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THE FEDERAL RESERVE'S LARGE-SCALE ASSET PURCHASE PROGRAMMES: RATIONALE AND EFFECTS*

Stefania D'Amico, William English, David López-Salido and Edward Nelson

We provide empirical estimates of the effect of large-scale asset purchases (LSAPs) on longer term US Treasury yields within a framework that allows for several transmission channels including the *scarcity* channel associated with the preferred-habitat literature and the *duration* channel associated with interest-rate risk. We also clarify LSAPs' role in the broader context of historical monetary policy strategy. Results indicate that LSAP-style operations mainly impact longer term rates via the nominal term premium; within that premium, the response is predominantly embodied in the real term premium. The scarcity and duration channels both seem to be of considerable importance.

Since late 2008, having brought the nominal federal funds rate down to its effective lower bound, the Federal Open Market Committee (FOMC) has taken steps to provide further monetary policy stimulus. One measure undertaken has been the provision of Committee guidance about the likely future path of the policy rate; for example, the Committee's statements from March 2009 to June 2011 indicated that economic conditions were 'likely to warrant exceptionally low levels of the federal funds rate for an extended period' (FOMC, 2009).[1] The FOMC has, however, also made use of monetary policy tools other than forward guidance. The Committee has provided further monetary policy accommodation by authorising a series of Federal Reserve purchases of longer term securities, a policy known as 'large-scale asset purchases' (LSAPs).

The first programme of LSAPs was announced in late November 2008, from which time the Federal Reserve purchased agency debt and agency-guaranteed mortgage-backed securities (MBS). In March 2009, the purchase programme was stepped up and was also broadened to include longer term Treasury securities. The first round of purchases was completed in March 2010. The next development in the Federal Reserve's purchase policy was the FOMC's announcement in August 2010 of reinvestment

* Corresponding author: Stefania D'Amico, Division of Monetary Affairs, Washington, DC 20551, USA. E-mail: stefania.d'amico@frb.gov.

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[1] Prior to adopting this statement language, the FOMC had referred for several months to its expectation that an exceptionally low funds rate would be in force 'for some time'. In August 2011, the FOMC changed the statement language from 'for an extended period' to 'at least through mid-2013' and then in January 2012 it changed this to 'at least through late 2014'.

arrangements, under which the Federal Reserve – by redeploying into longer term Treasury investments the principal payments from agency securities held in the System Open Market Account (SOMA) portfolio – would maintain the elevated level of holdings of longer term securities brought about by the first series of LSAPs. From November 2010 to the end of June 2011, the Federal Reserve undertook a second LSAP programme involving the purchase of $600 billion in longer term Treasuries. The FOMC decided to continue to maintain the level of securities holdings attained under the LSAPs and, in September 2011, the Committee made further adjustments to its investment policy including a shift towards a longer average maturity for its Treasury securities portfolio and reinvesting principal payments from agency securities in MBS rather than longer term Treasuries.

FOMC members (Kohn, 2009; Bernanke, 2011*a*; Williams, 2011; Yellen, 2011) have emphasised that LSAPs are designed to affect the term-premium component of longer term interest rates. Thus, while LSAPs differ from federal funds rate policy, which exerts its influence on longer term rates principally via an impact on the expectations component of these rates, they share with funds rate actions the intention of affecting the longer term interest rates that bear importantly on spending decisions. In outlining the effect of LSAPs on term premiums, Kohn (2009) and Yellen (2011) appeal to the preferred-habitat literature. This literature, developed at an early stage by Tobin (1961, 1963) and Modigliani and Sutch (1966, 1967), has received a modern formalisation in the work by Vayanos and Vila (2009).

The preferred-habitat approach is, however, one of several theoretical perspectives capable of rationalising the effects on longer term rates of LSAP-style operations. A major aim of this article is to provide empirical estimates of the effect of LSAP-style operations on longer term US Treasury rates within a framework that nests the alternative theoretical perspectives on LSAPs. As the principal channels through which LSAPs might matter for the long rate, we concentrate on (*i*) the 'available local supply', or 'scarcity', channel associated with the traditional preferred-habitat literature – a mechanism under which the purchase by the Federal Reserve of assets with a specific maturity leads to higher prices (and lower yields) of securities with similar maturities; (*ii*) the 'duration channel' – a mechanism under which the removal, by means of Federal Reserve purchases, of aggregate duration from the outstanding stock of Treasury debt reduces term premiums on securities across maturities[2] and (*iii*) the 'signalling', or 'expectations', channel mentioned above, which operates to the extent that LSAPs have an impact on market expectations of the short-term policy rate.[3]

This article also advances on existing empirical work, such as Greenwood and Vayanos (2010), D'Amico and King (forthcoming), Gagnon *et al.* (2011) and Hamilton and Wu (2012), in several ways.[4] First, by using CUSIP-level (i.e. security-specific) data, we can disaggregate bond supply by maturity class and thereby measure local supply or scarcity. Second, by analysing SOMA holdings at the CUSIP level, we can measure the

[2] In the context of LSAPs, this channel was first highlighted by Gagnon *et al.* (2011).

[3] We also have occasion to comment on the typology of channels offered by Krishnamurthy and Vissing-Jorgensen (2011), and to discuss why we omit (or condense) a number of channels that these authors list.

[4] The magnitude of the effect of LSAPs on longer term policy rates that is assumed in macroeconomic model simulations such as those in Chung *et al.* (2012) has been informed by these studies.

stock of *privately held* longer term Treasury securities more accurately[5] to pin down the responses to LSAP-style operations. We are therefore better equipped to address the key policy question empirically. Finally, by harnessing this finer degree of disaggregation, we can more definitively infer specific *aggregate* characteristics of the Treasury supply, such as the average duration of privately held Treasury securities. Compared with studies such as D'Amico and King (forthcoming) that also make use of CUSIP-level data, we flesh out the transmission channels involved in LSAPs, consider a different sample period and focus our analysis on a decomposition of longer term Treasury yields. Our approach thus aims to disentangle the channels through which LSAPs work rather than simply ascertain the magnitude of the overall response of yields to the operations.

We also clarify LSAPs' role in the broader context of monetary policy strategy. We highlight the connections between longer term asset purchases and historical Federal Reserve approaches to monetary policy. This historical overview brings out episodes and institutional features that support our view that the theoretical arguments against the effectiveness of LSAPs are of limited applicability.

Our results can be summarised briefly. The estimates indicate that local supply and aggregate duration of Treasury securities are positively and significantly related to longer term Treasury yields and term premiums. According to our estimates, a sizable portion of the impact of variations in scarcity and aggregate duration on longer term Treasury yields has been transmitted via the nominal term-premium component. Moreover, within the overall term premium, it is the *real* term-premium component that exhibits the greatest response to these two variables; the inflation risk premium's response, in contrast, is quite small and is not uniformly statistically significant across different specifications. These findings are robust to the addition of a set of explanatory variables, including a flight-to-quality proxy, to the baseline regression. Finally, our estimates suggest that both the local supply and aggregate duration channels have been of considerable importance in delivering effects of purchases on longer term Treasury yields.

This article proceeds as follows. Section 1 provides historical perspective on the Federal Reserve's longer term securities market operations. Section 2 discusses theoretical perspectives on LSAPs and our means of discriminating between them. Section 3 shows that a specific sequence of events in 2010 provides a case study that casts light on the main channels through which LSAPs may operate. Section 4 describes in detail the construction of the variables, ahead of the presentation of the main results in Section 5. Section 6 concludes by suggesting some implications of our results for the specification of macroeconomic models.

1. LSAPs in Historical Perspective

Section 14 of the Federal Reserve Act describes in these terms the open market operations which the Federal Reserve may conduct: 'any bonds, notes, or other obligations which are direct obligations of the United States or which are fully

[5] That is, those held by private households and private financial and non-financial firms (including foreign entities), rather than by the public sector (where 'public sector' includes the Federal Reserve).

guaranteed by the United States as to the principal and interest may be bought and sold without regard to maturities but only in the open market'.[6] The law's wording, 'without regard to maturities', helps to put the recent purchase programme into proper perspective. Compared with the previous decades' focus on short-term interest rate policy, LSAPs do mark a break with convention. However, viewed in terms of the tools that the Federal Reserve has historically had at its disposal and has had occasion to deploy, LSAPs do not amount to an altogether unconventional policy. Rather, they can be seen as the latest in a series of Federal Reserve operations in longer term securities markets. And, in common with short-term interest rate policy, the aim of these operations has been to affect aggregate demand by influencing longer term interest rates. We put LSAPs in historical context by reviewing Federal Reserve operations in long-term markets in the post-war period in Section 1.1. Then, Section 1.2 briefly reviews the chronology of the recent LSAPs.

1.1. *Operations in Longer Term Securities Markets in the Post-war Period before 2008*

The Federal Reserve's pegging of bond prices during and after World War II is discussed in Bernanke (2002), who cites this experience as demonstration of central banks' capacity to affect longer term rates directly if they transact in longer term securities markets. As part of the 'cheap money' policy instituted during the war, the Federal Reserve fixed a maximum value for very long-term interest rates of 2.5%, with the Federal Reserve standing ready to trade in longer term Treasuries to enforce the ceiling.

The bond price peg lasted from 1942–51. Over part of this period, from 1942–7, the pegging policy was undertaken in conjunction with the pegging of two other Treasury security rates: those on 90-day bills and one-year notes.[7] It is significant that the Federal Reserve's policy amounted for several years to enforcing values for a *set* of Treasury rates of different maturities. According to the pure expectations theory of the term structure, targeting three separate interest rates should succeed if and only if the private sector's expectations of the path of the short rate are aligned in a way that precisely generates the targeted configuration of rates. In this environment, for a given expected path for the short-term rate, direct intervention in longer maturity Treasury markets could not contribute to achieving the peg. Moreover, the slightest fluctuation in expectations of the short-rate path would immediately imperil the peg. The picture painted by this well-known theoretical benchmark contrasts with the actual practice of the pegging policy. The period of bond rate pegging witnessed direct Federal Reserve intervention in longer term markets which succeeded in delivering the three targeted rates. This suggests that central bank intervention in the longer term Treasury markets provided an extra degree of freedom for the management of rates. Equivalently, for each security price targeted, the Federal Reserve had two instruments for hitting the target: its influence on expectations of the short rate and its transactions in the market for

[6] See http://www.federalreserve.gov/aboutthefed/section14.htm.
[7] The targets for the shorter maturity rates were dropped in July–August 1947. See Friedman and Schwartz (1963, pp. 577–9) and Romer and Romer (1993, p. 81).

that security. Via direct intervention, the monetary authorities could achieve a configuration of interest-rate targets without having to rely on continuously maintaining a specific pattern of market expectations of future short-term rates.

Soon after World War II, senior staff at the Federal Reserve Board voiced their reservations publicly about the implications of the bond peg. These concerns about the pegging policy typically did not imply a denial of the *technical* feasibility of pegging a set of rates across the maturity spectrum; on the contrary, the observed stability of the market yields on the targeted securities seemed to confirm the feasibility of that policy.[8] The Federal Reserve's doubts about the pegging policy were instead grounded in the concern that it perpetuated an interest-rate structure that was incompatible with monetary stability.

With the outbreak of the Korean War in 1950, continuous upward pressure on aggregate demand emerged, and the incompatibility of the pegging policy with inflation control became manifest. The Federal Reserve stepped away from the pegging policy in 1951, with the advent of the Treasury/Federal Reserve Accord. The Accord marked an important step in restoring central bank independence in the US, and the accompanying abandonment of bond price pegging was important in achieving the goal of price stability. For the present discussion, however, the experience with the pegging policy provides an important case study. Although the lack of detailed market data on expectations of the short-term policy rate works against a clear-cut conclusion, the widely taken lesson of this case study appears to be that the Federal Reserve's longer term bond purchases did indeed stimulate aggregate demand and keep, for several years, the real-interest-rate component of longer term rates lower than would have been the case without the purchases.

Following the Accord, the Federal Reserve shifted to a policy of adjustable targets for short-term interest rates. As part of this framework, the Federal Reserve adopted a 'bills-only' policy which restricted to short-term Treasury securities the class of assets traded in open market operations. Bills-only, adopted in 1953, prevailed for the balance of the decade, interrupted by a brief period of Federal Reserve purchases of coupon Treasuries in response to bond market disruptions in late 1955 and mid-1958 (Cooper, 1967, pp. 14–5). Holdings of long-term bonds ran off the Federal Reserve's portfolio and declined sharply as a share of Federal Reserve assets in the course of the 1950s (Figure 1).

The thinking behind the bills-only policy was outlined by Riefler (1958*a*,*b*).[9] Riefler accepted that changes in the maturity composition of the Federal Reserve's balance sheet could affect longer term interest rates for a given path of short-term rates.[10] However, he argued that the Federal Reserve had ample scope to affect longer term

[8] Consistent with this, Thomas (1947, p. 210) considered the consequences of a scenario in which 'long-term rates were *permitted* to rise' (emphasis added), thereby accepting that the authorities could have prevented such a rise.

[9] Another publication by Board senior staff, Young and Yager (1960) outlined arguments similar to Riefler's.

[10] Consistent with this position, discussions within the Federal Reserve generally accepted that official purchases of longer term securities could affect bond rates. For example, Cooper (1967, p. 20) notes that while as of the early 1960s there were 'divergent and shifting opinions of members and staff throughout the period when operations in coupon issues were being discussed', it was nevertheless 'recognized that System purchases of intermediate- and long-term government securities... would tend to influence prices (and rates) as would any large-scale buying'.

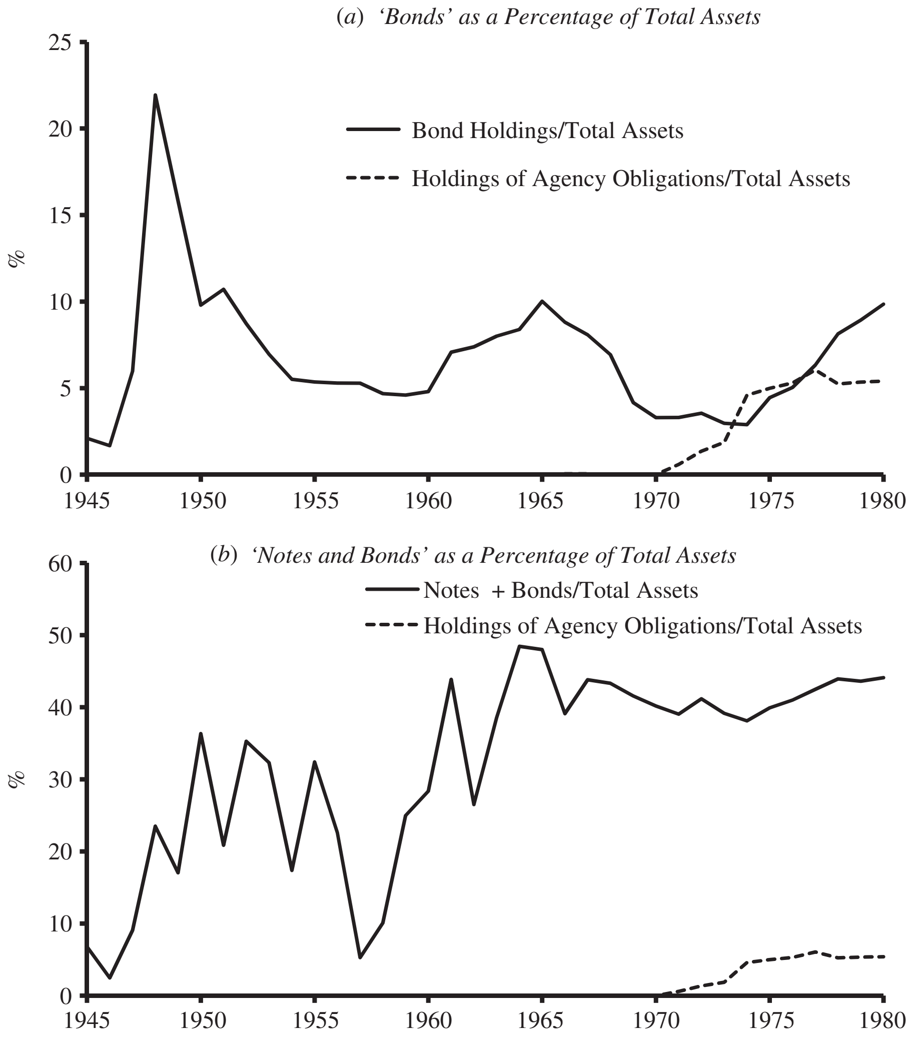

Fig. 1. *Longer Term Securities as Share of Federal Reserve assets,* 1945–80
Source. Federal Reserve balance sheet, Federal Reserve Board, Annual Report, various years.

rates by influencing market expectations of the short-term interest rate path. Riefler (1958*b*) accordingly concluded that the Federal Reserve could 'exert an influence on long-term interest rates without direct intervention in the long-term market'. This view was echoed in prominent market commentary.[11]

Outside criticism of the bills-only policy persisted, however, and was buttressed by the emerging academic literature on imperfect links between the short and long-term securities markets (Culbertson, 1957; Conard, 1959; Ascheim, 1961), a literature later put on a firmer theoretical footing by Tobin's (1961, 1963) work on debt management

[11] For example, the First National City Bank of New York (1959, p. 114) stated: 'Sustained movements in bill yields work their way throughout the rate structure and vitally affect the availability of credit, long-term as well as short-term, without direct Federal Reserve intervention in the long-term market'.

and the term structure and by Modigliani and Sutch's (1966, 1967) laying out of the preferred-habitat model. The incoming Administration in 1961 was sympathetic to the criticisms of the bills-only policy. The Kennedy Administration saw merit in measures that could lower longer term interest rates – which were widely regarded as more relevant for the determination of aggregate demand than were short-term rates – even as short-term rates were increased (a course for the policy rate designed to promote a greater rate of inflow of foreign capital). The resulting 'Operation Twist' policy was ratified by the Federal Reserve (as reported in FOMC, 1961). Longer term securities grew as a share of the Federal Reserve's assets (again, see Figure 1).

Initial verdicts on the success of the policy tended to be negative, with Marty (1962, p. 208) referring to the 'Federal Reserve's failure, in the early months of the Kennedy administration, to influence the rate structure'. The unfavourable assessment apparently was not due primarily to the behaviour of long-term rates; these yields did indeed fall slightly in the early 1960s (Figure 2), and were, as the Federal Reserve Board (1966, p. 1747) noted, more stable in the first half of the 1960s than they had been in preceding recoveries. But it was felt that this pattern of longer maturity rate behaviour was not obviously due to the Twist measures. Inflation expectations were likely declining during the early 1960s, and this has been singled out as the main factor driving the observed decline in longer term rates (Meigs, 1972, p. 271). Notwithstanding the emerging preferred-habitat literature, many economists at the start of Operation Twist were doubtful about portfolio effects of long-term bond purchases, and experience from the early 1960s probably reinforced their doubts.[12] For their part, adherents to preferred-habitat models could point out that the Treasury lengthened the maturity of its debt issues in the early 1960s, perhaps swamping the effect of the Federal Reserve purchases.[13] A recent study by Swanson (2011), however, finds that a negative effect on government bond yields of the 1961 Federal Reserve purchases can be discerned when an event-study approach is taken.

After 1963, the Federal Reserve largely returned to a bills-only policy. It continued to hold coupon securities in its portfolio; among these, holdings of agency securities issues grew after the late 1960s as the Federal Reserve took up some of the coupon issues of Fannie Mae and Freddie Mac, which, being government-guaranteed, were open market-operation-eligible instruments. The end of Operation Twist is nonetheless evident in Figure 1 in the diminishing fraction of longer term securities in the Federal Reserve's portfolio after the mid-1960s.

Notwithstanding the absence of major Federal Reserve activity in longer term markets, long-term interest rate behaviour played an important part in Federal Reserve thinking in the late 1960s and 1970s. Board staff viewed the transmission of federal funds rates to longer term rates as a key element in the transmission mechanism for monetary policy actions (Pierce, 1974). The topic of term-structure determination received particular prominence in 1975 when a sharp decline in the federal funds rate

[12] In a major understatement, a *Financial Times* article (1960) discussing preparations for Operation Twist noted, 'There is, it is true, some difference of opinion about how far it is possible to reduce long-term interest rates, while maintaining short-term rates'.

[13] See Meigs (1972, p. 271) and Culbertson (1973, p. 37). The position that Treasury debt-lengthening operations by the Treasury had swamped the effects of Operation Twist held by James Tobin while he served in the Kennedy Administration (Morris, 1968, p. 23; and Tobin, 1974, pp. 32–3) and he reaffirmed it subsequently (Tobin's testimony in Joint Economic Committee, 1992, p. 53). Franco Modigliani shared this view (Brookings Institution, 1978, p. 652).

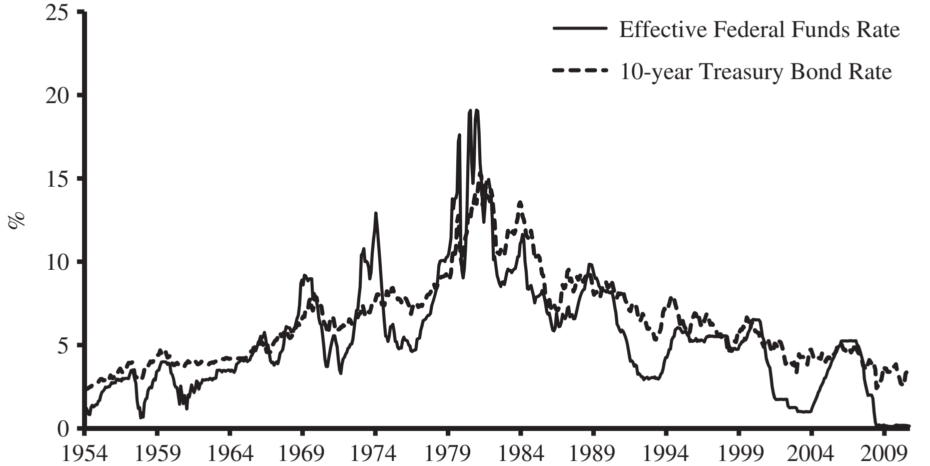

Fig. 2. *Effective Federal Funds Rate and* 10*-year Treasury Bond Rate: Monthly Averages, July* 1954–*March* 2011
Source. FRED portal, Federal Reserve Bank of St. Louis.

was associated with little decline in the bond rate (Figure 2). In light of the concern that longer term interest rates were aberrantly high, a Board staff analysis in 1975, quoted in Meltzer (2009, p. 1002), considered the possibility of Federal Reserve intervention in the bond market. The staff memo judged that the expectations theory was the appropriate baseline for thinking about the effects of policy actions on longer term rates. In such a framework, while term premiums could be a major factor driving bond yields, Federal Reserve asset purchases might not have reliable effects on premiums. Consequently, the Federal Reserve staff position in 1975 was that longer term securities purchases were not worthwhile as an expansionary measure and that the pure expectations theory provided the best benchmark for viewing the connections between Federal Reserve actions and long-term rates.

Likewise, in academia, with some exceptions (B.M. Friedman, 1978; Walsh, 1982), the expectations theory predominated in the 1970s and 1980s as the framework through which macroeconomists viewed long-term interest-rate determination, and preferred-habitat-style approaches to term-structure analysis fell into disfavour. In particular, the baseline term-structure equation in linearised rational expectations macroeconomic models treated the long-term rate as equal to the efficient forecast of the stream of policy rates, up to a premium which was treated as exogenous or constant; see Mishkin (1978) and Plosser (1982) for early examples. By the mid-1980s, Lucas (1987, p. 2) was looking back on Operation Twist as having involved 'issues that seemed so important as they were occurring and are so hard to remember now'.

The expectations theory benchmark predominated in policy circles in the 1980s. The Federal Reserve kept some longer term securities in its asset portfolio but officials were doubtful of the existence of portfolio effects. As one official put it (Davis, 1982, p. 56): 'I have always assumed that, in the US at least, the evidence and the theory have strongly argued against our ability to have significant and predictable effects on the yield curve, through changes in (the) maturity composition of the Fed's portfolio'.

Likewise, in testimony in early 1992 Federal Reserve Chairman Greenspan emphasised the expectations channel, arguing that it was 'only in that context that we believed we could get a significant decline initiated in long-term rates'.[14]

With the resurgence of monetary policy analysis in academic circles after the early 1990s, the pure expectations theory largely remained the baseline for thinking about longer term interest rates, most notably so in linearised dynamic macroeconomic models of the New Keynesian type. The short-term interest rate path was considered the critical variable under the control of monetary policy, and monetary policy analysis stressed the contribution that forward guidance about the funds rate could consequently make to stabilisation of aggregate demand and inflation (R.G. King, 1994; Rotemberg and Woodford, 1999).

The scope for monetary policy to affect longer term rates via means other than short-term rate policy was reconsidered, however, in a literature that emerged over the late 1990s and early 2000s. The zero lower bound had been reached in Japan, whereas in the US the federal funds rate target in 2002–4 took low values and the lower bound emerged as a possibility. Mervyn King (1999) and Bernanke (2002) suggested that central bank purchases of long-term bonds were a means of providing monetary policy stimulus when the short-term policy rate was at its lower bound. Around the same time, the information revealed by the Treasury buyback programme potentially offered new insight into the effect of debt-management operations on the term structure.[15] In particular, the buyback could throw light on the likely impact of other possible debt-management operations such as central bank purchases of long-term bonds. Bernanke *et al.* (2004) inferred from the experience of the buyback programme that Federal Reserve operations in long-term debt could have appreciable effects on the long-term interest rate for a given path of short-term interest rates. Nevertheless, considerable doubts about this policy option endured in the literature, with Eggertsson and Woodford (2003) providing a well-known critique.

1.2. *LSAPs, 2008–11*

The basic chronology of LSAPs was outlined in the Introduction. The original sequence of purchases, from November 2008 to March 2010, began with purchases of the debt securities issued by housing-related government-sponsored enterprises (GSEs) and agency-guaranteed MBS. As discussed previously, agency debt and agency-guaranteed securities are open market-operation-eligible securities. The Federal Reserve's first appreciable acquisition of agency-related securities was in the early 1970s; prior to recent years, the peak level of holdings was in 1981 (Meulendyke, 1998, pp. 40–1). The November 2008 decision to undertake large-scale Federal Reserve purchases of agency-related securities came in the wake of a widening spread of yields on these securities

[14] From Greenspan's 10 January 1992, testimony in Committee on Banking, Housing and Urban Affairs (1992, p. 68). In contrast, Paul Samuelson and James Tobin testified during this period in favour of Federal Reserve purchases of longer term securities to put downward pressure on longer term rates: see Joint Economic Committee (1992).

[15] Treasury debt-management operations, like Federal Reserve purchases or sales of longer term securities, can alter the composition of the outstanding debt, so the former can be informative about the effects of the latter. The fact that either the Treasury or the Federal Reserve can take actions to secure a particular maturity composition for the outstanding stock of Treasury debt was noted by Friedman and Schwartz (1963, p. 634).

compared with those on Treasuries and it was motivated by the desire to 'reduce the cost and increase the availability of credit for the purchase of houses, which in turn should support housing markets and foster improved conditions in financial markets more generally' (Federal Reserve, 2008). The scale of the LSAPs was expanded at the March 2009 FOMC meeting, when the Committee decided to bring its maximum purchases of agency MBS to $1.25 trillion and of agency debt to $200 billion (a maximum subsequently lowered to $175 billion); in addition, it decided to purchase up to $300 billion of longer term Treasury securities over the following six months (Federal Open Market Committee, 2009). The purchases of agency-related securities were completed in March 2010.

In August 2010, the FOMC adopted a policy of reinvesting principal payments on holdings of agency securities in longer term Treasury securities. The policy thus maintained the aggregate level of securities holdings and the associated degree of monetary accommodation in place at that time. In the face of signs of a slowing recovery, Bernanke (2010) listed a new LSAP programme as an option and, in November 2010, the Committee decided to purchase a further $600 billion of longer term Treasury securities by the end of the second quarter of 2011, a programme duly completed at the end of June 2011. More recently (September 2011), the Federal Reserve launched the Maturity Extension Program (MEP). Unlike LSAPs, these operations are largely sterilised and do not increase the Federal Reserve's overall securities holdings. Like LSAPs, however, they lengthen the maturity structure of the Federal Reserve's securities holdings and thus depend on channels like those underlying the rationale for LSAPs; in particular, MEP should work via the 'duration' channel discussed below. We turn now to a discussion of the transmission channels that might be associated with LSAPs.

2. Transmission Channels for LSAPs

In this Section, we outline some of the main channels through which LSAPs might work.

2.1. *Expectations/Signalling Channel*

The signalling or expectation effect captures those changes in the expected path of future short-term rates that arise from perceived new information that LSAP measures might relay about the state of the economy and the Federal Reserve's short-term interest-rate reaction function. This effect works through, and relies on, the standard expectation hypothesis concerning the connection between short- and long-term interest rates.

2.2. *Traditional Preferred-Habitat/Scarcity Channel*

Although the expectations channel is widely acknowledged as one means through which monetary policy affects longer term interest rates, its existence does not preclude the possibility that direct purchases of longer term securities act on the term-premium component of longer term rates by setting in motion a portfolio balance mechanism. Deviations of longer term interest rates from the predictions of the strict expectations theory have been repeatedly documented in the literature and the preferred-habitat approach advances the view that some of these deviations are attributable to variations in the relative supplies of outstanding stocks of debt. The position that longer term yields depend in part on the relative quantities outstanding of longer term assets in the hands of the private sector (including commercial banks) was the subject of a substantial literature in the 1950s and the 1960s (Culbertson, 1957; Modigliani and Sutch, 1966; Wallace, 1967; and the references discussed in Section 1). Recently, Vayanos and Vila (2009) have offered more rigorous foundations for this approach within a term-structure model with two types of investors. The preferred-habitat investors in this framework are disposed to purchasing securities of certain maturities, while arbitrageurs can profit by trading across maturities but risk aversion prevents these agents from taking complete advantage of profit opportunities.[16]

The preferred-habitat approach provides a rationale for asset price adjustments in the wake of a shift in the quantities of specific maturities of government debt held by private agents. Underlying the view that the maturity composition bears on asset prices is the premise that a permanent demand exists from a class of investors for marketable, fixed-income securities. Thus, in segmented-market models featuring imperfect asset substitution, a reduction in the stock of securities of a particular maturity in the hands of private investors creates a shortage of those assets that cannot be wholly relieved, at existing asset prices, by substitution into other securities. The shortage thus prompts an adjustment of financial market prices. Such a *scarcity effect* may be spread over time and it could be manifested in bond rates for a particular maturity.

An official purchase programme that makes longer term Treasuries scarcer is then likely to generate downward pressure on longer term Treasury yields. Such a 'local supply' (or scarcity) effect of LSAPs can be thought of as withdrawing longer term securities from the hands of the private sector and thereby creating a prospective excess of demand over supply for fixed-income assets. As a result, the market for long-term securities clears at a lower equilibrium quantity and a higher price, that is, a lower yield. This yield adjustment would not occur in simple representative-agent frameworks but becomes part of the adjustment process in an environment that allows for heterogeneity among private investors. Thus, when a class of investors underpins the demand for longer term securities, conditions are created that break the pure expectations theory of the term structure and make the term premium a function of the ratio of short-term to longer term securities outstanding. It is this departure from the representative-agent framework that implies that the result of Eggertsson and Woodford (2003), according to which monetary policy's effect on longer term rates is limited to the expectations channel, no longer holds.

2.3. *Duration Channel*

The Vayanos and Vila (2009) preferred-habitat framework referred to above, in addition to featuring local supply effects, also implies a direct relationship between the term

[16] Gagnon *et al.* (2011) and Hamilton and Wu (2012) use Vayanos–Vila as their baseline.

premium and the average duration risk faced by investors, in particular by the arbitrageurs.[17] To the extent that LSAP-style measures remove duration risk from the market by withdrawing a portion of long-term securities, the risk premium built into the price of such assets should decline. The removal of duration risk should generate reactions of yields across much of the maturity spectrum – not just on the yields of purchased securities and those of adjacent maturities.

2.4. *Comparison with Another Typology of Channels*

The preceding catalogue has allowed for three channels through which monetary policy might affect longer term interest rates: the expectations or signalling channel, the scarcity or local supply channel, and the duration channel. Krishnamurthy and Vissing-Jorgensen (2011, p. 2) endeavour to outline 'the principal theoretical channels through which quantitative easing (QE) may operate', and we now briefly compare our own typology with theirs.

Some channels are common to both typologies: Krishnamurthy and Vissing-Jorgensen consider duration and signalling channels, also included in our own list, while their 'safety premium channel' – under which a segmented demand for long-term safe assets tends to lower yields on those securities – is subsumed within the scarcity channel of the preferred-habitat literature. Krishnamurthy and Vissing-Jorgensen also refer to the 'liquidity channel', under which downward pressure on long-term rates emerges as reserves become plentiful relative to long-term bonds. We do not treat this as a distinct channel here; we focus on channels that remain in operation when short-term interest rates are at their lower bound. In the vicinity of the zero bound on short-term interest rates, commercial bank reserves and short-term Treasuries are largely equivalent; operations that exchange bills for longer term securities become analytically similar to those that exchange reserves for longer term securities, and the supply effect of either operation depends on a scarcity channel. Finally, Krishnamurthy and Vissing-Jorgensen classify the 'inflation channel', under which LSAPs change inflation expectations, as a separate channel. The reaction of inflation expectations, however, can be viewed as a consequence of the operation of the preceding channels, rather than as a channel in its own right. Thus, we believe that our typology of channels, although listing fewer transmission mechanisms than those given in Krishnamurthy and Vissing-Jorgensen (2011), covers all the channels likely to be relevant for the analysis of LSAPs. Our estimates in Section 5 below provide a way of determining the importance of each channel given above. Ahead of that, we briefly consider a case study.

3. Some Initial Empirical Evidence: A Case Study

The sequence of events following the FOMC meeting of 10 August 2010 throws considerable light on the impact of LSAP-style operations on longer term Treasury yields. In its statement after that meeting, the FOMC announced (at 2.15 p.m.) that principal payments from agency securities would be reinvested in longer term Treasury

[17] The model shares this feature with a class of models of the impact of second moments on term-structure behaviour.

securities. Soon thereafter, at 2.45 p.m., the Federal Reserve Bank of New York (FRBNY) issued a statement indicating that the purchases underlying the reinvestment policy would be concentrated in the 2- to 10-year sector of the nominal Treasury yield curve. Changes over this half-hour interval in market expectations (as ascertained from observed yield behaviour) are revealing about the respective roles of the scarcity and duration channels in determining Treasury yields.

Our analysis of this episode considers the prices of four previously issued 30-year Treasury bonds with remaining maturities just around 10 years or just above 14 years, shown in Figure 3.[18] Based on the 2:15 p.m. announcement, these classes of securities may well have been perceived as equally likely candidates for purchase by the Federal Reserve. Following the release of the statement by the FRBNY, however, investors should have assigned a smaller probability to the Federal Reserve purchasing securities with remaining maturities above 10 years.[19] We therefore would expect the second announcement to have no material impact on the prices of Treasury securities with 2 to 10-year maturities (the black solid lines, in Figure 3) but to exert a potentially sizable price impact on securities with maturities beyond 10 years (the dashed and dotted lines).

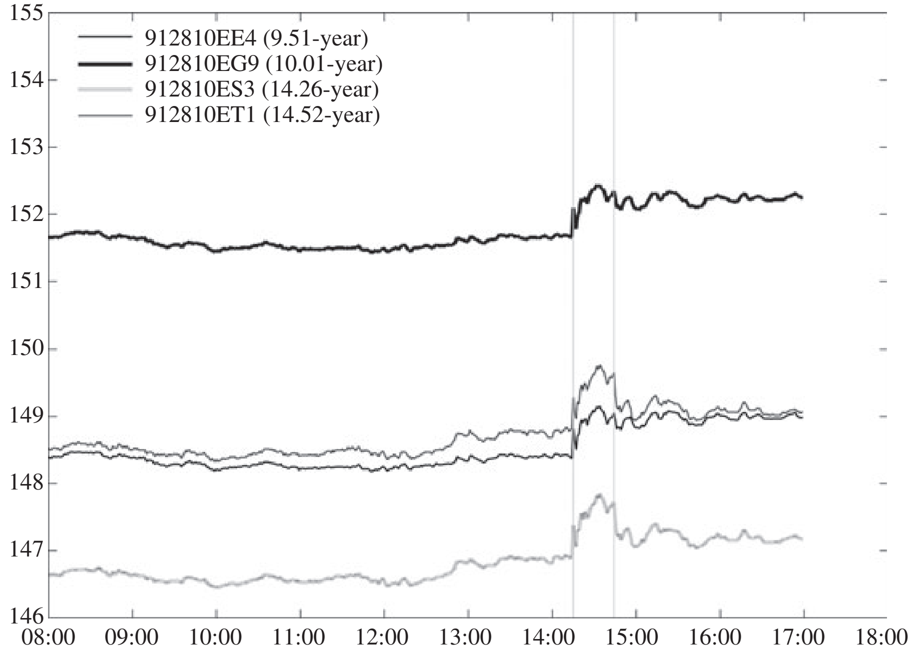

Fig. 3. *CUSIP-Level Intraday Prices on* 10 *August* 2010. *Vertical Lines Indicate Time of Announcements*
Source. Thomson Reuters Tick History database.

[18] We restrict the analysis to seasoned 30-year bonds for all the securities considered to feature similar characteristics on the dimension of their liquidity (using that term in its financial-market sense of 'marketability').

[19] The FRBNY release stated: 'The Desk will concentrate its purchases in the two- to ten-year sector of the nominal Treasury curve, although purchases will occur across the nominal Treasury coupon and TIPS yield curves'.

Table 1
Behaviour of Selected Longer Term Yields on 10 *August* 2010

Years to maturity		Maturity date	Simple returns (%) (1) 1.55 p.m.–2.35 p.m.	(2) 2.35 p.m.–3.35 p.m.	(2)/(1)
(1)	9.51	2/15/2020	0.44	−0.08	−18.9%
(2)	10.01	8/15/2020	0.45	−0.09	−20.1%
(3)	14.26	11/15/2024	0.64	−0.42	−65.7%
(4)	14.52	2/15/2025	0.65	−0.43	−66.2%

The first two rows of Table 1 establish that, in response to the FRBNY statement, the two securities with maturities close to or below 10 years experienced a reversal of only about 20% of the price increases that had come in the wake of the FOMC announcement.[20] In contrast, for the two securities with maturities above 14 years, about two-thirds of the initial price increase was reversed in the wake of the FRBNY announcement. The contrasting extent of price reversals across the two maturity groups suggests that roughly two-thirds of the decline in the 14-year Treasury yield is attributable to the anticipation of a reduction in supply around that maturity – which is to say, the *scarcity* channel.[21] The part of the price movement that endured in the wake of both announcements likely reflected the anticipation of reduction in aggregate *duration*.

Furthermore, in the wake of the second announcement, the on-the-run 30-year Treasury yield more than reversed its earlier decline, suggesting that the price action at this maturity was almost entirely driven by changing perceptions of the likelihood of purchases being conducted in this sector rather than by expected changes in duration. Although we cannot rule out the possibility that a fraction of these variations was due to revisions to funds rate expectations, it seems reasonable to assume that those would likely only have a minor impact on yields so far along the yield curve.

4. Data Description and Variable Construction

In this Section, we discuss our data sources and the series that we construct from the data. To generate accurate measures of *local* Treasury supply (i.e. the supply of the security in question and that of securities with nearby maturities) and to discern the aggregate characteristics of Treasury debt held by private investors, we start from CUSIP-level data (i.e. data delineated by the identification number of the issued Treasury security). For each CUSIP, we have available the total amount outstanding (*TAO*), the amount held in the Federal Reserve's SOMA portfolio (*SOMA*), and the cumulative amount of any Treasury buyback (*TB*), all of which are measured at par value. The

[20] Part of this reversal likely reflects investors' marking-down of the probability that 10-year Treasury securities would be among the bonds purchased. Most likely, investors initially interpreted the FOMC reference to 'longer term Treasury securities' as pertaining to maturities beyond seven years.

[21] As in the case of the 10-year rate, a minor part of this retracement may be attributable to the expectation that a smaller amount of duration would be withdrawn from the market, this expectation arising from the realisation that the Federal Reserve would not be buying any maturity beyond 10 years. The likelihood that the patterns of the 10- and 14-year rates are driven by the same factors is reinforced by the fact that the two securities considered are more similar to each other in duration than in maturity.

availability of these three components allows us to derive for each CUSIP the amount held by private investors (i.e. investors not including the Federal Reserve). This is a central variable in our analysis because it can be altered by Federal Reserve purchases of longer term Treasury securities, and because it is a possible influence on the behaviour of longer term Treasury yields.

Previous studies such as Greenwood and Vayanos (2010) and Hamilton and Wu (2012) documented the importance of certain aggregate characteristics of the Treasury debt for the determination of the term structure. Owing to data limitations, these studies did not, however, exclude actual Federal Reserve securities holdings from the totals of Treasury debt outstanding. Consequently, the holdings aggregates used in these studies suffer from the shortcoming that they are not ideal for addressing the impact of LSAP-style purchases.

Furthermore, to compute correctly the average maturity or duration remaining in the market in the wake of Federal Reserve purchases, it is crucial to employ the share of each CUSIP held by the private investors, as those shares determine the appropriate weights in the aggregation. It is also important to have data recorded at high frequency, as quantities outstanding experience frequent changes as a result of Treasury auctions and Federal Reserve operations. This finer level of data disaggregation does, however, come with the cost that we are limited to a shorter sample period in our estimation, as data on SOMA holdings at the CUSIP level are available only from December 2002.

4.1. *Constructing Our Variables*

We use these data to construct our proxies for scarcity and duration. Consistent with a concept of scarcity that corresponds to *the local availability of securities of a particular maturity*, we split the available CUSIPs into distinct 'buckets' according to maturity. For each of these buckets b_{m-n}, we compute privately held nominal Treasuries (*PHNT*) as a fraction of total Treasury debt outstanding (*TDO*):[22]

$$PHNT(m-n) = \sum_{m \leq i < n} (TAO_i - SOMA_i - TB_i)/TDO, \quad (1)$$

where i is the index for the CUSIP, and m and n are the indexes for the maturities. We exclude indexed Treasury bonds (TIPS) and Treasury bills from our computations. Our proxy for the *aggregate duration risk* (*ADR*) remaining in the market is computed as a weighted average of the *modified duration* (*MD*) in each bucket (the thinner the bucket, the more accurate is the measure, prompting our choice that each bucket contains only one CUSIP, i.e. $b_{m-n} = i_m$):

$$ADR = \sum_{i_m} PHNT(i_m) \times MD(i_m), \quad (2)$$

for every available maturity m up to 30 years. We face a possible simultaneity problem arising from the fact that a lower yield would imply a lengthening of the duration of any

[22] As indicated earlier, 'privately held' here refers to holdings outside the federal government and the Federal Reserve. It includes the holdings of both the non-bank private sector (including foreign entities and state and local governments) and commercial banks.

Treasury coupon security. To mitigate this simultaneity problem, we compute the difference between *ADR* and the duration of on-the-run 10-year Treasury notes (*D10y*).[23] We define the duration gap (*DG*) as follows:

$$DG = ADR - D10y. \tag{3}$$

As both the variables on the right-hand side of the preceding expression are affected by the mechanical element of the change in duration, a focus on fluctuations in the difference between the two series is likely to pinpoint the more meaningful movements in duration.

It is useful to note, in comparing our results with existing studies, that the derivation of our proxy for the ADR remaining in the market simply amounts to an alternative means of weighting the Treasury securities contained in each maturity bucket b_{m-n}. On the other hand, taking into consideration the fact that our series includes only those Treasury securities held by private investors and the fact that the sensitivity to interest-rate risk of a bond of a particular maturity depends on its duration, we contend that our *ADR* (and hence *DG*) series are closer in spirit to the concept of aggregate risk of the arbitrageurs' portfolio underlying the Vayanos and Vila (2009) analysis.

To the extent that investors are principally concerned with the duration risk of their portfolio, *ADR* provides the most convenient summary of the degree of interest-rate risk in the market. It should therefore contribute to the explanation of the behaviour of bond risk premiums. If, however, this constituted the *only* relevant channel connecting Federal Reserve bond purchases to longer term Treasury yields, we would observe yield changes that were monotonic in the amount of duration. Thus, if Federal Reserve operations tended to reduce the amount of duration that private investors were required to absorb, the impact on the 30-year Treasury yield would considerably outweigh the impact on the 10-year yield. The available empirical evidence on the effect of LSAPs, as well as on the announcements concerning reinvestments of proceeds from agency securities, suggests that this is not the case (Krishnamurthy and Vissing-Jorgensen, 2011; D'Amico and King, forthcoming). This lends weight to the view that additional channels might be important. Moreover, the occurrence of larger impacts in sectors in which most of the purchases were concentrated points towards local supply and demand effects. With this in mind, we constructed our scarcity proxy in the manner described above.

Figure 4 displays the time series of *PHNT* and *ADR*, as constructed from weekly CUSIP-level data from December 2002 to August 2011. The periods of the first and second LSAP programmes are indicated by shaded regions in the Figure. As expected, in these periods the share of Treasury securities held by private investors exhibited a large decline, reflecting the securities added to the SOMA portfolio. In contrast, *ADR*, which is measured in units of years, recorded only a modest decline during the first and second LSAPs, as most of the purchases were concentrated in the 2 to 10-year sector. Counterfactual computations indicate that during the first LSAPs the average duration of privately held *TDO* was reduced from 4.42 to 4.30 years and was reduced by a similar extent in the course of the second LSAP programme. These patterns indicate that very large policy interventions in the sector

[23] We are grateful to Canlin Li for this suggestion.

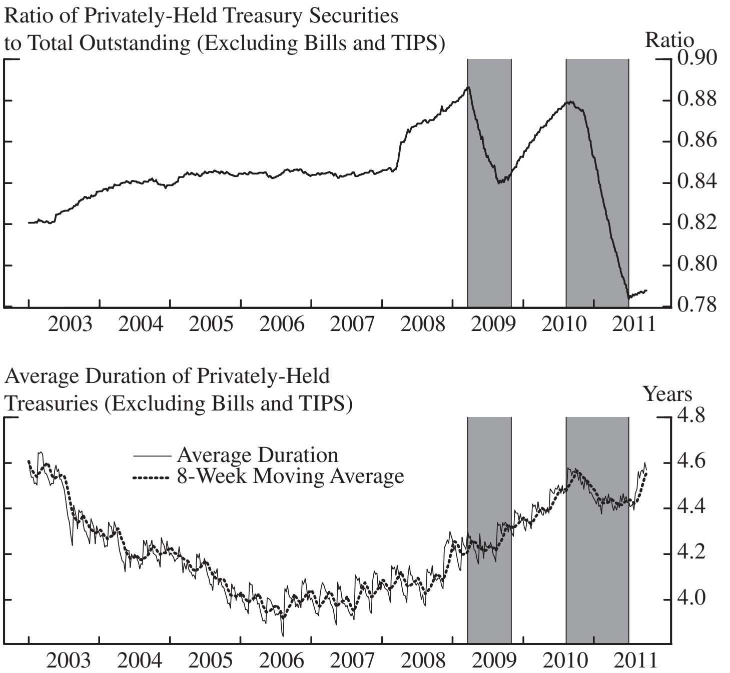

Fig. 4. *Privately Held Nominal Treasuries and Average Duration*

beyond the 10-year maturity are required to remove a significant amount of duration from the market.

4.2. *A Look at the Data Correlations*

Here, we illustrate how our decomposition of *PHNT* into thin buckets highlights key aspects of the correlation structure between longer term Treasury yields and the *available* supply for each bucket. Table 2 displays correlations between constant-maturity yields and local Treasury security supply as measured by the relevant *PHNT*s, where (here and below) the notation *PHNT*(m: a–b) denotes the bucket covering maturities from a years up to, but not including, b years. The correlation structure for December 2002 to October 2008 – a sample that precedes the inception of LSAPs – is suggestive of a role for imperfect substitution across sectors of the yield curve. Treasury yields at maturities between 2 and 10 years are positively correlated only with Treasury supply with a maturity between 2 and 12 years, and they are negatively correlated with the supply with maturity between 12 and 28 years. In contrast, Treasury yields with a maturity of 15 years and beyond are positively correlated only with the supply concentrated in maturity buckets beyond 12 years.

This correlation pattern is wholly reversed in the sample period that includes the two LSAPs (see the bottom panel of Table 2). This might suggest that the activity of the Federal Reserve in longer term Treasury markets is the main factor driving the change in sign. If the Federal Reserve bought large quantities of securities whose yields exhibited the strongest upward trend over the sample, then we would observe

Table 2

*Correlation Matrix for Nominal Yields, Maturity Buckets and Duration**

Buckets/Yields	2-years	5-years	7-years	10-years	15-years	20-years	25-years	30-years
Sample Period: 2002:12–2008:10								
$PHNT$ (m: 2–4)$_t$	0.92	0.85	0.75	0.47	−0.11	−0.40	−0.49	−0.52
$PHNT$ (m: 6–8)$_t$	0.53	0.42	0.35	0.17	−0.24	−0.47	−0.56	−0.60
$PHNT$ (m: 8–10)$_t$	0.60	0.51	0.42	0.20	−0.23	−0.44	−0.52	−0.54
$PHNT$ (m: 10–12)$_t$	0.58	0.47	0.34	0.07	−0.36	−0.53	−0.59	−0.61
$PHNT$ (m: 12–14)$_t$	−0.61	−0.55	−0.44	−0.19	0.20	0.35	0.38	0.39
$PHNT$ (m: 16–18)$_t$	−0.48	−0.37	−0.31	−0.15	0.23	0.44	0.53	0.56
$PHNT$ (m: 18–20)$_t$	−0.75	−0.66	−0.54	−0.26	0.25	0.48	0.56	0.59
$PHNT$ (m: 22–24)$_t$	−0.29	−0.18	−0.12	0.01	0.29	0.45	0.53	0.56
$PHNT$ (m: 24–26)$_t$	−0.55	−0.42	−0.34	−0.14	0.29	0.52	0.62	0.65
$PHNT$ (m: 26–28)$_t$	−0.87	−0.78	−0.67	−0.38	0.21	0.49	0.59	0.61
Duration Gap$_t$	−0.15	0.01	0.13	0.34	0.58	0.67	0.71	0.74
Sample Period: 2008:11–2011:2								
$PHNT$ (m: 2–4)$_t$	−0.52	−0.22	−0.24	−0.27	−0.13	0.22	0.51	0.66
$PHNT$ (m: 6–8)$_t$	−0.42	−0.18	−0.17	−0.19	−0.11	0.13	0.36	0.49
$PHNT$ (m: 8–10)$_t$	−0.45	−0.29	−0.32	−0.33	−0.20	0.12	0.38	0.52
$PHNT$ (m: 10–12)$_t$	0.55	0.31	0.33	0.35	0.21	−0.12	−0.40	−0.54
$PHNT$ (m: 12–14)$_t$	0.49	0.22	0.21	0.20	0.05	−0.29	−0.56	−0.70
$PHNT$ (m: 16–18)$_t$	0.45	0.19	0.20	0.22	0.09	−0.24	−0.51	−0.65
$PHNT$ (m: 18–20)$_t$	0.47	0.16	0.15	0.15	−0.02	−0.36	−0.62	−0.74
$PHNT$ (m: 22–24)$_t$	0.66	0.40	0.40	0.41	0.27	−0.07	−0.37	−0.54
$PHNT$ (m: 24–26)$_t$	−0.50	−0.36	−0.35	−0.35	−0.24	0.03	0.26	0.39
$PHNT$ (m: 26–28)$_t$	0.03	0.16	0.12	0.08	0.13	0.26	0.35	0.39
Duration Gap$_t$	0.08	0.30	0.31	0.29	0.27	0.31	0.36	0.40

Notes. *The buckets contain privately held nominal Treasury securities outstanding grouped by maturity class, and the Treasury yields are zero-coupon rates obtained by fitting the Svensson (1995) yield-curve approximation.

a combination of rising yields on those Treasury securities and *decreasing* quantities available to private investors. Such a pattern should be more evident for the maturity sectors in which the Federal Reserve concentrated its purchases, namely the 2 to 15-year sectors.

This result points to the likelihood that the purchase strategy over sample periods that include LSAPs is a factor that hinders attempts to determine by statistical methods the structural relationship between yields and quantities. This endogeneity problem, which is stressed in D'Amico and King (forthcoming), underscores the importance of our subsample analysis for bringing out the underlying relationship between longer term Treasury yields and the securities supply available to private investors. The preliminary data analysis also indicates that yields and quantities are highly correlated in some of the buckets, and it suggests that it would be preferable to group the buckets according to common correlation patterns. In particular, we can group together *PHNT* from 2 to 10-year maturity buckets and *PHNT* from 12 to 28-year maturity buckets without losing much of the information contained in the data. Finally, it is important to note that only in the first subsample do we observe a monotonic pattern of the kind we would expect for the correlation between longer term Treasury yields and the duration gap, the correlation being, by contrast, quite flat in the second subsample.

5. Empirical Specification and Results

This Section provides our estimated specifications. We initially consider the levels of nominal Treasury yields at different maturities, obtained by fitting the Svensson (1995) yield-curve approximation, and present results that are largely model-independent, in the sense that only quite general assumptions are required to generate the dependent variables. Then, using different specifications of a Gaussian three-factor model of the term structure, we focus on the term-premium component of longer term Treasury yields.[24] We also consider whether these results are robust to alternative specifications. Finally, using the affine term-structure model (ATSM) augmented with TIPS – the model for which we have the greatest confidence when it comes to the decomposition of nominal term premiums – we estimate impacts on the real term premium and the inflation risk premium.[25]

Table 3 reports estimates that result from regressing nominal Treasury yields at different maturities on our proxies for scarcity and aggregate duration after controlling for the slope of the term structure, which is measured by the spread between the 2 and 10-year yields. The slope variable has been widely found to be a predictor of both economic activity and Treasury returns.[26] Accordingly, we regard its inclusion as important for establishing whether our proxies (scarcity and aggregate duration) are important in their own right in accounting for the behaviour of longer term rates.[27] We

Table 3

*Baseline Specification**

Regressors	7 years	10 years	15 years	20 years	25 years	30 years
$PHNT(m\text{: } 2\text{–}10)_t$	8.34	7.61				
	(2.03)	(1.47)				
$Duration\ Gap_t$	222.14	197.72				
	(25.39)	(19.34)				
$[y(m) - y(2)]_{t-1}$	−0.28	−0.01				
	(0.06)	(0.03)				
$PHNT(m\text{: } 14\text{–}30)_t$			3.98	6.45	7.03	5.94
			(2.05)	(1.98)	(1.85)	(1.76)
$Duration\ Gap_t$			118.59	120.18	140.66	169.27
			(26.75)	(25.44)	(25.14)	(25.69)
$[y(10) - y(2)]_{t-1}$			−0.07	−0.02	0.02	0.05
			(0.02)	(0.02)	(0.03)	(0.03)
Adjusted R^2	0.71	0.51	0.46	0.52	0.56	0.56

Notes. *The regressions estimated take the form: $y(m)_t = a + bPHNT(m: 2-10)_t + cDurationGap_t + d[y(m) - y(2)]_{t-1}$ The dependent variable is the nominal yield of maturity m (obtained by fitting the Svensson (1995) yield-curve approximation). The regressors are two policy-related variables, privately held nominal Treasuries (*PHNT*) as percentage of total Treasury debt outstanding (*TDO*) and the duration gap defined as the difference between aggregate duration risk (*ADR*) and the duration of the on-the-run 10-year Treasury notes. Finally, the yield spread is included to proxy the slope of the yield curve. The sample period consists of weekly data from December 2002 until October 2008. Standard errors are computed using Newey and West (1987) procedure allowing for four lags.

[24] See Kim and Wright (2005) and Kim and Orphanides (2005).
[25] See D'Amico *et al.* (2008).
[26] See, for example, Fama and Bliss (1987) and Estrella and Hardouvelis (1991).
[27] Inclusion of the slope term in the regression improves the explanatory power of the regression but has little effect on the estimated impact of the scarcity and duration regressors.

note that our equations, like those in all previous studies of LSAPs, are specified in terms of *actual* scarcity and duration proxies rather than the expected path of these variables. This specification might not be wholly appropriate for the LSAP period, as LSAP programmes consisted largely of purchases announced some time in advance, and announcements of future effects on scarcity and duration are likely to have figured in the reaction of longer term rates. This issue, however, is less problematic for our estimated specifications, since – in light of the analysis of the preceding Section – our estimation period predates the LSAP programmes.

We consider only securities with at least seven years to maturity (7 to 30-year nominal yields); shorter term yields for our sample appear to exhibit clearly non-stationary time series behaviour, reflecting both the fact that our sample features only two funds rate 'cycles' – one tightening and one easing – and the fact that shorter term yields, presumably being dominated by the expectations component rather than term-premium behaviour, tend to mimic funds rate behaviour more closely. The top panel of Figure 5 confirms that the main driver of shorter yields is the expectations component. In contrast, the term-premium component seems to be the dominant source of fluctuations in yields when longer term rates are considered – as can be seen in the lower half of Figure 5. The latter pattern implies more stationary behaviour of interest rates, as the term-premium component in this sample is less persistent than the expectations component.

A further consideration that reinforces the desirability of concentrating on pre-crisis behaviour when ascertaining the effect of LSAP-style operations is that the residual or 'fitting error' for the term-structure specification used to decompose longer term rates became unusually large in late 2008 and early 2009. Thus, over this period, our scope to make judgments about overall longer term interest rate behaviour based on the decomposition is reduced. Since our econometric work concentrates on the determination of these systematic terms, it seems all the more appropriate to confine our estimation sample periods to the pre-crisis period.

The specification of the nominal yield equation is (neglecting the error terms):

$$y_t(m) = a + b_1 PHNT_t(m:2-10) + b_2 DG_t + b_3[y_{t-1}(m) - y_{t-1}(2)], \tag{4}$$

for $m \leq 10y$, and

$$y_t(m) = a + b_1 PHNT_t(m:14-30) + b_2 DG_t + b_3[y_{t-1}(10) - y_{t-1}(2)], \tag{5}$$

for $m > 10y$, where all the variables are observed weekly. As we are considering persistent variables and some of the data's persistence might carry through to the behaviour of the estimated residuals, the t-statistics are computed using Newey and West (1987) standard errors, allowing for a four-week window. The estimated coefficients for our measures of scarcity and aggregate duration are both positive and statistically significant across all maturities even after controlling for the slope of the yield curve, with the adjusted R^2's varying from 0.46–0.70.[28] The signs of the estimated coefficients are in the predicted direction: the lower is the volume of privately held Treasury securities in a specific maturity sector, the lower the yield

[28] We caution against direct comparison of the coefficient on duration in these estimated specifications with those in studies such as Greenwood and Vayanos (2010) and Hamilton and Wu (2012), as we are using a gap variable rather than the level of aggregate duration or average maturity.

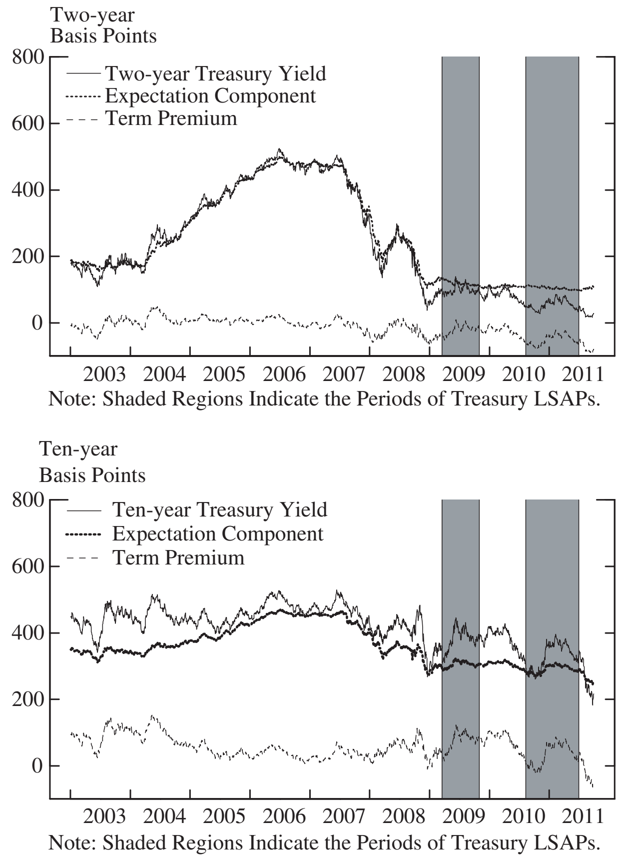

Fig. 5. *Decomposition of Treasury Yields*
Notes. Shaded regions indicate the periods of Treasury LSAPs.

prevailing in that sector; likewise, the smaller the amount of aggregate duration left in the market, the lower should be the yields.

Table 4 displays results for a set of regressions similar to the baseline but, instead of aggregating *PHNT* into only two broad maturity buckets, we consider two-year-wide buckets with maturities within few years of the yield's maturity. That is, we seek to test further the impact of scarcity, or local supply. In particular, we restrict attention to the bucket centred on the yield's maturity and to the two buckets with maturities just above and below it.[29] For the majority of the yields, the results appear to suggest that the *PHNT* buckets with the closest maturity to the yield tend to exhibit higher positive correlations and/or stronger statistical significance.

We now consider results for the nominal term-premium (*TP*) component of longer term Treasury yields. The upper panel of Table 5 reports the results for the following regression:

[29] An exception is the 30-year yield, for which the buckets of interest are empty for the bulk of the sample period.

Table 4

*Extensions of the Baseline Specification**

Regressors	7 years	10 years	15 years	20 years	25 years
$PHNT\ (m\text{: }4\text{–}6)_t$	0.52				
	(5.52)				
$PHNT\ (m\text{: }6\text{–}8)_t$	5.46	7.58			
	(2.98)	(3.11)			
$PHNT\ (m\text{: }8\text{–}10)_t$	14.26	12.60			
	(9.62)	(7.37)			
$PHNT\ (m\text{: }10\text{–}12)_t$		4.15			
		(8.72)			
$Duration\ Gap_t$	176.86	167.92			
	(29.91)	(28.80)			
$[y(m) - y(2)]_{t-1}$	−0.41	−0.08			
	(0.08)	(0.04)			
$PHNT\ (m\text{: }12\text{–}14)_t$			16.61		
			(5.63)		
$PHNT\ (m\text{: }14\text{–}16)_t$			26.80		
			(8.33)		
$PHNT\ (m\text{: }16\text{–}18)_t$			0.28		
			(3.86)		
$PHNT\ (m\text{: }18\text{–}20)_t$				−7.10	
				(7.21)	
$PHNT\ (m\text{: }20\text{–}22)_t$				32.39	
				(11.65)	
$PHNT\ (m\text{: }22\text{–}24)_t$				17.24	24.91
				(4.80)	(7.63)
$PHNT\ (m\text{: }24\text{–}26)_t$					−2.03
					(7.50)
$PHNT\ (m\text{: }26\text{–}28)_t$					3.31
					(12.87)
$Duration\ Gap_t$			109.59	117.98	141.41
			(19.73)	(22.03)	(22.15)
$[y(10) - y(2)]_{t-1}$			0.04	0.14	0.07
			(0.04)	(0.04)	(0.07)
Adjusted R^2	0.66	0.44	0.55	0.58	0.58

Note. *See notes for Table 3 for further details on the estimated specifications.

$$TP_t(m) = a + b_1 PHNT_t(m : 2 - 10) + b_2 DG_t + b_3[y_{t-1}(m) - y_{t-1}(2)], \tag{6}$$

where the *TP* series has been derived using an ATSM with TIPS.[30] In light of the fact that, over this sample, the *TP* component of medium-term yields appears to be stationary, we also consider results using the two and five-year term premiums as the dependent variable.

The first notable feature of the results, previously found for our nominal yield regressions, is that the coefficients on our measures of scarcity and aggregate duration are positive and statistically significant. Another notable feature is that the magnitude of the coefficients seems to indicate that a large part of the impact of scarcity and aggregate duration on longer term Treasury yields has been transmitted via the term-premium component. Put another way, the effects on the term premiums found here are similar in size to those on the entire yields. Finally, for both

[30] We also considered specifications based on an ATSM without TIPS. The resulting estimates of the key coefficients were very similar.

Table 5

*Estimates of Term-Premium Specification**

Regressors	2 years	5 years	7 years	10 years
Dependent variable: Nominal term premium for maturity				
$PHNT\ (m\text{: } 2\text{–}10)_t$	3.98	5.11	4.63	4.34
	(1.05)	(1.32)	(1.44)	(1.48)
$Duration\ Gap_t$	93.15	120.32	122.59	123.47
	(16.51)	(17.34)	(18.75)	(19.41)
$[y(m) - y(2)]_{t-1}$	0.21	0.32	0.26	0.24
	(0.04)	(0.06)	(0.04)	(0.03)
R^2	0.35	0.45	0.51	0.60
Dependent variable: Real term premium for maturity				
$PHNT\ (m\text{: } 2\text{–}10)_t$	2.64	3.78	3.73	3.63
	(0.58)	(0.81)	(0.87)	(0.92)
$Duration\ Gap_t$	62.76	93.17	97.89	99.93
	(7.09)	(10.06)	(11.19)	(12.06)
$[y(m) - y(2)]_{t-1}$	0.11	0.11	0.09	0.11
	(0.02)	(0.03)	(0.02)	(0.02)
Adjusted R^2	0.45	0.44	0.44	0.48
Dependent variable: Inflation risk premium for maturity				
$PHNT\ (m\text{: } 2\text{–}10)_t$	1.33	1.33	0.90	0.71
	(0.58)	(0.67)	(0.73)	(0.75)
$Duration\ Gap_t$	30.38	27.14	24.69	23.54
	(12.19)	(11.69)	(12.15)	(12.16)
$[y(m) - y(2)]_{t-1}$	0.11	0.21	0.16	0.14
	(0.03)	(0.03)	(0.03)	(0.02)
Adjusted R^2	0.21	0.51	0.59	0.66

Notes. *The regressions are of the form: $z(m)_t = a + bPHNT(m: 2-10)_t + cDurationGap_t + d[y(m) - y(2)]_{t-1}$ where the dependent variable, $z(m)_t$, is equal to the nominal term premium, the real term premium, and the inflation risk premium respectively. The decomposition of the yields among real term premium and inflation risk premium is based on a Gaussian three factors model described in D'Amico *et al.* (2008) using TIPS. See Table 1 for further description of the regressors and the specification. In the case of the two-year term premium, the slope regressor is defined in relation to the one-year yield.

variables, beyond the two-year maturity, the coefficient estimates are fairly similar across the different maturities.

The presence of significant impacts of scarcity and duration in the term-premium regressions strongly suggests that the significance of these variables for long-term interest rate variation is not arising from their correlation with expected future policy rates. LSAP-style operations would appear to exert a distinct impact on longer term interest rates for a given path of the short-term policy rate. The signalling channel, while present, is evidently not the main means by which LSAPs can reduce longer term interest rates.[31]

To illustrate the scarcity and duration effect of LSAP-style operations, we construct counterfactual yield curves obtained using the results in Table 5 for the nominal term premium. The resulting yield curves are shown in Figure 6. For simplicity, the counterfactual exercise starts from the actual yield curve as of 29 October 2009 – at the

[31] Our finding of effects of LSAP-style operations on longer term interest rates, although based on estimates from the pre-LSAP period, is consistent with several studies noted above that focus on the periods of the LSAPs. An exception, which emphasises the signalling channel, is Bauer and Rudebusch (2011).

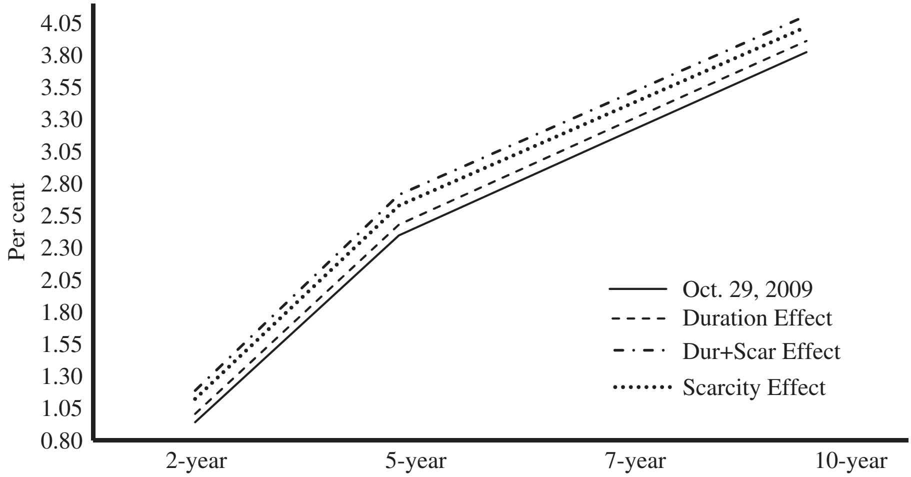

Fig. 6. *Counterfactual Yield Curves*

conclusion of the first Treasury LSAP programme – and treats all purchases ($300 billion) as concentrated in the 2 to 10-year sector. In addition to the actual yield curve (solid line) that incorporates the effect of the first Treasury LSAP programme, the Figure plots the estimated yield curves that would have prevailed without the scarcity effect of LSAP (dotted line), without the aggregate duration effect (dashed line), and without either of these effects – that is, the no-LSAP case (the combined dashed/dotted line). The scarcity effect is the largest for the five-year yield at about 23 basis points and is slightly smaller for the 2 and 10-year yield at about 18 and 20 basis points, respectively. The aggregate duration effect is larger for longer maturities: it is about 6.5 basis points for the two-year yield; about 8.7 basis points for the 10-year yield.

The middle and bottom panels of Table 5 provide results for the real term premium (*RTP*) and the inflation risk premium (*IRP*) components of longer term yields. The estimated regression specifications take the form:

$$RTP_t(m) = a + b_1 PHNT_t(m:2-10) + b_2 DG_t + b_3[y_{t-1}(m) - y_{t-1}(2)], \tag{7}$$

and:

$$IRP_t(m) = a + b_1 PHNT_t(m:2-10) + b_2 DG_t + b_3[y_{t-1}(m) - y_{t-1}(2)]. \tag{8}$$

In the specification with *RTP* as the dependent variable, the coefficients on both scarcity and aggregate duration are positive and statistically significant across all maturities. For the specifications with the inflation risk premium as the dependent variable, only aggregate duration seems to be consistently significant across the different maturities. Further, comparison of the coefficient estimates across the regressions reveals the extent to which *PHNT* and *DG* impact *TP*, thus confirming that the bulk of the response is in the *RTP* component – as one would expect if preferred-habitat mechanisms are operative.

In Table 6, we show that our results are robust to controlling for additional explanatory variables. The results in the Table also reflect our attempt to address a potential simultaneity problem. If the aggregate characteristics of *PHNT*, such as average maturity and duration, are in part driven by macroeconomic variables, then they would be likely to have predictive content for longer term Treasury yields and term premiums even in the absence of a structural relationship. In light of this consideration, we estimate regressions with *PHNT* and *DG* as regressors alongside the following variables: the Aruoba *et al.* (2009) index (whose inclusion is a means of controlling for real-time business conditions at the weekly frequency),[32] the weekly average of intraday correlation between stock returns and changes in the 10-year bond yield (so as to control for 'flight-to-quality' episodes),[33] and Treasury option-implied volatility (to control for interest-rate uncertainty).[34] Table 6 presents estimates of the specification

$$TP_t(m) = a + b_1 PHNT_t(m:2-10) + b_2 DG_t + b_3[y_{t-1}(m) - y_{t-1}(2)] + b_4 X_t, \qquad (9)$$

where X_t varies across specifications depending on which of the three candidate additional explanatory variables is being employed.

The regression results for the nominal term premium and the real term premium indicate that the coefficients on scarcity and duration remain positive and statistically significant after including each of the new explanatory variables. Moreover, the key estimated coefficients are little altered, as is clear by a comparison across the three columns for each yield (with each column corresponding to a specification with a particular additional explanatory variable). Also noteworthy is that the specification that includes the flight-to-quality proxy is the equation with the highest explanatory power. Thus, flight-to-quality considerations would appear to be an important factor in the determination of longer term Treasury rates.

More importantly, scarcity and duration remain highly significant even after controlling for the flight-to-quality proxy. Krishnamurthy and Vissing-Jorgensen (2012) point to the flight-to-quality episodes as occasions on which there is a sharp increase in the utility derived from the 'convenience'-style vehicles such as longer term Treasury securities. This observation might suggest that controlling for flight to quality could render insignificant the variables designed to stand-in for preferred-habitat-type effects but that is not the case in our results. Our results also suggest, consequently, that for Treasury securities, absence of default risk is not the main source of preferred-habitat behaviour or market segmentation.[35]

In the case of the regressions with the inflation risk premium as the dependent variable, the results are more sensitive to the inclusion of the additional explanatory variables. In particular, when we control for Treasury option-implied volatility (see the first column of each Table), *DG* is no longer statistically significant, perhaps because a single variable is an adequate stand-in for interest-rate risk. Moreover, for the 7 and 10-year yields, when we control for the flight-to-quality variable or the business conditions index, *PHNT* is not

[32] Inclusion of this variable amounts to an attempt to control for macroeconomic developments that are not already proxied by variation in the yield-slope regressor.

[33] The rationale for this variable is that a 'flight to quality' should feature falling equity prices and a marking-up of prices of Treasury securities, in response to investors' shift from more risky assets into Treasury securities. This process should lead to a positive correlation between equity returns and Treasury yields.

[34] This is measured by Merrill Lynch's weighted average of implied volatilities of the 2-year (20% weight), 5-year (20%), 10-year (40%), and 30-year (20%) Treasury securities.

[35] As stressed above, in preferred-habitat models, it is features other than the absence of default risk that make investment in longer term securities attractive to certain investors. In particular, institutional investors tend to favour a fixed-income stream that helps match the maturity of assets and liabilities.

Table 6

*Term-Premium Regression: Sensitivity Analysis (Additional Explanatory Variables)**

	Term-premium, scarcity, and duration											
	2 years			5 years			7 years			10 years		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Left-hand side variable: nominal term premium												
$PHNT_t$	4.35	3.07	4.37	5.89	4.02	5.38	5.24	3.65	4.78	4.63	3.49	4.40
	(1.07)	(1.08)	(1.11)	(1.37)	(1.33)	(1.40)	(1.52)	(1.37)	(1.50)	(1.57)	(1.35)	(1.51)
DG_t	49.96	73.15	63.98	81.88	97.99	91.55	91.40	101.30	96.23	99.78	104.60	100.60
	(14.19)	(14.12)	(16.18)	(15.81)	(16.17)	(18.37)	(17.23)	(16.85)	(18.96)	(17.92)	(16.83)	(18.74)
$y(m) - y(2)$	0.27	0.10	0.15	0.53	0.32	0.36	0.42	0.31	0.33	0.37	0.31	0.32
	(0.07)	(0.05)	(0.06)	(0.09)	(0.06)	(0.07)	(0.07)	(0.04)	(0.05)	(0.05)	(0.03)	(0.04)
Adj. R^2	0.35	0.40	0.29	0.47	0.52	0.43	0.59	0.65	0.57	0.71	0.76	0.71
Left-hand side variable: real term premium												
$PHNT_t$	2.84	2.46	3.00	4.03	3.54	4.09	3.88	3.56	4.04	3.57	3.50	3.89
	(0.58)	(0.52)	(0.54)	(0.87)	(0.77)	(0.79)	(0.97)	(0.83)	(0.87)	(1.04)	(0.88)	(0.93)
DG_t	55.93	60.36	56.68	88.84	90.48	88.17	96.05	95.85	93.85	100.40	98.43	96.92
	(7.23)	(6.32)	(6.97)	(9.78)	(9.53)	(9.93)	(10.94)	(10.64)	(11.03)	(11.88)	(11.56)	(11.91)
$y(m) - y(2)$	0.15	0.12	0.14	0.15	0.12	0.13	0.11	0.11	0.11	0.10	0.12	0.12
	(0.04)	(0.02)	(0.03)	(0.05)	(0.03)	(0.04)	(0.04)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)
Adj. R^2	0.47	0.55	0.49	0.44	0.50	0.45	0.43	0.49	0.45	0.47	0.52	0.48
Left-hand side variable: inflation risk premium												
$PHNT_t$	1.92	1.08	1.54	2.16	1.05	1.58	1.79	0.70	1.17	1.54	0.56	0.99
	(0.53)	(0.51)	(0.58)	(0.59)	(0.59)	(0.66)	(0.69)	(0.67)	(0.75)	(0.74)	(0.68)	(0.77)
DG_t	10.57	26.97	26.88	12.88	23.93	23.15	13.99	22.29	21.18	15.82	21.75	20.37
	(9.80)	(10.76)	(12.49)	(9.32)	(10.28)	(11.86)	(10.11)	(10.69)	(12.24)	(10.55)	(10.71)	(12.19)
$y(m) - y(2)$	0.24	0.12	0.12	0.36	0.22	0.23	0.26	0.17	0.18	0.21	0.15	0.15
	(0.04)	(0.03)	(0.03)	(0.05)	(0.03)	(0.04)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)
Adj. R^2	0.36	0.37	0.22	0.60	0.61	0.53	0.64	0.67	0.59	0.69	0.72	0.66

Notes. *The regressions are of the form: $z(m)_t = a + bPHNT(m:2-10)_t + cDurationGap_t + d[y(m) - y(2)]_{t-1} + \delta X_{t-1} + u_t$ where the dependent variable, $z(m)_t$, is equal to the nominal term premium, the real term premium, and the inflation risk premium respectively. In column (1), the variable X is the Treasury option-implied volatility, in column (2) the variable X is the weekly average of the intraday correlation between the ten-year yield changes and the returns on the S&P500, and in column (3) the variable X is the Auroba, Diebold and Schotti index of business conditions. See Table 3 for details.

significant. Finally, when, in the third column, we control for business conditions, *DG* is no longer significant in explaining longer term yield behaviour. More importantly, when we introduce additional explanatory variables, the estimated coefficient on *DG* becomes considerably smaller while that on *PHNT* is not affected. The sensitivity of these results for the inflation risk premium supports the position that the main means through which LSAPs impact longer term yields is via the real term premium.

One difficulty with the interpretation of our baseline regressions is that variations in the slope of the yield curve should partly reflect the impact of changes in *PHNT* and *DG*. Thus, our inclusion of a proxy for this explanatory variable in the regressions could be reducing the estimated effects of scarcity and duration, leading to an understatement of the effects on longer term yields that arise from LSAP-style actions. To address this difficulty, we attempt to control for the influence of the slope factor by including a variable that is not directly altered by purchases of longer term Treasury securities. In particular, we employ the slope of the swap term structure rather than that of Treasury yields.[36] As the upper panel of Table 7 shows, results are not substantially changed by the employment of this alternative measure; the estimated coefficients on scarcity and on aggregate duration both become modestly smaller.[37]

In a separate online Appendix, we present supplementary results that establish the robustness of our baseline estimates to variations in the specification and also show that our proxies for scarcity and duration are important in accounting for the observed variations in fixed-income securities other than Treasury bonds. The online Appendix also presents estimated impact of our scarcity and duration variables on corporate bond rates, measured as zero-coupon yields obtained via the Nelson and Siegel (1987) yield-curve approximation.

Finally, the lower panel of Table 7 shows the results of our preferred specification:

$$TP_t(m) = a + b_1 PHNT_t(m:2-10) + b_2 DG_t + b_3[s_{t-1}(m) - s_{t-1}(2)] + b_4 X_{t-1}. \qquad (10)$$

This specification includes both the slope of the swap yield curve and (as the X_t variable) the flight-to-quality proxy, which is the only other explanatory variable that is statistically significant across all maturities and which greatly increases the explanatory power of the regression.[38] The magnitude of the coefficient estimates suggests that purchases with a maturity between 2 and 10 years that reduce *PHNT* by 1% – which, at the end of the first LSAP programme, amounted to roughly $64 billion – would be associated on average with about a five basis point decrease in yields of comparable maturity. This estimate implies that the scarcity effect from the first of the Treasury LSAPs (which totalled $300 billion) was about 23 basis points.

In addition, a one-year decrease in the aggregate duration of Treasury securities held by the public is estimated to push the 5 to 10-year yields about 100 basis points lower. As indicated in Section 4.1, the first LSAP programme reduced average duration by 0.12 years, which in turn translates into a 12 basis point reduction in longer term Treasury yields. Thus, the total impact from the first LSAP programme would, on this calculation, be about 35 basis points. These estimates are about in line with the estimates of D'Amico and King (forthcoming) but larger than the estimates reported in Gagnon *et al.* (2011). Similarly, our results suggest that the scarcity effect from the second LSAP programme is about 35 basis points (taking into account the fact that at the end of the second LSAP programme 1% of *PHNT* amounted to $86 billion) and the duration effect is about 10 basis points, as this programme – although larger in dollar size than the first LSAP for Treasuries – removed only 0.1 year of duration from the market because all the purchases were concentrated in the 2 to 10-year sector. Thus, the total effect on longer term

[36] On the other hand, we might expect the reaction of swap rates to changes in aggregate duration to be similar to that of longer term Treasury securities.

[37] The similarity to the previous estimates might be a result of transmission to other interest rates of responses of longer term Treasury yields to LSAP-style operations.

[38] The significance of the key parameter estimates is robust to the choice of length of the Newey–West lag window. The final regression in Table 7 has a coefficient on *PHNT* of 5.79 with standard error 1.45. This standard error only rises to 1.78 if instead 52 lags are used in calculating the Newey–West standard errors. Likewise, the standard error for the coefficient on the duration gap term rises from 15.8–18.4 if the Newey–West lag window becomes 52 weeks; this standard error is still small in relation to the coefficient estimate of 107.4.

Table 7

*Term-Premium Specifications with Additional Regressors**

Regressors	2 years	5 years	7 years	10 years
Dependent variable: Nominal term premium for maturity				
$PHNT\ (m{:}\ 2\text{–}10)_t$	3.99	5.43	5.89	6.19
	(1.45)	(1.61)	(1.60)	(1.55)
$Duration\ Gap_t$	91.51	113.46	115.17	112.31
	(18.04)	(18.70)	(18.47)	(17.67)
$[s(m) - s(2)]_{t-1}$	0.12	0.21	0.27	0.34
	(0.05)	(0.05)	(0.05)	(0.05)
Adjusted R^2	0.22	0.39	0.55	0.60
Dependent variable: Nominal term premium for maturity				
$PHNT\ (m{:}\ 2\text{–}10)_t$	3.56	4.98	5.45	5.79
	(1.31)	(1.48)	(1.49)	(1.45)
$Duration\ Gap_t$	86.30	107.97	109.88	107.43
	(15.75)	(16.44)	(16.37)	(15.84)
$[s(m) - s(2)]_{t-1}$	0.14	0.22	0.28	0.36
	(0.04)	(0.04)	(0.04)	(0.04)
$[corr(d10y,\ S\&P500ret]_{t-1}$	−0.30	−0.32	−0.31	−0.28
	(0.05)	(0.06)	(0.06)	(0.05)
Adjusted R^2	0.43	0.52	0.60	0.69

Notes. *The regressions are of the form: $z(m)_t = a + bPHNT(m:2-10)_t + cDurationGap_t + d[s(m) - s(2)]_{t-1} + \delta\ [corr(d10y, S\&P500ret)]_{t-1}$ where the dependent variable, $z(m)_t$, is the nominal term premium. In the upper part of the Table, we control only for the slope of the swap yield curve, setting $\delta = 0$. In the lower part of the Table, we allow for non-zero δ by entering the weekly average of the intraday correlation between ten-year yield changes and S&P500 returns as a proxy for flight to quality.

Treasury yields of the second LSAP programme is estimated to be about 45 basis points. Our results indicate that the two channels were both quantitatively significant, affecting longer term Treasury yields in proportions similar to those suggested by the event study in Section 3. It is notable that a different sample period and a different methodology generate estimates quite similar to D'Amico and King (2010), whose results were obtained from data covering the recent crisis period. This finding suggests that the strains in financial markets caused by the crisis were *not* crucial in delivering the effectiveness of LSAPs. Rather, a picture emerges of sizable effects of LSAPs on longer term yields across different samples and alternative estimation approaches.

6. Conclusions and Implications

For longer term Treasury securities, the first LSAP programme (undertaken in 2009) consisted of \$300 billion of Federal Reserve purchases, whereas the second programme (in late 2010 to mid-2011) consisted of \$600 billion of purchases. Our preferred estimates suggest that, taking scarcity and duration together, the first programme of LSAPs reduced longer term Treasury yields by about 35 basis points; the second programme, larger in dollar amount but smaller in its impact on duration, reduced longer term Treasury yields by about 45 basis points. These estimates are somewhat higher than most existing estimates in the literature. Direct comparability with other estimates in the literature is not possible because of differences in methodology and samples across papers. Several other studies use event studies of LSAP rather than regression procedures; we focus on the Treasury market, while the first LSAP covered both agency and Treasury securities; and our estimates are based on the pre-LSAP period, while the possibility of structural changes in markets, especially during the financial crisis, could complicate the task of inferring with precision the effects of LSAPs from results based on an earlier sample. But another important reason why our estimates are higher than those in other studies is that we endeavour to estimate both the scarcity and duration effects of LSAP-style purchases, rather than one or the other effect.

Judged by our estimates, each LSAP programme amounted to a substantial monetary policy easing. An appreciation of the magnitude of the easing is provided by considering what degree of federal funds rate movement would, in the pre-2008 positive funds rate environment, have been required to generate such a response of longer term Treasury yields. Bernanke (2011*b*) and Chung *et al.* (2012) suggest that a 25 basis point change in the long-term rate is on average associated with a roughly 100 basis point change in the federal funds rate.[39] Applied to our estimates, this rule of thumb suggests that the first LSAP programme was tantamount to a federal funds rate cut of about 140 basis points; the second programme, to a cut of about 180 basis points.

Our results thus affirm the potency of LSAPs as a monetary policy tool. This in turn has important implications for the direction in which the building of models for monetary policy analysis should go, especially when taken in conjunction with previous findings for the US (noted in the introduction) and for the UK (Joyce *et al.*, 2011). Our empirical results suggest that LSAPs do not operate solely or even primarily via the expectations channel.[40] Accordingly, macroeconomic models that permit LSAP-style operations to matter for long-term rates only to the extent that they signal future short-term policy rates do not adequately encompass the effects of LSAPs. A rethinking of the specification in macroeconomic models of term-structure behaviour seems to be called for.[41] In particular, it appears that departures from the representative-agent/investor framework are required, so that models used for monetary policy analysis develop in a direction that admits preferred-habitat elements. Our estimates suggest that the required elements comprise not only the scarcity channel emphasised in the traditional preferred-habitat literature but the duration channel highlighted by Vayanos and Vila (2009). Moreover, it does not appear to be the case that such modifications are only necessary for analyses in which the short-term policy rate is at the zero lower bound. Rather, because our

[39] This conversion factor is based on an OLS regression of the first difference of the 10-year rate on the first difference of the funds rate. Such a regression is reported in Chung *et al.* (2012, p. 68). Clearly, this simple procedure for determining the relationship between longer term rates and the short-term rate does raise a number of econometric issues and comes with many caveats. We note, however, that the '25 basis point on the longer term rate for a 100 basis points on the short-rate' rule is also implied by Evans and Marshall's (1998, p. 68) VAR-based estimates of the effect of monetary policy shocks on the term structure of interest rates.

[40] Recall that we found significant coefficients on scarcity and duration in our regressions even when conditioning on proxies for expectations of the short-term policy rate.

[41] This would also likely entail modifications to the IS function as well as term-structure equations. For some suggestions about how to modify the IS equation of dynamic general equilibrium models to allow for an explicit influence of longer term interest rates on spending decisions, see Andrés *et al.* (2004), and for a recent extension, see Chen *et al.* (2011).

results arise from evidence from data points largely accumulated prior to 2008, preferred-habitat elements appear to be a necessary model ingredient in obtaining a better understanding of monetary policy transmission even when short-term rates are away from the zero lower bound.

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Additional supporting information may be found in the online version of this article:

Appendix. Robustness Checks.

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