be a first step in normalizing the size of the portfolio.[25] For our analysis, we take SOMA holdings as of 2014:Q4 and simulate the securities rolling off the portfolio as they mature. This decline in the portfolio is then characterized as continuing until 2021:Q3, when SOMA holdings must increase to support currency and other liability and capital growth. 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 (the gray shaded region). As the Treasury is issuing securities over this period but

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

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 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 6: Market and Liquidity Measures

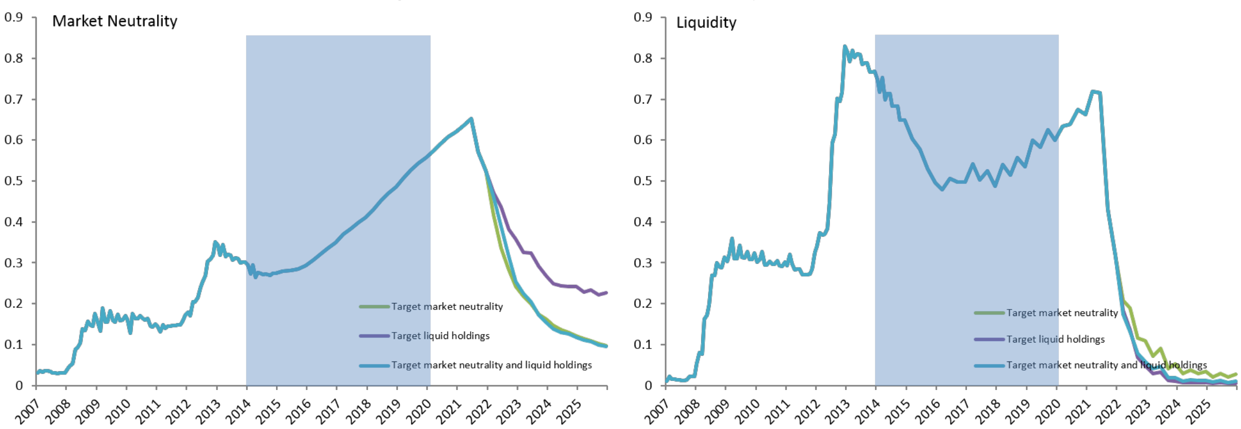


Figure 7 depicts SOMA holdings at the end of the projection for the equally weighted purchase path. Not surprisingly, actual SOMA holdings lie between the neutral target and the liquid target.

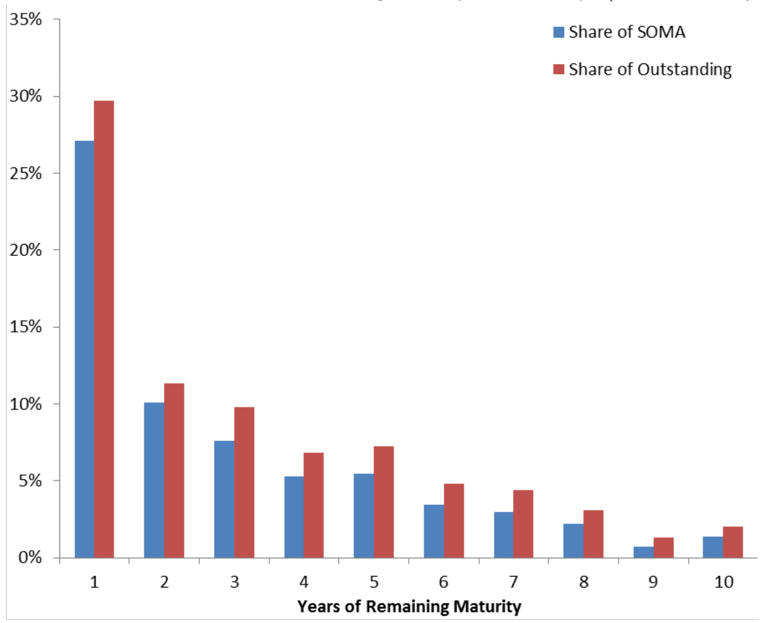
5 Empirical results: Aggregate

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, 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, Sutch (1966), who

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



investigated the existence of supply effects in the Treasury market within the context of the Operation Twist portfolio policy of the 1960s. More modern approaches to this question include Swanson (2011) and Kuttner (2006). These two papers use different methodologies. Swanson (2011) uses an event study framework to show that shifts in the Federal Reserve's portfolio during Operation Twist had effects on Treasury yields. His framework relies on high-frequency data, identifying movements in yields around annoucements. In contrast, Kuttner evaluates a pricing equation in the spirit of Cochrane, 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, he uses the share of SOMA holdings with greater than five years remaining maturity as an explanatory variable in the regression. Our approach is most similar to that of Kuttner. That said, 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, not just the share of longer-dated securities held in SOMA. Moreover, our econometric approach controls for the possible endogeneity of this measure, which is discussed at length below.

Following the notation in Cochrane, Piazzesi (2005), we can define:

- $p_t^{(n)}$: – log price of n-year discount bond at time t
- $y_t^{(n)} = -\frac{1}{n} p_t^{(n)}$ – log yield
- $f_t^{(n)} = p_t^{(n-1)} - p_t^{(n)}$ – forward rate
- $r_{t+1}^{(n)} = p_{t+1}^{(n-1)} - p_t^{n}$ – log holding period return, and
- $rx_{t+1}^{(n)} = r_{t+1}^{(n)} - y_t^{(1)}$ – excess log holding period return

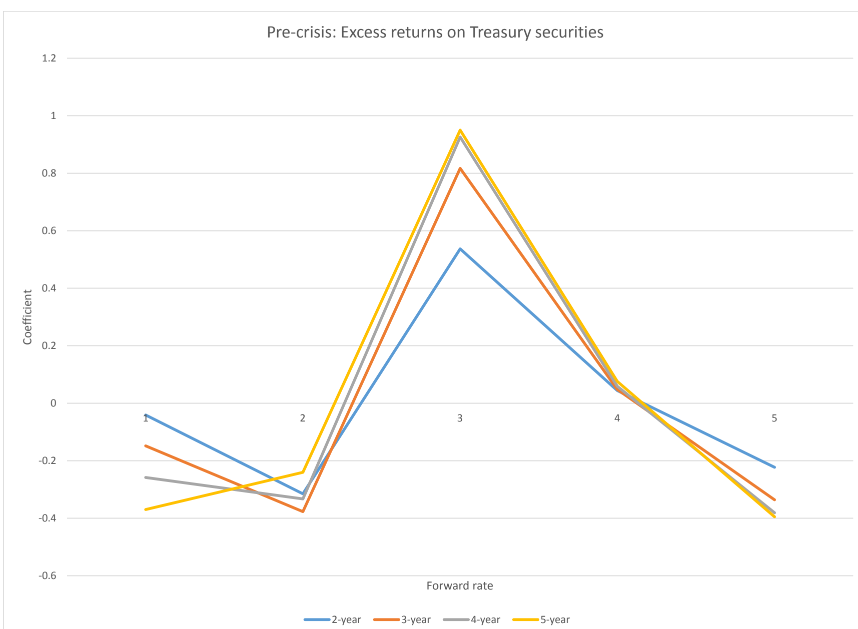
The question is whether the excess return on Treasury securities is affected by SOMA holdings. To start, we construct the Cochrane-Piazzesi forward factors; their paper and subsequent literature expects that these factors can explain a large share of the variation in excess returns. Specifically, we evaluate the following specification:

$$rx_{t+1}^{(n)} = \gamma_0 + \gamma_1 y_t^{(1)} + \gamma_2 f_t^{(2)} + \cdots + \gamma_5 f_t^{(5)} + \epsilon_{(t+1)} \tag{10}$$

for excess log holding period returns for securities with $n = 2, ..., 5$ years remaining maturity. The independent variables and their associated coefficients $\gamma_i f_t^{(i)}$ are the one-year log forward rate i years hence. All calculations use Gurkaynak et al. (2007) yields for the excess log holding period returns and Fama-Bliss yields for the forward factors included in the monthly CRSP dataset. As discussed in Cochrane, Piazzesi (2008), calculating the forward factors using the smoothed yields in Gurkaynak et al. (2007) can lead to biased coefficients and problems of multicollinearity, and so we use the Fama-Bliss yields. The data are at a monthly frequency and the sample period is from December 1985 to December 2014.

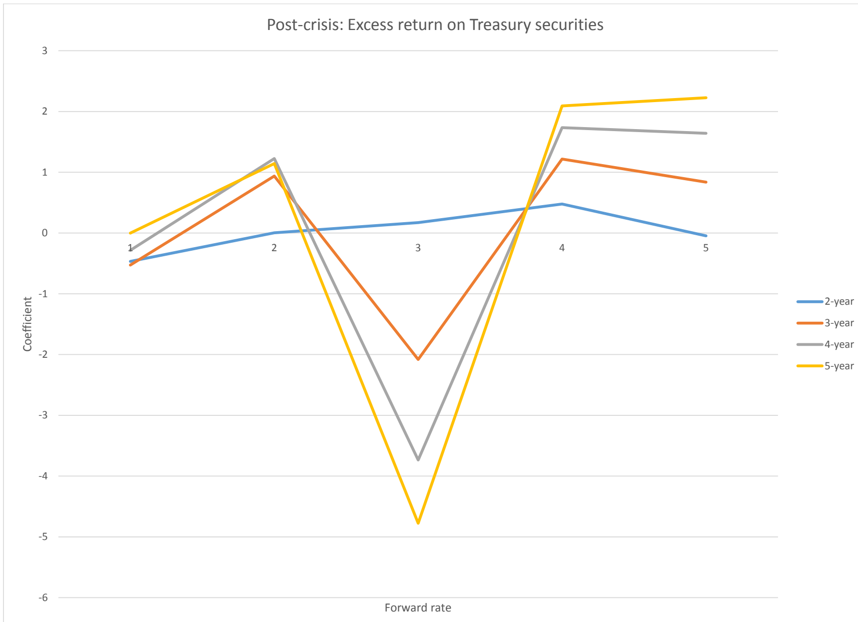
Our results are depicted graphically in figures 8 and 9. Pre-crisis, the estimated coefficients on the forward factors follow the familiar "tent" shape, as in Cochrane, Piazzesi (2005). In fact, across maturities, the pattern is very similar, so one can use an average of the excess returns as the dependent variable when calculating the effect of the five forward factors.

Figure 8: Forward factors: pre-crisis



The overall pattern post-crisis is notably different. Specifically, instead of a "tent," the coefficients reflect more of a "valley." That said, it is still the case that the estimated coefficients follow a similar pattern across maturities. As such, it is still possible to use the average of the excess log holding period returns as the dependent variable.

Figure 9: Forward factors: post-crisis



To that end, we evaluate the following specification for average excess log holding period returns:

$$\frac{1}{4}\sum_{n=2}^{5} rx_{t+1}^{(n)} = \gamma_0 + \gamma_1 y_t^{(1)} + \gamma_2 f_t^{(2)} + \cdots + \gamma_5 f_t^{(5)} + \overline{\epsilon_{(t+1)}} \tag{11}$$

where $\frac{1}{4}\sum_{n=2}^{5} rx_{t+1}^{(n)}$ is the average excess log return across remaining maturities from two to five years, and $\gamma_i f_t^{(i)}$ is the one-year log forward rate i years hence. We evaluate this specification using three different time periods: full sample, pre-crisis, and post-crisis. To determine the post-crisis sample, we use a Bai-Perron series break test on the market neutrality measure; this test indicates a break in the sample at June 2008. Results using the average excess return in the break test are similar.

Table 1 reports the coefficients and the standard errors from the forward factor regression. The three columns report results for the full sample, pre-crisis sample, and post-crisis sample. The pre-crisis forward factors fit the expected "tent" pattern evident in Cochrane and Piazzesi. The post-crisis forward factors are inverted relative to the pre-crisis ones, and the pattern is a little less smooth. However, similar to the pre-crisis ones, the coefficients on the forward factors follow the same general pattern for each tenor. The difference in the patterns across subsamples leaves an imprint on the pattern for the full sample; again, the shape is similar across tenors. While the pattern is different than in pre-crisis, as illustrated by the chi-squared statistics in the table, in all cases one can reject the null that the sum of the coefficients are zero, suggesting that the forward factors have the ability to predict excess returns. In addition to the statistical significance of the factors, a surprising amount of the variation in the excess log returns can be explained by the forward factors. Specifically, the pre-crisis adjusted R-squared is about 27 percent, a little less than that found in Cochrane and Piazzesi. In contrast, the post-crisis adjusted R-squared is almost 90 percent, a remarkably high share. The pattern of the influence suggests a fundamental change in the yield curve over the financial crisis; part of the purpose of this paper is to explore whether the composition of the SOMA portfolio is at least partly responsible.

Table 1: Cochrane-Piazzesi forward factor coefficients: Dependent variable: average excess log holding period return

	γ_0	γ_1	γ_2	γ_3	γ_4	γ_5	R-squared	Chi-squared
Full								
OLS estimates	-1.425	0.198	-1.589	0.039	2.215**	-0.465	0.185	
Standard	(0.585)	(0.364)	(0.721)	-0.753	(0.49)	(0.389)		77.75
NW, 11 lags	(1.33)	(0.931)	(1.396)	(1.486)	(0.88)	(0.776)		592.4
Pre-crisis								
OLS estimates	-2.757	-0.583	-1.07	2.365	1.655	-1.817	0.275	
Standard	(0.756)	(0.425)	(0.818)	(0.947)	(0.665)	(0.518)		100.15
NW, 11 lags	(1.838)	(0.988)	(1.471)	(1.929)	(1.00)	(0.924)		592.4
Post-crisis								
OLS estimates	-2.073**	-0.384	2.050**	-2.307**	1.314**	0.959**	0.9	
Standard	(0.237)	(0.218)	(0.483)	(0.438)	(0.174)	(0.18)		566.05
NW, 11 lags	(0.341)	(0.226)	(0.575)	(0.415)	(0.198)	(0.223)		950.8

Note: **indicates significant at 5 percent confidence level with respect to NW standard errors.

The next step is to use the forward factors to explore their effect on the excess log return as well as that of the SOMA portfolio. To that end, we evaluate

$$rx_{t+1}^{(n)} = \alpha_0^{(n)} + \beta_1^{(n)} N_t + \beta_2^{(n)} \gamma' \mathbf{f_t} + \beta_3^{(n)} V_t + \beta_4^{(n)} S_t + \beta_5^{(n)} C_t + \epsilon_{t+1}^{(n)}, n = 2, ..., 10 \tag{12}$$

where N_t is our neutrality measure and $\gamma' \mathbf{f_t}$ are the Cochrane and Piazzesi forward factors. In addition, we add the first three principal components calculated on the Fama-Bliss yields of the respective sample to construct the level, V_t, slope, S_t, and curvature, C_t terms. [26] These measures can help to control for time-specific effects that may indicate the overall state of the economy, or at least the reflection of that state in the yield curve.

Unlike Cochrane, Piazzesi (2008), we do not orthogonalize the principal components with respect to the forecasting factors; as a result, there may be some collinearity between those terms. As Cochrane, Piazzesi (2008) and Swanson (2007) explain, the forward recursive expectation of the

[26] The yields used to calculate the principal components are the 2, 3, 5, 7, 10 and 30 year maturities.

dependent variable in these regressions 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. Using the Gurkaynak et al. (2007) yields allows us to evaulate a larger portion of the term structure; analysis in Cochrane, Piazzesi (2008) and Sack (2006) suggest the results are similar to those using the Fama-Bliss yields. 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.[27]

We take a few steps to control for the possibility of the endogeneity of our metric. 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, Zhu (2012) and D'Amico, 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. More broadly, the approach assumes that the Treasury has target for the overall maturity of marketable debt outstanding, including debt held both by the Federal Reserve and by private investors. Any changes to the Federal Reserve's portfolio should affect private sector portfolios, holding the overall distribution of Treasury marketable debt constant.

To control for possible endogeneity, we use an instrumental variables approach. For our instruments, and similar to Greenwood, Vayanos (2014), we first use three lags of the neutrality metric, reflecting that the portfolio is a "stock" variable and has some state-dependence. Moreover, and by construction, lagged levels of the neutrality metric will not be correlated with the current period error term. (This period's term premium has no effect on last period's portfolio composition.) In addition, we use the number of CUSIPs as an instrument. As discussed in section 3, the neutrality measure depends in part on the number of CUSIPs. Importantly, it is likely that the number of CUSIPs is independent of unobserved factors affecting the term premium. And finally, as in Krishnamurthy, Vissing-Jorgensen (2011) and Greenwood, Vayanos (2014), we use the ratio of total Treasury debt outstanding to nominal GDP as an instrument. 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

[27] Evaluating with 18 lags as in Cochrane, Piazzesi (2005) does not affect the statistical significance of the results.

variable.

We use a two-stage least squares estimation procedure. 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 table 2 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.

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 overidentifying 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.

Table 2 presents the results. As in the previous table, we present results for the full sample, as well as for the pre-crisis and post-crisis subsample. We find that the distance of the SOMA portfolio from the Treasury's portfolio significantly affects the excess log holding period return on Treasury securities of different tenors, and most notably, for the excess log holding period returns in the middle of the yield curve. This result is evident from the coefficients on the market neutrality terms, which are illustrated in figure 10. The coefficients are negative, suggesting that the distance of the SOMA portfolio from Treasury's portfolio was in a such a way so as to generate a negative effect on the term premium. Indeed, particularly post-crisis, Federal Reserve actions were intended to put downward pressure on longer-term rates, consistent with a negative term premium. The coefficients suggest that for every 1 percentage point increase in the distance between the SOMA portfolio and the Treasury portfolio, the excess log holding period return at the 10 year remaining maturity point falls by 1 percentage point pre-crisis and 20 basis points post-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). The standard deviation of this metric was 3 percentage points pre-crisis and 7 percentage points post-crisis, which translates into *roughly* a 3 percentage point move in the excess log holding period return pre-crisis and a 1.3 percentage point move post-crisis. Although these seem like large yield effects, they are roughly in line with those found in other works, including Meaning, Zhu (2012), who use an error correction model to form their estimates.

Turning to the other control variables in the specification, as in Cochrane, Piazzesi (2005) and Cochrane, Piazzesi (2008), the common factor continues to be a statistically significant predictor of the term premium in the pre- and post-crisis subsamples, also supporting the conclusion that the expectations hypothesis is not satisfied and forward rates can predict the term premium. The effect of the factor on the excess log holding period return increases with the tenor of the return. The level and slope principal components are not statistically significant at most tenors, although the curvature principal component is more frequently so. Perhaps some of the explanation of the lack of statistical significance for the level term is its collinearity with the Cochrane-Piazzesi factor; indeed, the correlation ranges from -0.77 to -0.96, depending on the sample period.

Table 2: Excess log holding period returns and SOMA market neutrality

	2			3			4			5		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
N_t	-0.009	-0.368**	0.005**	-0.016	-0.720**	-0.018**	-0.025	-1.007**	-0.074**	-0.035	-1.248**	-0.143**
	(0.03)	(0.11)	(0.00)	(0.05)	(0.20)	(0.01)	(0.07)	(0.27)	(0.01)	(0.08)	(0.34)	(0.01)
Level	0	0.011*	-0.002**	0.001	0.019	-0.001**	0.001	0.022	0.001	0.002	0.023	0.004**
	(0.00)	(0.01)	0.00	(0.00)	(0.01)	0.00	(0.00)	(0.01)	(0.00)	(0.00)	(0.02)	(0.00)
Slope	0.01	0.014	0	0.009	0.018	0.001	0	0.014	0.003	-0.015	0.005	0.005
	(0.01)	(0.01)	0.00	(0.02)	(0.02)	(0.00)	(0.03)	(0.03)	(0.00)	(0.04)	(0.04)	(0.00)
Curvature	0.007	-0.127**	0.006**	0.007	-0.211**	0.010**	-0.01	-0.259**	0.007	-0.042	-0.285**	-0.008
	(0.04)	(0.03)	(0.00)	(0.08)	(0.06)	(0.00)	(0.10)	(0.08)	(0.00)	(0.13)	(0.10)	(0.01)
Factor	0.45	0.756**	0.113**	0.734	1.289**	0.581**	0.858	1.609**	1.267**	0.863	1.786*	2.063**
	(0.24)	(0.19)	(0.02)	(0.42)	(0.39)	(0.08)	(0.55)	(0.57)	(0.16)	(0.66)	(0.73)	(0.25)
Constant	0.404	-2.121**	-0.199**	0.661	-3.608**	-1.033**	0.777	-4.497**	-2.252**	0.787	-4.981*	-3.670**
	(0.21)	(0.54)	(0.04)	(0.37)	(1.11)	(0.15)	(0.49)	(1.62)	(0.30)	(0.58)	(2.08)	(0.45)
Observations	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	1.23	4.2	1.49	0.71	4.58	0	0.35	4.63	0.09	0.1	4.56	0
p_{endog}	0.27	0.04	0.23	0.4	0.03	0.98	0.56	0.03	0.77	0.75	0.03	0.97
$F_{firststage}$	1581.72	879.28	247.66	1581.72	879.28	247.66	1581.72	879.28	247.66	1581.72	879.28	247.66
$p_{firststage}$	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	1.11	5.7	2.51	0.98	6.5	1.29	0.84	6.84	0.68	0.7	6.76	0.8
p_{overid}	0.77	0.13	0.47	0.81	0.09	0.73	0.84	0.08	0.88	0.87	0.08	0.85

	6			7			8			9			10		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
N_t	-0.063	-1.471**	-0.206**	-0.058	-1.382**	-0.216**	-0.05	-1.305**	-0.212**	-0.042	-1.236**	-0.200**	-0.034	-1.174**	-0.182**
	(0.09)	(0.39)	(0.02)	(0.08)	(0.37)	(0.03)	(0.08)	(0.35)	(0.03)	(0.07)	(0.33)	(0.04)	(0.07)	(0.32)	(0.05)
Level	0.012**	0.029	0.012**	0.012**	0.024	0.013**	0.012**	0.019	0.014**	0.012**	0.015	0.015**	0.012**	0.011	0.015**
	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)
Slope	-0.018	0.002	0.011*	-0.033	-0.013	0.011	-0.045	-0.025	0.011	-0.053	-0.034	0.01	-0.06	-0.042	0.01
	(0.05)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.04)	(0.01)
Curvature	-0.063	-0.275*	-0.026**	-0.081	-0.222	-0.045**	-0.095	-0.179	-0.061**	-0.104	-0.144	-0.074**	-0.108	-0.115	-0.083**
	(0.15)	(0.12)	(0.01)	(0.15)	(0.12)	(0.01)	(0.14)	(0.11)	(0.02)	(0.14)	(0.11)	(0.02)	(0.13)	(0.10)	(0.02)
Factor	0.787	1.824*	2.940**	0.549	1.507	3.152**	0.36	1.238	3.284**	0.214	1.009	3.360**	0.107	0.815	3.403**
	(0.75)	(0.88)	(0.33)	(0.71)	(0.85)	(0.33)	(0.68)	(0.83)	(0.34)	(0.66)	(0.81)	(0.35)	(0.65)	(0.80)	(0.37)
Constant	0.677	-5.131*	-5.256**	0.467	-4.235	-5.639**	0.298	-3.475	-5.877**	0.168	-2.829	-6.019**	0.072	-2.281	-6.102**
	(0.66)	(2.50)	(0.59)	(0.62)	(2.42)	(0.61)	(0.60)	(2.36)	(0.61)	(0.58)	(2.31)	(0.63)	(0.57)	(2.27)	(0.66)
Observations	333	266	67	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	0	4.31	0.24	0.1	4.19	1.4	0.41	4.06	3.65	0.9	3.94	6.67	1.53	3.83	9.93
p_{endog}	1	0.04	0.63	0.75	0.04	0.24	0.52	0.04	0.06	0.34	0.05	0.01	0.22	0.05	0
$F_{firststage}$	1581.72	879.28	247.66	1581.72	879.28	247.66	1581.72	879.28	247.66	1581.72	879.28	247.66	1581.72	879.28	247.66
$p_{firststage}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	0.54	6.1	1.34	0.38	5.49	2.05	0.41	4.96	1.55	0.8	4.52	1.03	1.44	4.13	0.79
p_{overid}	0.91	0.11	0.72	0.94	0.14	0.56	0.94	0.17	0.67	0.85	0.21	0.79	0.7	0.25	0.85

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Neutrality is instrumented with three lags of itself, marketable debt over GDP, and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

Figure 10:

Our next exercise uses a similar specification to evaluate the effect of our liquidity metric on the term premium. As shown in table 3, the distance of the SOMA portfolio from its liquidity goal also appears to affect the term premium. At the same time, the magnitude of the effect is smaller than that for portfolio neutrality (roughly 1/3 that of the market neutrality metric), and less significant overall, save in the post-crisis period. Of course, there may be other implications of portfolio liquidity that are more important. In particular, one goal of the liquidity portfolio was the ability to sell securities quickly to offset any unanticipated expansion of the Federal Reserve's balance sheet, such as through discount window borrowings. Perhaps consistent with the purpose of the liquidity of the portfolio, the regressor Q_t does not appear to be endogenously determined with the term premium in the pre-crisis period. The Cochrane and Piazzesi factor continues to be significant in this specification with coefficients close to those seen in table 2, suggesting little correlation of the factor with the portfolio distance measures studied here.

Table 3: Excess log holding period returns and SOMA market liquidity

	2			3			4			5		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
Q_t	0.003	-0.121	0.002**	0.007	-0.231	-0.006**	0.007	-0.31	-0.024**	0.007	-0.364	-0.045**
	(0.01)	(0.12)	0.00	(0.02)	(0.23)	0.00	(0.03)	(0.33)	0.00	(0.03)	(0.40)	0.00
Level	0	0.014**	-0.002**	0	0.024*	-0.001**	0	0.03	0.001	0.001	0.032	0.004**
	0.00	(0.01)	0.00	0.00	(0.01)	0.00	0.00	(0.02)	0.00	0.00	(0.02)	0.00
Slope	0.007	0.024	0.001	0.004	0.036	0.001	-0.007	0.039	0.003	-0.023	0.035	0.004
	(0.01)	(0.01)	0.00	(0.02)	(0.03)	0.00	(0.03)	(0.04)	0.00	(0.04)	(0.05)	0.00
Curvature	0.002	-0.074	0.006**	-0.002	-0.106	0.010**	-0.022	-0.113	0.004	-0.057	-0.104	-0.013
	(0.04)	(0.04)	0.00	(0.07)	(0.08)	0.00	(0.10)	(0.11)	0.00	(0.13)	(0.14)	(0.01)
Factor	0.403	0.725**	0.113**	0.647	1.224*	0.580**	0.739	1.512**	1.265**	0.717	1.655	2.061**
	(0.23)	(0.26)	(0.02)	(0.41)	(0.51)	(0.08)	(0.54)	(0.73)	(0.16)	(0.65)	(0.93)	(0.24)
Constant	0.362	-2.050**	-0.198**	0.582	-3.461**	-1.032**	0.669	-4.273**	-2.254**	0.655	-4.674	-3.676**
	(0.20)	(0.73)	(0.04)	(0.36)	(1.46)	(0.15)	(0.48)	(2.09)	(0.29)	(0.58)	(2.64)	(0.43)
Observations	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	0.44	0.93	0.13	0.32	1.11	1.1	0.17	1.17	0.05	0.04	1.15	0.42
p_{endog}	0.51	0.33	0.71	0.57	0.29	0.3	0.68	0.28	0.83	0.83	0.28	0.52
$F_{firststage}$	3698.93	313.17	2661.77	3698.93	313.17	2661.77	3698.93	313.17	2661.77	3698.93	313.17	2661.77
$p_{firststage}$	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	3.11	4.1	3.41	3.16	6.1	1.58	2.88	7.56	1.46	2.6	8.32	1.22
p_{overid}	0.54	0.39	0.49	0.53	0.19	0.81	0.58	0.11	0.83	0.63	0.08	0.88

	6			7			8			9			10		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
Q_t	-0.001	-0.401	-0.065**	0	-0.353	-0.068**	0.003	-0.309	-0.066**	0.006	-0.27	-0.062**	0.009	-0.234	-0.056**
	(0.04)	(0.46)	(0.01)	(0.04)	(0.42)	(0.01)	(0.03)	(0.39)	(0.01)	(0.03)	(0.36)	(0.01)	(0.03)	(0.34)	(0.02)
Level	0.011**	0.04	0.011**	0.011**	0.033	0.013**	0.011**	0.028	0.014**	0.011**	0.023	0.014**	0.010**	0.019	0.015**
	0.00	(0.03)	0.00	0.00	(0.02)	0.00	0.00	(0.02)	0.00	0.00	(0.02)	0.00	0.00	(0.02)	0.00
Slope	-0.027	0.037	0.01	-0.042	0.02	0.01	-0.053	0.005	0.01	-0.062	-0.006	0.009	-0.068	-0.016	0.009
	(0.05)	(0.06)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)
Curvature	-0.079	-0.061	-0.033**	-0.097	-0.021	-0.052**	-0.111	0.011	-0.068**	-0.119	0.036	-0.080**	-0.124	0.056	-0.089**
	(0.15)	(0.16)	(0.01)	(0.15)	(0.15)	(0.02)	(0.14)	(0.14)	(0.02)	(0.14)	(0.13)	(0.02)	(0.13)	(0.12)	(0.02)
Factor	0.601	1.656	2.939**	0.373	1.337	3.153**	0.192	1.065	3.286**	0.053	0.833	3.365**	-0.048	0.636	3.410**
	(0.76)	(1.10)	(0.32)	(0.72)	(1.05)	(0.33)	(0.69)	(1.01)	(0.34)	(0.68)	(0.98)	(0.35)	(0.67)	(0.95)	(0.37)
Constant	0.508	-4.731	-5.268**	0.306	-3.825	-5.655**	0.145	-3.054	-5.897**	0.022	-2.398	-6.042**	-0.069	-1.839	-6.126**
	(0.67)	(3.14)	(0.58)	(0.63)	(3.00)	(0.59)	(0.61)	(2.88)	(0.61)	(0.60)	(2.79)	(0.64)	(0.59)	(2.71)	(0.67)
Observations	333	266	67	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	0	1.03	1.99	0.07	0.92	4.53	0.23	0.81	7.69	0.44	0.69	11.03	0.69	0.59	14.14
p_{endog}	0.96	0.31	0.16	0.79	0.34	0.04	0.63	0.37	0.01	0.51	0.41	0	0.41	0.44	0
$F_{firststage}$	3698.93	313.17	2661.77	3698.93	313.17	2661.77	3698.93	313.17	2661.77	3698.93	313.17	2661.77	3698.93	313.17	2661.77
$p_{firststage}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	2.71	8.49	0.82	3.04	8.41	0.85	3.46	8.14	0.81	3.79	7.8	1.08	3.98	7.44	0.81
p_{overid}	0.61	0.08	0.94	0.55	0.08	0.93	0.48	0.09	0.94	0.44	0.1	0.9	0.41	0.11	0.94

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.
Liquidity is instrumented with three lags of itself and the number of CUSIPS.
The instrument set passes first-stage instrument tests.

Our third exercise explores the effect of duration absorption on the term premium. As reported in table 4, the pattern of results is similar to that of market neutrality, with slightly smaller coefficients for the pre-crisis sample, and larger ones for the post-crisis sample. All told, the coefficients at the 10-year maturity point suggest that for a 1 percentage point increase in the duration measure, the term premium drops roughly 30 basis points. This result suggests some increased sensitivity to the relative amount of risk absorbed by the SOMA portfolio. The p-values from the Wooldridge endogeneity test suggest some endogeneity of the duration measure so an instrumental variables approach is necessary; first-stage results, not shown, suggest the instruments are sufficient for controlling for this endogeneity.

Table 4: Excess log holding period returns and duration neutrality

	2			3			4			5		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
D_t	-0.06	-0.210**	0.019**	-0.114	-0.410**	-0.026	-0.161	-0.580**	-0.148**	-0.202	-0.732**	-0.295**
	(0.05)	(0.06)	(0.01)	(0.08)	(0.10)	(0.03)	(0.11)	(0.13)	(0.07)	(0.13)	(0.15)	(0.11)
Level	0	0.011*	-0.002**	0	0.019	-0.001**	0.001	0.022	0.002**	0.001	0.023	0.007**
	(0.00)	(0.01)	0.00	(0.00)	(0.01)	0.00	(0.00)	(0.01)	(0.00)	(0.00)	(0.02)	(0.00)
Slope	0.013	0.012	0	0.015	0.014	0.002	0.007	0.008	0.004**	-0.006	-0.004	0.008**
	(0.01)	(0.01)	0.00	(0.02)	(0.02)	(0.00)	(0.03)	(0.03)	(0.00)	(0.04)	(0.04)	(0.00)
Curvature	0.006	-0.139**	0.006**	0.006	-0.233**	0.009**	-0.012	-0.292**	0.001	-0.046	-0.330**	-0.019
	(0.04)	(0.03)	(0.00)	(0.07)	(0.05)	(0.00)	(0.10)	(0.08)	(0.01)	(0.13)	(0.09)	(0.01)
Factor	0.567**	0.714**	0.091**	0.961*	1.206**	0.627**	1.172**	1.496**	1.486**	1.249	1.648*	2.493**
	(0.26)	(0.22)	(0.02)	(0.44)	(0.44)	(0.05)	(0.57)	(0.65)	(0.08)	(0.67)	(0.83)	(0.15)
Constant	0.511**	-2.011**	-0.160**	0.868**	-3.392**	-1.117**	1.062**	-4.199**	-2.651**	1.138	-4.619**	-4.452**
	(0.23)	(0.62)	(0.03)	(0.39)	(1.26)	(0.08)	(0.50)	(1.84)	(0.15)	(0.59)	(2.34)	(0.27)
Observations	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	2.18	3.46	2.17	1.92	3.84	2.57	1.37	3.56	3.6	0.84	3.17	5.27
p_{endog}	0.14	0.06	0.15	0.17	0.05	0.11	0.24	0.06	0.06	0.36	0.08	0.03
$F_{firststage}$	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65
$p_{firststage}$	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	2.06	5.35	1.21	1.47	6.43	0.76	1.38	6.86	0.89	1.65	6.95	0.69
p_{overid}	0.72	0.25	0.88	0.83	0.17	0.94	0.85	0.14	0.93	0.8	0.14	0.95

	6			7			8			9			10		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
D_t	-0.272	-0.887**	-0.413**	-0.256	-0.851**	-0.423**	-0.239	-0.819**	-0.402**	-0.222	-0.791**	-0.359**	-0.207	-0.765**	-0.305**
	(0.15)	(0.17)	(0.14)	(0.14)	(0.16)	(0.15)	(0.13)	(0.16)	(0.15)	(0.13)	(0.15)	(0.15)	(0.13)	(0.15)	(0.15)
Level	0.011**	0.029	0.014**	0.011**	0.023	0.016**	0.011**	0.018	0.017**	0.011**	0.014	0.017**	0.011**	0.01	0.017**
	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)
Slope	-0.008	-0.009	0.015**	-0.024	-0.023	0.015**	-0.036	-0.035	0.015**	-0.044	-0.045	0.014*	-0.051	-0.053	0.013*
	(0.04)	(0.05)	(0.00)	(0.04)	(0.05)	(0.00)	(0.04)	(0.05)	(0.01)	(0.04)	(0.05)	(0.01)	(0.04)	(0.04)	(0.01)
Curvature	-0.072	-0.335**	-0.042**	-0.09	-0.283**	-0.061**	-0.102	-0.242*	-0.076**	-0.109	-0.208*	-0.088**	-0.111	-0.181	-0.097**
	(0.15)	(0.11)	(0.02)	(0.14)	(0.11)	(0.02)	(0.13)	(0.10)	(0.02)	(0.13)	(0.10)	(0.03)	(0.13)	(0.10)	(0.03)
Factor	1.259	1.668	3.551**	0.997	1.364	3.785**	0.788	1.107	3.894**	0.627	0.889	3.921**	0.507	0.704	3.897**
	(0.75)	(0.98)	(0.25)	(0.70)	(0.94)	(0.31)	(0.67)	(0.91)	(0.37)	(0.65)	(0.89)	(0.42)	(0.64)	(0.87)	(0.47)
Constant	1.106	-4.721	-6.368**	0.873	-3.86	-6.791**	0.687	-3.131	-6.991**	0.543	-2.513	-7.043**	0.435	-1.989	-7.006**
	(0.66)	(2.79)	(0.44)	(0.62)	(2.68)	(0.56)	(0.59)	(2.60)	(0.66)	(0.57)	(2.52)	(0.76)	(0.56)	(2.47)	(0.84)
Observations	333	266	67	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	0.47	2.67	7.47	0.21	2.41	9.89	0.07	2.18	12.12	0.01	1.98	13.73	0	1.8	14.51
p_{endog}	0.49	0.1	0.01	0.65	0.12	0	0.8	0.14	0	0.93	0.16	0	0.96	0.18	0
$F_{firststage}$	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65
$p_{firststage}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	2.17	6.71	0.53	2.88	6.62	0.54	3.68	6.45	0.51	4.47	6.18	0.43	5.18	5.82	0.36
p_{overid}	0.7	0.15	0.97	0.58	0.16	0.97	0.45	0.17	0.97	0.35	0.19	0.98	0.27	0.21	0.99

Newey-West standard errors in parentheses. ** significant at the 5 percent level.

D_t is instrumented with three lags of itself, marketable debt to GDP, and the number of CUSIPs.

The instrument set passes first-stage instrument tests.

Our final experiment investigates whether there are independent effects of the ratio of private Treasury holdings in terms of 10-year equivalents to nominal GDP. Research including Li, Wei (2012) suggests this measure is an important determinant of the term premium. We also include the duration-absorption measure, to investigate whether these two factors have separate and distinct effects on the term premium.

As suggested by table 5, the duration absorption measure continues to be statistically significant and the magnitude of the coefficients across tenors are roughly in line with the analogous ones in table 4. In the pre-crisis sample, private ten-year equivalents scaled by nominal GDP appears to have the "wrong" sign and significantly depresses the term premium. However, in the post-crisis sample, it does not appear to be statistically significant at most maturities. That said, there appears to be significant collinearity of these two measures potentially diminishing the effect of the private ten-year equivalents to GDP ratio. In the pre-crisis sample, these two measures have a statistically significant correlation coefficient of -0.18, and in the post-crisis sample, the correlation jumps up and switches sign to 0.43. Still, in results not shown, we evaluate a specifiation that includes only private ten-year equivalents over nominal GDP as a control variable and instrument this measure with three lags of itself plus the marketable debt to GDP ratio as well as the number of CUSIPs. In this specification, private ten-year equivalents to nominal GDP does not appear to significantly predict the Cochrane and Piazzesi measure of the term premium at most tenors. Of course, other specifications or structural approaches to determinants of the term premium could have different results.

Table 5: Excess log holding period returns, $\frac{privateTYEholdings}{GDP}$, and D_t

	2			3			4			5		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
D_t	-0.061	-0.219**	0.014	-0.122	-0.429**	-0.034	-0.184	-0.606**	-0.147**	-0.251	-0.764**	-0.274**
	(0.06)	(0.06)	(0.01)	(0.10)	(0.10)	(0.03)	(0.14)	(0.14)	(0.07)	(0.17)	(0.17)	(0.10)
$\frac{PrivateTYE}{GDP}$	0.005	-0.423**	0.029	0.049	-0.869**	0.044	0.145	-1.228**	-0.002	0.296	-1.507**	-0.111
	(0.19)	(0.16)	(0.02)	(0.36)	(0.31)	(0.09)	(0.50)	(0.44)	(0.20)	(0.61)	(0.56)	(0.33)
Level	0	0.007	-0.002**	0.001	0.009	-0.001**	0.002	0.009	0.002**	0.003	0.007	0.006**
	(0.00)	(0.01)	0.00	(0.00)	(0.01)	0.00	(0.00)	(0.01)	(0.00)	(0.00)	(0.02)	(0.00)
Slope	0.013	-0.002	0.001	0.016	-0.015	0.002	0.01	-0.033	0.004	0	-0.054	0.007
	(0.01)	(0.01)	0.00	(0.03)	(0.02)	(0.00)	(0.03)	(0.03)	(0.00)	(0.04)	(0.04)	(0.00)
Curvature	0.006	-0.146**	0.006**	0.005	-0.248**	0.009**	-0.016	-0.313**	0.001	-0.054	-0.355**	-0.02
	(0.04)	(0.03)	(0.00)	(0.08)	(0.05)	(0.00)	(0.10)	(0.07)	(0.01)	(0.13)	(0.09)	(0.01)
Factor	0.567**	0.667**	0.090**	0.957**	1.108**	0.625**	1.160**	1.357**	1.486**	1.224	1.479**	2.498**
	-0.253	-0.18	-0.02	-0.439	-0.362	-0.046	-0.571	-0.525	-0.082	-0.677	-0.673	-0.156
Constant	0.510**	-1.849**	-0.158**	0.862**	-3.058**	-1.115**	1.045**	-3.728**	-2.651**	1.103	-4.040**	-4.458**
	(0.22)	(0.52)	(0.04)	(0.39)	(1.04)	(0.08)	(0.51)	(1.50)	(0.15)	(0.60)	(1.92)	(0.28)
Observations	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	2.11	2.26	1.05	2.52	2.4	1.21	2.84	2.19	2	3.23	1.96	2.87
p_{endog}	0.12	0.11	0.36	0.08	0.09	0.31	0.06	0.11	0.14	0.04	0.14	0.06
$F_{firststage(1)}$	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65
$p_{firststage(1)}$	0	0	0	0	0	0	0	0	0	0	0	0
$F_{firststage(2)}$	66.96	165.89	16.57	66.96	165.89	16.57	66.96	165.89	16.57	66.96	165.89	16.57
$p_{firststage(1)}$	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	1.81	5.46	3.32	1.43	5.79	1.05	1.17	5.85	0.93	0.97	5.77	0.7
p_{overid}	0.61	0.14	0.34	0.7	0.12	0.79	0.76	0.12	0.82	0.81	0.12	0.87

	6			7			8			9			10		
	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis	full	pre-crisis	post-crisis
D_t	-0.351	-0.923**	-0.363**	-0.352	-0.884**	-0.353**	-0.350**	-0.849**	-0.315**	-0.346**	-0.819**	-0.261**	-0.341**	-0.791**	-0.198
	(0.19)	(0.20)	(0.12)	(0.18)	(0.19)	(0.11)	(0.17)	(0.19)	(0.12)	(0.16)	(0.19)	(0.13)	(0.16)	(0.18)	(0.15)
$\frac{PrivateTYE}{GDP}$	0.48	-1.698**	-0.276	0.591	-1.555**	-0.385	0.686	-1.428**	-0.474	0.764	-1.316**	-0.542	0.825	-1.219**	-0.589
	(0.71)	(0.67)	(0.46)	(0.67)	(0.65)	(0.50)	(0.64)	(0.63)	(0.56)	(0.61)	(0.62)	(0.63)	(0.59)	(0.61)	(0.70)
Level	0.014**	0.011	0.014**	0.015**	0.007	0.016**	0.015**	0.003	0.016**	0.016**	0	0.017**	0.016**	-0.002	0.016**
	(0.01)	(0.02)	(0.00)	(0.01)	(0.02)	(0.00)	(0.01)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.02)	(0.00)
Slope	0.002	-0.065	0.013**	-0.012	-0.075	0.012	-0.022	-0.083**	0.01	-0.029	-0.089**	0.009	-0.034	-0.094**	0.008
	(0.05)	(0.05)	(0.01)	(0.04)	(0.04)	(0.01)	(0.04)	(0.04)	(0.01)	(0.04)	(0.04)	(0.01)	(0.04)	(0.04)	(0.01)
Curvature	-0.085	-0.364**	-0.044**	-0.105	-0.310**	-0.065**	-0.12	-0.266**	-0.081**	-0.129	-0.231**	-0.094**	-0.133	-0.201**	-0.103**
	(0.15)	(0.11)	(0.02)	(0.14)	(0.11)	(0.03)	(0.14)	(0.10)	(0.03)	(0.13)	(0.10)	(0.04)	(0.13)	(0.10)	(0.04)
Factor	1.22	1.477	3.563**	0.948	1.189	3.802**	0.731	0.946	3.915**	0.564	0.74	3.944**	0.439	0.566	3.922**
	-0.761	-0.809	-0.263	-0.715	-0.786	-0.33	-0.686	-0.77	-0.391	-0.669	-0.758	-0.444	-0.657	-0.749	-0.49
Constant	1.049	-4.068	-6.383**	0.803	-3.263	-6.811**	0.606	-2.582	-7.016**	0.453	-2.007	-7.072**	0.338	-1.52	-7.037**
	(0.68)	(2.31)	(0.47)	(0.64)	(2.24)	(0.59)	(0.62)	(2.19)	(0.69)	(0.60)	(2.16)	(0.79)	(0.59)	(2.13)	(0.87)
Observations	333	266	67	333	266	67	333	266	67	333	266	67	333	266	67
F_{endog}	3.81	1.66	3.84	4.3	1.54	4.81	4.71	1.45	5.78	5.02	1.4	6.64	5.21	1.37	7.32
p_{endog}	0.02	0.19	0.03	0.01	0.22	0.01	0.01	0.24	0.01	0.01	0.25	0	0.01	0.26	0
$F_{firststage(1)}$	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65	5234.65	2594.69	268.65
$p_{firststage(1)}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$F_{firststage(2)}$	66.96	165.89	16.57	66.96	165.89	16.57	66.96	165.89	16.57	66.96	165.89	16.57	66.96	165.89	16.57
$p_{firststage(2)}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$score_{overid}$	0.85	5.44	0.71	0.85	5.06	0.93	1.01	4.7	1.29	1.32	4.41	1.61	1.73	4.23	1.86
p_{overid}	0.84	0.14	0.87	0.84	0.17	0.82	0.8	0.2	0.73	0.73	0.22	0.66	0.63	0.24	0.6

Heteroskedastic-autocorrelation robust standard errors in parentheses. ** significant at the 5 percent level.

D_t and Private TYE/GDP are instrumented with three lags of D_t, marketable debt to GDP, and the number of CUSIPS. The instrument set passes first-stage instrument tests.

6 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, 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 2014Q4 for a total of 58,012 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 nine quarters but the sample period for individual securities varies widely, as shown in table 6. Table 7 provides information suggesting that the distribution of CUSIPS by original security type differs greatly, with most issues concentrated in bills and notes, and comparatively fewer bonds.

Table 6: Distribution of the number of quarters of individual CUSIPs in sample

	min	5%	25%	50%	75%	95%	Max
Number of Quarters	1	2	2	4	9	32	117

Table 7: Number of CUSIPs by Security Type

	Bills	Notes	Bonds
Number of CUSIPS	1,545	1,050	87

6.1 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, α_{it}. Our independent variable of interest is the CUSIP-level neutrality measure, n_{it}, defined in section 3.1. Table 8 displays summary statistics of these variables.

Table 8: Summary Statistics

	Mean	Std. Dev.	Min	Max
Pricing Error (α_{it})	-0.39	2.23	-35.43	23.08
Market Neutrality Metric (n_{it})	0.0	0.004	-0.02	0.03

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:

$$\alpha_{it} = \sum_{j=1}^{J} \beta_{-j}\alpha_{i,t-j} + \delta_1 V_t + \delta_2 S_t + \delta_3 C_t + \sum_{k=0}^{K} \gamma_{-j} n_{i,t-j} + \epsilon_{it} \tag{13}$$

where α_{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 used in the aggregate analysis. n_{it} is defined as

$$n_{it} = s_{it} - g_{it} \tag{14}$$

where s_{it} and g_{it} are as defined in equations 1 and 2.

We evaluate our specification over two sample periods. As in the aggregate results, the overall sample runs from 1985 to 2014. 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 α_{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,

$$\epsilon_{i,t} = \mu_i + \nu_{i,t} \tag{15}$$

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 $\alpha_{i,t-3}, ..., \alpha_{i,t-5}$ to instrument for the lagged dependent variable terms and $n_{i,t-3}, ..., n_{i,t-5}$ as instruments for the market neutrality terms. For our post-crisis panel results, we trim the number of lags used for instruments and use $\alpha_{i,t-6}$ and $n_{i,t-6}$. 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 9. 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 1.4 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, pricing errors were more sensitive to Fed holdings, as the effect of a 1 percentage point increase in the neutrality metric more than doubles to 3.6 cents on the dollar. 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.

6.2 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 6.2, 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:

$$\omega_{it} = \sum_{j=1}^{J} \beta_{-j}\omega_{i,t-j} + \delta_1 V_t + \delta_2 S_t + \delta_3 C_t + \sum_{k=0}^{K} \gamma_{-j} q_{i,t-j} + \epsilon_{it} \tag{16}$$

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 less liquid portfolio were associated with a higher bid-asked spread. The sum of the liquidity coefficients suggests that this effect was roughly 46 basis points on the dollar. Post-crisis, this effect changed in sign, to negative, and also fell in magnitude. An increase in the liquidity metric suggests a narrowing of the bid-asked spread of 12 basis points on the dollar. Put another way, purchases post-crisis had the effect of promoting liquidity in the government securities sector.

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, 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.

7 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 9: Panel Results: Pricing Errors

	pre-crisis	post-crisis
$\alpha_{i,t-1}$	0.381**	0.461**
	(0.01)	(0.01)
$\alpha_{i,t-2}$	-0.308**	-0.764**
	(0.01)	(0.02)
$\alpha_{i,t-3}$		0.560**
		(0.02)
$\alpha_{i,t-4}$		-0.288**
		(0.01)
$\alpha_{i,t-5}$		0.151**
		(0.01)
n_{it}	37.906**	-769.773**
	(14.98)	(135.65)
$n_{i,t-1}$	74.561**	643.351**
	(13.33)	(119.87)
$n_{i,t-2}$	27.764**	188.908**
	(7.16)	(71.74)
$n_{i,t-3}$		297.802**
		(80.90)
Level	0.927**	0.489**
	(0.08)	(0.04)
Slope	1.209**	1.067**
	(0.17)	(0.16)
Curvature	-3.525**	1.663**
	(0.55)	(0.20)
Factor	24.556**	-46.852**
	(3.94)	(9.23)
Constant	-70.241**	83.897**
	(11.21)	(16.61)
Observations	44319	16919
Number of CUSIPs	1934	670
Sum of neutrality coefficients	**140.23**	**360.29**
t-statistic	5.25	4.1
Robust standard errors in parentheses		
** significant at 5% level		

	Mean	Std. Dev.	Min	Max
Bid-Ask Spread	0.056	0.069	0.0	1.0
Liquidity Metric (q_{it})	0.0	0.006	-0.058	0.092

Table 10: Liquidity and the bid-asked spread

	Pre-crisis	Post-crisis
$\omega_{i,t-1}$	0.421**	0.209**
	(0.044)	(0.037)
$\omega_{i,t-2}$	0.189**	0.197**
	(0.038)	(0.035)
$\omega_{i,t-3}$	0.100**	0.055**
	(0.026)	(0.015)
$\omega_{i,t-4}$	0.144*	
	(0.066)	
q_{it}	0.055	-0.086**
	(0.066)	(0.037)
$q_{i,t-1}$	-0.309**	-0.047
	(0.076)	(0.042)
$q_{i,t-2}$	0.104**	0.012
	(0.036)	(0.033)
$q_{i,t-3}$	0.145	
	(0.112)	
$q_{i,t-4}$	0.462**	
	(0.133)	
Level	-0.001	0.000**
	(0.002)	(0)
Slope	-0.001	0.001**
	(0.002)	(0)
Curvature	-0.022**	-0.002**
	(0.009)	(0.001)
Factor	0.015	0.03
	(0.052)	(0.016)
Constant	-0.032	-0.034
	(0.15)	(0.03)
Observations	40489	18200
Number of CUSIPs	1585	832
Sum of liquidity coefficients	**0.46**	**-0.12**
t-statistic	4.01	-2.45
Robust standard errors in parentheses		
** significant at 5%		