

The Ins and Outs of LSAPs

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Large-scale asset purchases (LSAPs), also often referred to as quantitative easing (QE), are a tool first deployed in 2001 by the Bank of Japan, and then used more widely since the financial crisis by the Federal Reserve, European Central Bank and the Bank of England. The workings of LSAPs are far less well understood by both central banks and investors than the central banks' traditional tool of targeting the overnight interbank interest rate. Over the last few years, given their widespread use by central banks, there has been a surge of empirical and theoretical research that aims to shed light on the workings of LSAPs. In the first part of this paper, we draw from this literature, adding some new theory and evidence and explain the main channels through which LSAPs affect asset prices and the real economy. In the second part, based on our findings, we elaborate on the effects of the end of QE, either a cessation of purchases and/or the sale of the Fed's portfolio. We discuss which asset prices are likely to be most affected, the dynamics of these prices and the principal challenges the Fed will face in an exit.

The Findings of the First Part of Paper can be Summarized as Follows:

The portfolio balance channel of QE works largely through narrow channels that affect the prices of purchased assets, with spillovers

depending on particulars of the assets and economic conditions. It does not work through broad channels such as affecting the term premium on all long-term bonds.

For the U.S., purchasing mortgage-backed securities (MBS) has had a beneficial impact on asset prices through a capital constraints channel and a scarcity channel. During the crisis, this occurred because the risk premiums on MBS assets were particularly high due to distressed conditions in the intermediary sector feeding into illiquidity and high-risk premiums on MBS. We describe the effect of MBS purchases during this period of distress in terms of a capital constraints channel. There is now a theoretical literature that demonstrates that central bank purchases of assets whose prices are low because of distress in the financial intermediary sector can have beneficial effects (Curdia and Woodford 2011; Gertler and Karadi 2011; and He and Krishnamurthy 2013). Many researchers understand the Fed's MBS purchases during the financial crisis in these terms.

We describe and provide evidence for a new channel, the scarcity channel, which has been the dominant channel for MBS purchases over the last two years. MBS risk premiums came down substantially by 2011 as financial conditions stabilized, yet empirical evidence shows that MBS purchases by the Fed continued to have a beneficial effect in lowering MBS yields. This has occurred through a scarcity channel. The Fed's purchases of a substantial amount of the new issuance of MBS has led to a scarcity premium on the production coupon MBS (i.e., MBS backed by new mortgage originations), at times driving spreads on MBS relative to Treasury yields below zero. The scarcity of the production coupon MBS generates incentives for banks to originate more loans and relieve the shortage of the production coupon MBS. The lowering of secondary market MBS rates through both capital constraints and scarcity channels likely have had beneficial macroeconomic effects.

The Fed's purchases of long-term U.S. Treasury bonds significantly raised Treasury bond prices, but has had limited spillover effects for private sector bond yields, and thus limited economic benefits for the private sector. Investors have a demand for long-term safe assets that result in a safety premium on Treasury bonds. The safety premium is

driven by the economic benefit Treasury bonds provide as high-quality collateral and a long-term extremely safe (in nominal terms) store of value. The Fed's purchases of long-term safe assets reduce this supply and hence increase the safety premium on long-term safe bonds. While Treasury LSAPs lower long-term Treasury yields, they have ambiguous welfare effects. The primary beneficial effect of these purchases results from a spillover that raises the prices of private sector safe bonds (which are substitutes for safe Treasury bonds). However, due to the private sector's limited ability to produce long-term safe assets (i.e., Aaa corporate bonds are few), these beneficial economic effects are limited. Moreover, since the safety premium on Treasury bonds stem from the economic benefits they provide to investors, by reducing the supply of Treasury bonds, the economy is deprived of extremely safe and liquid assets and welfare is reduced.

We find little evidence of a broad channel through which purchases of long duration assets, both MBS and long-term Treasury bonds, reduce a duration risk premium (term premium) on all long-term fixed income assets. While the Fed has alluded to this channel in discussing the beneficial effects of QE, the empirical evidence is more consistent with narrow channels where asset purchases principally affect the price of the asset that is purchased. The impact on assets that are not purchased depend on a given policy's impact on the economy, for example through reduced credit risk lowering corporate bond yields. In addition, while in the data asset purchases may seem to have broad effects, we show that these broad effects occur for conventional reasons: the asset purchases convey a signal that monetary policy is likely to be easier going forward, which reduces investors' expectations of the path of the federal funds rate and thereby has a broad impact on asset prices.

We Evaluate the Impact of an Exit from QE in the Second Part of the Paper:

We present stripped-down dynamic models of the main portfolio balance channels that we identify to explain the effects of an exit. In all of the models, asset prices react immediately to the news of an exit. Thus to determine the impact of exit, we trace the effect on bond yields of unanticipated news of an exit, defined to include

a cessation of purchases, including reinvestment of maturing assets and a sale of the Fed's portfolio. For the sake of clarity, we study the consequences of exit under the assumption that the path of monetary policy is held fixed. For example, in contrast to the Fed, were the U.S. Treasury to sell long-term bonds, this sale would have no implications for the path of monetary policy. Thus our Treasury bond exit scenario is equivalent to analyzing the effect of news of increased issuance of long-term Treasury bonds.

Our models clarify when news of a sale of the Fed's portfolio and a cessation of Fed purchases are two points along a continuum of exit strategies. In both the MBS capital constraints channel and the Treasury bond scarcity channel, asset prices are a function of the expected stock of assets (MBS or Treasury bonds) held by the private sector. For example, suppose currently investors expect to be holding \$100 of MBS going forward, and this \$100 is based on expectations that the Fed will purchase a total \$50 of MBS going forward. Then, news that the Fed will stop purchasing MBS will affect market prices based on new expectations that investors will be holding \$150 of MBS going forward. Additional news that the Fed will sell its current portfolio, say of \$100 of MBS, will affect asset prices based on expectations that investors will be holding \$250 of MBS going forward. In these channels, the sale of the Fed's portfolio is just a larger "exit" compared to the cessation of purchases.

In the MBS scarcity channel, the model has a subtle and novel implication. Since current MBS prices depend on the expectations of the Fed's purchases of the production coupon MBS relative to its supply, news that the Fed will stop purchases has a different effect than news of the sale of the existing portfolio. Sales of higher coupon, older MBS from the Fed's portfolio will have minimal negative spillover effects. This is because these MBS in the portfolio do not have the same characteristics and hence scarcity as the new purchases of production coupon MBS. Thus in this channel if markets anticipate that the Fed is likely to cease its purchases, yields on production coupon MBS will rise immediately and independently of what the Fed does with its held portfolio. Dynamically, if the Fed tapers its purchases of MBS, the scarcity premium will gradually diminish

further. After the Fed ceases its purchases, this diminished scarcity premium will fully disappear as new loans are originated.

Under the capital constraints channel, news about either a cessation of purchases or sales of the Fed's portfolio will increase MBS yields. The effects will be immediate and persistent. Significantly, this channel implies spillovers to other mortgage securities with prepayment risk, such as jumbo mortgage rates, whereas the scarcity channel implies effects only on the agency mortgage rate.

To help think about the relative relevance of these effects, we present evidence that currently (as of 2013) the primary channel at work for MBS purchases is the MBS scarcity channel.

We then consider the effects of the exit from the Treasury bond QE. We argue that a sale or cessation of Treasury bond purchases will have minimal negative effects. While it will raise the rates on long-term Treasury bonds and affect financing conditions for the U.S. government, it will have limited negative consequences to private borrowers. This result is a corollary to our finding that the Treasury purchases themselves have had limited beneficial spillovers to private borrowers.

From this analysis of the mechanics of LSAPs, we conclude that an exit should proceed in the following sequence: The Fed should first cease its purchases of Treasury bonds and then sell down its Treasury portfolio. Second, the Fed should sell its higher-coupon MBS as this will have small effects on primary market mortgage rates. The last step is that the Fed should cease its purchases of current-coupon MBS as this tool is currently the most beneficial source of economic stimulus.

We next discuss the communication challenges in the LSAP exit. In all of the channels we study, asset prices react today to news of changes in the total expected future LSAPs. Indeed, one of the main distinguishing features of QE relative to traditional monetary policy is that QE entails buying assets of substantially longer maturity assets. Since the prices of long maturity assets are much more sensitive to expectations about future policy than short maturity assets, controlling these expectations is of central importance in the transmission mechanism of QE. Therefore, how an exit is communicated to investors matters greatly.

The Fed has been imprecise in its communication about LSAP policies. It has provided information about the quantity and timing of LSAP purchases under the modal forecast of the economy, with imprecise information about the state-dependence of policy. The Fed has chosen this communication strategy to retain flexibility given its partial knowledge of the transmission mechanism for LSAP policy.

There is a long-standing debate in monetary policy on the relative merits of state-contingent policy rules and discretion. With conventional monetary policy, this debate has been settled in favor of state-contingent policy rules. Likewise, LSAP policy actions can be communicated either through a rule or through unanticipated discretionary announcements. Without revisiting all aspects of the rules-versus-discretion debate, we note that the benefits of rules are likely higher for LSAPs than conventional monetary policy. This is because LSAPs target long-term bonds, whose prices are especially sensitive to expectations of future policy. Lacking clear guidance on the states that drive LSAP policy, investors will react to any information regarding the Fed's intentions over LSAPs. The large moves in asset prices around the June 19, 2013, FOMC meeting is evidence of the high sensitivity of prices to expectations regarding the evolution of LSAP policies. Asset price volatility is one drawback of the Fed's discretion strategy. Another drawback is that the Fed cannot tailor an exit. We have suggested an exit sequence, from Treasury bond sales to the cessation of MBS purchases. But, such exit steps cannot be precisely implemented in a situation where investors face uncertainty over the Fed's LSAP policy rule. Currently, with the Fed's discretion strategy, any exit step will be taken by investors as a signal of policymaker preferences, which can then have wider consequences. We argue that an example of this phenomenon can be seen in investors' response to the FOMC meeting on June 19, 2013. From June 18 to June 20, in response to information regarding LSAPs, investors revised their monetary policy forecast, expecting the Fed to tighten faster. This reaction underscores the potential benefits of offering an LSAP policy rule.

The paper proceeds as follows. Section I presents theory and empirical evidence for the primary channels through which QE has

worked. Section II expands the theory to clarify the dynamic response of asset prices to QE under the channels which we find to be the main ones of interest. Section III discusses implications of our findings on a QE exit.

I. QE and Portfolio Balance Channels

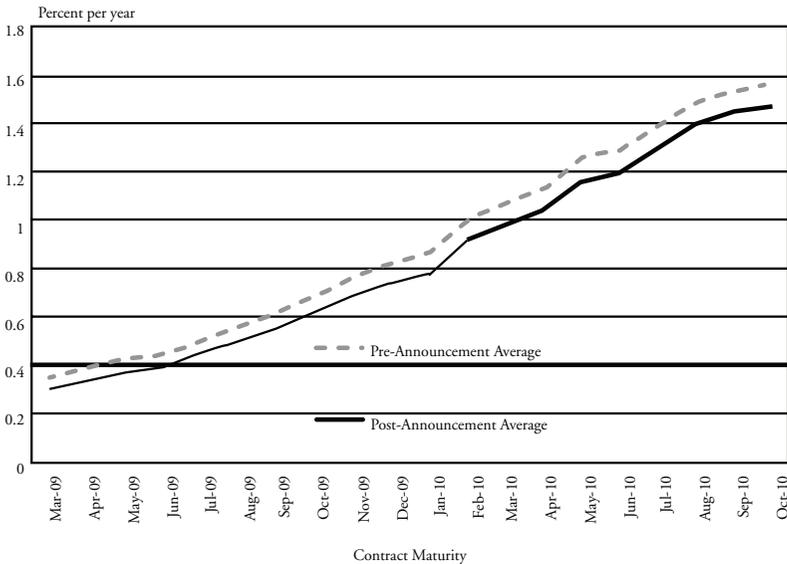
We describe the effects of asset purchases by the central bank, and how these effects depend on the type of asset purchased and the economic conditions under which the purchases take place. Broadly speaking, central bank purchases have been safe and liquid government debt and risky and less-liquid debt, either private or government. These purchases have taken place during periods of financial instability as well as more quiet periods. We primarily analyze the Fed's purchases of Treasury bonds and agency MBS, although we will discuss which of our conclusions accord with evidence from asset purchases by the Bank of England and Bank of Japan.

We focus on what many commentators describe as the "portfolio balance effect," which is how the purchase of a given asset pushes up the price of that asset and its substitutes. The portfolio balance effect is too generic a term to be useful for guiding policy decisions. We will be more specific and link asset price changes to specific theoretically motivated mechanisms of the portfolio balance effect.

1.i Signaling

Asset purchases have effects in addition to the portfolio balance effects.¹ They are often interpreted by investors as signals regarding the central bank's intentions over the path of the short-term interest rate (see Clouse, Henderson, Orphanides, Small and Tinsley 2000; Eggertson and Woodford 2003; and Woodford 2012). Chart 1 graphs the yields on the monthly federal funds futures contract, for contract maturities from March 2009 to October 2010, across a set of five LSAP event days (QE1) analyzed in Krishnamurthy and Vissing-Jorgensen (2011) (these dates were first studied by Gagnon, et. al., 2010, although they do not analyze the shift in the federal funds futures contracts). The pre-announcement average yield curve is computed on the day before each of the five QE1 events and then averaged across these dates. The post-announcement average yield

Chart 1
Yield Curves From Fed Funds Futures
Pre- and Post-QE1 Event Days



Source: Krishnamurthy and Vissing-Jorgensen (2011).

curve is computed likewise based on the five days after the QE1 event dates. The graph suggests that QE announcements delayed an anticipated rate hike cycle by the Federal Reserve, which is clear evidence of a signaling channel.² In fact, Krishnamurthy and Vissing-Jorgensen show that a considerable fraction of the movement in non-Treasury and non-mortgage yields (particularly default-adjusted corporate bond yields) can be explained through the change in market expectations over the rate hike cycle (see the implied signaling effects in Table 1, which are computed based on the methodology outlined in the Appendix).³

The signaling channel appears to be an important way in which LSAPs have affected long-term interest rates, as discussed by Woodford (2012). However, this point should not be overemphasized. There are additional effects of LSAPs on Treasury and mortgage yields even after stripping out these signaling effects. We are particularly interested in analyzing these other effects and under what conditions they are present.

I.ii QE That Purchases Mortgage-Backed Securities

We next discuss theory and evidence for a set of channels through which purchases of MBS or Treasury bonds have effects on asset prices beyond the signaling effect. Our main finding is that MBS purchases and Treasury purchases work through distinct channels, each having effects primarily on the asset purchased (i.e., MBS yields in the case of MBS purchases). The MBS purchases lower MBS yields because of capital constraints in the MBS market and because the Fed's purchases are concentrated in the production coupon MBS where the Fed's purchases create a shortage of the cheapest-to-deliver MBS. Our second finding is that Treasury purchases are likely less beneficial for the economy than MBS purchases. Finally, we do not find support for a broad channel whereby removing duration risk from the broad bond market reduces long-term interest rates. We begin by discussing the MBS channels and then turn to the Treasury channel.

Capital Constraints Channel

There has been a collection of recent papers demonstrating theoretically a role for LSAPs in the presence of capital constraints (see Vayanos and Vila 2009; Cúrdia and Woodford 2010; Gertler and Karadi 2010; He and Krishnamurthy 2013; and Del Negro, Eggertson, Ferrero and Kiyotaki 2013).⁴ For example, in the context of MBS, consider a setting in which a certain set of sophisticated investors (banks, dealers, asset managers) are the only investors in the MBS market (i.e., it is costly for new investors to enter the market) and these investors have limited access to capital, so that there are limits to arbitrage. Denote the Lagrange multiplier on their capital constraint as $\theta > 0$. This is an environment in which MBS yields will be inflated relative to an Arrow-Debreu complete markets benchmark in which MBS risks are broadly diversified across all savers. Moreover, if the capital constraint is tighter so that θ is higher, MBS returns will have to be commensurately higher to compensate sophisticated investors for their use of scarce capital.

This is also an environment where we can expect large sales or purchases of MBS to have significant effects on market prices. For example, suppose that a fraction of the MBS investors are in distress

and have to sell their assets. The remaining investors will have to absorb these sales with their limited capital. As the investors' limited capital has to be deployed toward absorbing the purchases, the Lagrange multiplier on the capital constraint will tighten, causing θ to rise. As a result, MBS prices will fall while yields or option-adjusted spread (OAS) will rise. This exercise in reverse, with the Fed purchasing MBS, is the channel through which LSAPs affect MBS prices in these models.

A key identifying feature of the environment where the capital constraints channel may operate is that asset risk premiums (i.e., expected returns) are high. In particular, this channel is likely to be particularly important for (1) assets that are complex, causing risk to be concentrated in specialized investors' portfolios; and (2) times where segmentation and capital constraints are high. For example, if capital constraints are slack, i.e., $\theta=0$, there will be no effects of an MBS purchase on prices. The economy then resembles the frictionless economy of Woodford (2012) where LSAPs have no effect on asset prices. On the other hand, if capital is scarce, as was likely in 2008-09, there will be effects on prices. While it is hard in practice to directly measure capital constraints, the connection between θ and MBS risk premiums offers an indirect way of measuring constraints. If risk premiums are high then capital constraints are likely to be tight and LSAPs should have a large effect on prices. This logic also offers a way of thinking about diminishing returns to LSAPs. In the capital constraints models, as LSAPs progressively lower MBS risk premiums, the marginal effect of a further LSAP also falls.

The MBS market fits the conditions necessary for the capital constraints channel. MBS are complex assets because their value depends on how households are expected to prepay mortgage loans. Most MBS investors have developed sophisticated models to assess this prepayment risk, and these models are a cost of entry into the market. As a result, MBS is held and traded primarily by sophisticated investors such as banks, hedge funds and other asset managers.

We note also that the U.S. Treasury market does not fit these conditions. We return to this discussion when discussing the

mechanisms through which the Fed's purchases of Treasury bonds have been effective.

Finally, the capital constraints channel is narrow compared to the signaling channel. Asset purchases can have effects precisely because the asset is traded in a narrow and segmented market. Nevertheless, spillovers may arise in this channel. First, to the extent that the LSAP lowers θ (i.e., strengthens intermediaries' balance sheets, relaxes capital constraints), other assets that are traded in a segmented market and concentrated in the portfolios of the MBS specialized investors will also rise in price. For example, if the specialized investors trade both agency MBS and non-agency MBS, then the Fed purchases of agency MBS can be expected to spillover to the prices of non-agency MBS. Second, there is a possible macroeconomic spillover. If the affected assets are central to economic activity, then the policy may have significant macroeconomic effects and this indirectly spills over to other asset prices. For example, in the context of MBS, the Fed often references the housing market as being important to the economic recovery. Note that conceptually the latter effect is through stimulating a particular sector of the economy rather than through an effect on a broad set of interest rates that apply to many sectors of the economy.

MBS Scarcity Channel

A second mechanism that has played a role in the effect of Fed purchases is a "scarcity" channel that arises because of the heterogeneity in the characteristics of mortgage loans. As we explain, we think this mechanism has been important in 2012 and 2013. For the most part, the literature on QE has not investigated the MBS scarcity mechanism.⁵ However, there are papers in the finance literature that study mortgage loan heterogeneity and its effect on MBS pricing (see Downing, Stanton and Wallace 2009; and Vickery and Wright 2010).

The Fed has purchased MBS in what is known as the to-be-announced market, or TBA. In a TBA trade, the buyer purchases a contract to take delivery of securitized mortgage loans at a future date, say one month from today. A unique feature of the contract is that the buyer does not know the actual identify of the securitized

mortgage loans that will be delivered when the contract is purchased. Instead, participants only agree on general parameters, such as the issuer, maturity, coupon, etc. The buyer only learns the actual parameters of the underlying loans 48 hours prior to the settlement date of the forward contract. This structure has evolved in the MBS market because it allows for liquidity out of a heterogeneous pool of underlying mortgage loans (see Vickery and Wright 2010). Vickery and Wright report that 90 percent of MBS trading volume concentrates in this forward TBA market rather than in trading of unique specified mortgage pools.

The TBA structure offers the seller a “cheapest-to-deliver” option. That is, a bank that has sold \$100 million in the TBA market and is due to deliver on this contract has a choice of what to deliver. If the bank has a portfolio of \$200 million of mortgage loans that all meet the parameters of the TBA contract, it will have an incentive to deliver the cheapest \$100 million of its loans, and retain the remaining \$100 million (cheapest for MBS will typically mean the securities that prepay most quickly). The Fed has been active in the TBA market, at times purchasing a large fraction of new issuance (see Hancock and Pasmore 2011 for estimates in 2009 and 2010). As the Fed purchases and takes delivery of an increasing volume of securities, market equilibrium dictates that the sellers will have to deliver better securities in the TBA trade. That is, following along the example, if the Fed purchased \$200 million of securities from the bank, then the bank would have to deliver all of its mortgage loans and not just the cheapest ones. But to be induced to do this, the price of the TBA contract has to rise. Effectively, as the Fed induces a high volume of TBA settlements, the cheapest-to-deliver securities become scarce, and more expensive securities are delivered, driving up the price of the TBA forward contract. Section II.i presents a formal model of this mechanism.

The scarcity mechanism operates through a narrow channel in which spillovers are limited. Securities purchased by the Fed that fit the parameters of the TBA contract rise in price. For example, MBS coupons that the Fed is not purchasing, or non-agency MBS that the Fed is not purchasing, will be unaffected by this scarcity

mechanism. However, all securities that meet the TBA parameters will rise in price. Note that the average production coupon securities not delivered in the TBA market will also be more valuable through a composition effect: As the cheapest-quality securities are delivered into TBA, the remaining securities reflect pools of better quality. Nonpublic data from an investment bank confirms that if one compares the pools of which the Fed has taken delivery to a matched pool of loans not delivered to the Fed, the Fed's pools prepay faster than the remaining pools.⁶ In the mortgage market, this faster prepayment speed is equivalent to a worse-quality pool.

Finally, under the scarcity mechanism, the shortage of the current-coupon MBS induces the private sector to create more of the scarce asset. That is, banks have an incentive to make new mortgage loans that are then deliverable into the TBA market to ease the shortage of the production coupon MBS.

Evidence That MBS Purchases Lower MBS Yields More Than Treasury Yields

Both the capital constraints channel and the MBS scarcity channel predict that MBS purchases should lower MBS yields, but should only affect other bond market yields through any impact on the macroeconomy.

Table 1 presents event-study evidence from four episodes of QE initiation, as well as an episode that increased the likelihood of exit from QE. We discuss the exit episode in detail in Section III.iv, and focus in this section only on the four QE initiation episodes. The first episode, QE1, begins with the Fed announcement on Nov. 25, 2008, that it intended to purchase \$500 billion of agency MBSs and \$100 billion of agency debt. This announcement was followed by others, culminating with the March 19, 2009, announcement of its intent to purchase up to \$1.25 trillion of agency MBS, \$200 billion of agency debt and \$300 billion of long-term Treasury bonds. The QE2 episode corresponds to Fed announcements that it would use principal payments received from its agency debt and agency MBS holdings to purchase Treasury bonds and would purchase an additional \$600 billion of long-term Treasury bonds, but no additional MBS. The

Table 1
Changes in Asset Prices Around QE1, QE2, MEP, QE3 and
Exit Event Dates^a

	Events				
	QE1	QE2	MEP	QE3	Exit
Asset Purchase News	MBS & Treasury	Treasury only	MBS & Treasury	MBS only	MBS & Treasury
<i>Treasury Yields (CMT)</i>	Basis points				
5-year	-74	-17	3	-6	24
10-year	-107	-18	-7	-3	21
30-year	-73	-9	-17	1	15
<i>Inflation Swaps</i>					
10-year	96	5	-4	4	-9
<i>Corporate Bonds^b</i>					
Aaa	-77	-9	-16	4	23
Baa	-81	-7	-15	0	28
Aaa CDS	-7	2			
Baa CDS	-40	2			
IG CDS 10-year			9	0	12
<i>Agency MBS^c</i>					
15-year	-88	-9	-7	-16	26
30-year	-107	-12	-23	-15	30
<i>Swaption vol^d</i>	-38	-3	2	-1	4
<i>Fed Funds Futures</i>					
12th month	-33	-4	0	0	3
24th month	-40	-11	-1	-3	15
<i>Implied Signaling Effect^e</i>					
5-year	-35	-18	0	-1	18
10-year	-20	-12	0	-1	13

- a. We give two-day changes for QE1 and Exit, and one-day changes for QE2, MEP, and QE3. Data for QE1 and QE2 are from Krishnamurthy and Vissing-Jorgensen (2011, 2012b).
- b. For QE3 and Exit, corporate yields are Barclays long-term bond index and CDS is from MARKIT.
- c. We report yield changes averaged across the FNMA, Freddie Mac, and GNMA production coupon MBS. For the 30-year MBS, we use the GNMA 3 percent, FNMA 3.5 percent and Freddie Mac 3.5 percent (for QE3 and Exit). For the 15-year MBS, we use the 2.5 percent coupon for all three securities.
- d. Swaption vol is the change in the BBOX index.
- e. Computation based on extrapolating movements in fed funds futures contract. See Appendix.
- Sources: Federal Reserve, Bloomberg, Datastream.

third episode corresponds to the maturity extension program (MEP) announced on Sept. 21, 2011, in which the Fed announced that it would extend the maturity of its portfolio by purchasing long-term Treasury bonds and selling off short-term Treasury bonds. A second important feature of this announcement is that the Fed surprised markets by announcing that it would reinvest principal payments from its holdings of agency debt and agency MBS in agency MBS. This latter news indicated further purchases of MBS. The last episode, QE3, is the Fed's announcement on Sept. 13, 2012, that it will purchase an additional \$40 billion of Agency MBS, monthly. This announcement was open-ended in that it indicated the purchases would continue until the labor market improved, within the context of price stability.

Each of these QE episodes reflects a different mix of securities purchased by the Fed. The QE1 and MEP episode involves purchases of MBS, agency debt and Treasury securities. The QE2 episode involves purchases of only Treasuries, while QE3 involves purchases of only MBS. This variation allows us to learn separately the effects of Treasury purchases and the effects of MBS purchases.

The first two of these episodes (QE1 and QE2) were analyzed and discussed in greater detail in our earlier paper, Krishnamurthy and Vissing-Jorgensen (2011). Here we highlight the most instructive evidence some of which is from the MEP and QE3, and confirm our initial understanding of the channels for LSAPs.

Consider the column corresponding to QE3, where the Fed only announces new purchases of MBS. For this event, 15-year and 30-year MBS yields decline by 16 and 15 basis points, respectively, with negligible effects on other bond yields. The limited spillovers to Treasury and corporate bonds are consistent with the narrow channels we have outlined for MBS purchases. Contrast this evidence with the QE2 evidence where the Fed does not purchase MBS. In this episode, the reduction in MBS yields is fully explained by the signaling effects (the 15-year MBS has duration of three years while the 30-year MBS has duration of seven years). The largest fall in this episode is in Treasury yields, which is the target of purchases in QE2, with

the 10-year Treasury bond falling by 18 basis points, more than what can be explained with signaling effects.

The QE3 evidence clearly indicates that LSAPs in which MBS is purchased affect MBS rates more they affect Treasury yields. Equally important, the QE2 evidence suggest that Treasury purchases have limited effectiveness in lowering MBS yields. The other two episodes also support these conclusions. The QE1 announcements lower 30-year MBS yields by 107 basis points. The 30-year MBS is an amortizing security, so its duration is shorter than 30 years and is closer to seven years during this period. The pure signaling benchmark (bottom lines of table) is between 20 and 35 basis points. Moreover as another benchmark, corporate bond yields, adjusted for changes in default risk using information from credit-default swaps, fall by 70 basis points (long maturity Aaa bonds) and 41 basis points (long maturity Baa bonds). That is, the reductions in MBS yields exceed the movements in general market interest rates.⁷

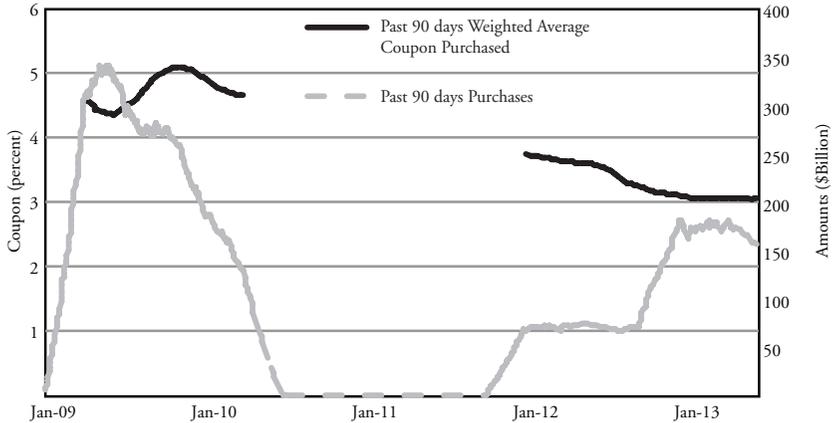
During the third episode (MEP), we see that the 30-year MBS yield falls by 23 basis points while the 10-year Treasury bonds only fall 7 basis points. The federal funds futures curve moves negligibly, suggesting almost no signaling effect. That is the effects on MBS yields are primarily driven by the expected purchases of MBS from the reinvestment of the agency and agency MBS portfolio. The fact that MBS move more than Treasury bonds indicates an MBS-specific effect of MBS purchases in line with the MBS channels we have described.

Evidence for Each of the MBS Channels

We next present evidence that suggest that both MBS capital constraints and scarcity channels have played a role in the effect of LSAPs in lowering MBS yields.⁸ Many papers, including our own past work, have ascribed the effects of Fed purchases on MBS yields to the capital constraints channel. We provide new evidence of the importance of the scarcity channel, especially since 2011.

Chart 2 presents data on the MBS purchases. We graph the amounts of MBS actually purchased, over a rolling 90-day window, as well as the weighted-average coupon of these past 90-days' purchases. Agency MBS securities are demarcated by different coupons, corresponding

Chart 2
Average Coupon and Amounts of Fed MBS Purchases over
Prior 90 Days



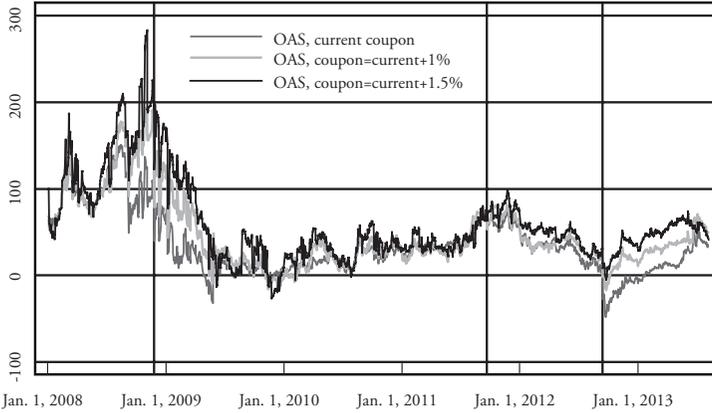
Source: Federal Reserve.

to the interest rate on the underlying mortgage loans. The Fed’s purchases have concentrated in the MBS whose coupons are near those of new mortgage loan originations. These securities are often called the current-coupon or production-coupon MBS. From the chart we can see the typical coupon targeted by the Fed’s purchases (Fed purchases are within a small range around this coupon). Although the Fed’s purchases are concentrated in the production coupon, the market trades a whole range of coupons, which over this period has meant MBS with coupons from 2.5 percent to 7.5 percent.⁹

Chart 3 graphs the option-adjusted spreads (OAS) on Fannie Mae MBS, across three of the coupons traded from January 2008 to June 2013. We define the “production coupon” to be the MBS whose coupon is closest to its yields.¹⁰ Thus the underlying MBS labeled the production coupon changes over the sample. We also plot the OAS for two higher coupon MBS. The vertical lines indicate the beginning of QE1 (Nov. 25, 2008), MEP and QE3.

The OAS is a model-based measure of the risk premium on MBS over the Treasury curve that is computed based on assumptions regarding prepayment risk.¹¹ The OAS we present is based on the model of one investment bank. Because prepayment assumptions

Chart 3
Option-Adjusted Spreads (OAS Relative to Treasuries), In Basis Points, on FNMA MBS January 2008 to June 2013



Source: OAS estimates from Investment Bank.

differ across models, different banks will compute different OAS. In addition, because it is a model-based measure, one should not over-interpret high frequency variation in the OAS. There are some sharp ups and downs in Chart 3 that are likely due to model error and not risk premium variation. Subject to those caveats, our investigations suggest that the broad patterns presented in Chart 3 are similar across different models' OAS and we focus on these broad patterns.

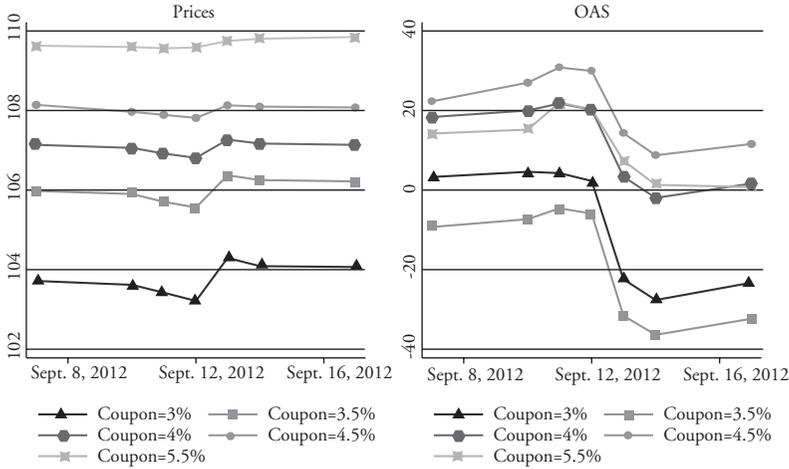
The two noteworthy patterns are that (a) the OAS were high in the fall of 2008 and came down substantially to near zero by the summer of 2009 (Hancock and Passmore 2010 also find this pattern); and (b) the OAS fall to near zero, with the current-coupon becoming occasionally negative, beginning just after the QE3 announcement in 2012.

There is a large body of evidence from the 2008-09 crisis showing that capital constraints affected many asset markets, including the swap market, the CDS market, and the exchange rate market, among others (see, for example, Krishnamurthy 2010). From this standpoint, it is likely that these effects were also present in the MBS market. Thus the fact that the OAS were high in fall 2008 is consistent with an environment where the capital constraints channel operates. Furthermore, in Chart 3 we graph the evolution of the OAS

across different coupons. The higher coupon securities have a higher OAS because they have higher prepayment risk. Note that all of these OAS fall over this period. Moreover, the spreads between high and low coupon OAS falls, indicating a smaller risk premium demanded by investors for bearing prepayment risk. On the main event date of QE1, Nov. 25, 2008, when bond yields move the most, the OAS across all of the coupons fall, and not just the MBS purchased by the Fed. The evidence is more mixed in the other QE1 event dates, but the market moves are smaller on these dates, and the OAS model specifications issues likely affect high-frequency inference. Subject to this caveat, this spillover effect is consistent with the capital constraints channel for MBS purchases, but not with the scarcity channel. To summarize, the capital constraints channel operates when OAS are high and predicts that LSAPs will lower these risk premiums as well as compress the OAS across the coupon stack. The 2008-09 data is consistent with these predictions.

The low and sometimes negative risk premiums in 2012 are inconsistent with the capital constraints channel, and instead suggest a scarcity channel environment. The scarcity channel further predicts that LSAP effects should primarily be present in the production coupon MBS that the Fed targets. LSAPs will create a divergence in the risk premiums across the coupon stack, in contrast to the convergence prediction of the capital constraints channel. Chart 4 plots the market prices of the MBS across the coupon stack over the days surrounding the Sept. 13, 2012, announcement of QE3. Market prices are not subject to the model specification issues that arise with the OAS (although, the effects present over this episode are so significant that the OAS evidence also shows that production coupon MBS moves the most).¹² The chart reveals the clear difference between the low-coupon and high-coupon mortgages. The 3-percent coupon MBS rises in price by almost 1 percent over this period (roughly the 16-basis-point change in yield presented in Table 1), while the 5.5-percent coupon MBS does not change in price. A possible objection to our inference is that the low- and high-coupon MBS have different durations (e.g., the 5.5-percent coupon has duration of about three-and-a-half years, compared to the seven years of the 3-percent coupon). However, note that broad market interest rates, from Table

Chart 4
Prices and OAS of FNMA MBS, by Coupon,
Around Sept. 13, 2012 Announcement

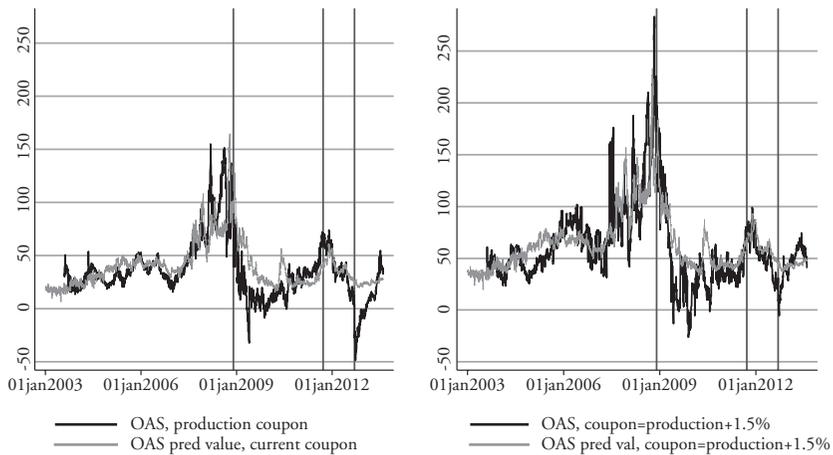


Source: Investment Bank.

1, do not move much over this period. That is even though the duration of the high-coupon MBS is lower than that of the low-coupon MBS, the fact that general market discount rates do not change implies that duration should not be a factor in explaining these bond price changes. Indeed, the fact that the prices of the high-coupon MBS do not change is consistent with this explanation.

Chart 5 provides one more piece of evidence consistent with the scarcity channel. We estimate regressions of the OAS of the current-coupon MBS and the current-coupon+1.5 percent on the one-year swap spread to proxy for time-varying risk premiums that may be relevant to MBS pricing. We estimate the regression over a sample from Aug. 7, 2003, to October 2008.¹³ We use this regression model to predict the OAS over the crisis period beginning in November 2008, focusing on the difference between the actual OAS and the predicted OAS as a simple gauge of the “overpricing” of the MBS. The left panel of Chart 5 corresponds to the production coupon. The predicted values are significantly above actual values in the QE3 period consistent with the scarcity premium in prices we have discussed. The graph also shows a scarcity premium on the production coupon during the QE1 period. That is, both the scarcity and the capital

Chart 5
OAS and Predicted-OAS, in Basis Points, on FNMA MBS



Sources: Investment Bank, Federal Reserve.

constraints channel likely operated in the QE1 period. The caveat here is that the OAS models during the QE1 period were likely misspecified given the unprecedented events over the 2008-09 period. The right panel of the chart corresponds to an MBS 1.5 percent over the production coupon. There is some overpricing during the QE3 period, but less than for the production-coupon series, consistent with the scarcity channel. There is also some evidence of overpricing in the QE1 period, subject to the misspecification caveat.

Economic Benefits of MBS Purchases

Under both the capital constraints and scarcity channels, the Fed's purchases of MBS lower the yield on secondary market production MBS. Under the capital constraints channel, even yields on non-agency MBS such as jumbo mortgages may fall since this channel implies greater spillovers. The yield on the production MBS is an important factor in determining the cost to a bank of making a new agency-securitizable mortgage loan. Thus the fall in the yield on the production MBS that we have documented should affect the interest rate on new mortgage loans, which can have a beneficial effect on the housing sector. Hancock and Passmore (2010) and Fuster and Willen (2010) discuss these issues thoroughly and show evidence of effects on primary market mortgage rates. One issue that some

observers have commented on is that the pass-through from secondary market MBS rates to primary market loan rates has been less than one for one (see Fuster, Goodman, Lucca, Madar, Molloy and Willen 2012). The reasons for this are not yet clear, although some researchers have pointed to market power by banks (see Scharfstein and Sundaram 2013).

I.iii Treasury Bonds

There is considerable evidence, from our work as well as other researchers' work, that the Fed's long-term Treasury bond purchases reduce Treasury yields. We discuss some of this evidence below.

The more difficult issue in evaluating the Fed's Treasury bond purchases is how to interpret the evidence in terms of specific underlying portfolio balance mechanisms.

The evidence certainly cannot be interpreted in terms of the capital constraints channel. This channel requires that the Treasury market reflects a risk premium over other asset classes, that the Treasury market be illiquid and that entry of new investors into this market be costly. None of these statements fits Treasury bonds. During the financial crisis, Treasury bond yields fall relative to other benchmarks (see Krishnamurthy 2010), so that the premium on Treasury bonds is likely negative. At the peak of the financial crisis in fall 2008, three-month Treasury yields fell to near zero, while other benchmarks such as the federal funds target or the three-month OIS were near 2 percent. Longer-term Treasury bonds also benefitted from a flight to quality during fall 2008, with two- and five-year bond yields falling by nearly 1.5 percent relative to other benchmarks such as the FNMA agency debt (i.e., FNMA non-MBS debt). Furthermore, almost all measures of liquidity in the Treasury bond market place this market among the most liquid in the world, far more liquid than either the stock market or the corporate bond market. For example, an asset market liquidity comparison presented in the IMF's Fall 2012 Global Financial Stability Review puts the annual turnover of the Treasury market at 14.2, while equities are 1.2 and corporate bonds are 0.5. Finally, there is no evidence that capital faced impediments to enter the Treasury market during the crisis. For example, Krishnamurthy,

Nagel and Orlov (2013) report that repo haircuts on Treasury securities remained stable over the financial crisis, while haircuts on other bonds rose over the crisis.

Safety Premium (Asset Scarcity) Channel

We argue in Krishnamurthy and Vissing-Jorgensen (2012a) that investors have a special demand for liquid and safe assets such as Treasury bonds. Given a limited supply of such assets, investors' demand induces a convenience yield or scarcity premium in the pricing of these assets. The key identifying feature of the scarcity channel is that the price of the scarce asset will be inflated relative to other benchmarks, or equivalently, its yield will be lower than benchmarks. This feature is in line with the flight to safety phenomena often associated with U.S. Treasury bonds.

The safety dimension of the theory requires further explanation. Krishnamurthy and Vissing-Jorgensen argue that assets offering an almost sure promise of nominal repayment are especially valuable because they are used as collateral in financial transactions (e.g., derivatives, repo) with very low haircuts and because for regulatory, institutional, or informational reasons certain investors have investment needs that can only be satisfied by holding safe assets (e.g., insurance companies, foreign central banks, some institutional investors, unsophisticated retail investors). Note that long-term Treasury bonds have low haircuts, similar to short-term Treasury bonds, indicating that they are perceived as good collateral.

The scarcity channel predicts an effect of QE on Treasury bonds. To the extent that LSAPs reduce the supply of safe/liquid assets in the hands of the private sector, they can be expected to increase the convenience yield on Treasury bonds and hence raise Treasury bond prices/lower their yields. Moreover, spillovers to the other assets are limited to bonds that are also viewed by investors as extremely safe assets. That is the scarcity channel for Treasury bonds is also a narrow channel, similar to the mortgage channels we have discussed.

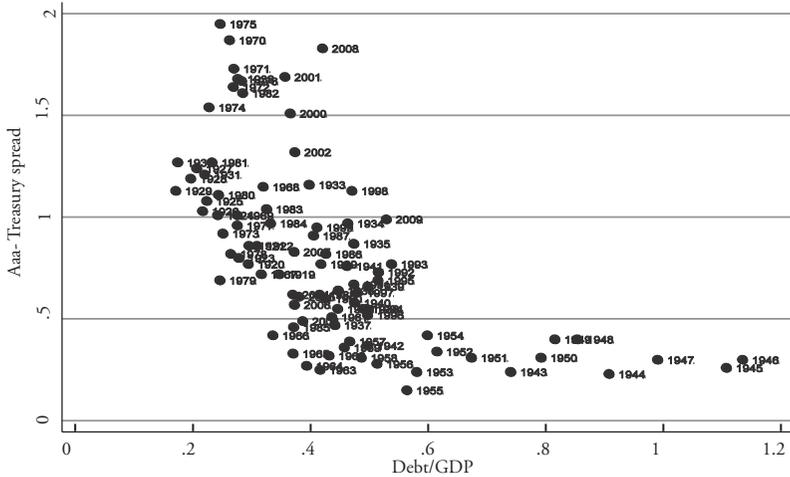
There is one subtlety in thinking through QE and the Treasury bond scarcity channel. It is possible that the Fed's purchases merely swaps one type of safe/liquid asset (e.g., bank reserves or short-term

Treasury bills) for another that is equivalently safe/liquid (e.g., long-term Treasury bonds). In this case, QE does not affect the total supply of scarce safe/liquid assets, and hence there should be no effect on Treasury bond yields. For QE to affect scarcity premiums, they must shrink the supply of scarce assets. There are two possible ways that this may happen in practice. First, investors may have a maturity-specific demand for safe assets. That is, a 10-year safe bond is not a substitute for one-year safe bond in the eyes of investors. Certain investors such as insurance companies have date-specific demands for cash-flows arising from their contracted obligations. Thus, a swap of long-term Treasury bonds for short-term Treasury bills or bank reserves should be expected to have an effect on the convenience yield on long-term Treasury bonds. Second, it is likely that bank reserves and Treasury bonds provide convenience for a different set of investors. Since bank reserves are only held by commercial banks they provide liquidity/safety services only to commercial banks. To the extent that Treasury bonds provide these services to noncommercial bank investors, removing Treasury bonds and replacing them with bank reserves reduces the supply of convenience assets held by nonbank investors. We will provide evidence for this maturity specific safety demand below.¹⁴

Evidence That Treasury Bond Purchases Lower Treasury Yields More Than Other Yields

We discuss evidence in favor of the scarcity channel from studies of time series variation in the outstanding amount of Treasury bonds and from event studies. The main prediction of the scarcity channel is that Treasury bonds carry a convenience premium and changes in the supply of Treasury bonds, induced for example either by LSAPs or by issuance of the U.S. Treasury, will then change the convenience premium. A way to think about this prediction is to graph the price of a defaultable bond against default risk. This slope, under the Treasury scarcity channel, is very steep near zero-default-risk, over and above the negative relation implied by a standard pricing model. Furthermore, the slope of this curve near zero-default-risk is decreasing in Treasury supply. This latter prediction generates a negative relation between the corporate-Treasury bond spread and Treasury supply (at

Chart 6
Spread Between Aaa Corporate and Treasury Bonds Versus U.S. Debt/GDP Ratio



Source: Krishnamurthy and Vissing-Jørgensen 2012a.

a given level of corporate bond default risk) and is how to distinguish the safety explanation from a standard bond pricing explanation (Figure 1 in Krishnamurthy and Vissing-Jørgensen 2011 illustrates this relation).

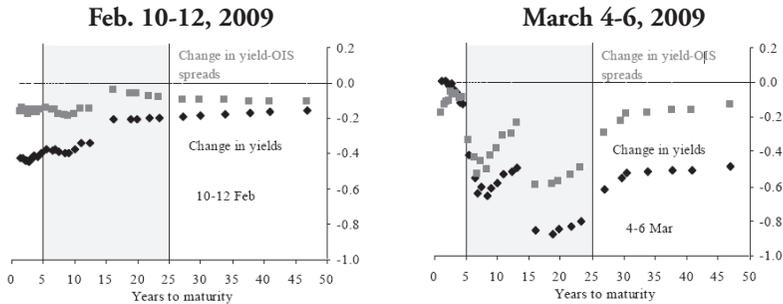
Chart 6 is from Krishnamurthy and Vissing-Jørgensen (2012a) and provides visual evidence in favor of this hypothesis by exploiting low frequency variation in U.S. Treasury issuance. The chart plots the spread in yields between Aaa rated corporate bonds and Treasury bonds against the supply of outstanding U.S. Treasury bonds normalized by GDP, annually from 1919 to 2008.¹⁵ Interpreting a portion of the Aaa-Treasury spread as reflecting a convenience yield, the chart shows that reductions in the supply of Treasury bonds increase the convenience yield. The relation is not altered by controlling for the default risk of corporate bonds. Thus the chart is evidence that (a) Treasury bonds are overpriced relative to corporate bonds due to a scarcity premium; and (b) reductions in the supply of Treasury bonds increase this scarcity premium (lowering the yield).

Joyce, Lasaoa, Stevens and Tong (2011) present evidence that long-term Treasury bonds are not substitutes for short-term bonds,

which is an ingredient necessary to see effects of QE. These authors study a set of dates in 2009 and early 2010 associated with Bank of England announcements of purchases of U.K. government bonds. On Feb. 11, 2009, the Inflation Report and the associated press conference gave a strong indication that the Bank would do QE. Markets interpreted this to mean that the Bank would purchase bonds out to around 15 year maturity bonds. On March 5, 2009, the Bank announced that purchases would be in the five to 25 year range. Figure 4 of their paper shows that the yields on government bonds in the announced purchase range (i.e., maturities targeted for purchase) fall substantially relative to benchmark OIS yields while the differences in the nonpurchase range are much smaller. We reproduce the relevant panels from their paper in Chart 7. The left panel shows the market reaction to the February announcements. Yields fall, with the largest changes out to 15 years. Also plotted is the yield-OIS spread change, attempting to strip out signaling effects. These spreads show the effect on U.K. gilts in the expected purchase range. The right panel shows market reaction to the March announcement. The effect is concentrated in the five to 25 year range, which the Bank indicated as the target of QE purchases, with yields in the 15 to 25 year range falling dramatically on news that these maturities would also be purchased.

D'Amico, English, Lopez-Salido and Nelson (2012) have another example of the maturity specific effect (see Figure 3 of their paper). They study Treasury bond yields around the Aug. 10, 2010, FOMC meeting. The statement from that meeting suggested that the FOMC would invest in longer-term Treasury securities, which was taken by the market to mean all long-term Treasury bonds. But the statement was clarified later in the day to indicate that the investment would be concentrated in two- to 10-year maturity Treasury bonds. The authors present data on a sample of Treasury bonds with maturity around 10 years and around 14 years. Both the 10-year and the 14-year bonds rise in price upon the initial announcement. Upon the second announcement, the prices of the 14-year bonds fall, reversing two-thirds of the initial price run-up. The bonds with maturities of just less than 10 years experience a reversal of only about 20 percent

Chart 7
Yield Changes by Maturity from U.K. QE for U.K. Gilts and Gilt-OIS Spreads (percent)



Source: Joyce, Lasaosa, Stevens and Tong 2011.

of the initial price run-up. Thus, the net effect is that bonds that are targeted rise in price substantially more than other bonds with maturities not that far apart. D’Amico et al. present detailed evidence of this nature, based on differences between expected purchases of a given maturity of bond and the actual purchases of the bond, and find that there are large effects on the bonds purchased.

The evidence from Joyce et al. and D’Amico et al. is also interesting because it shows that LSAPs mostly affect the price of the asset purchased, as we have emphasized (these authors call this a “local supply” effect). In their evidence, even within the Treasury market, the bonds that are targeted for purchase see their prices rise the most. That is, the evidence cuts against theories that suggest significant spillover effects from LSAP purchases.¹⁶

Evidence Against a General Duration Risk Premium Channel

The portfolio balance channels we have discussed for both MBS and Treasury QE have narrow effects, limited to the assets purchased with spillovers to others assets depending on circumstances. The Fed in public statements has discussed these types of narrow effects (see for example, Bernanke 2012, or Stein 2012). Federal Reserve Bank of San Francisco President John Williams, in comments to the press and consistent with our findings, states that “the evidence shows pretty convincingly that MBS purchases have had the biggest bang

for the buck on private borrowing rates in the economy” (Reuters, May 16, 2013). Other statements by the Fed additionally emphasize that LSAP policy works in broader ways. For example, the FOMC statement from March 18, 2009, says that “to help improve conditions in private credit markets, the committee decided to purchase up to \$300 billion of longer-term Treasury securities.” The Fed often suggests that the Treasury purchases work by removing long-duration assets in the hands of the private sector and causing the risk-premium the private sector charges for bearing duration risk to fall (see, for example, Yellen 2012). To the extent that the duration risk premium applies when discounting any long-term cash flow, whether coming from a mortgage or a corporate loan, this mechanism describes a broad channel.

The event-study evidence from Table 1, especially on QE3, cuts against the view that LSAPs lower term premiums broadly. In QE3, the Fed announced purchases of MBS. The 30-year agency MBS has duration of about seven years. Under the broad duration channel, this purchase should have reduced the interest rate on all long duration bonds. In Table 1, the MBS rates fall by 15 basis points, while other long-term bond yields move negligibly. The evidence is more consistent with the narrow channels we have discussed.

There is further evidence along these lines in Table 1, especially when considering the impact of LSAPs on the typical corporate bond borrower, the Baa credit. From Table 1, we see that in QE1 Baa bonds fell in yield by 81 basis points. However, 40 basis points of this fall is due to a reduction in the default likelihood of a Baa borrower, presumably due to the macroeconomic improvement expected by the Fed’s purchase of MBS and lowering of short-term rates. Thus, the default adjusted Baa bond fell 40 basis points. This reduction can be largely explained by the signaling effect of 20 to 35 basis points. Thus, it appears that over the QE1 period, the impact of Treasury purchases via a portfolio balance channel do not extend to a lower risk corporate bond borrower. The same pattern is evident in QE2. The movements in Baa yields, with or without CDS adjustment, along with mortgage yields are largely explained by signaling effects. The portfolio balance effects only occur for Treasury bond yields.

In addition to this empirical evidence, the theory on the effect of LSAPs is more consistent with narrow channel effects.¹⁷ Under the capital constraints channel, for LSAPs to affect term premiums broadly, the entire fixed income market must be segmented. This is an unusually strong assumption to extend to a market of over \$20 trillion in size. Another possible channel for the effect of LSAPs on term premiums is the maturity-specific bond scarcity channel. Under this channel, QE can have an effect if there are significant clienteles who are willing to pay a convenience yield for investing in long-term bonds, and there is a scarcity of such bonds. However, empirically there is no evidence for clienteles for all long-term fixed income assets. Rather, there is a growing literature emphasizing the importance of shortages of long-term safe assets in the world economy (see Caballero, Farhi and Gourinchas 2006; Caballero and Krishnamurthy 2008). We discussed above the evidence from Krishnamurthy and Vissing-Jorgensen (2012a) in favor of a clientele for long-term safe assets. The corporate bond pricing literature has pointed to the importance of convenience yields in pricing safe corporate bonds, but not risky ones (typically bonds rated Baa and below). See Longstaff, Mithal and Neis (2005). Thus, both theory and empirical evidence shows that LSAPs do not substantially affect broad market long-term interest rates via a duration risk premium channel.

Economic Benefits of Treasury Purchases

The welfare benefits of Treasury LSAPs under the safety scarcity channel are ambiguous. If Treasury bonds are valued because they offer unique convenience services, then reducing their supply may actually reduce welfare (see Krishnamurthy and Vissing-Jorgensen 2012b). This argument is a variant of the well-known Friedman rule (Friedman 1969). However, the issue is more complex when other private sector assets also offer convenience services. In this case, the reduction of Treasury supply lowers the yield on all convenience assets including private sector convenient assets. Since the private sector then has an incentive to supply more of the convenient asset, the LSAP can stimulate private issuance of convenience assets and private economic activity.

There is evidence of spillovers to private assets, but this is limited to high-grade bonds such as Aaa bonds. Moreover, note that the supply of Aaa rated corporate debt is small, so that these spillover effects likely have a limited beneficial effect on the economy.¹⁸ In Krishnamurthy and Vissing-Jorgensen (2012) we show, using the same data underlying Chart 6, that reductions in the supply of Treasury bonds decrease the yield on Aaa corporate bonds relative to Baa bonds. This evidence suggests that Aaa rated bonds also help satisfy investors' demand for long-term safe assets and thus carry a convenience yield.

II. Expectations and LSAPs

The event-study evidence we have provided in the previous section is based on announcements regarding future LSAPs. That is, they reflect price reactions today to expectations over LSAPs.¹⁹ In this section, we discuss how expectations of asset purchases affect asset prices currently in the capital constraints markets and the asset scarcity channels we have outlined as being the principal portfolio balance channels. We clarify a few questions in each of these channels:

- a. How does unanticipated news that changes the total expected purchases (or sales) by the Fed affect asset prices today?
- b. How does the timing of expected purchases (or sales) by the Fed affect the path of asset prices going forward?

Capital Constraints Channel

Consider an MBS whose price at date T is denoted P_T . Consider time $T-1$. The return on purchasing the bond at P_{T-1} and selling at P_T is (assuming zero coupons for simplicity),

$$R_T = \left(\frac{P_T}{P_{T-1}} - 1 \right)$$

If the expected return is large, an investor will use its capital, accounting for the fact that it may be scarce, borrow via the repo market, and take advantage of the return.²⁰ If capital is scarce, then the MBS investor will require a return commensurate to θ_{T-1} to do this trade. Thus, it also follows that the expected return is closely related

to the Lagrange multiplier θ_{T-1} . Let us for the sake of simplicity assume a parametric form that,

$$E_{T-1}[R_T] = r + \theta_{T-1},$$

where r is a benchmark discount rate. Then it follows that,

$$P_{T-1} = \frac{E_{T-1}[P_T]}{1 + r + \theta_{T-1}}$$

Iterating backward one more step it is easy to see that,

$$P_{T-2} = \frac{E_{T-2}[P_T]}{(1 + r + \phi_{T-1})(1 + r + \phi_{T-2})}$$

and so on to any date $t < T$.

Asset purchases affect the Lagrange multiplier θ_t . By purchasing risky MBS, the Fed removes risk (i.e., prepayment risk, credit risk, real estate exposures) from the balance sheet of specialized investors and frees up scarce capital. Denote the total quantity of risky assets with mortgage-like exposure held by specialized investors as Q_t , and denote the riskiness of each asset as σ_t . Then the multiplier is some increasing function,

$$\theta_t = \theta(Q_t \sigma_t).$$

At time $T-2$, an unanticipated announcement that an LSAP will occur at time $T-1$ will be expected to lower θ_{T-1} and hence cause P_{T-1} to rise. Even if there is no LSAP at $T-2$, the price P_{T-2} rises simply because the MBS is a long-lived asset and prices of long-lived assets are forward looking functions of future expected returns.²¹

This simple model tells us that the prices of MBS depend on the present and expected future stock of $\{Q_t \sigma_t\}$ held by the specialized investors. In answer to question (a), today's price depends on the expectations of all future LSAPs (a "stock" effect). And, announcements that change investors' expectations of LSAPs change prices today by affecting this stock. In answer to question (b) the timing of purchases matters to the extent that it affects how much of a given bond's "life-time" is affected by Fed intervention. Specifically, if the Fed executes

a large LSAP at T , θ_T falls which affects the expected return between T and $T+1$, but the LSAP has persistent effects on expected returns since $\theta_T, \theta_{T+1}, \theta_{T+2}$, etc. all fall as long as the Fed does not reverse the LSAP. Importantly, realized price changes (and realized returns) will react mainly upon announcement, with only smaller changes later as expected returns change as a function of the path of Fed holdings.

Treasury Bond Scarcity Channel

The logic of the above model carries over almost exactly to the Treasury bond channel, with an appropriate redefinition of θ_t . If Treasury bonds are scarce, investors are willing to overpay for these assets, or equivalently, accept a lower return to hold them. Denote the convenience yield on safe/liquid assets as ϕ_t . The convenience yield is a decreasing function of the total stock of safe/liquid assets Q_t ,

$$\phi_t = \phi(Q_t).$$

Since investors are willing to forgo returns to own these assets,

$$E_{T-1}[R_T] = r - \phi_{T-1},$$

where r is a benchmark discount rate. Then it follows that,

$$P_{T-2} = \frac{E_{T-2}[P_T]}{(1+r+\phi_{T-1})(1+r+\phi_{T-2})}$$

Once again we conclude that any announcement that changes expectations of future LSAPs move prices today and that the path of expected returns depend on the path of the stocks (after Fed purchases) of liquid/safe assets, $\{Q_t\}$. The answers to the two questions are the same as for the capital constraints channel.

MBS Scarcity Channel

Things change in the MBS scarcity channel, and in particular, the stock of assets expected to be held by investors is not the primary factor driving prices. Instead, the expected amount of purchases by the Fed relative to the supply of new production coupon MBS originated is the critical factor.²² Consider at date T the supply of MBS that are available for delivery into the production coupon TBA where the Fed concentrates its purchases. There are M_T total MBS, but each

has different prepayment characteristics and hence valuations. Without loss of generality we order the MBS from low to high valuation and denote the value of m -th MBS as $V_T(m)$. Suppose that the Fed purchases X_T of these mortgages. Then to be induced to deliver the marginal mortgage, we must have that,

$$P_T = V_T(X_T)$$

The function $V_T(m)$ is a supply curve for the current-coupon MBS. As the Fed purchases more TBA contracts, it rides up this supply curve, pushing prices up.^{23, 24} This is the scarcity mechanism we have described earlier.²⁵

Next, consider date $T+1$, in order to clarify how prices depend on the timing of purchases and total expected purchases. The supply at $T+1$, $V_{T+1}(m)$, increases with new loan originations and is reduced based on deliveries at T . If the Fed purchases X_{T+1} of these new mortgages delivered at $T+1$, then to be induced to deliver the marginal mortgage, we again have $P_{T+1} = V_{T+1}(X_{T+1})$, so that if X_{T+1} is high, then P_{T+1} rises.

Suppose at T there is an unanticipated announcement that X_{T+1} will be high (the news reveals X_{T+1} with certainty at T). If an investor anticipates a high price for delivering MBS next period, then the investor will not deliver at T and instead deliver at $T+1$. The reduction in delivery at T , shifts $V_T(X_T)$ inward. This logic implies that the price P_T is increasing in both X_T and X_{T+1} . The fact that an MBS holder can wait to deliver MBS causes future price increases to be immediately reflected in today's price through the inequality,

$$P_T \geq \frac{E_T [P_{T+1}]}{1+r}$$

If we roll this back one more date, then,

$$P_{T-1} \geq \frac{E_{T-1} [P_T]}{1+r}$$

Thus, in answer to question (a) today's price reflects the expectation of all future Fed purchases, rather than the stock of MBS

expected to be held by investors. Announcements that change the market's expectations of total future purchases are impounded into the current MBS price.

In addition to this effect based on the expectation of total future purchases, it is possible that an unusual amount of purchases, X_T raises prices so that $P_T - \frac{E_T[P_{T+1}]}{1+r} > 0$. This occurs in a situation when supply is tight at time T , but there are expected to be new loan originations that will relax the tight supply at $T+1$. Even though prices are expected to fall in the next period, this does not lower today's prices because the expected supply is not available for time T delivery.²⁶ Therefore, in answer to question (b), timing matters in that a large LSAP today can increase today's price in a way that may be disconnected from tomorrow's price.

Summing up, the commonality across all of the mechanisms described is that future LSAPs affect prices today, even if today is a date where no LSAPs are executed. In both the MBS capital constraints channel and the Treasury bond scarcity channel, asset prices are a function of the expected stock of assets (MBS or Treasury bonds) held by the private sector. The LSAPs affect prices through changes in the expected amount of this stock. In the MBS scarcity channel current MBS prices depend on the expectations of the Fed's purchases of the production coupon MBS relative to its supply. So it is changes in this expectation that affects asset prices.

Finally, we discuss whether or not LSAPs have permanent effects under these channels. In the capital constraints channel, if markets anticipate a reduction in $\{Q_t \sigma_t\}$ that will never be reversed—i.e., a permanent LSAP—then prices will be permanently affected. The one caveat here is that the capital constraints channel only operates if capital market frictions remain significant. If investors anticipate that at some date in the future, financial conditions normalize so that θ equals zero, then the future marginal effect of LSAPs also goes to zero. Since this is likely to be the empirically relevant case, the effects of LSAPs eventually disappear as private capital moves into the segmented market and risk premiums fall.

In the MBS scarcity channel, the LSAP effects are also likely to eventually disappear. That is, if the Fed purchased a large fraction of MBS over some period of time and then stopped, for some time after the purchases cease, supply conditions are still likely to be tight since the stock of TBA deliverable MBS will be low. However, with time as new mortgages are originated, supply will normalize and the effect of the Fed's purchases will disappear.

In the Treasury bond scarcity channel, if the LSAP permanently reduces the supply of safe/liquid assets, then the effect on prices is permanent. The evidence in Krishnamurthy and Vissing-Jorgensen (2012) is for long-lasting effects of Treasury supply on convenience yields.

III. Implications of our Findings for an Exit

The results of the previous sections offer guidance on the mechanisms through which an exit from LSAPs may affect interest rates. They also allow us to get a sense of the magnitude of these effects, although the uncertainty of these magnitudes is large.

III.i Implications of Surgical Exit

We consider the effect of a "surgical" exit of the Fed's LSAP portfolio. By a surgical exit, we mean an exit that has no added implications for current or future Fed policy. Thus our Treasury bond exit scenario is equivalent to analyzing the effect of increased issuance of long-term Treasury bonds. Of course in practice, any announcements by the Fed to exit LSAPs will also be interpreted to have implications for future policy, so that the surgical exit is not an achievable result. In this context, communications over policy becomes important. We discuss communication in Section III.iii.

Treasury Bonds

Our evidence from Treasury bond QE suggests that sales of Treasury bonds will have effects primarily on Treasury bond yields, with limited spillovers into private debt. Thus, either the cessation of Treasury purchases or a sale of Treasury bonds will have small negative effects on the private sector.

We estimate that as of June 18, 2013, the scarcity premium on long-term Treasury bonds was 122 basis points. We follow the

approach outlined by Krishnamurthy and Vissing-Jorgensen (2012b) to compute this premium. The yield on Barclays' U.S. corporate long-term investment grade bond index was 4.95 percent. Barclays states that the duration of this index was 13.4 years. The Markit index for investment grade CDS for 10-year tenor was 1.26 percent. Thus, a credit-risk adjusted long-term bond yield is 3.69 percent. This yield corresponds to an asset that through a derivative is a riskless bond. The 10-year Treasury yield was 2.20 percent and the 20-year Treasury yield was 3.00 percent. Linearly interpolating between these dates, we compute that a 13.4-year Treasury would have a yield of 2.47 percent. Thus an estimate of the scarcity value of the Treasury is 122 basis points. A similar calculation using intermediate maturity yields (maturity around five years) results in a scarcity value of Treasuries at this maturity of about 46 basis points. As an overestimate, if the Fed sold its long- and intermediate-term Treasury holdings and this eliminated the scarcity of such safe bonds, then long-term Treasury yields would rise by 122 basis points with intermediate Treasury yields rising by about 46 basis points. This is an overestimate because it is likely that a Fed sale will reduce but not fully eliminate the scarcity premium.

Table 2 provides data on holders of U.S. Treasury debt, broken down into Fed holdings and the private sector's holdings. The Fed's holdings of medium and long-term Treasury bonds have risen by about \$1.6 trillion. However, issuance by the U.S. Treasury has meant that the private sector's holdings of medium and long-term Treasury bonds have risen by almost \$4 trillion from 2008 to 2013. Despite the large increase in stock of medium and long-term debt held by the private sector, the scarcity premium on long-term safe bonds has remained high and long-term Treasury rates have remained low. From this standpoint, it seems clear that investor demand for safe long-term bonds is far from satiation and while a sale of the Fed's Treasury portfolio will reduce the scarcity premium, it is unlikely to eliminate it.

Mortgage-Backed Securities

Under the scarcity channel we have outlined, the principal effect of an exit would come through the cessation of the Fed's purchases of the production coupon MBS. If investors anticipate that the Fed

Table 2
Holdings of U.S. Treasury Debt, by Holder (in billions of \$)

	Short-term (<1)		Medium (1-5)		Long (>5)	
	Fed	Private	Fed	Private	Fed	Private
30-Jun-08	\$117	1,545	173	1,389	183	1,275
30-Jun-12	47	2,756	516	3,710	1,092	2,335
30-Jun-13	0	2,879	552	4,125	1,382	2,392

Source: Federal Reserve, U.S. Treasury.

is likely to stop purchasing the production coupon MBS, the prices of these MBS will fall immediately. Moreover, there will be limited spillovers to other MBS such as high-coupon MBS or non-agency jumbo mortgages.

Somewhat surprisingly, under the scarcity channel, the Fed could auction off its high-coupon MBS with little effect on the production coupon MBS. This is because spillovers are localized in this channel, and what mainly matters for pricing of the production coupon is the supply/demand dynamics in the production coupon MBS.

Under the capital constraints channel, any announced sale of MBS will also lead to a fall in MBS prices. The effects will be largest for sales of the riskiest (i.e., highest prepayment risk) securities. But these effects will spillover across all of the MBS coupons, and possibly into non-agency MBS.

Relative Size of MBS Channels

The average OAS on the production coupon MBS, the FNMA 3 percent and 3.5 percent, over the month from May 20, 2013, to June 18, 2013, is 27 basis points. The average OAS on two higher-coupon MBS, the 5 percent and 5.5 percent, over the same period is 72 basis points. One estimate of the scarcity premium is the premium on the production coupon relative to the high coupon, which is 45 basis points. This computation is subject to error because the prepayment risks on these two securities are different, so that our spread measure should only be viewed as a rough benchmark.

It is harder to provide an estimate of the capital constraint channel. We have noted earlier that the capital constraints effect is strongest when risk premiums are high. In November 2008, the average OAS across the FNMA MBS from 4 percent to 6.5 percent was 129 basis points. In May 2013, the average OAS across the FNMA MBS from 3 percent to 5.5 percent was 47 basis points. Thus the effects of MBS purchases or sales will be much lower at present than the large effects documented during QE1. Chart 9 later in the paper allows for a more quantitative evaluation of the size of this channel compared to the scarcity channel.

III.ii Dynamics

Drawing from the models of Section II, we discuss the dynamic response of prices to a QE exit.

In all of the channels we have discussed, prices respond immediately to changes in the total expected amount of LSAP purchases. News regarding either improvements in the economy, which would then indicate a reduction in LSAPs, or news that the Fed is likely to reduce LSAPs faster than expected would both immediately impact prices. If the Fed made an unanticipated announcement that over a one-year period LSAPs would be tapered to zero, we can ask how this will impact the dynamics of asset prices. Consider the MBS scarcity channel. To the extent that this news reduces expected future LSAP purchases, there will be an immediate news effect that will reduce prices and the scarcity premium. Over the one-year tapering period, the scarcity premium will either remain constant or more likely fall over consecutive dates, T to $T+1$, depending on the change in the amount of new supply entering the market relative to the change in Fed's purchases. Once the Fed stops purchasing assets, the scarcity premium will remain, but will gradually disappear as new supply eventually normalizes the market.

In the MBS capital constraints channel, if θ is currently positive, prices will immediately fall to account for the expected larger amount of risk borne by investors. The effect will be persistent, and prices will only rise again if capital market frictions disappear so that θ becomes zero.

In the Treasury bond scarcity channel, if the LSAP news permanently increases the expected supply of safe/liquid assets, then the effect on prices is permanent.

III.iii Communication

The preceding section describes the response of asset prices to unanticipated policy news, or a “policy shock.” The occurrence of policy shocks are within the control of the Fed. If the Fed had fully described the state dependence of its rule for LSAPs, then asset prices would respond only to news regarding the state and the implied policy change and there would be no policy shocks leading to additional asset price volatility. But, the Fed has by design been noncommittal regarding its QE plans. It has chosen not to fully describe the states that drive LSAP policy decisions or the specific dependence of policy on these states.

A basic implication of our models is that since QE targets the prices of long-term assets, and the prices of such assets are forward looking, asset prices will be very sensitive to policy shocks. This observation suggests that communicating a policy rule is likely more important for LSAP policy than conventional monetary policy. We next discuss the costs and benefits of the Fed’s strategy.

The Fed’s rationale for its conservative communication strategy is that faced with uncertainty over the transmission mechanisms of QE policy, unlike that of conventional monetary policy, it is prudent to not commit to a state-contingent plan over QE. Stein (2013), in a speech, argues that “given the uncertainty regarding the costs of an expanding balance sheet, it seemed prudent to preserve some flexibility.” Williams (2013) offers a slightly different argument also motivated by uncertainty. He shows that the optimal response of LSAPs to an underlying economic shock in an environment where the central bank faces uncertainty over the effect of LSAPs is muted relative to the case of no uncertainty. In Williams, the central bank computes that its instrument has an expected effect on economic outcomes plus a stochastic set of unintended consequences (e.g., “reaching for yield”), and given a convex loss function over outcomes, optimal policy uses LSAPs less than the case where these unintended

consequences are known. Williams' argument is not the same as preserving flexibility, but is instead one about muted policy response to shocks.

Without minimizing these considerations on the part of the Fed, it is also important to note that policy uncertainty has an effect on investors and through investors' behavior on the effect of LSAPs on the economy. We know from a large literature in finance that uncertainty can have significant effects on the pricing of long-term assets. An investor in the MBS market, or a bank originating a loan today, needs to forecast the time and state dependence of the Fed's LSAP policy in deciding how to invest today. What is the dependence of the Fed's purchases on the unemployment rate? If the unemployment rate falls below 7 percent, will the Fed only cease its purchases or will it sell off its portfolio? Any uncertainty over the Fed's future policy will carry a risk premium today, causing today's MBS prices to fall. It is therefore theoretically possible that the Fed's noncommittal policy undercuts the benefits of LSAP policies. These risk premium effects are reinforced in today's unique circumstances. There is no clear historical reference to understand the effects of the unwinding of LSAPs. Investors have to forecast a new equilibrium given limited data. History suggests when investors are faced with this type of environment, a common behavior is to treat such uncertainty as Knightian and assume a worst-case scenario (Caballero and Krishnamurthy 2008).

There is a conflict here between investors' need for certainty and the Fed's need for flexibility. The information provided by the Fed on its LSAP policies is most directly about the quantity of LSAP purchases under the modal forecast of the economy. The Fed has announced its current rate of asset purchases and indicated that it may increase or decrease these purchases depending on economic developments. The only information that investors have on which to base decisions is how the Fed will act if the economy follows an expected trajectory, and there is no concrete information on how the Fed will behave in trajectories that are much better than expected or much worse than expected.

In an environment of uncertainty, investors are particularly sensitive to information about the tails of the distribution. As an example,

drawing from our observation regarding Knightian uncertainty, investors likely derive more benefits from commitment in the tails of the distribution than the Fed derives benefits from retaining flexibility in these tails. A commitment to act in an adverse state—e.g., a commitment to expand QE if MBS-Treasury spreads widened above 150 basis points—can maximize the ratio of investor benefits to Fed costs in a Knightian environment.²⁷ More generally, communicating not a full state-contingent plan but only a floor on MBS prices that is linked to observables is a way of offering some certainty while retaining substantial flexibility.

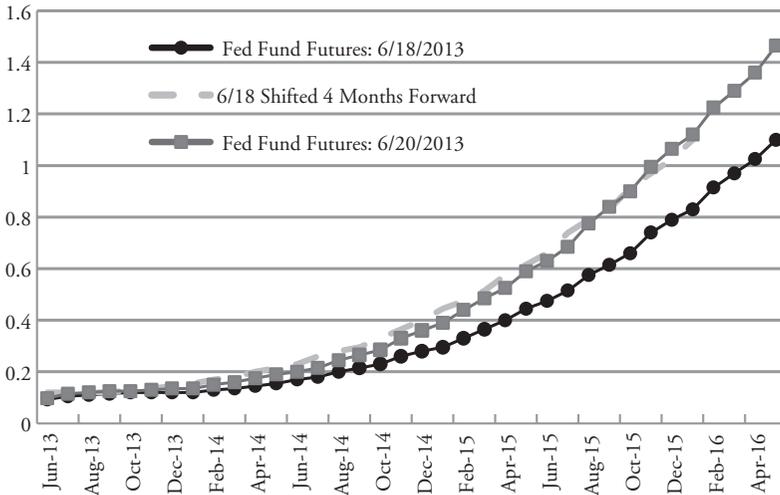
The Fed's imprecise communication over LSAPs has another drawback. It restricts the Fed's ability to fine-tune an exit. For example, our analysis of the mechanics of LSAPs indicates that a fine-tuned exit would start with sales of the Treasury portfolio, followed by sales of higher-coupon MBS, and end with cessation of the purchases of current-coupon MBS. But given investors' limited knowledge of the Fed's intentions over LSAP policy, any of these actions will be taken by investors as a signal regarding the Fed's preferences, which will then have widespread consequences. We will argue that this phenomenon is present in the market reactions around the June 19, 2013, FOMC meeting.

III.iv Event Study, June 19, 2013

By being imprecise in the state-dependence of LSAP policy, the Fed has left it to investors to form expectations over the future of LSAPs. In turn, this has led to market volatility. In this section, we present data from an event study around the June 19, 2013, FOMC meeting which set into motions expectations that the Fed was nearing the end of its LSAP program. We aim to identify how investor expectations changed over this event date. In particular, the large moves in rates on this day is clear evidence of the role of policy shocks—if investors found it easy to predict Fed policy changes, one should not see large moves in rates upon announcements. The event study is also helpful for further documenting the channels through which LSAPs work.

Chart 8 plots the federal funds futures curve on June 18 and June 20. Also pictured is the curve for June 18, shifted forward by four

Chart 8
Yield Curves from Fed Funds Futures, in Percentage



Source: Bloomberg.

months (i.e., the graphed point for January 2014 is the futures yield for the May 2014 contract). The shift is an easy way to see how the market updated its expected path for the federal funds rate in response to the FOMC news: The market pulls forward the timing of a rate-tightening cycle by about four months. We follow the methodology of Krishnamurthy and Vissing-Jorgensen (2011), also outlined in the Appendix, to compute the implied effect of this tightening cycle on longer-term rates. For a five-year bond, the signaling effect implies a change of 18 basis points, while it is 13 basis points for 10 years.

The last column of Table 1 (“Exit”) reports the changes in a collection of asset prices from June 18 to June 20. These changes can be fully explained by signaling effects and the local effects of an exit from Treasury and MBS LSAP.

The yields on assets most closely tied to LSAPs, Treasury bonds and agency MBS, rose more than the implied signaling effects, consistent with an expected exit from LSAPs. The 10-year Treasury bond yield moves by 21 basis points, which is higher than the signaling benchmark of 13 basis points for a 10-year bond, and is thus consistent with an expected exit from Treasury LSAP. The Aaa bond yield increases as much as Treasury bonds, consistent with our observation

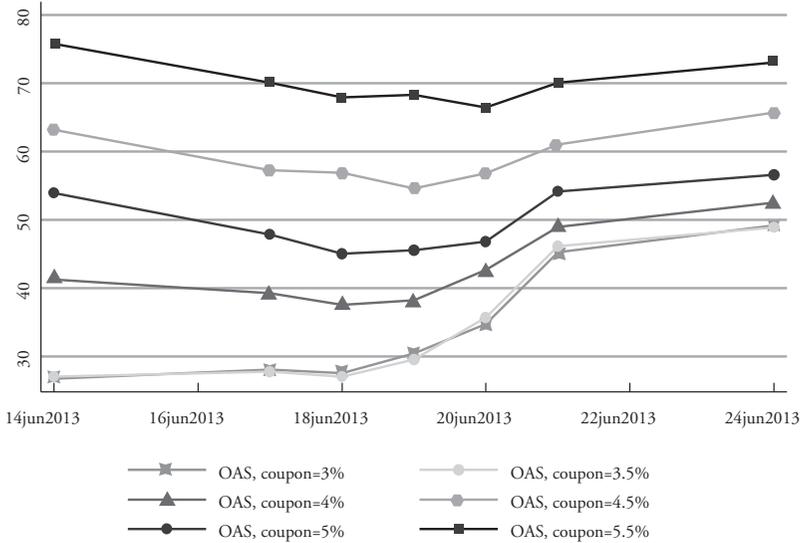
that Aaa bonds are substitutes for Treasury bonds. Moreover, while the Baa corporate bond yields rises 28 basis points, some of the rise in these yields reflecting a worsening economic outlook as reflected by the increase of 12 basis points in the 10-year investment grade CDS index. The pure signaling effect for a 10-year bond of 13 basis points plus the 12-basis-point rise in the investment grade CDS can account for the rise in the Baa bond yield of 28 basis points (keep in mind that investment grade refers to the universe of bonds with credit ratings better than or equal to Baa so the credit risk for Baa bonds likely increases more than 11 basis points). The 30-basis-point rise in the 30-year MBS yield is the largest in the table. The 30-year MBS has approximately seven-year duration, and the expectations hypothesis channel outlined above results in an estimated 17-basis-point change in the seven-year yields. Thus the MBS move is also consistent with an expected exit from MBS LSAP.

Chart 9 plots the OAS on different coupon MBS across this event date. We can see that the OAS on the low coupon MBS' rise the most of the coupons, approaching that of the higher-coupon MBS, consistent with our prediction that the effects of an exit on MBS rates will work predominantly through the scarcity channel. Indeed the fact that high coupon OAS remain relative constant suggests a small role currently for the capital constraints channel.

Finally, from Table 1, we see that inflation expectations, a principal macroeconomic factor driving long-term rates, fell over these dates. The 10-year inflation swap rate, which reflects market expectations of inflation over 10 years, respectively, falls by 9 basis points. Along with the change in the corporate CDS rate, this fact underscores the perceived negative impact of monetary tightening on the macroeconomy. Interest rate volatility, as a measure of uncertainty, rises by 4 basis points.²⁸ We do not report the data on the table, but another uncertainty measure, the VIX, rises from 16.6 percent to 20.9 percent over this episode.

The movements in asset prices over this event reflect a quickening of expectations over the rate-tightening cycle and expectations of an unwinding of LSAPs. These effects underscore the challenges of

Chart 9
OAS on FNMA MBS in Basis Points



Source: Investment Bank.

communicating any plans to exit QE. Investors appear to price in a more aggressive taper than the Fed likely intended.

An important observation around this event is that tapering fears led investors to shift their expectations over the path of the federal funds rate. One interpretation of this shift is that investors perceived the news about tapering as representing a shift in policymaker preferences, and this has changed the markets perception of the Fed’s commitment to forward guidance. Another explanation for the shift in investor expectations is that the Fed has indicated that it will taper first, then shrink its balance sheet, and then raise the federal funds rate. If so, then the news that tapering will occur sooner than anticipated moves forward the whole schedule and leads to an increase in the expected federal funds rate.

III.v Rising Long-term Rates: May 1, 2013, to Aug. 23, 2013

The rising rate pattern of the June 19 event study is also present over a longer period. Over the past few months interest rates have broadly risen as Fed statements have triggered tapering fears. Chart 10 plots yields for 10-year Treasury bonds and long-term corporate

bonds (represented by the Barclays long Aaa bond index). From May 1, 2013, to Aug. 23, 2013, these long-term yields have increased by about 1 percent.

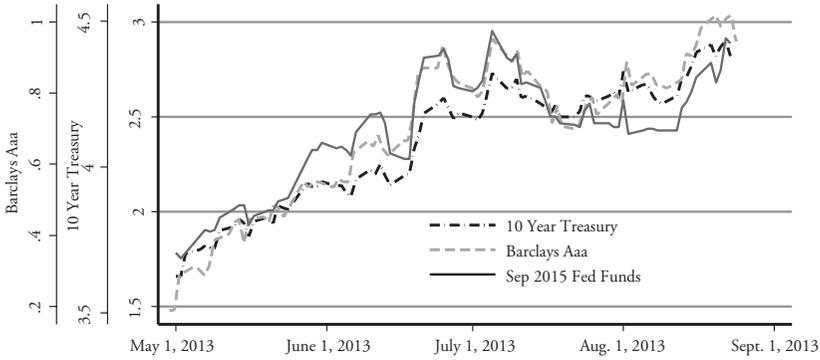
While these yield changes are likely due to news regarding tapering, it is incorrect to conclude from this data that the Fed's LSAPs have direct broad effects on long-term rates via changes in the duration risk premium. As we have noted, fears of tapering have two potential effects on long-term rates: a direct effect based on sales of LSAP assets and an indirect effect based on shifts in the expected path of the federal funds rate.

Chart 10 also plots the yield on the federal funds futures contract for September 2015. We have chosen the two-year contract because it is far enough into the future to be sensitive to investor reassessments of the path of the federal funds short-term rate, but not too far so that its movements are unduly influenced by movements in bond risk premiums. Thus the contract is a proxy for how quickly investors expect the Fed to raise the federal funds short-term rates. Over the period graphed, these expectations have increased by nearly 0.60 percent. It is also apparent from the chart that the movements in federal funds short-rate expectations closely mirror the movements in long-term rates. This shift in expectations can have a direct effect on long-term rates through the expectations hypothesis whereby long-term rates depend on the expected path of the federal funds short rate. The expected rise in federal funds short-term rates may also have led to an unwinding of carry trades which can also increase long-term rates. This factor is known to have been important in the 1994 bond-market selloff, even before the era of QE.²⁹

IV. Conclusion

We have presented theory and evidence that the portfolio rebalancing effects of LSAPs work through narrow channels in which asset purchases affect the prices of the assets that are purchased. The primary channels for the operation of LSAPs in the U.S., and likely around the world, are the capital constraints and scarcity channels. We find that MBS LSAPs are more economically beneficial than Treasury LSAPs. There is little evidence for the operation of a broad channel through which LSAPs lower the yield on all long-term bonds.

Chart 10
Bond Yields, May 1, 2013 to Aug. 23, 2013



Source: Bloomberg, Datastream.

The Fed's cessation of MBS purchases or sale of MBS are likely to be more economically important for the private sector than a sale of Treasury bonds, which by itself will affect mainly government borrowing costs. Within the MBS channels, we find that the scarcity channel is currently a more important factor for MBS yields than the capital constraints channel. The scarcity channel predicts that the news of the cessation of MBS purchases will raise yields on the production coupon MBS and the primary mortgage rate. A sale of the Fed's MBS portfolio will also increase MBS yields through the capital constraints channel, and this increase will spill over to other mortgage assets.

Because LSAPs target the prices of long-term assets, and the prices of such assets are based on forward-looking expectations, the Fed's communication over how its LSAP policies will evolve can have significant effects on asset prices. The market's response to news from the June 19, 2013, FOMC meeting underscores this point and the importance of communicating a clear LSAP policy rule.

Our paper has three broad lessons for central banks. First, LSAPs targeted at markets affected by financial stress conditions can be beneficial. It is worth noting that this conclusion is likely to hold independent of whether or not the zero lower bound is binding. Second, it matters which assets are purchased. Third, it is imperative that

central banks outline a framework for the use of LSAPs. Without such a framework, investors do not know the condition under which LSAPs would occur or would be unwound, which undercuts the efficacy of policy targeted at long-term asset values.

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Appendix Implied Signaling Effect

We describe the computation for the June 19, 2013, event.

The interest rate on a T -year bond in a world where the expectations hypothesis applies exactly (e.g., no segmentation, liquidity, scarcity effects) is:

$$E[i_T] = \frac{1}{T} \int_{t=0}^T i_t^{ff} dt,$$

Let $i_{t,prior}^{ff}$ denote the path described by the federal funds rate as expected by the market before a given event. Suppose that an announcement changes investor expectations so that the rate at time t is now expected to be $i_{t+4/12,prior}^{ff}$. That is, it is the rate that would have prevailed four months from today under the prior expectations. That is, an anticipated rate-hike cycle is shifted forward by four months. Then the increase in the expectations hypothesis driven yield of a T -year bond is

$$\Delta E[i_T] = \frac{1}{T} \int_{t=T}^{T+4/12} i_{t,prior}^{ff} dt - \frac{1}{T} \int_{t=0}^{4/12} i_{t,prior}^{ff} dt.$$

We use the federal funds futures contract to compute the shift in expectations, i.e., four months, which is the critical number in this computation. The computation also requires an estimate of the forward rate, although the results are insensitive to the exact rate. As a rough estimate of the forward rate, we use forwards from the Treasury yield curve on June 18. We use 0.105 percent for $i_{t,prior}^{ff}$ from zero to four months, which is the average of the first four months federal funds futures, while $i_{t,prior}^{ff}$ from T to $T + 4/12$ depends on the maturity T .

For a five-year bond, this computation implies a change of 18.2 basis points, while it is 16.8 basis points for the seven-year bond and 12.6 basis points for 10 years.

Endnotes

¹Asset purchases can also have effects on expected inflation. We present evidence for this effect in Table 1, although we do not discuss the evidence in detail given our focus on portfolio balance channels. We discuss the effects on expected inflation more thoroughly in Krishnamurthy and Vissing-Jorgensen (2011).

²Some QE1 announcements explicitly indicated a change in the stance of monetary policy with respect to the short-term rate.

³We use a simple methodology to measure shifts in the stance of monetary policy based on changes in near-term federal funds future contracts. By using the near-term contracts, our methodology is less affected by bond risk premiums, which play a role particularly for long-term bonds. Christensen and Rudebusch (2012) also study how changes in the stance of monetary policy affect long-term rates over the QE1 period. They explicitly model both the expectations component of short-term rates and the risk premium component using a dynamic term structure model. The findings from their more sophisticated model are broadly in line with ours. For the five QE1 dates we analyze, they estimate that the signaling effect for the 10-year yield totaled -45 basis points (see Table 8, Preferred AFNS). We report -20 basis points in Table 1. If we were to use their larger magnitudes, we would conclude that a smaller portion of the general move in long-term interest rates is due to LSAPs, and in particular we would find an even smaller role for a duration risk premium channel to affect the general level of long-term rates.

⁴These theoretical results on the effects of LSAPs also apply broadly to the other liquidity provision actions of the Fed during the crisis. Duca (2012) analyzes the Fed's commercial paper funding facility and presents evidence that the facility prevented a meltdown of the commercial paper market. He argues that the high commercial paper spreads were indicative of high liquidity/risk premiums and thus a sign of capital constraints and this is why the Fed's facility was effective.

⁵Hancock and Passmore (2011) discuss the possibility of a shortage of the production coupon MBS, but suggest it played little role during the QE1 period. They do not study the QE3 period where we find evidence of the scarcity channel.

⁶Exhibit 3 in Himmelberg, Young, Shan and Henson (2013) also shows this pattern.

⁷Stroebel and Taylor (2012) note that during the QE1 period a possible factor behind the MBS rate reductions was that investors viewed the Fed's purchases as a signal regarding the government's guarantee of Fannie and Freddie. That is, even though the government had taken over Fannie and Freddie in 2008, investors may have had some residual uncertainty regarding the extent of the backing. The QE announcements reduced this uncertainty. For the MEP and QE3 dates, at which point this uncertainty was resolved, this factor should play little role.

⁸Note that it is possible for both channels to operate at the same time, so our evidence should be read as only demonstrating that both have been important.

⁹Higher coupon MBS over this period typically reflect older mortgage loans rather than new loans.

¹⁰For part of 2012 and 2013, this definition leads to a production coupon of 2.5 percent. We do not use the 2.5 percent over this period because the Fed purchased only a small amount of this bond compared to its purchases of the 3 percent coupon bond.

¹¹As with any model-based measure, it is possible that the OAS patterns are the result of model misspecification and do not reflect a risk premium. For evidence connecting the OAS and risk premiums see Gabaix, Krishnamurthy and Vigneron (2005).

¹²We omit the 5-percent coupon bond from Chart 4 because the OAS movements appear inconsistent with the price movements. The price movements are in line with our observations regarding spillovers.

¹³The coefficient and t-statistics on the swap spread are 0.78 (6.84) for the production coupon and 1.05 (9.68) for the current+1.5. The R^2 are 0.61 and 0.57. The pattern of a higher coefficient for the higher coupons is consistent with the notion that the higher coupons have more prepayment risk.

¹⁴Treasury QE changes both the stock of liquid and safe assets in private sector hands. We present evidence in Krishnamurthy and Vissing-Jorgensen (2011) that the primary effects on asset prices in 2010 and beyond are through the safety channel, which is what we emphasize here. The reason is that liquidity premiums have been low since 2010, possibly with the fading of the U.S. financial crisis and the continued large stock of liquid reserve balances.

¹⁵Other studies that offer evidence linking Treasury supply-to-bond yields include Hamilton and Wu (2010) and Li and Wei (2013). Each study consistently shows that Treasury supply has effects on Treasury yields.

¹⁶Ueda (2012) studies the Bank of Japan's QE programs. Table 5 of the paper summarizes findings from event-studies of QE by the BoJ. Ueda reports that JGB purchases lower JGB yields, but effects on corporate bonds are smaller. This effect is consistent with our findings that asset purchases mostly affect the price of the asset purchased. He also reports that when purchases are focused on inflation-indexed bonds, ABS, and corporate bonds—all of which he identifies as illiquid securities—the purchases cause corporate bond yields to fall. The evidence here is consistent with the capital constraints channel we have found for agency MBS.

¹⁷The Vayanos and Vila (2009) model, the standard reference for the connection between asset purchases and the duration risk premium, is a mixture between a pure capital constraints model and the scarcity model. The model predicts a term premium effect but only within the class of safe assets. This is because the model posits a set of preferred habitat investors that have a special demand for only risk-free bonds of a given maturity. These investors are willing to pay a convenience

yield for long-term risk-free bonds. Thus, the model is compatible with a negative term premium in the case where long-term risk-free bonds are scarce. Starting from this situation, when the supply of long-term risk-free bonds is reduced, the yields of those bonds fall. Arbitrageurs take short positions in the scarce bond, matched by long positions in other maturity bonds to smooth out this fall. Yields on all risk-free bonds then reflect a duration risk premium that is influenced by the LSAP. There is evidence in support of the preferred habitat element of the Vayanos and Vila model both from event studies surrounding LSAPs (see D'Amico et al. 2013). But, for the discussion at hand, the Vayanos and Vila model does not predict that LSAPs will have broad effects of term premia in fixed income markets.

¹⁸Stein (2012) notes that issuance of investment grade and high-yield debt was at a record in 2012. He cites this as evidence of spillovers from LSAPs to the private sector. One issue with this argument though is that over the LSAP period from 2008 to 2013 the U.S. Treasury increases issuance of long-term bonds (Table 2) over and above purchases by the Fed, so that any spillover channel should predict a reduction in issuance of long-term bonds. Another possible explanation for the issuance patterns is that term premiums, for non-LSAP reasons, have fallen from 2008 to 2013, and this is the reason why issuance has boomed.

¹⁹Pressure-pressure effects at the time of the purchase are present but appear to be small and quickly reversed. See for example D'Amico and King (2013) for estimates based on LSAPs. Lou, Yan and Zhang (2012) study a large panel of U.S. Treasury auctions from 1980 to 2008 and show that Treasury bond prices do fall on the day of the auction, but the effects are reversed fully within a week.

²⁰In the most distressed periods of the financial crisis, the haircuts on agency MBS rose. But the rise was modest, going from 2 percent pre-crisis to at most 5 percent. See Krishnamurthy (2010).

²¹In the He and Krishnamurthy (2013) model, there is also an effect of the future LSAP on today's multiplier. This happens because since today's asset price rises, investor balance sheets are strengthened today, which relaxes capital constraints and the Lagrange multiplier.

²²The word "flow" has been used to mean different things in the discussion on QE and to avoid confusion we will not use the word. Sometimes "flow" is used to describe a price-pressure channel through which fully anticipated purchases change asset prices. Price-pressure effects are not implied by the scarcity channel.

²³Note also that the seller of the inframarginal mortgage m collects a surplus from delivering its mortgage to the Fed when $P_T > V_T(m)$.

²⁴We have omitted purchases by the private sector in describing equilibrium. There are mortgage investors that typically purchase securities on a consistent basis in the TBA market in order to match a mortgage index. If such funds purchase Y_T securities, than market clearing will be based on $X_T + Y_T$.

²⁵We have motivated the upward sloping supply based on the heterogeneity of MBS values among MBS investors. Another source of slope in the supply function comes from the supply from new homeowners. Clearly, to induce more homeowners to take on mortgages the mortgage rate has to fall. If new homeowners represent the marginal supply that the Fed is purchasing, then Fed purchases push up mortgage prices, and one does not need to invoke heterogeneity in valuations to get an upward slope in the supply curve. However, the homeowner story is less plausible because it requires that the Fed's purchases exhaust the entire supply of TBA deliverable MBS, whereas supply should include both the supply of new MBS and the MBS held by existing investors, where the latter's supply should be thought of as elastic. Nevertheless, most of the implications for pricing and exit are the same across these two versions of upward sloping supply.

²⁶If there is uncertainty in the value of the MBS that is resolved between T and T+1 (e.g., prepayment history is observed), then there is an option value term that can influence price dynamics. Suppose there is a possibility that MBS-*m* whose current value is below P_{T+1} may rise in value tomorrow so that $V_{T+1}(m) > P_{T+1}$. In this case, the present value of the mortgage is,

$$\frac{E_T \max[V_{T+1}(m) - P_{T+1}, 0] + P_{T+1}}{1 + r}$$

If the marginal mortgage loan that is delivered at date T is one where this option value consideration is important, then P_T will equal the present value of P_{T+1} plus the option value.

²⁷This observation is drawn from Caballero and Krishnamurthy (2008) who present an analysis of optimal lender of last resort policy in a Knightian environment.

²⁸Note that a rise in swaption volatility will also lead to a rise in MBS yields since there is an embedded interest rate option in MBS.

²⁹Hanson and Stein (2013) show that long-term rates "overreact" to monetary policy shocks, measured from changes in the short-term rate. It is possible that the recent moves in long-term rates are also a reflection of this phenomenon, as short-term rates have risen based on anticipations of tighter monetary policy.

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