The Efficacy of Large-Scale Asset Purchases at the Zero Lower Bound

By Taeyoung Doh

During the recent financial crisis, the Federal Reserve took unprecedented actions to prevent the economy from collapsing. First, the Federal Open Market Committee (FOMC) lowered the short-term federal funds rate nearly to its zero lower bound. Then, several months later, the FOMC began making large-scale purchases of long-term Treasury bonds to lower long-term interest rates by reducing the supply of long-term assets. The FOMC's announcement of its intent led to immediate and substantial declines in the yields of long-term Treasury bonds.

While these results suggest that changing the supplies of bonds available to the private sector brought about the changes in prices and, in turn, long-term interest rates, some economists disagree. Most economic models of the term structure of interest rates, including the widely known expectations theory, assume that supply shifts of bonds do not matter in determining prices.

In various speeches, however, policymakers have suggested that a different economic model motivated the asset purchases. One such model, the preferred-habitat theory, assumes that some investors have

---

Taeyoung Doh is an economist at the Federal Reserve Bank of Kansas City. This article is on the bank's website at ***www.KansasCityFed.org.***

preferences for bonds of specific maturities. If this assumption is valid, the supplies of bonds would directly affect their prices and, in turn, their yields.

The preferred-habitat model was proposed in the 1950s. It was widely accepted through the 1960s when it was challenged by the lack of empirical evidence. New empirical findings for impacts of supply shifts on bond yields renewed interest in the model, but the existing literature has never considered how it might be affected by the zero lower bound.

Interest in the theory increased when the short-term policy rate approached the zero lower bound and policymakers used asset purchases as a policy alternative. But some observers have questioned whether asset purchases could really lower long-term interest rates.

To answer this question, this article uses a preferred-habitat model that explicitly considers the zero bound for nominal interest rates. The analysis suggests that purchasing assets on a large scale can effectively lower long-term interest rates. Furthermore, when heightened risk aversion disrupts the activities of arbitrageurs, policymakers may lower long-term rates more effectively through asset purchases than through communicating their intentions to lower the expected path of future short-term rates.

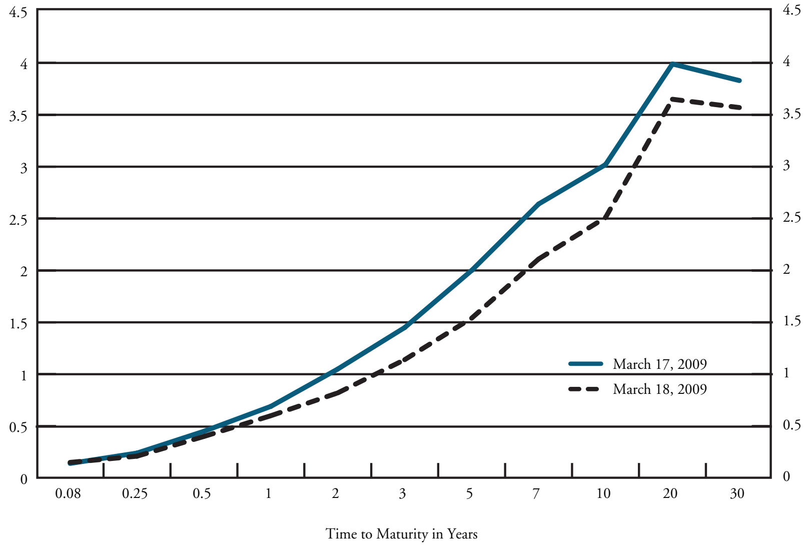
The first section of this article reviews economic theories of the term structure of interest rates and identifies the effects of supply shifts on bond yields. The second section describes a baseline model in which relative supplies of bonds of different maturities determine bond yields. The third section extends the baseline model by explicitly incorporating the zero bound for nominal interest rates and discusses when asset purchases can be a more effective policy tool than other policy alternatives.

I. TERM STRUCTURE THEORIES AND PRICE IMPACTS OF BOND SUPPLY SHIFTS

When the Federal Reserve purchased long-term Treasury bonds as a policy tool, the rationale was that, by causing the supplies of bonds to contract, bond prices would rise. The higher prices, in turn, would cause long-term interest rates to fall. The downward shift of the yield curve of Treasury bonds after the announcement of asset purchases supports such a view (Chart 1). However, widely known term structure models,

Chart 1

TREASURY YIELD CURVE AFTER THE MARCH 2009 FOMC ANNOUNCEMENT



Source: Federal Reserve Board, Thornton (2009)

such as the expectations model, imply that supplies do not matter in determining prices. The preferred-habitat model, by contrast, supports the idea that supplies matter. This section examines the two theories and reviews the empirical evidence supporting the opposing views.

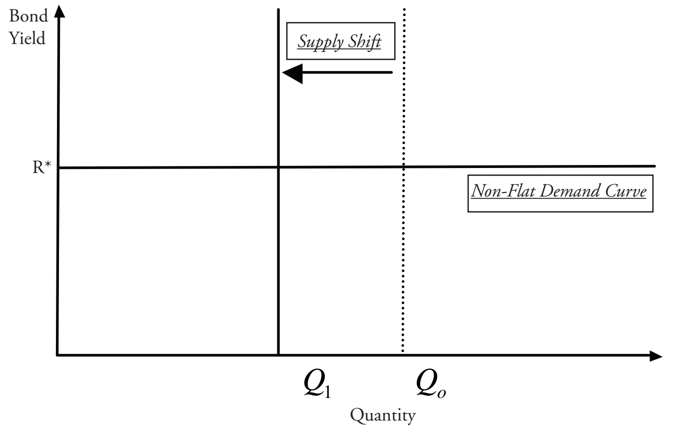
Relative supplies do not matter

The expectations hypothesis of the term structure of interest rates assumes that current and expected yields of short-term bonds determine yields of long-term bonds, while the supplies of the bonds do not affect yields. The theory is based on the view that when the expected return of one asset is higher than that of another asset, investors will trade those assets to make a profit. In other words, short-term and long-term bonds are substitutes for one another.

As Chart 2 shows, when the assets are perfect substitutes, the demand curve for assets is flat. For example, suppose that the long-term bond yield is higher than the average of the current short-term interest rate and short-term rates expected over the life of the long-term bond.

Chart 2

FLAT DEMAND CURVE AND SUPPLY SHOCK



In this case, investors can earn a positive expected return from buying a long-term bond by borrowing money in the short-term bond market. Similarly, when the long-term rate is lower than current and future expectations of the short-term rate, investors can earn a positive expected return from buying short-term bonds consecutively and short-selling a long-term bond. This strategy equalizes the expected return on long and short-term bonds, making them perfect substitutes.

With flat demand curves, the relative supplies of the assets do not matter because they do not affect the current short rate or future expectations of the short rate. A reduction in the supply of the bond does not have any impact on the bond yield (Chart 2).

In the expectations hypothesis, investors are risk-neutral. They want to maximize their expected return, regardless of maturity, and do not demand additional compensation for exposing themselves to the future uncertainty of investing in long-term bonds. Therefore, long-term bonds carry no term premia, which are excess returns over the average of the current and future expectations of the short rate.

In reality, however, investors are risk-averse and demand term premia. The term premia of long-term bonds are time-varying and positive on average (Campbell and Shiller). Models more elaborate than the expectations hypothesis allow term premia for long-term bonds to be time-varying. In such models, long-term bond yields deviate somewhat from the values implied by the expectations hypothesis due to the term premia.

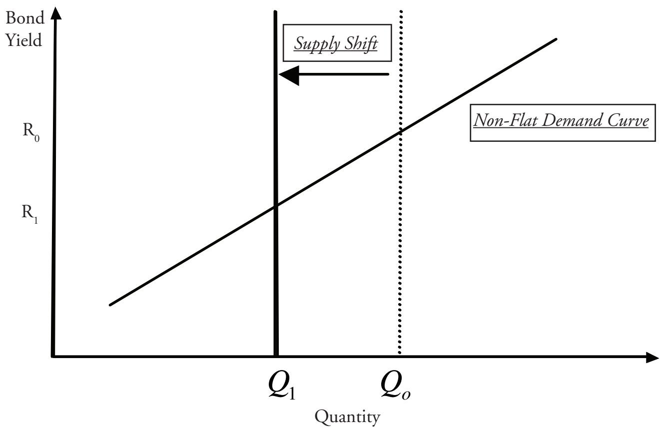
Term premia are determined as the product of the amount of risk and the compensation per one unit of risk measure. We typically measure the amount of risk by the variance of a variable. The additional compensation per one unit of risk measure is often called the "market price of risk." The market price of risk can be specified as constant as in Vasicek (1977) or time-varying as in Cox, Ingersoll, and Ross (1985). Alternatively, it can be derived from consumers' risk aversion toward varying their spending over time and the covariance of bond prices with consumption (Piazzesi and Schneider). But in all these cases, it does not depend on bond quantities.[1]

When term premia are sufficient to compensate for differences in risk between short-term and long-term bonds, investors view the expected returns to the bonds as being equal, taking risk into account. In this case, investors are indifferent to bond maturities. For example, suppose the yield on three-month bonds is expected to remain at 5 percent from today through the next five years. Suppose further that, as compensation for holding a five-year bond instead of three-month bonds, investors require an additional 1 percent in interest. Then investors will be equally willing to hold a five-year bond that pays 6 percent interest and three-month bonds that pay 5 percent interest. As a result, investors view these bonds of different maturities as perfect substitutes, and relative supplies will not affect the yields on the bonds because they do not change the amount of risk or investors' risk aversion. This theory, like the expectations hypothesis, implies demand curves for bonds are flat.[2]

Relative supplies matter

The preferred-habitat theory assumes that bonds of different maturities are not perfect substitutes because investors often have preferences for bonds with specific maturities (Culbertson; Modigliani and Sutch). For example, pension funds prefer long-term bonds, while money market mutual funds prefer short-term bonds. For these investors, bonds of different maturities are not perfect substitutes.[3] As a result, as indicated in Chart 3, the demand curve for a bond of any particular maturity is not flat and supply shifts directly affect bond yields (in the chart, the demand curve slopes up as a function of yield, but it would slope down as a function of price).[4]

Chart 3
NON-FLAT DEMAND CURVE AND SUPPLY SHOCK



In an extreme version of the preferred-habitat model, each group of investors wants to buy a bond of a particular maturity, and no one participates in bond markets of different maturities. In such a case, the bond markets are completely segmented, and each bond yield is determined solely by the demand of the preferred-habitat investors for a particular maturity and the available supply of the bond.

In reality, arbitrageurs such as investment banks and hedge funds trade bonds of different maturities to make profits. By buying a low-valued bond and selling a high-valued bond, these arbitrageurs integrate bond markets of different maturities. For example, suppose that the supply of the 10-year bond suddenly increases. With the demand of preferred-habitat investors unchanged, this supply shock will induce a jump in the yield of the 10-year bond. This jump in the 10-year yield triggers arbitrageurs to buy the 10-year bond and sell bonds of other maturities. As a result, the 10-year bond yield increases less, and other bond yields increase.

When arbitrageurs coexist with preferred-habitat investors, the risk aversion of arbitrageurs plays an important role in determining the slope of demand curves for bonds. If arbitrageurs are risk-neutral, bonds of different maturities are perfect substitutes. Since arbitrageur demand can dominate that of the preferred-habitat investors, the demand curves for bonds would be flat at levels dictated by the expectations hypothesis.

In contrast, if arbitrageurs are extremely risk-averse, they would not be willing to trade bonds, and the preferred-habitat investor demand will be dominant in determining bond yields. In this case, demand curves will be steep.

In the intermediate case in which arbitrageurs are risk-averse but willing to trade bonds of different maturities if there are significant discrepancies in yields, demand curves won't be flat. Risk-averse arbitrageurs care about both the expected return and the risk of trading profits for a short time period. Compared to short-term bonds, long-term bond prices are more sensitive to changes in the future short-term interest rates. The duration of a bond measures this sensitivity, and long-term bonds have higher duration than short-term bonds. As a result, given the potential for changes in short-term interest rates, arbitrageurs who have relatively more long-term bonds now take bigger risks of trading profits than others with relatively fewer long-term bonds. Accordingly, a higher premium is required to induce arbitrageurs whose bond portfolio has a longer duration to take a given amount of risk. In other words, the market price of risk increases as the duration of arbitrageurs' bond portfolios lengthens. Therefore, term premia are higher when there are relatively more supplies of long-term bonds, and arbitrageurs have to hold them in equilibrium.

For risk-averse arbitrageurs, the maturity structure of their bond holdings affects their subjective valuation of a payoff to an investment. Thus, bonds of different maturities are imperfect substitutes for them even though they do not have inherent preferences for specific maturities like preferred-habitat investors. Consequently, demand curves for bonds from these risk-averse arbitrageurs are not flat, and relative supplies of bonds do matter in this model. In this case, the central bank's direct purchases of long-term bonds can lower long-term rates.

Empirical evidence on price impacts of supply shifts

Since economic theories generate different predictions for the effect of supply shifts on the prices of bonds of different maturities, empirical studies are necessary for evaluating which theory better describes the real world. A few past episodes permit identification of shifts in the supplies of bonds available to the private sector.

Early empirical studies focused on the effectiveness of Operation Twist (OT) in 1962-64. The U.S. Treasury and the Federal Reserve raised the supply of short-term government debt while simultaneously lowering the supply of long-term debt. The main goal of this operation was to reduce the capital account deficit by elevating short-term interest rates and to stimulate investment by lowering long-term interest rates. In order to accomplish this, the Federal Reserve sold short-term bonds and purchased long-term bonds. The U.S. Treasury also purchased an unspecified volume of long-term bonds for its investment accounts.

Several studies found that OT was not effective in flattening the term structure (Modigliani and Sutch; Kuttner). The impact of the operation on the spread between the long rate and the short rate was found to be small and could be explained by changes in regulations, such as the successive increases in the ceiling for time deposit rates under Regulation Q. The lack of empirical evidence for price impacts of OT cast doubts on the preferred-habitat view on which the operation was based.

However, more recent studies caution against reading too much into this episode. For example, Kuttner (2006) argues that OT was not definitive evidence against large-scale asset purchases because the size of operations was relatively modest. In fact, the Fed's purchases of government securities with a maturity of more than one year in 1961 totaled only $2.6 billion. This amount was less than 3 percent of the marketable amount of these securities at that time.

The size of operation matters in determining the price impacts of supply shifts. Another, more revealing example is the Treasury buyback program of 2000-01. As the federal government's budget surplus swelled in the United States in 2000, the Treasury began repurchasing long-dated bonds that were issued at higher interest rates. Between March 2000 and December 2001, the Treasury conducted 40 buybacks, covering 42 long-term bonds with a combined face value of $63.5 billion. The size of this operation amounted to about 10 percent of the December 1999 outstanding value of marketable long-term government bonds (Greenwood and Vayanos 2010a).

Unlike OT, the announcement of the buyback program significantly affected long-term bond yields. The buybacks narrowed the spread between the 20-year rate and the one-year rate by 0.75 percent three weeks after the announcement (Garbade and Rutherford).

Bernanke, Reinhart, and Sack (2004) provide additional evidence of price impacts of supply shifts. In this case, large-scale purchases of long-term U.S. Treasury bonds by the Japanese government from 2003 to 2004 lowered the yields of five-year and 10-year bonds by an average of 0.5 to 1 percent.

In sum, recent empirical studies support price impacts of supply shifts in bonds of different maturities, at least for large-scale operations. This evidence might have motivated large-scale purchases of long-term government bonds by major central banks during the recent financial crisis.

But unlike the previous episodes, recent interventions were made under extraordinary circumstances—a short rate near the zero lower bound and the collapse of major financial intermediaries. Theoretical and empirical studies reviewed in this section do not explicitly consider such extraordinary conditions. The following sections use a modern version of the preferred-habitat theory of the term structure of interest rates to explore the rationale for large-scale asset purchases in situations similar to the recent financial crisis.

II. A MODERN VIEW OF THE PREFERRED-HABITAT THEORY

In a preferred-habitat model that includes risk-averse arbitrageurs, the choices that arbitrageurs make about their bond portfolios play an important role in determining interest rates. This section uses a formal framework based on a preferred-habitat model developed by Vayanos and Vila (2009) to analyze the effects of asset purchases on the portfolio choices of arbitrageurs and, in turn, bond yields. The appendix provides the details of the model.

The baseline model

The preferred-habitat model has two central ingredients (Cochrane). First, preferred-habitat investors trade bonds of their preferred maturities and do not buy or sell bonds across maturities, while arbitrageurs buy and sell across maturities. Second, arbitrageurs choose bond portfolios to maximize their expected future wealth, adjusted for risk.

In principle, the bond demand of preferred-habitat investors can be derived from their underlying objectives under some technical assumptions.[5] For this analysis, it suffices to assume their demand to be a linear function of the bond yield. For example, investors with a preference for five-year maturities buy or sell five-year bonds based on their yields. Since the relationship between the yield and demand is linear, investors buy or sell the same amount of the bond for a given change in the bond yield. Movements in yields on bonds of different maturities have no effect on demand for the five-year bond.

Supplies of bonds available to arbitrageurs are determined by subtracting the demand of preferred-habitat investors from the government's net issuance. In determining how to maximize risk-adjusted future wealth, arbitrageurs adjust for the risk of their bond portfolio by subtracting from expected future wealth (the mean of future wealth) an amount proportional to the variance of their future wealth. Thus, an arbitrageur's portfolio choice depends on risk aversion. If arbitrageurs are more risk-averse, they deduct a larger amount from the mean of their future wealth for a given magnitude of the variance. In the model, they have a short planning horizon and care only about wealth in the next period. Their objective is to maximize the mean of their next period's wealth, adjusted by the variance of future wealth and by their risk aversion.

The model of Vayanos and Vila assumes that preferred-habitat investors and arbitrageurs continuously trade bonds of many different maturities even over a very short time. Deriving equilibrium bond yields under this setting is mathematically complicated. This article's analysis uses a simplified model with three periods and two types of bonds. The short-term bond matures one period after its issue date, while the long-term bond matures after two periods.

In this simplified model, the only source of uncertainty is the short-term interest rate. The short rate follows a mean-reverting process. If there is a gap between the current short rate and the mean, the gap is expected to decrease gradually to zero over time. However, a random shock in each period can cause the realized short rate to differ from the expected value. This assumption is common to many term structure models (for example, Vasicek; Cox and others) and parsimoniously captures the risk factors that determine the term structure of interest rates.[6]

The time variation of the short-term rate introduces a risk to arbitrage activities. Arbitrageurs who borrow money at the short rate to buy a long-term bond face an uncertain future short rate. How much this uncertainty affects the long-term bond yield depends on various factors. One crucial factor is the coefficient determining the risk adjustment for the variance of arbitrageurs' future wealth. If this coefficient is high, arbitrageurs will demand a greater increment in expected wealth for taking a given amount of risk. Hence, the coefficient shows up in the market price of risk in the model.[7] Hereafter, this parameter will be referred to as the risk-aversion coefficient of arbitrageurs.

Price impacts of supply shifts in the baseline model

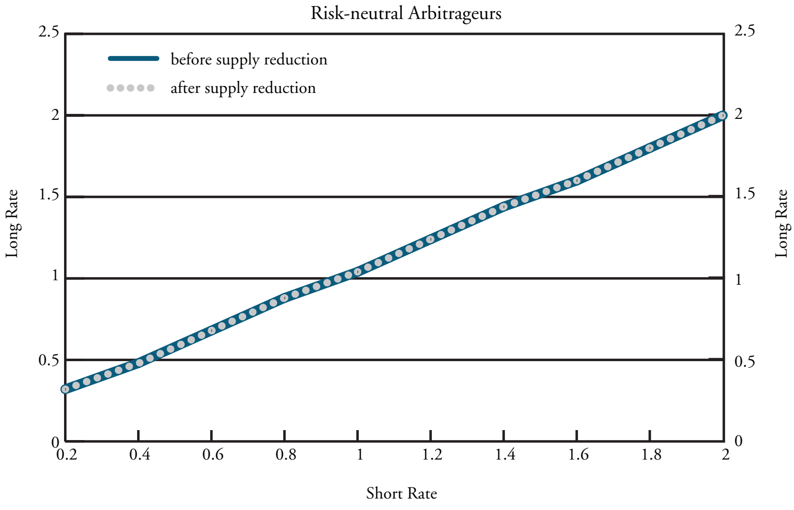
As a first step in exploring policymakers' rationale for purchasing bonds, this analysis considers an experiment using the baseline model. Suppose a supply shock changes the quantity of long-term bonds available for arbitrageurs. In this case, the shock comes from the central bank directly purchasing long-term bonds to reduce their supply.

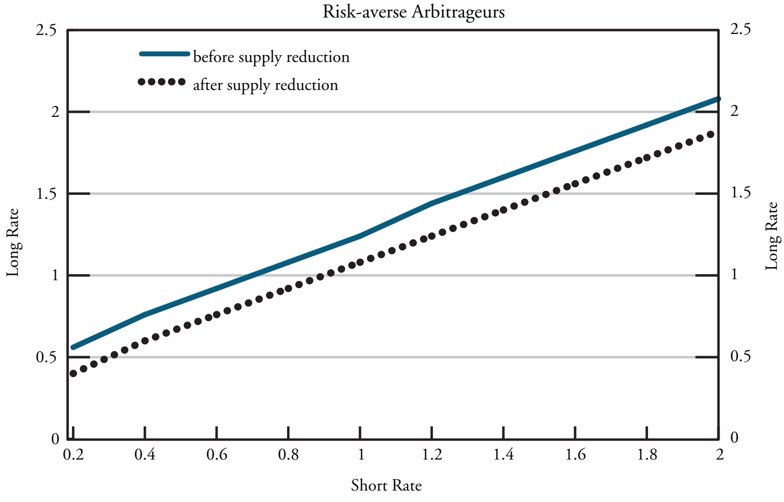
The effects on bond yields of shifting supplies depend on multiple factors. These factors include the size of the purchases, the elasticity of the preferred-habitat investors' demand for the bonds, and the magnitude of uncertainty about the future short rate. This discussion will focus on the risk-aversion coefficient of arbitrageurs, which helps to determine the slope of the demand curve for long-term bonds.[8] This coefficient is particularly interesting because its magnitude can be matched with the degree of financial market stress that depresses arbitrage activities. The parameter is particularly relevant in evaluating the effectiveness of asset purchases in the context of a financial crisis.[9]

Chart 4 shows the model's predicted response of long-term bond yields to a reduction in the supply of bonds for two different levels of risk aversion.[10] In each panel, the horizontal axis shows a range of possible values of the short-term interest rate. The lines give the level of the long-term interest rate consistent with the optimal portfolio choice of arbitrageurs at the level of the short rate indicated on the horizontal axis. By assumption, the short rate evolves independently of arbitrage activities, and supply shifts do not affect the short rate.

Chart 4

IMPACT OF A REDUCTION IN THE SUPPLY OF THE LONG-TERM BOND ON THE LONG-TERM INTEREST RATE





When arbitrageurs are risk-neutral, long-term interest rates are determined by the current and expected future short-term rates (Chart 4, top panel). In this case, a supply shock that reduces the supply of the long-term bond available to arbitrageurs has no effect on the long-term bond yield. In contrast, when the risk-aversion coefficient is high, the same supply shock can significantly change the level of the long-term bond yield (bottom panel).

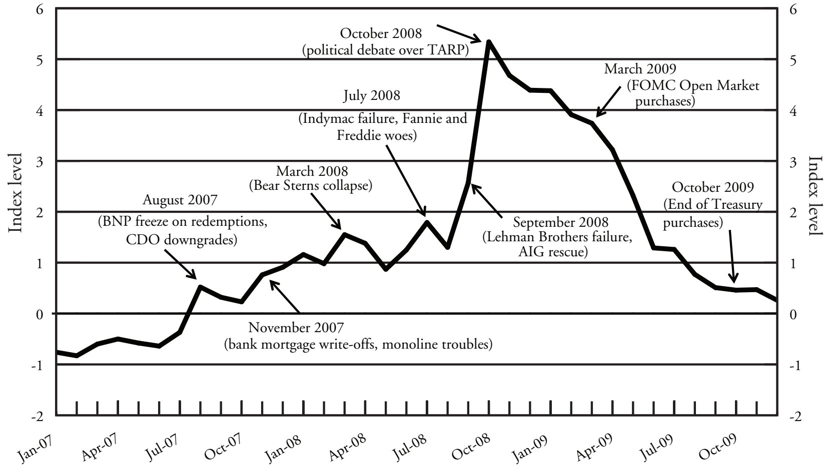
Directly estimating the risk-aversion coefficient is difficult, but empirical evidence suggests that the risk aversion of arbitrageurs was heightened during the recent financial crisis. After the failure of Lehman Brothers, arbitrage activities of major financial institutions were severely hampered, leading to abnormal price dispersion of relatively similar Treasury securities.[11] For example, the 10-year bond issued in 2002 and the five-year bond issued in 2007, bonds that would mature at similar dates, provided about the same cash flows to bond holders. Under normal situations, arbitrage activities would have made the prices of the two bonds very similar. However, the bonds traded at substantially different prices during the period of financial turmoil.[12]

Additional information on the risk aversion of arbitrageurs can be gleaned from other spread measures between financial assets with similar cash flow streams and risk characteristics. The Kansas City Financial Stress Index describes financial market stress by extracting a common component from 11 financial market variables (Hakkio and Keeton). The index captures the decreased willingness of arbitrageurs to hold risky or illiquid assets and the increased uncertainty about asset prices. Not surprisingly, the index shows a spike after the failure of Lehman Brothers (Chart 5).

Under such circumstances, the central bank's direct purchases of long-term assets might be expected to substantially affect the prices of these assets, shedding light on policymakers' actions.[13] When arbitrage activities of financial markets are disrupted, and deteriorating macroeconomic conditions warrant lower long-term interest rates, long-term asset purchases by the central bank can be an effective policy tool.

Chart 5

KANSAS CITY FINANCIAL MARKET STRESS INDEX



Source: Hakkio and Keeton (2009)

III. THE ZERO LOWER BOUND FOR NOMINAL INTEREST RATES AND THE EFFICACY OF ASSET PURCHASES

The zero lower bound is relevant for evaluating the effectiveness of long-term bond purchases by central banks during the recent financial crisis for two reasons. First, the zero lower bound became a binding constraint as the Federal Reserve, the Bank of England, and the Bank of Japan pushed down short-term policy rates. Second, the zero lower bound decreases the uncertainty about the future short rate by capping the possible decline of the short rate.

Declining uncertainty about the future short rate can affect the size of the term premium of the long-term bond. In the preferred-habitat model, the term premium of the long-term bond changes with shifts in supply. Hence, it is important to examine whether long-term bond purchases remain effective in affecting the long-term bond yield at the zero bound for nominal interest rates. This section reviews some implications of the zero bound for the term structure of interest rates in the modern preferred-habitat model. The model is also used to compare the relative effectiveness of pursuing policy through asset purchases versus managing expectations of the future short rate.

Implications of the zero lower bound for long-term interest rates

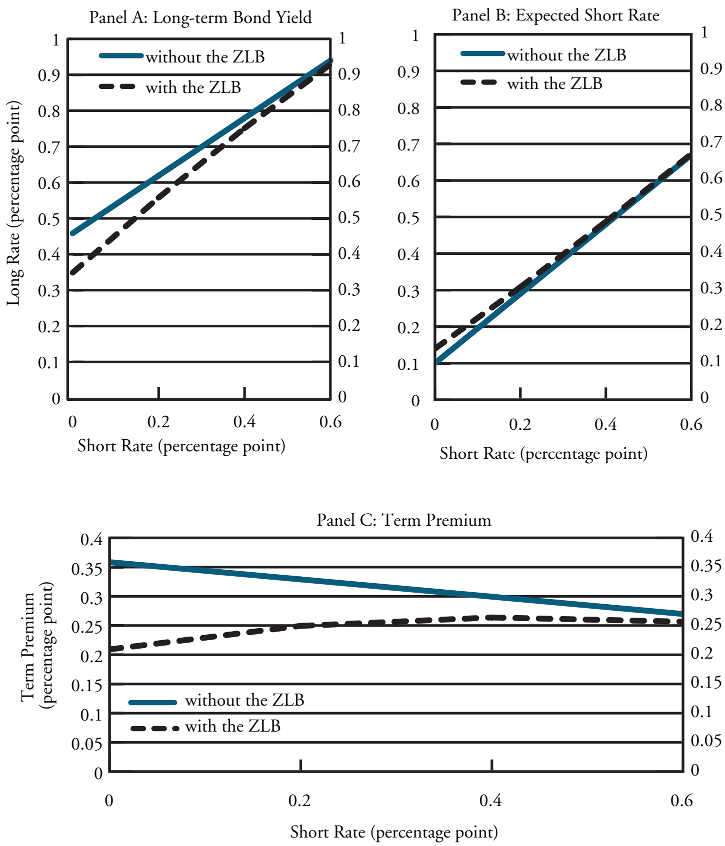
Once the short rate hits the zero bound, the future short-term rate cannot fall below the current level, and the expectations of future short rates are higher than otherwise (Ruge-Murcia). However, the zero lower bound reduces the effective variation of the future short-term rate and may cause the term premia of long-term bond yields to drop. To precisely identify channels through which the zero lower bound affects long-term bond yields, it is useful to decompose long-term bond yields into two components: 1) the average of current and future expectations of the short rate and 2) the term premium.

Chart 6 illustrates the impacts of the zero lower bound for the overall level and each component of the long-term bond yield, as implied by the preferred-habitat model. Panel A, which shows the overall level of the long-term bond yield, suggests that the existence of the zero lower bound decreases the level of the long-term bond yield.

To understand why, it is useful to begin with the implications of the expectations hypothesis. In the expectations hypothesis, the term premium is constant and does not depend on the level of the short rate. Therefore, because the zero lower bound implies a path of short-term interest rates steeper than the path might otherwise be, it implies a higher level of the long-term interest rate when the short rate is close to zero. Why, then, does the preferred-habitat theory result in the fall in the long-term bond yield shown in Chart 6 (Panel A)?

The preferred-habitat theory implies a lower long-term interest rate because the zero lower bound affects the term premium as well as the expectations of future short-term rates. In the preferred-habitat model, as in the expectations hypothesis, expectations of future short rates are higher near the zero bound (Chart 6, Panel B). So the difference in the overall level of the long-term bond yield across the two theories can be attributed to the term premium. In the preferred-habitat theory, the term premium can actually be lower near the zero bound (Panel C). With the zero lower bound, the overall level of the long-term bond yield is reduced because the smaller term premium more than offsets higher expectations of future short-term rates.[14]

Chart 6
LONG-TERM BOND YIELD AND TERM PREMIUM



Why is the term premium lower in the preferred-habitat model near the zero lower bound? Recall that the term premium is determined by the market price of risk and the amount of risk. For the zero lower bound to alter the term premium, it should affect at least one of these two determinants. In the preferred-habitat model, the market price of risk is determined by the risk-aversion coefficient of arbitrageurs and the duration of their bond portfolios, but not directly by the existence of the zero lower bound. However, the amount of risk (which is the variance of the future short rate in the model) is directly affected by the zero lower bound. The zero lower bound reduces the variance of the future short-term rate when the current short rate is close to zero.

Hence, the term premium can decrease when the current short rate is close to the zero lower bound.

The efficacy of asset purchases as a way to lower long-term interest rates at the zero lower bound

As shown above, without the zero lower bound, long-term asset purchases can be more effective in lowering the term premium when the risk aversion of arbitrageurs is high. However, highly risk-averse arbitrageurs will be more sensitive to changes in the amount of risk. Since arbitrageurs will consider that their risk will decrease near the zero lower bound, the size of the impact of long-term asset purchases on the term premium will also change, depending on the degree of the risk aversion of arbitrageurs.

Further, the preferred-habitat model with the zero lower bound is a useful framework to evaluate the relative effectiveness of various policy options at the zero lower bound. This framework is suitable because both asset purchases and managing the expectations of the future short rate can affect long-term interest rates.

In the preferred-habitat model, policymakers have at least three tools to lower long-term interest rates when the current short-term rate is sufficiently above the zero bound. First, they can cut the current short rate and expect arbitrageurs to push down the long-term rate. Second, they can communicate that the future path of the short rate is likely to be lower than previously thought by the private sector. This strategy also relies on arbitrageurs taking advantage of lower expectations of the future short rates. Third, the central bank can reduce relative supplies of long-term bonds available to the private sector by making direct purchases.

When the economy is near the zero bound, however, the first option is not effective, leaving a central bank with two options for lowering long-term interest rates: purchasing long-term bonds and communicating that the future path of short-term interest rates is likely to be lower than normally justified by the state of economy.

Eggertsson and Woodford (2003) argue in the context of a common small-scale macroeconomic model that this communication strategy is indeed the best monetary policy tool at the zero bound. They argue that asset purchases are ineffective unless they change expectations of future short rates. However, in their model relative supplies of bonds do not matter in determining bond yields. Hence, it is not surprising that the communication strategy is more effective in such a model.

In the preferred-habitat model, arbitrageurs make profits by borrowing money at the short-term rate and buying the long-term bond when the current short rate is low. Promising to keep the short rate at a low level for a longer period than normally justified boosts the profit opportunities of arbitrageurs because the risk of facing a higher short-term interest rate in the future is reduced. This communication strategy lowers the long-term interest rate directly by reducing the expected future short rate and indirectly by lowering the term premium through reducing the risk of arbitrage activities.

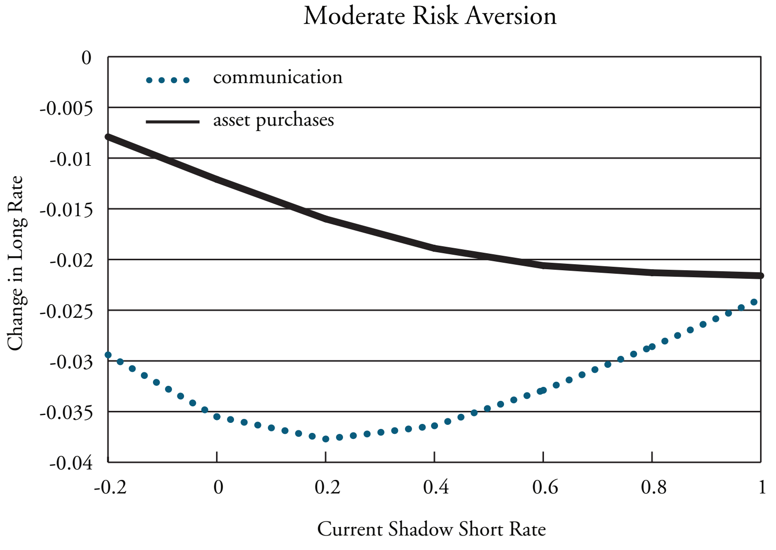
The communication strategy can be incorporated into the preferred-habitat model in a simple way. The expected future short rate in the model is a weighted average of the current short rate and the long-term average (or "normal") level of the short rate. The communication strategy can be captured by increasing the model's weight on the current short rate in determining the expected future short rate when the current rate is low. In other words, the communication strategy can be modeled by assuming that policymakers can increase the expected time for the short rate to reach the normal level from the current low level.

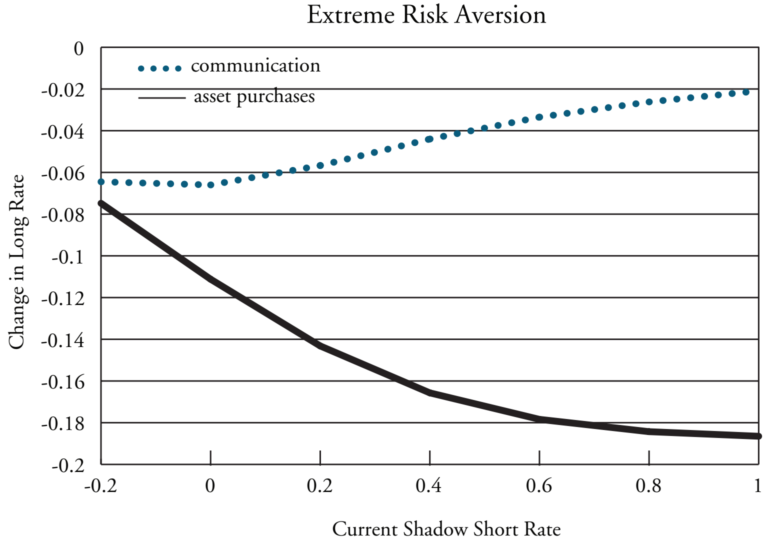
In this framework, when are asset purchases more effective in lowering long rates than lowering the future path of the short-term interest rate? The risk-aversion coefficient of arbitrageurs again plays an important role in this comparison. When the coefficient is higher, arbitrageurs are less willing to purchase long-term bonds, other things being equal. Accordingly, more profits would be required to induce them to buy a given amount of long-term assets from preferred-habitat investors. The implication is that, if risk aversion is high, the central bank needs to promise a more extended period of low rates in the future in order to lower long-term rates via a communication strategy. Under these circumstances, the central bank's direct purchases would be more effective.[15]

Chart 7 compares how these two policy options affect long-term interest rates. In the bottom panel, the risk-aversion coefficient of arbitrageurs is roughly ten times that in the top panel. The magnitude is in line with the spike of the financial market stress index in Hakkio and Keeton from the beginning of the recent financial crisis (August 2007)

Chart 7

RISK AVERSION AND RELATIVE EFFECTIVENESS OF ASSET PURCHASES





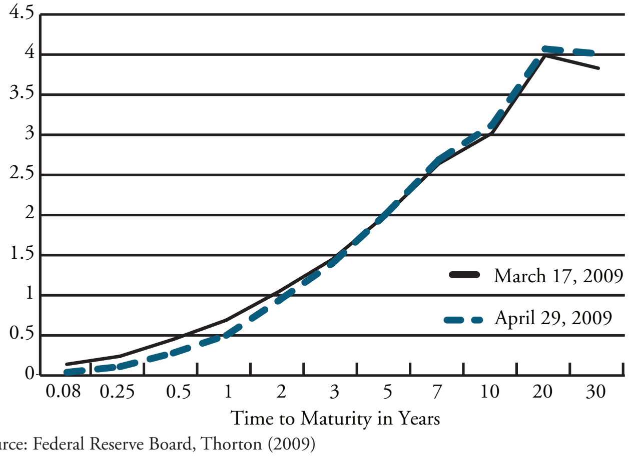
Note: The horizontal axis is the shadow short rate which can be negative. The shadow rate describes the state of economy but the short-term bond yield stays at zero when the shadow rate is negative. When the shadow rate is positive, it is equal to the actual short-term bond yield. The idea of using the shadow rate as describing the state of economy at the ZLB is from Black (1995).

EMPIRICAL EVIDENCE ON THE IMPACTS OF THE FEDERAL RESERVE'S RECENT LONG-TERM TREASURY BOND PURCHASES

The quantitative effects of the Federal Reserve's recent asset purchase program to influence long-term bond yields have been the subject of some debate. Some researchers noted that the 10-year Treasury yield returned to its pre-announcement level in only five weeks, as shown in Chart B1 below. The relatively quick reversion of the 10-year Treasury bond yield may indicate the asset purchases were ineffective.

Chart B1

CHANGES IN THE TREASURY YIELD CURVE



Source: Federal Reserve Board, Thorton (2009)

However, a number of factors may have affected long-term Treasury bond yields during this five-week period. For example, the improved economic outlook and diminished financial market stress may have pushed up expectations of future short rates, in turn increasing long-term interest rates. Indeed, the dates that the 10-year Treasury yield jumped by double-digit basis points usually coincided with new signs that the housing market improved (March 25, April 28), with the release of better-than-expected consumer confidence survey data (April 17), and with news of a positive outlook for the financial sector (April 9).[19] Carefully sorting out these complicating factors is critical for making precise estimates of the price effects of asset purchases.

These factors can be accounted for by including them as explanatory variables for changes in yields. A regression can then be run with the 10-year yield using proxies for policy expectations and the real activity index published by the Federal Reserve Bank of Philadelphia, as well as dummies for the break before and after the FOMC announcement in March 2009 of its plan to make the asset purchases.

The two-year overnight index swap rate captures the market's expectations of the average short rate over the time period. News about improving economic conditions can push up the market's expectations of future short rates. Also, the real activity index reflects the changing economic outlook. Both of these variables are used as proxies for the shadow short rate, which can be negative while the observed short rate is at the zero bound.

This regression sets the dummy value to zero for the pre-March announcement days and to one thereafter. If there are no persistent price effects of asset purchases, the coefficient of the dummy variable should be close to zero. Regression results in Table B1 suggest that the Federal Reserve's purchase announcement reduced the 10-year Treasury yield. Hence, there seems to be at least some empirical support for the reduction of the term premium due to the bond purchases, as implied by the preferred-habitat theory. This finding is consistent with the conclusion from a more extensive empirical study (Gagnon and others).

Table B1
REGRESSION OF THE 10-YEAR YIELD

Regressor	Coefficient	Standard Error
Constant	4.39	.69*
2-year Overnight Index Swap	.28	.32
Business Cycle Index	.66	.10*
Dummy for Asset Purchases	-.39	.17*

R^2=0.82

Source: Author's calculation. Weekly average data from January 2009 to June 2009 are used in case of the 10-year yield, overnight index swap, and business cycle index. An asterisk indicates that a coefficient is statistically significant at the 5 percent level.

to the peak (October 2008).[16] As indicated in the lower panel of the chart, when risk aversion is high and short-term interest rates are very low, policymakers may be able to lower long-term bond yields somewhat more effectively through asset purchases than through a communication strategy.[17] (For empirical evidence on the impacts of the recent large-scale purchases of long-term Treasury bonds, see box.)

Another cost of managing expectations by communication is that this strategy is prone to the risk of destabilizing inflation expectations when the central bank's credibility for pursuing low inflation is not perfect. Policymakers seem to be worried about this risk (Kohn). Large-scale asset purchases could be a more reliable option for policymakers at the zero lower bound since they do not directly target expectations.[18]

IV. CONCLUSIONS

The recent financial crisis demanded innovative ideas from policymakers. Examining the Federal Reserve's rationale for taking unconventional policy actions during the crisis is important for future guidance. This article focused on the efficacy of large-scale purchases of long-term Treasury bonds as a policy option when nominal interest rates were near the zero lower bound.

Using a simplified version of the preferred-habitat model developed by Vayanos and Vila, this article finds that by altering the supplies of long-term bonds, the central bank's large-scale purchases of the bonds can decrease the term premia in long-term bond yields. The magnitude of the decline in the term premium depends crucially on the risk aversion of arbitrageurs. If the risk aversion of arbitrageurs is high, as in the recent financial crisis, large-scale asset purchases can induce a more substantial decline in the term premium. In addition, when the arbitrage activities of the private sector are disrupted and the economy is near the zero lower bound, large-scale asset purchases may lower long-term interest rates more effectively than other policy options, such as a commitment to keep rates lower than otherwise justified.

APPENDIX

This analysis considers a simplified version of the Vayanos and Vila (2009) model. The simplified model assumes three periods with two types of default-free bonds available for investors. The first type is a short-term bond that matures in the next period. The second type is a long-term bond that matures two periods later. In this model, the only risk factor is the shadow interest rate for the short-term bond (x_t) The variable evolves according to the following AR (1) process:

$$x_{\{t+1\}} = (1-\rho)\bar{r} + \rho x_t + \sigma\varepsilon_{t+1}.$$

Here, ε_{t+1} is a standard normal random variable. $\bar{r}$ is the unconditional mean of the shadow short rate. ρ and σ are parameters governing the persistence and conditional standard deviation of the shadow rate, respectively. When the shadow rate is nonnegative, it is the same as the realized short-term interest rate. However, the realized short-term interest rate (r_t) is zero if the shadow rate is negative.

Investors have preferences for the long-term bond and do not participate in the short-term bond market. Net supply of the long-term bond available to arbitrageurs (Y_t)is obtained by subtracting the demand by preferred-habitat investors from the net issuance of the total government bond supply. The model assumes that the net supply of the long-term bond depends linearly on its yield (R_t). The price sensitivity of bond demand by the preferred-habitat investors is characterized by α. The parameter β determines the intercept of the net supply of the long-term bond available to arbitrageurs.

$$Y_t = \alpha(\beta - R_t).$$

Arbitrageurs participate in both short-term and long-term bond markets and take positions to maximize the following objective function defined over the mean (E_t) and the variance (V_t) of the next period's wealth (W_{T+1}):

$$E_t(W_{t+1}) - \frac{\tau}{2}V_t(W_{t+1}), \qquad W_{t+1} = W_t e^{r_t} + L_t(e^{2R_t - r_{t+1}} - e^{r_t}).$$

In these equations, τ is the risk-aversion coefficient, and L_t is the holding of the long-term bond by arbitrageurs. In equilibrium, $L_t = Y_t$. The short-term interest rate affects demand for the long-term bond by arbitrageurs and in turn influences the equilibrium long-term bond yield. With the zero lower bound, the relevant state variable determining the equilibrium long-term bond yield is not the realized short-term interest rate but the shadow rate.

Equilibrium conditions are highly nonlinear with respect to bond yields, especially when the zero lower bound is considered. Nonetheless, it is easy to figure out that the risk aversion would show up in the equilibrium condition only in the form of being multiplied by the price sensitivity of bond demand of preferred-habitat investors. This occurs because the derivative of expected wealth with respect to the amount of the long-term bond held by arbitrageurs is constant while the derivative of the variance of wealth is proportional to the holding by arbitrageurs.

In equilibrium, arbitrageurs' bond holding is equal to the bond supply of the preferred-habitat investors, which is linear with respect to the price sensitivity parameter. Thus, the equilibrium condition takes the following form:

$$k = \tau\alpha g\left(R_t, x_t; \rho, \bar{r}, \sigma\right),$$

where κ is a constant determined by other parameters in the model. The solution for the long-term bond yield can be found by using a numerical nonlinear equation solver at each grid point.

If we assume that the time interval is small, we can approximate the next period wealth of arbitrageurs as follows:[20]

$$W_{t+1} = W_t(1 + r_t) + L_t(2R_t - r_{t+1} - r_t)$$

Using the optimality condition for arbitrageurs' long-term bond holding and equilibrium condition, it is possible to derive the expression below for the long-term bond yield. To further simplify the model, it is assumed that the net supply of bond available to arbitrageurs is inelastic with respect to the bond yield as in Cochrane (2008). In other words, $L_t = \bar{\beta}$. Then the equilibrium long-term bond yield is given by

$$R_t = \max\left\{0, \frac{(1+\rho)x_t + (1-\rho)\bar{r} + \tau\beta\sigma^2}{2}\right\}.$$

When the long rate is not at the zero bound, we obtain the following closed form expression for the market price of risk, which is the expected excess return of buying the long-term bond divided by the conditional variance of the shadow rate:

$$\frac{2R_t - r_t - E_t\left(r_{t+1}\right)}{\sigma^2} = \tau\bar{\beta}.$$

Notice that the supply of the long-term bond directly affects the market price of risk in this case. Policies affecting supplies of bonds available to the private sector can be modeled by changing a parameter determining the intercept of the net supply of bonds available to arbitrageurs ($\bar{\beta}$). Reducing $\bar{\beta}$ decreases the long-term bond yield. Interestingly, the impact is larger when arbitrageurs are more risk-averse (higher τ) or the uncertainty of the shadow rate is greater (higher σ^2).

The communication strategy of lowering the future policy path of the short rate can be modeled by increasing the persistence parameter of the short rate process (ρ) so that the short rate moves up more slowly once it approaches the zero bound. When the current short rate is smaller than the mean, increasing ρ can also decrease the long-term bond yield. However, unlike asset purchases, its effectiveness depends on the distance between the current shadow rate and the mean short rate, not on the risk aversion coefficient or the uncertainty of shadow rate. Therefore, a higher risk-aversion coefficient can increase the relative effectiveness of asset purchases compared to the communication strategy.

ENDNOTES

[1]Krishnamurthy and Vissing-Jorgensen (2008) assume that investors benefit directly from holding Treasury assets due to their convenience in easy trading. This benefit is independent of their consumption. In this case, relative supplies can matter if Treasury bonds of different maturities are imperfect substitutes for investors due to different degrees of convenience benefit.

[2]However, due to term premia, the levels of demand curves implied by this theory differ from the levels implied by the expectations hypothesis.

[3]Greenwood and Vayanos (2010a) document the clientele effects for pension funds in the U.K. government bond markets. In the U.S., the Treasury department's decision to reissue the 30-year nominal bond in 2006 was regarded as a response to demands from pension funds seeking longer-dated securities to match liabilities (*Chicago Tribune*, August 3, 2005 "U.S. bringing back 30-year Treasury bond").

[4]Kuttner (2006) also emphasizes that non-flat demand curves are essential for obtaining price impacts of relative supply shifts in bonds of different maturities.

[5]The appendix in Vayanos and Vila (2009) shows that if investors want to minimize the maximum risk of their consumption at a particular maturity, their bond demand would be similar to the one assumed in the paper.

[6]Suppose that the short rate is set by a version of Taylor rule in which policymakers adjust the short rate by responding to macroeconomic variables. If macroeconomic variables fluctuate over time and policymakers respond to them in a stable way, the short rate itself can summarize the evolution of macroeconomic variables.

[7]The appendix provides a complete description of the market price of risk in a special case of the baseline model using the approximation to budget constraints of arbitrageurs.

[8]Price impacts are greater when the scale of purchases is greater, preferred-habitat investors' demand is more price-sensitive, or the uncertainty about the future short rate is higher.

[9]Vayanos and Vila (2009) emphasize that high risk-aversion can mitigate the transmission of the central bank's decision on the short-term interest rate to long-term interest rates. They conjecture that direct purchases of long-term bonds might be more effective in influencing long-term rates when arbitrageurs are highly risk-averse.

[10]In the model, we can capture this supply shock in a reduced form as a shift in the intercept of the net supply of the bond available to arbitrageurs.

[11]Price dispersion can be measured by the prediction errors of the smoothed yield curve. During the financial crisis, that measure increased from the normal level of 2 basis points to 20 basis points (Macroeconomic Advisers).

[12]Gromb and Vayanos (2002) provide an example of two identical risky assets traded at different prices when financially constrained arbitrageurs cannot integrate segmented markets.

[13]One important issue is whether or not the central bank should hold purchased long-term assets until they mature. In fact, if the central bank will sell these assets later, a supply shock is only temporary while it is permanent if the central bank holds them until they mature. The simple two-period model considered in this article cannot distinguish a temporary shock from a permanent shock and the issue is beyond the scope of this article.

[14]Even when the short rate is somewhat away from the zero bound, the term premium and the long-term interest rate are different. depending on the existence of the zero lower bound. If we consider the zero bound, the future possibility of hitting the bound alters the expected returns on the long-term bond and the short-term bond although the current short rate is not at the zero bound.

[15]The public sector can be less risk-averse than the private sector because it can credibly pool the future economy-wide income by the taxing authority (Holmström and Tirole). However, if the reduced arbitrage activities of the private sector are not driven by the heightened risk aversion of arbitrageurs but by the higher price sensitivity of the demand of the preferred-habitat investors, the public sector's intervention is not necessarily recommended.

[16]The financial stress index jumped from about 0.5 in August, 2007 to around 5.3 in September, 2008.

[17]Other than the risk aversion, the size of purchase will also matter. However, calibrating the parameter to match the actual operation which targeted 2-to-10 year bonds is difficult in this simple model with only two nearby bonds.

[18]Recent empirical work by Gagnon and others (2010) shows that the implicit forward guidance in FOMC statements did not have a substantial effect on the expected future short rate, while asset purchases decreased term premia significantly during 2009.

[19]Two other dates when the 10-year Treasury yield increased by double-digit basis points are March 19 and April 3. The 10-year yield increased by 10 basis points on March 19 after a 51 basis point decline on March 18, indicating that arbitrageurs took profits after the big price movements in the previous day. On the other hand, the 10-year yield jumped by 14 basis points on April 3 without news on the improvement of economy. This can be attributed to expectations of the price pressure from the increased new issues of Treasury bonds coming in the next week. Thanks to Jonathan Wright for suggesting a check of these daily variations.

[20]This approximation becomes exact at the time interval shrinks to zero.

REFERENCES

Bean, Charles. 2009. "The Great Moderation, the Great Panic, and the Great Contraction," Schumpeter Lecture at the Annual Congress of the European Economic Association, Barcelona, Spain, August 25, 2009, at *http://www.bankofengland.co.uk/publications/speeches/2009/speech399.pdf*.

Bernanke, Ben. S., Vincent R. Reinhart, and Brian P. Sack. 2004. "Monetary Policy Alternatives at the Zero Bound: An Empirical Assessment," Federal Reserve Board Working Paper, no. 2004-48.

Black, Fischer. 1995. "Interest Rates as Options," *Journal of Finance*, vol. 50, pp. 1371-76.

Campbell, John Y., and Robert J. Shiller. 1991. "Yield Spread and Interest Rates: A Bird's Eye View," *Review of Economic Studies*, vol. 58, pp. 495-514.

Cochrane, John H. 2008. Comments on "Bond Supply and Excess Bond Returns," eds. Robin Greenwood and Dimitri Vayanos, University of Chicago.

Cox, John C., Jonathan E. Ingersoll, and Stephen A. Ross. 1985. "A Theory of the Term Structure of Interest Rates," *Econometrica*, vol. 53, pp. 385-407.

Culbertson, John. 1957. "The Term Structure of Interest Rates," *Quarterly Journal of Economics*, vol. 71, no. 4, pp. 485-517.

Eggertsson, Gauti, and Michael Woodford. 2003. "The Zero Interest-Rate Bound and Optimal Monetary Policy," *Brookings Papers on Economic Activity*, no. 1, 2003, pp. 139-211.

Gagnon, Joseph, Matthew Raskin, Julie Remache, and Brian Sack. 2010. "Large-Scale Asset Purchases by the Federal Reserve: Did They Work?" Federal Reserve Bank of New York, Staff Report, no. 441.

Garbade, Kenneth D., and Matthew Rutherford. 2007. "Buybacks in Treasury Cash and Debt Management," Federal Reserve Bank of New York, Staff Report, no. 304.

Greenwood, Robin, and Dimitri Vayanos. 2010a. "Price Pressure in the Government Bond Market," *American Economic Review, Papers and Proceedings*, forthcoming.

____________. 2010b. "Bond Supply and Excess Bond Returns," London School of Economics, Working Paper.

Gromb, Denis, and Dimitri Vayanos. 2002. "Equilibrium and Welfare in Markets with Financially Constrained Arbitrageurs," *Journal of Financial Economics*, vol. 66, pp. 361-407.

Hakkio, Craig S., and William R. Keeton. 2009. "Financial Stress: What Is It, How Can It Be Measured, and Why Does It Matter?" Federal Reserve Bank of Kansas City, *Economic Review*, Third Quarter, pp. 5-50.

Holmström, Bengt, and Jean Tirole. 1998. "Private and Public Supply of Liquidity," *Journal of Political Economy*, vol. 106, no. 1, pp. 1-40.

Kohn, Donald. 2009. "Comments on 'Interpreting the Unconventional U.S. Monetary Policy of 2007-2009,'" Brookings Institution, Washington, September 10, at *http://www.federalreserve.gov/newsevents/speech/kohn20090910a.htm*.

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen. 2008. "The Aggregate Demand for Treasury Debt," Northwestern University, Working Paper.

Kuttner, Kenneth N. 2006. "Can Central Banks Target Bond Prices?" National Bureau of Economic Research, Working Paper, no. 12454.

Macroeconomic Advisers. 2008. "Dispersion of Treasury Yields," October 31.

Modigliani, Franco, and Richard Sutch. 1966. "Innovations in Interest-Rate Policy," *American Economic Review*, vol.56, no. 1/2, pp. 178-97.

Piazzesi, Monica, and Martin Schneider. 2006. "Equilibrium Bond Yields," in Daron Acemoglu, Kenneth Rogoff, and Michael Woodford, eds., *NBER Macroeconomics Annual.* Cambridge: MIT Press.

Ruge-Murcia, Francisco J. 2006. "The Expectations Hypothesis of the Term Structure When Interest Rates Are Close to Zero," *Journal of Monetary Economics*, vol. 53, pp. 1409-24.

Sack, Brian P. 2009. "The Fed's Expanded Balance Sheet," remarks at the Money Marketeers of New York University, December 2, 2009, at *http://www.newyorkfed.org/newsevents/speeches/2009/sac091202.html*.

Vasicek, Oldrich. 1977. "An Equilibrium Characterization of the Term Structure," *Journal of Financial Economics*, vol. 5, pp.177-88.

Vayanos, Dimitri, and Jean-Luc Vila. 2009. "A Preferred-Habitat Model of the Term Structure of Interest Rates," National Bureau of Economic Research, Working Paper, no. 15487.