FLOW AND STOCK EFFECTS OF LARGE-SCALE TREASURY PURCHASES

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ABSTRACT

Using a panel of daily CUSIP-level data, we study the effects of the Federal Reserve's program to purchase $300 billion of U.S. Treasury coupon securities announced and implemented during 2009. This program represented an unprecedented intervention in the Treasury market and thus allows us to shed light on the price elasticities and substitutability of Treasuries, as well as on the ability of large-scale asset purchases to reduce overall yields and improve market functioning. We find that each purchase operation, on average, caused a temporary decline in yields in the sector purchased on the order of 4 basis points (the "flow effect" of the program). In addition, the program as a whole resulted in a persistent downward shift in the yield curve of as much as 45 basis points, with the largest impact in the 10- to 15-year sector (the "stock effect").

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1. Introduction

During the crisis of 2008, policymakers took a number of extraordinary steps to improve the functioning of financial markets and stimulate the economy. Among the most important of these measures, in terms of both scale and prominence, were the Federal Reserve's purchases of large quantities of government-backed securities in the secondary market, conventionally known as the Large Scale Asset Purchase—or "LSAP"—programs. The LSAPs included debt obligations of the government-sponsored enterprises Fannie Mae and Freddie Mac, mortgage-backed securities (MBS) issued by those agencies, and coupon securities issued by the U.S. Treasury, and they collectively amounted to $1.7 trillion over a period of about 15 months—the single largest government intervention in financial-market history. Given the unprecedented size and nature of these programs, and the speed with which they were proposed and implemented, policymakers could have had, at best, only a very rough *ex ante* sense of their potential impact. The minutes of the December 2008 Federal Open Market Committee meeting summarized the prospects thus: "The available evidence indicated that [LSAP] purchases would reduce yields on those instruments, and lower yields on those securities would tend to reduce borrowing costs for a range of private borrowers, although participants were uncertain as to the likely size of such effects."

There was particular cause for skepticism regarding the Treasury program. The market for U.S. government debt is among the largest and most liquid in the world, and it was not obvious that even such a large intervention (the $300 billion purchased by the Fed constituted about 8 percent of the market at the time) would have significant effects, given the large number of other securities that serve as potential substitutes for Treasuries. Indeed, while the MBS and agency-debt LSAP programs were quickly judged successful (conventional mortgage rates dropped about 1 percentage point after the announcement of these programs and remained in the range of 5 percent for the duration of the crisis), the effects of the Treasury program were far from obvious. Treasury yields fell notably when the program was announced on March 18, 2009, but they retraced these declines in subsequent weeks. Some observers even speculated that the program could perversely serve to increase yields if the accompanying rise in reserve balances were seen as inflationary or if the Fed were viewed as accommodating fiscal expansion by "monetizing the debt."[1]

In this paper, we study the effects of the Treasury LSAP program on pricing in the nominal Treasury coupon market. Although smaller than the MBS program in dollar volume and smaller than the

[1] For example, former Fed Governor Gramley told Reuters in June, 2009, "I don't think they can afford to go out and aggressively buy longer-term Treasuries or even step-up aggressively their purchases of mortgage debt… There is this fear going around in financial markets that the Fed is going to monetize the debt, and we're going to have big inflation. I don't believe that for a minute, but the perception is a reality that the Fed is going to have to deal with." (Bull, 2009).

agency-debt program as a fraction of its respective market, the Treasury program merits special study for several reasons. First, while the agency-debt and MBS programs were primarily focused on reducing mortgage rates and stimulating the housing market, the Treasury program was seen as having the ability to contribute to reductions in the cost of credit across a range of markets. Indeed, there were those on the FOMC who argued for a greater role for the Treasury program, rather than the other two, on precisely these grounds.[2] Second, , understanding the effects of changes in the supply of Treasury debt available to the public is likely to have broader policy importance. Under normal circumstances, the Fed conducts most of its open-market operations in Treasuries, the Treasury Department may worry about the interest-rate effects of introducing new supply, and foreign central banks conduct sizeable interventions in this market to maintain their reserves. Partly with these features of the market in mind, a number of previous studies have attempted to estimate the responses of Treasury yields to changes in the Treasury supply available to the public (Tarhan, 1995; Bernanke et al., 2004; Engen and Hubbard, 2005). As Kuttner (2006) notes in his literature review, results have generally been mixed. Kuttner's own analysis—based on "excess returns" regressions in the style of Cochrane and Piazessi (2005)—suggests that Fed purchases of Treasuries have significant effects on term premia and thus on yields. The LSAP program provides a large natural experiment for testing this hypothesis.

Our analysis uses daily CUSIP-level data on LSAP purchases and price changes. The price differentials that emerge between the securities that were purchased in different amounts identify the impact of the purchases—that is, the Treasury price elasticity. The CUSIP-level data also allow us to control for substitution effects across securities by constructing for each CUSIP buckets of Treasuries with similar remaining maturities. Including these substitute purchases is important as it enables us to estimate cross-elasticities of Treasury prices with respect to purchases of other Treasuries, which are crucial for determining how the aggregate level and term structure of interest rates were affected by the LSAP program.[3]

We distinguish between two types of impact that the program might have had—flow effects and stock effects. Flow effects are defined as the response of prices to the ongoing purchase operations and could reflect on top of portfolio rebalancing activity due to the unexpected outcome of the purchases, impairments in liquidity and functioning of the Treasury market that allowed even anticipated withdraws of supply to have short-run effects on prices. In contrast, stock effects are the permanent changes in price

[2] See, for example, the minutes of the January 2009 FOMC meeting (Federal Reserve, 2009).

[3] As stressed in Thornton (2009), under the assumption of perfect substitutability—that is, the expectation hypothesis—the only possible effect of the purchase of long-term securities would be on the position of the yield curve. In contrast, under the assumption of imperfect substitutability, the Fed would be able to affect permanently the slope of the yield curve (implying a reduction in term premia) by intervening on the long-term portion of the curve. Toward this end, the use of CUSIP-level data, by allowing us to estimate the degree of substitutability, might help to determine if the Fed Treasury purchases had an impact on the position and/or the slope of the yield curve.

that result from movements along the Treasury demand curve and include the market reaction due to changes in expectations about future withdraws of supply. To estimate flow effects, we model the percentage change in each CUSIP's price on each day that purchase operations occurred as function of the amount purchased of that CUSIP and the amounts of substitute securities purchased. To estimate the stock effects, we model the cumulative change in each CUSIP's price between March 17, 2009 and October 29, 2009 (i.e., the cross section of Treasury returns) as a function of total own and substitute Treasury purchases. Because, over the life of the program, purchased amounts could have responded endogenously to price changes, we instrument LSAP purchases with the purchased securities' characteristics prior to the announcement of the program when estimating stock effects.

The results suggest that, on average, Treasury purchases reduced yields by about 30 basis points across the yield curve over the life of the program (the stock effect) and led to a further 4 basis point decline on the days when purchases occurred (the flow effect). The latter is due to the fact that , on the days when a security was eligible to be bought, purchases of its close substitutes had almost as large effects on its yield as did purchases of the security itself—that is, the cross- and own elasticities for flow effects were nearly identical at about 0.7 basis points per billion dollars purchased. The flow effects were concentrated among securities with remaining maturities of less than 15 years but were otherwise remarkably consistent across security characteristics. The stock effects were most pronounced among securities with 10 to 15 years of remaining maturity—which we estimate would have had yields as much as 45 basis points higher in the absence of the program—but less pronounced among the relatively liquid note securities

We view these results as economically important. A decline in Treasury yields on the order of 30 to 50 basis points, if passed through to private credit markets, would have represented a substantial reduction in the cost of borrowing for businesses and households. It thus appears that the Treasury LSAP program was probably successful in its stated goal of reducing interest ratesand in its secondary goal of improving market functioning, as it was most effective in the portion of the yield curve characterized by the largest fitting errors.

The following section of the paper describes the mechanics of the Treasury LSAP and related issues, including previous government programs of similar nature. Section 3 discusses our measurement of flow effects, and Section 4 deals with stock effects. Section 5 offers concluding thoughts.

2. A Review of Treasury LSAPs and Related Programs

The Federal Reserve's programs to purchase debt obligations and MBS issued by Fannie Mae and Freddie Mac were announced in December 2008, largely in response to increases in mortgage rates that threatened to put further downward pressure on the already beleaguered housing market.[4] Although rates on these securities and on fixed-rate mortgages responded promptly to the programs' announcement, yields in other debt markets remained elevated through the winter, and functioning and liquidity in many markets was impaired.

The program to purchase up to $300 billion of Treasury coupon securities was announced in the FOMC statement on March 18, 2009, and the first operation was conducted on March 25.[5] On August 12, the Committee announced that it would purchase the full $300 billion and would wind down the program in October. Nominal purchases (as opposed to purchases of inflation-protected securities) included 160 unique CUSIPs, spanning remaining maturities of about two to thirty years. $300 billion represented about 2.7 percent of the total stock of outstanding Treasury debt as of the time of the announcement. Most purchases were concentrated in the 2- to 7-year sectors, although, as a percentage of total outstanding Treasuries within each sector, purchases across maturities look less concentrated (Figure 1). Approximately 70 percent of purchases were off-the-run issues.

The timing of the purchase operations was as follows. Every-other Wednesday, the Desk announced the broad maturity sectors in which it would be buying over the subsequent two weeks and the days on which it would be conducting these operations. Auctions took place from Monday of the first week through Friday of the second week and typically settled on the following day.[6] At 10:15 on the morning of each auction, the Desk published a list of CUSIPs that were eligible for purchase, which generally included nearly all securities in the targeted sector,[7] and began accepting propositions. At 11:00 AM, the auction closed. The Desk then determined which securities to buy from among the submitted bids based on a confidential algorithm, and it published the auction results within a few minutes of the auction close. Market participants were not aware in advance of the total amount to be purchased or of the distribution of purchases across CUSIPs.

Federal Reserve officials put forth a variety of objectives for the Treasury purchases and for the LSAP programs more generally, including the provision of liquidity and the improvement of market

[4] The MBS program was authorized to purchase $1.25 trillion out of a market that totaled about $3.4 trillion when the program was initiated. The agency-debt program was authorized to purchase $175billion out of a total market of about $700 billion. The size of the Treasury coupon market was about $3.9 trillion in March 2009. As a practical matter, it would be impossible to study the effects of the MBS program using our approach because the necessary data are not publicly available.

[5] Although policymakers had floated the possibility of Treasury purchases prior to the announcement, market participants did not appear to place high odds on this decision. For instance, the morning of the FOMC announcement, Bloomberg reported that Goldman Sachs and several other banks believed that policymakers would not introduce such a program and that the March FOMC statement would be largely similar to the January statement: http://www.bloomberg.com/apps/news?pid=20601087&sid=aIt7yEi9XAhc&refer=home

[6] In practice, the Desk avoided conducting Treasury operations on Fridays, preferring to reserve these days for agency purchases.

[7] The securities that were excluded were the cheapest-to-deliver in futures markets, those with high scarcity value in the repo market, and those for which 35 percent of the issue has already been purchased under the LSAP program.

functioning, but by far the most frequently cited objective was to increase the flow of credit to businesses and households by reducing the general level of interest rates.[8] Two previous policy experiments in the United States had come close to the LSAP program in intent and mechanics, if not in scale, and could have served to guide policymakers' thinking. First, the Federal Reserve's attempt to increase long-term yields relative to short-term yields in the early 1960s—termed "Operation Twist"—involved the purchase of short-term Treasury debt and the sale of long-term debt. This program was analyzed contemporaneously by Holland (1969) and more recently by Hakim and Rashidian (2000). The second policy experiment that resembled the Treasury LSAP program was the Treasury Department's repurchase of long-term debt during the early 2000's. In total, repurchases under this program amounted to $67.5 billion (about 1.2 percent of outstanding Treasury debt), entirely in off-the-run issues with original maturities of 30 years. In many details, the operations were similar to LSAP purchases—for example, the broad sector for each operation was announced in advance, but Treasury could choose which securities to purchase from among submitted bids within that sector.[9] Longstaff (2004) found that the Treasury buyback program had significant effects on spreads between Treasuries and other government-guaranteed debt (RefCo bonds). Depending on the maturity, these effects averaged about 2 basis points per billion dollars purchased. On the other hand, Han et al. (2005) found small and statistically insignificant differences in yield changes between bonds that were purchased and those that were not. Bernanke et al. (2004) argued that the buyback program had significant effects, although they did not provide precise estimates of the magnitude.[10]

Despite these precedents, policymakers repeatedly expressed uncertainty about the possible size of such effects.[11] This uncertainty likely reflected, in part, the high degree of market volatility at the time, which rendered suspect the few econometric estimates of Treasury price elasticities that were available. Indeed, implied volatilities from options on Treasuries climbed to historic highs around this time, spreads between on- and off-the-run securities widened dramatically, and standard term structure models exhibited pronounced fitting errors, all suggesting an impairment of liquidity.

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[8] See, for example, Chairman Bernanke's April 3 speech (Bernanke, 2009).

[9] Importantly however, in contrast to the LSAP program, the Treasury buyback program specifically attempted to *minimize* the effects of operations on market prices, since increases in prices would have driven up the cost of the purchases.

[10] Bernanke et al. (2004) also examine two other episodes that may pertain to the effects of changing Treasury supply on yields—the initiation of large purchases of Treasuries by Asian central banks in 2002 and the market perception that the Fed might undertake an LSAP-type program in 2003. Kuttner (2006) also provides a narrative overview of several instances of large interventions in Treasury markets and suggests that most of these interventions have had economically significant effects.

[11] Even halfway through the program's execution, San Francisco Fed President Yellen remained unsure of its consequences: "… [T]here is still a lot we don't know about the magnitude and duration of the effects of these policies. Our standard monetary models do not incorporate financial frictions that lead to asset purchases having real effects. We lack both the data and the theory to provide strong guidance on these policies. Truly, we are sailing in uncharted waters, marking our maps with every bit of information along the way." [Yellen, 2009]

3. Flow Effects

Because the sectors of purchase operations were announced in advance and both the list of CUSIPs and sizes of these operations were fairly predictable, one could expect that examining yield changes as function of contemporaneous purchases would reveal no statistically significant responses. While this may well have been the case at the aggregate level, however, it need not be the case at the CUSIP level. Because the particular CUSIPs that were purchased and the amounts of these purchases were not known in advance to the market, yield differentials should have emerged on the days of purchases between those that are purchased and those that are not (assuming the demand for Treasury securities is sufficiently elastic). In addition, market illiquidity and other technical factors could cause yields to move in response to purchases, even if those purchases were perfectly predictable. We group both of these phenomena together as "flow effects."

A central element in our approach is the possibility that the price of a given security may also move in response to purchases of other securities for which it is a substitute. Toward this end, we define buckets of substitutes for each security. Although in principle we could choose the size and number of the substitute buckets in a variety of ways, a division into three buckets based on remaining-maturity ranges seemed to provide a good combination of parsimony and flexibility. In particular, for each security i, we define our most narrow bucket to include all securities having remaining maturities within two years of security i's maturity. We refer to these securities as "near substitutes" for security i. The second bucket, which we call "mid-substitutes" for i, includes all securities having remaining maturities that are between two and six years different from security i's. The third bucket ("far substitutes") includes all securities having remaining maturities between six and fourteen years different from security i's. We denote the amount of each bucket purchased by the Desk on day t by s_{ijt}, where $j = \{1, 2, 3\}$ indexes the degree of substitutability. In addition, we let q_{it} denote the amount of security i purchased. We normalize q_{it} and s_{ijt} by the total amount of securities outstanding that have remaining maturities within two years of security i (that is, the sum of a security's own amount outstanding and the amount of its near substitutes). This normalization generates coefficients that all take the same units, allowing us to compare the effects of a given dollar amount of purchases across different sectors.[12] (In economic terms, the rationale for this denominator is that it proxies for the relevant measure of supply within a given sector.)

With these variables in hand, our regressions take the following general form:

[12] We tried various alternative normalization schemes and generally found results consistent with those reported below.

$$\Delta p_{it} = \alpha_i + \delta_t + \beta q_{it} + \sum_{j=1}^{3} \gamma_j s_{ijt} + \varepsilon_{it}$$

where Δp_{it} is the percentage change in the price of Treasury security *i* on day *t*, α_i is a security-specific fixed effect, δ_t is a time dummy, and ε_{it} is an error term. The panel structure of our data, by allowing for both CUSIP-level fixed effects and daily time dummies, enables us to control for a host of factors that might otherwise cloud the analysis. The parameter β reflects the *own*-price elasticity of Treasury securities, while the parameters γ_j primarily reflect the *cross*-elasticities of Treasury security prices with respect to other Treasury securities. These latter elasticities depend on the degree of substitutability between different Treasury issues, which in turn depends upon the liquidity of the Treasury market and the ability of participants to arbitrage away price inefficiencies in this market. The own-price response β is of some interest, as its magnitude is indicative of the purchases' effects on the yield-curve fitting errors. The cross-responses γ_j, however, are likely to be much more important in terms of the aggregate level and term structure of interest rates. This is because the purchase of a particular security affects that security's yield alone through the $\beta\Delta q_t$ term, but it affects *every* security's yield through the applicable $\gamma\Delta S_t$ terms.

Our data consist of daily observations on the universe of outstanding nominal Treasury coupon securities from March 25 through October 30, 2009. To simplify the analysis, we exclude TIPS and securities with remaining maturities of less than 90 days, leaving us with an unbalanced panel of 204 CUSIPs (including 44 securities that were never purchased under the LSAP program). We use data on percentage change in each CUSIP's price (measured from the end of the previous day) on each day that LSAP purchases of nominal Treasury securities occurred. For the independent variables, we use the amounts purchased for each security and total outstanding amounts for each of these CUSIPs.[13]

Because the broad maturity sectors within which securities were purchased on any given day were announced in advance, we may expect that securities within those sectors might have reacted differently to the purchase operations than securities that were outside the purchased sectors. To examine this possibility, we split the sample into (1) observations of securities on days when those securities were within the announced purchase sectors (defined as "eligible" securities) and (2) observations of securities on days when purchases took place in different sectors (defined as "not eligible"). These subsets are mutually exclusive and exhaustive within the set of days on which purchases took place.

[13] Purchased amounts by CUSIP are publicly available on the Federal Reserve Bank of New York's website, and amounts outstanding are based on information from the Treasury Department. Daily pricing data come from Bloomberg.

In Table 1 we report the baseline results. Initial tests suggested that the coefficients were not stable for securities with very long remaining maturities, so we report a sample split at the midpoint maturity of 15 years. (As seen in Figure 1, the vast majority of purchases were in the less-than-15-year sector.) Focusing on the first column of the table, which pertains to eligible securities with remaining maturities of less than 15 years, the results suggest that, on average, purchasing $1 billion of Treasuries reduced the yield on the securities purchased by about 0.7 basis points.[14] More importantly, we find that, on the days when a security was eligible to be bought, purchases of its close substitutes had almost as large effects on its yield as did purchases of the security itself, pointing to a very high degree of substitutability among these securities.[15] Intuitively, the coefficient gets smaller as the degree of substitutability decreases. Applying the aggregate coefficients to averages of the dependent variables, we find that the typical effect of each operation was on the order of -3.5 basis points for the sector being purchased, consistent with the elasticity reported above and the average operation size of around $5 billion. The second column of Table 1 shows that these results did not generally hold for longer-maturity issues. In addition, as can be seen in the right-hand columns, a security was essentially insensitive to the purchases of its substitutes on days when it was not eligible to be purchased itself. In the remainder of this section, to illustrate the robustness of the main results reported in the first column of Table 1, we focus only on securities with less than 15 years to maturity.

The first two columns of Table 2 and Table 3 show that the estimates of the price elasticity are quite robust to different cuts of the data, such as notes versus bonds and on-the-run versus off-the-run issues, respectively. In particular, in the case of the eligible securities, the coefficients for notes and bonds are very close to each other and in turn to those reported in the first column of Table 1. One exception is the value of the coefficient on mid-substitute purchases for bonds, which is smaller than in the pooled sample and is not significant, most likely due to the small number of observations. The same results hold also when the eligible securities are divided according to their time since origination. In particular, we include in the "near on the run" sample all the CUSIPs that are less than 6 issues off the run, and in the "far off the run" sample those that are more than 5 issues off-the-run. (This split of the data was necessary to avoid a small number of observations in the on-the-run sample.) However, since the on-the-run sample includes only notes, to consider all the possible combinations, we further split the off-the-run securities in bonds versus notes and analyze these two additional subsamples. The results are reported in Table 4 and again confirm the robustness of the original findings. Overall, the principal conclusion from

[14] Specifically, -0.29 *(1/1203)*0.2763=-0.000067. $1203 is the average amount of (in billions) of near substitutes outstanding, 0.2763 is the coefficient from the regression shown in Table 1, and 0.29 is the average of the inverse of the modified duration employed to convert the results from prices into yields.

[15] Because it was rare to purchase securities with maturities more than six years apart in the same operation, the far-substitute variable is omitted from this regression.

these robustness exercises is that in the less-than-15-year sector, the strong effects that the amounts purchased have on the eligible securities and their near substitutes are not driven by the type of security or by liquidity issues. [16]

4. Stock Effects

By "stock effects" we mean the impact that the LSAP program had on yields by permanently reducing the total amount of Treasury securities available for purchase by the public. Of course, expectations of such effects should have been impounded into Treasury prices as soon as the market became aware of the program, before any purchases took place—presumably, this mechanism accounted for much of the 25 to 50 basis point drop in Treasury yields on the day the program was announced. Thus, it is crucial to account for expectations when measuring stock effects.

Our identification relies on two ideas. First, preferred-habitat or portfolio-balance effects are large enough such that reducing the available supply of a particular security should have greater effects on that security (and its near substitutes) than on securities that are of much different maturities. Second, we note that the expectation effects mentioned above only matter prior to the conclusion of the program. In other words, while there may be temporary price fluctuations reflecting changing expectations of future purchases, these expectations become irrelevant once the actual amounts and distribution of purchases is revealed. Thus, all else equal, the difference in price changes across two securities between the time the program was announced and the time it was concluded should depend only on the relative amount of each security that was actually purchased over the life of the program. With this in mind, our regressions for the stock effects use the cross section of total price changes for all nominal Treasury coupon securities between March 17 and October 30, 2009.

There is an obvious danger of endogeneity in this exercise—if the Fed was deliberately targeting securities that were underpriced, purchases may have been higher among issues whose yields rose the most during the life of the program. To control for this, we use two-stage least squares. In the first stage, we instrument the LSAP purchase amounts of each security using information available as of March 17, 2009. In the second-stage regression, we use instrumented purchases from the first stage as independent variable for changes in Treasury prices. We also include remaining maturity and remaining maturity squared as regressors to account for secular changes in the slope and curvature of the yield curve that were unrelated to the LSAP program, such as macroeconomic conditions and new Treasury issuance.

[16] These results raise the following question: if the effects of purchases are similar across security type and liquidity and the degree of substitutability is high, how long lasting can the effect be? In preliminary work, not shown, we find some evidence that these effects are retraced on the days following purchase operations, consistent with our assumption that flow effects should be transitory.

Our procedure departs from standard two-stage least-squares in two ways that deserve mention. First, as in the flow-effect regressions, we want to account for the possible effects of substitute purchases. This variable is subject to the same endogeneity concerns as own purchases, but rather than instrumenting it separately we construct substitutes by adding up the instrumented values of own purchases from the first stage. This ensures consistency across our regressors.[17] Second, we allow for different second-stage coefficients depending on security characteristics. In particular, we again divide the sample into bonds with less than 15 years of remaining maturity, bonds with more than 15 years of remaining maturity, notes more than five issues off the run, and notes zero to five issues off the run. The small number of observations makes running separate regressions on these sub-samples problematic, and, moreover, there is no particular reason to think that the remaining-maturity coefficients should vary across them. Therefore, we run a single regression but use interactive dummies to allow the coefficients on own and substitute purchases to differ across the subsamples.[18]

In summary, our two-stage system takes the form

$$Q_i = \boldsymbol{\theta}\mathbf{x}_i + u_i$$
$$\Delta P_i = \alpha + \beta_k \hat{Q}_i + \gamma_k \hat{S}_i + \varphi_1 R_i + \varphi_2 R_i^2 + \varepsilon_i$$

where $\mathbf{x}_i$ is the vector of instruments, hats indicate instrumented values from the first stage, capital letters indicate totals over the sample period, $k = \{1, \ldots, 4\}$ indexes the security type, and R_i is the remaining maturity as of March 17. Because we are using a cross section, we exclude securities that matured or were issued while the program was in progress, leaving us with 148 observations.

The results of the first-stage regression are shown in Table 5. The coefficients on the maturity variables suggest that purchases depended strongly on remaining maturity, peaking (in percentage terms) around the ten-year sector. While fitting errors were important, it turned out that their sign was not. Finally (contrary to some market commentary) the Desk was more likely to purchase on-the-run than off-the-run issues, controlling for other factors. The remaining variables in our first stage regression were not individually significant, although they are jointly significant, arguing for their inclusion.[19]

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[17] We do not use the mid- or far-substitute categories in the cross section because of the high degree of collinearity, especially given our inclusion of the remaining maturity variable.

[18] Note that neither of these departures from standard 2SLS changes the consistency of the usual standard-error computation, which we use below.

[19] One interpretation of these results is that savvy market participants could have predicted with a fair degree of accuracy which securities would be purchased the most. Indeed, it appears that this occurred to some extent. For example, on the day the program was announced, yields on securities that were ultimately purchased fell by an average of 39 basis points, while yields on securities that did not end up being purchased fell by only 27 basis points, even though the announcement gave no specific indication of which securities would be purchased.

The results are presented in the top panel of Table 6. Own-purchase effects for off-the-run notes and both categories of bonds are large, positive, significant, and of similar magnitudes. The coefficients on near substitutes for these sub-samples, though all positive, are statistically insignificant. This suggests that, while stock effects were important among these classes of Treasuries, illiquidity or security-specific features prevented purchases from having price effects beyond the specific securities that were bought.

In contrast, the results for near-on-the-run-notes indicate that the effects of near-substitute purchases were highly significant and fairly large. The coefficient of 0.166 implies that, on average, $1 billion of purchases decreased the yield on every near-substitute security by about half a basis point. Meanwhile, for near-on-the-run notes, the coefficient on own purchases is considerably smaller than for the other types of securities, and it is not statistically significant. Indeed, we cannot reject the equality of the own-purchase and near-substitute-purchase coefficients for this sub-sample, suggesting that substitutability among these securities is quite high. This is precisely the behavior we would expect for near-on-the-run notes, which constitute the most liquid and widely traded segment of the Treasury market.

The bottom panel of the table illustrates that, when we exclude price changes that occurred on the day of the announcement, our coefficient estimates are unchanged, although the standard errors are larger. In other words, while variation stemming from the announcement effect appears to have contributed important identification power, behavior during the remainder of the sample period was consistent with the price movements on that day.

To summarize the stock effects of the LSAP program, we construct a counterfactual yield curve using the results just presented. In particular, by using the actual value of purchases of each security and its near substitutes, together with the coefficients for the appropriate sub-sample, we compute the estimated amount by which the price of that security changed as a result of LSAP purchases. Subtracting this value from the actual price at the end of the program gives the counterfactual price of each security that would have obtained if the LSAPs had not occurred. These prices are then smoothed using a Svensson (1994) yield curve, following Gurkaynak et al. (2007). Positive and negative two-standard-error bands around the counterfactual prices are treated in the same way.

The results are shown, together with the actual yield curve on October 30, 2009, in Figure 2. The difference between the solid red and solid blue lines represents the stock effects of the LSAP program on the yield curve. From this picture, we can see that the effects were statistically significant over maturities of about 5 to 20 years and were largest—with a point estimate of about 45 basis points—in the 10- to 15-year sector. The reason that the biggest effects occur in this region is a combination of the relatively large coefficients on old bonds and the relatively large amount of purchases (as a fraction of outstandings) within this sector.

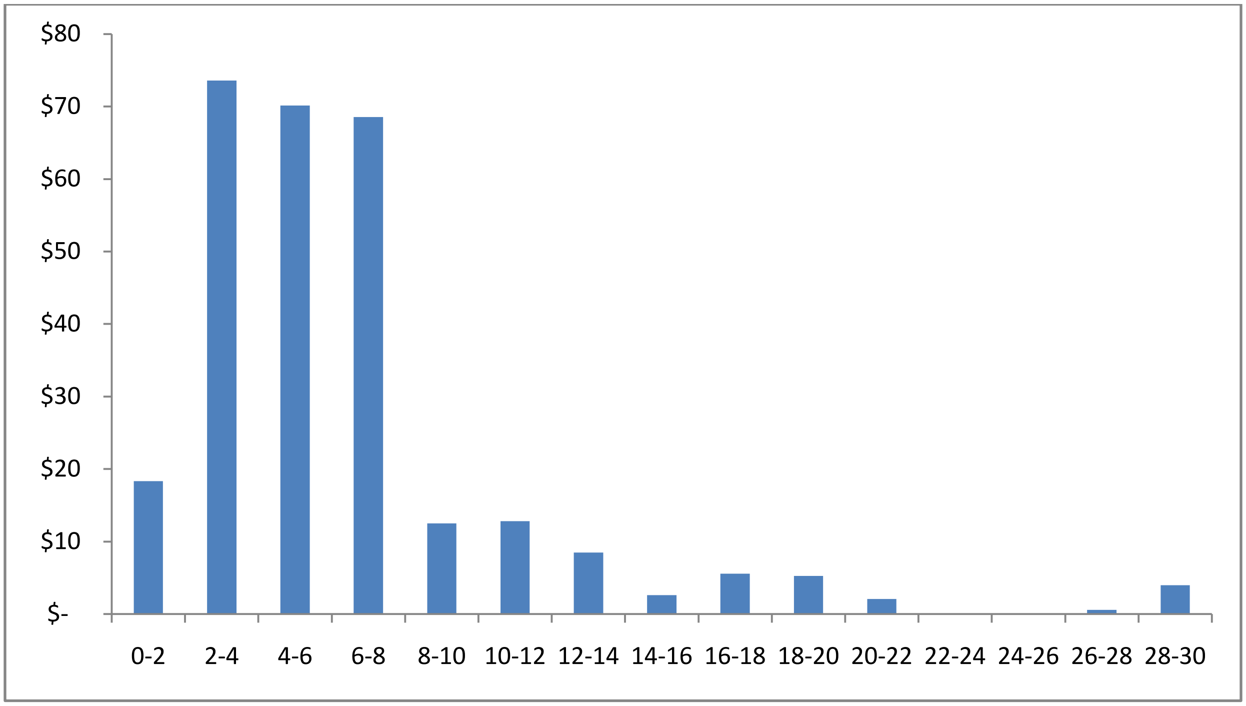
5. Conclusion

In this paper, we have used CUSIP-level data to estimate the flow and stock effects of the Federal Reserve's 2009 program to purchase nearly $300 billion of nominal Treasury coupon securities. We find that both types of effect were statistically and economically significant. Specifically, we estimate that the average purchase operation temporarily reduced yields by about 3.5 basis points and that the program as a whole shifted the yield curve down by up to 45 basis points. It thus seems likely that the Treasury LSAP program met the Federal Reserve's objectives of improving Treasury market liquidity and contributing to a reduction in the cost of credit.

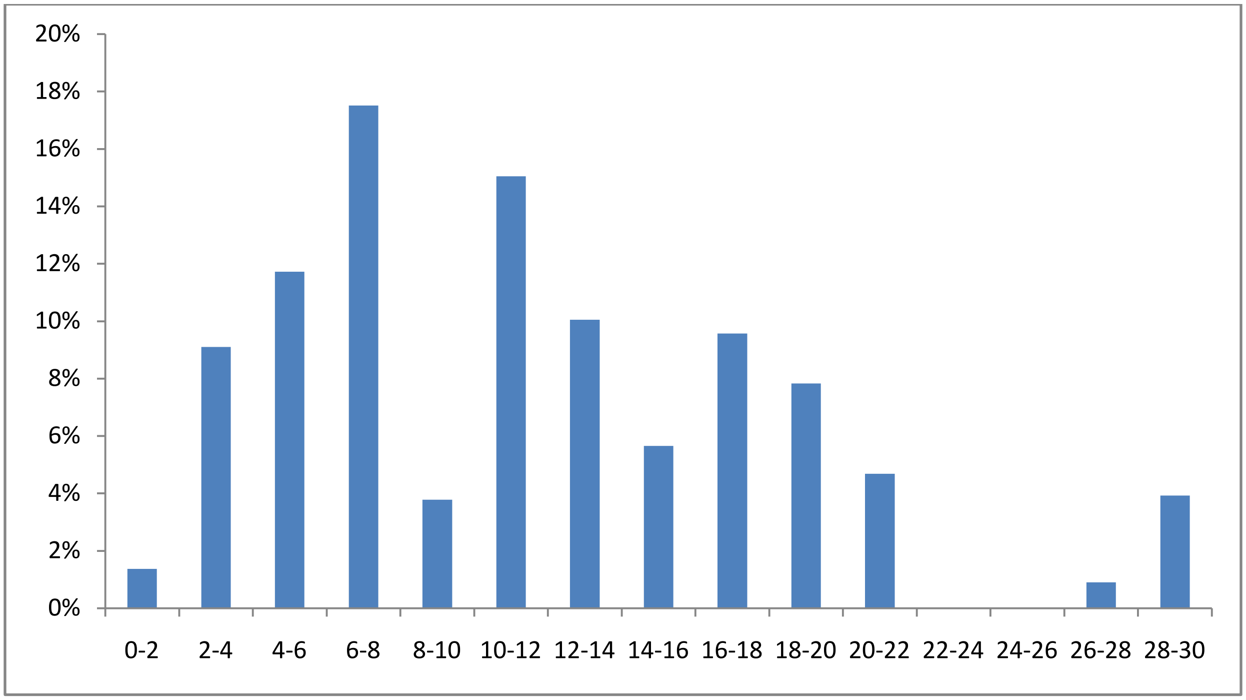
Although our study is the first to specifically treat the effects of substitute cross-elasticities, the magnitudes of our stock-effect estimates are roughly comparable to Treasury price elasticities found in some previous studies, such as Kuttner (2006). As far as we are aware, no other study has estimated flow effects as we have defined them. Nevertheless, we caution that the environment that produced our data involved exceptional conditions in the Treasury market that could make extrapolation of these results to other situations problematic.

Figure 1. Maturity Distribution of Nominal Treasury LSAP Purchases

Billions of Dollars

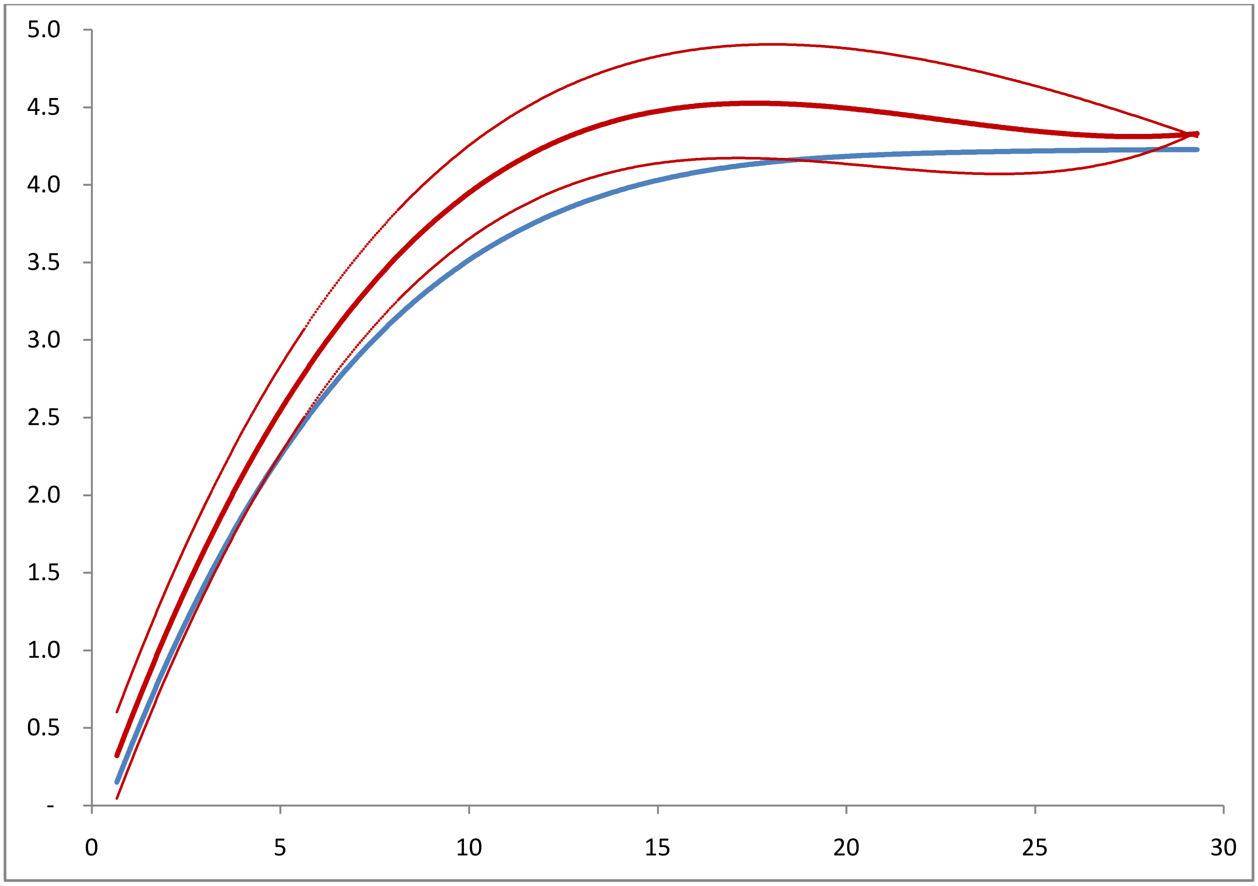


Percentage of Sector



Note: Denominator is par value of outstanding securities in each sector as of July 13, 2009.

Figure 2. Stock effects of the LSAP program on the nominal yield curve



Notes: The blue line is the nominal yield curve constructed as in Gurkaynak et al. (2007) on October 30, 2009. The solid red line is the counterfactual yield curve on that day, using Treasury prices with the estimated effects of LSAP purchases removed, according to the coefficients in Table 6. Dotted lines show smoothed curves based on a 90% confidence interval around the counterfactual prices.

Table 1. Flow Effects—All Securities

	Eligible <15y to maturity	Eligible >15y to maturity	Not Eligible <15y to maturity	Not Eligible >15y to maturity
Own Response (*β*)	0.2763*** (0.053)	-0.1063 (0.098)	---	---
Cross Responses (γ_j):				
Near substitutes (within 2 years)	0.2403*** (0.048)	-0.1238*** (0.044)	0.0665*** (0.018)	-0.0268 (0.053)
Mid-substitutes (2 to 6 years away)	0.1700*** (0.045)	0.0501* (0.026)	0.0047 (0.0099)	-0.007 (0.021)
Far substitutes (6 to 14 years away)	---	---	-0.0238** (0.008)	0.0021 (0.003)
# Obs.	923	145	8008	1104
# CUSIPS	146	23	181	23
Adj. R^2	0.64	0.76	0.51	0.96

Notes: The dependent variable is the daily percentage price change in each outstanding CUSIP. Only days when LSAP purchases occurred are included. Standard errors in parentheses. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

Table 2. Flow Effects by Security Type (remaining maturity < 15 years)

	Eligible Type=Note	Eligible Type=Bond	Not Eligible Type=Note	Not Eligible Type=Bond
Own Response (*β*)	0.2669*** (0.068)	0.2498*** (0.090)	---	---
Cross Responses (γ_j):				
Near substitutes (within 2 years)	0.2503*** (0.062)	0.1694** (0.083)	-0.0157 (0.027)	-0.044 (0.033)
Mid-substitutes (2 to 6 years away)	0.2088** (0.055)	0.0929 (0.080)	-0.0928*** (0.023)	0.0078 (0.013)
Far substitutes (6 to 14 years away)	---	---	-0.0249 (0.025)	-0.0074 (0.008)
# Obs.	769	154	6851	1157
# CUSIPS	123	23	158	23
Adj. R^2	0.75	0.83	0.49	0.94

Notes: The dependent variable is the daily percentage price change in each outstanding CUSIP. Only days when LSAP purchases occurred are included. The sample is limited to securities with less than 15 years of remaining maturity. Standard errors in parentheses. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

Table 3. Flow Effects by Vintage (remaining maturity < 15 years)

	Eligible Near on-the-run	Eligible Far off-the-run	Not Eligible Near on-the-run	Not Eligible Far off-the-run
Own Response (*β*)	0.2318** (0.107)	0.2488*** (0.065)	---	---
Cross Responses (γ_j):				
Near substitutes (within 2 years)	0.2435** (0.105)	0.1584*** (0.057)	-0.0578 (0.058)	0.0811*** (0.020)
Mid-substitutes (2 to 6 years away)	0.2501*** (0.092)	0.0744 (0.055)	-0.0939** (0.045)	0.0141 (0.010)
Far substitutes (6 to 14 years away)	---	---	-0.0403 (0.046)	-0.0238*** (0.008)
# Obs.	249	674	1463	6545
# CUSIPS	53	114	58	151
Adj. R^2	0.69	0.47	0.70	0.47

Notes: The dependent variable is the daily percentage price change in each outstanding CUSIP. Only days when LSAP purchases occurred are included. The sample is limited to securities with less than 15 years of remaining maturity. Standard errors in parentheses. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

Table 4. Flow Effects by Security Type (far off-the-run; remaining maturity < 15 years)

	Eligible Bond	Eligible Note	Not Eligible Bond	Not Eligible Note
Own Response (*β*)	0.2498** (0.090)	0.3041** (0.137)	---	---
Cross Responses (γ_j):				
Near substitutes (within 2 years)	0.1694** (0.083)	0.2131** (0.104)	-0.0441 (0.033)	-0.0207 (0.032)
Mid-substitutes (2 to 6 years away)	0.0929 (0.080)	-0.0228 (0.098)	0.0078 (0.013)	-0.0891** (0.029)
Far substitutes (6 to 14 years away)	---	---	-0.0075 (0.009)	-0.0273 (0.038)
# Obs.	154	520	1157	5388
# CUSIPS	23	91	23	128
Adj. R^2	0.39	0.43	0.94	0.46

Notes: The dependent variable is the daily percentage price change in each outstanding CUSIP. Only days when LSAP purchases occurred are included. The sample is limited to securities with less than 15 years of remaining maturity and more than 5 issues off the run. Standard errors in parentheses. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

Table 5. First Stage IV Regression for LSAP Purchases

Intercept	0.0043 (0.0053)
Remaining maturity	0.0018*** (0.0003)
Remaining maturity squared	-0.00006*** (0.000009)
Fitting error	-0.0008 (0.0047)
Fitting error squared	-0.0560*** (0.0147)
Average near-substitute fitting error	0.0050 (0.0080)
Average near-substitute fitting error squared	-0.1241 (0.1230)
Price	-0.00007 (0.00005)
On-the-run dummy	0.0045*** (0.0015)
"Old bond" dummy	0.0022 (0.0018)
# Obs	148
Adjusted R^2	0.525

Notes: The dependent variable is the total amount of each security purchased under the LSAP program, normalized by the total amount of Treasuries outstanding with remaining maturities within two years. All independent variables are as of March 17, 2009. Standard errors in parentheses. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

Table 6. Stock Effects

Full Cross Section of Price Changes (3/17 – 10/30/2009)

	Bonds < 15 years	Bonds > 15 years	Notes Far off-the-run	Notes Near-on the-run
Own Response	4.00*** (0.97)	3.18* (1.90)	4.57** (2.03)	1.06 (1.24)
Cross Responses Near substitutes (within 2 years)	0.04 (0.08)	0.10 (0.21)	0.01 (0.06)	0.17** (0.07)
Remaining maturity	-0.006*** (0.001)			
Remaining maturity squared	0.00006 (0.00004)			
Intercept	0.00005 (0.00169)			
# Obs	148			
Adj. R^2	0.786			

Notes: The dependent variable is the cumulative percentage change from March 17 to October 30, 2009. Regression is 2SLS with March 17-dated variables used as instruments. All purchase variables are normalized by the total quantity of near substitutes outstanding. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

Excluding Announcement Date

	Bonds < 15 years	Bonds > 15 years	Notes Far off-the-run	Notes Near-on the-run
Own Response	4.97** (2.15)	4.00 (4.22)	4.43 (4.52)	1.03 (2.76)
Cross Responses Near substitutes (within 2 years)	0.05 (0.17)	0.23 (0.48)	0.03 (0.13)	0.17 (0.16)
Remaining maturity	-0.012*** (0.003)			
Remaining maturity squared	0.00027*** (0.00009)			
Intercept	0.0058*** (0.0019)			
# Obs	148			
Adj. R^2	0.93			

Notes: The dependent variable is the cumulative percentage change from March 17 to October 30, 2009. is 2SLS with March 17-dated variables used as instruments. All purchase variables are normalized by the total quantity of near substitutes outstanding. Standard errors in parentheses. Asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) levels.

References

Babbel, D. F.; Merrill, C. B.; Meyer, M. F.; and de Villiers, M., 2004. "The Effect of Transaction Size on Off-the-Run Treasury Prices." *Journal of Financial and Quantitative Analysis* 39(3): 595-611.

Bernanke, B. S., 2009. "The Federal Reserve's Balance Sheet." Speech delivered at the Federal Reserve Bank of Richmond 2009 Credit Markets Symposium, Charlotte, North Carolina, April 3.

Bernanke, B. S.; Reinhart, V. R.; and Sack, B. P., 2004. "Monetary Policy Alternatives at the Zero Bound: An Empirical Assessment." *Brookings Papers on Economic Activity* (2): 1 – 78.

Bull, A., 2009. "FED Focus—Fed seen extending, not increasing Treasury buys." Thomson Reuters, June 16.

Cochrane, J. and Piazessi, M., 2005. "Bond Risk Premia." *American Economic Review* 95(1): 138-60.

Engen, Eric, and R. Glenn Hubbard. 2005. "Federal Government Debt and Interest Rates." In Gertler and Rogoff (eds.), NBER *Macroeconomics Annual* 2004. Cambridge, MA: The MIT Press.

Federal Reserve, 2008. Minutes of the Federal Open Market Committee, December 15-16, 2008. Washington, DC. http://www.federalreserve.gov/monetarypolicy/files/fomcminutes20081216.pdf

Federal Reserve, 2009. Minutes of the Federal Open Market Committee, January 27-28, 2009. Washington, DC. http://www.federalreserve.gov/monetarypolicy/files/fomcminutes20090128.pdf

Greenwood, R. and Vayanos, D., 2008. "Bond Supply and Excess Bond Returns." NBER Working Paper 13806.

Gurkaynak, R. S.; Sack, B.; and Wright, J. H., 2007. "The U.S. Treasury Yield Curve: 1961 to the Present." *Journal of Monetary Economics* 54(8): 2291-304.

Hakim, S. R. and Rashidian, M., 2000. "Testing for Segmentation in the Term Structure: Operation Twist Revisited." *Quarterly Journal of Business and Economics* 39(1): 3-21.

Han, B.; Longstaff, F. A.; and Merrill, C., 2007. "The U.S. Treasury Buyback Auctions: The Cost of Retiring Illiquid Bonds." *Journal of Finance* 62(6): 2673-93.

Holland, T. E., 1969. "'Operation Twist' and the Movement of Interest Rates and Related Economic Time Series." *International Economic Review* 10(3): 260-5.

Krishnamurthy, A. and Vissing-Jorgensen, A., 2007. "The Demand for Treasury Debt." NBER Working Paper 12881.

Kuttner, K., 2006. "Can Central Banks Target Bond Prices?" NBER Working Paper 12454.

Longstaff, F. A., 2004. "The Flight-to-Liquidity Premium in U.S. Treasury Bond Prices." *Journal of Business* 77(3): 511-26.

Stroebel, J. C. and J. B. Taylor, 2009. "Estimated Impact of the Fed's Mortgage-Backed Securities Purchase Program." NBER Working Paper 15626.

Svensson, L. E. O., 1994. "Estimating and Interpreting Forward Rates: Sweden 1992-4," NBER Working Paper 4871.

Tarhan, V., 1995. "Does the Federal Reserve Affect Asset Prices?" *Journal of Economic Dynamics and Control* 19: 1199-222.

Thornton D. L., 2009. "The Effect of the Fed's Purchase of Lon-Term Treasuries on the Yield Curve," Economic Synopses number 25, St. Louis Fed.

Warnock, F., and V. Warnock. 2009. "International Capital Flows and U.S. Interest Rates." *Journal of International Money and Finance* 28:

Yellen, J., 2009. Panel discussion for the Federal Reserve Board/*Journal of Money, Credit, and Banking* conference on "Financial Markets and Monetary Policy." Washington, DC, June 5.