

An empirical decomposition of risk and liquidity in government bonds

Carolyn E. Pflueger and Luis M. Viceira¹

Abstract

This paper empirically analyzes the Expectations Hypothesis (EH) in inflation-indexed (or real) bonds and in nominal bonds in the US and in the UK. We strongly reject the EH in inflation-indexed bonds, and also confirm and update the existing evidence rejecting the EH in nominal bonds. We explain time variation in the inflation-indexed bond risk premium as the result of time variation in the real interest rate risk premium as well as in the liquidity risk premium. We also find robust empirical evidence of a time-varying inflation risk premium in the returns on nominal bonds. Thus changes in breakeven inflation, or the yield spread between nominal and inflation-indexed bonds, not only reflect changes in bond market expectations of future inflation. They also reflect changes in the inflation risk premium that investors demand for holding nominal bonds, and changes in the liquidity premium that investors demand for holding inflation-indexed bonds. We estimate the liquidity premium to be 70 bps during times with no extraordinary liquidity events and find it to be highly time-varying. Our results do not appear to be driven by shocks to the amount of inflation-indexed debt outstanding.

¹Pflueger: Harvard Business School, Boston MA 02163. Email cpflueger@hbs.edu. Viceira: Harvard Business School, Boston MA 02163 and NBER. Email lviceira@hbs.edu.

1 Introduction

This article conducts an empirical exploration of the sources, magnitude and time variation of risk premia in inflation-indexed and nominal government bonds, using data on US Treasury bonds and UK gilts. By testing the expectations hypothesis in inflation-indexed bonds as well as in nominal bonds we can disentangle the sources of variation in bond risk premia, since inflation-indexed bonds are not subject to inflation risk. We find support for both time-varying real interest rate risk premia in inflation-indexed bonds and inflation risk premia in nominal bonds. Understanding the sources of systematic risk in government bonds is fundamental in thinking about the term structure of interest rates. Moreover, it is also of first order importance for investors, since government bonds typically constitute the anchor of fixed income portfolio allocations.

The most common form of government bonds are nominal bonds that pay fixed coupons and principal, although in recent times governments around the world, including the U.S. Treasury, have started issuing significant amounts of inflation-indexed bonds (Campbell, Shiller and Viceira 2009). Inflation-indexed bonds, which in the U.S. are known as Treasury Inflation Protected Securities (TIPS), are bonds whose coupons and principal adjust automatically with the evolution a consumer price index¹. They aim to pay investors a fixed inflation-adjusted coupon and principal. For this reason they are also known as real bonds, and their yields are typically considered the best proxy for the term structure of real interest rates in the economy.

Although government bonds in large stable economics are generally free from default risk, they expose investors to other risks. Investors holding either inflation-indexed or nominal government bonds are exposed to the risk of changing real interest rates. For any investor the riskless asset is an inflation-indexed bond whose cash flows match his consumption plan (Campbell and Viceira 2001, Wachter 2003). If future real interest rates are uncertain, investors will view bonds not matching the timing and length of their consumption plans as risky, leading to a risk premium for holding such bonds. This real interest rate risk premium will be a function of investors' risk tolerance, and it can be time-varying if investors' tolerance for risk changes over the business cycle (Campbell and Cochrane 1999, Wachter 2006). A time-varying correlation of real interest rates with investor well-being can also make

¹In the US, TIPS payments are linked to the Consumer Price Index for All Urban Consumers (CPI-U). The relevant index in the UK is the Retail Price Index (RPI).

the real interest rate risk premium vary over time (Campbell, Sunderam, and Viceira 2010).

In addition to real interest rate risk, nominal government bonds expose investors to inflation risk. When future inflation is uncertain, the coupons and principal of nominal bonds can suffer from the eroding effects of inflationary surprises. If inflation is negatively correlated with economic conditions, as in times of stagflation, the real payoffs of nominal bonds will tend to decline when economic conditions worsen. Risk averse investors will therefore demand a positive inflation risk premium for holding nominal bonds. But if inflation is positively correlated with economic conditions, nominal bonds will have hedging value to risk-averse investors (Piazzesi and Schneider 2007, Campbell, Sunderam, and Viceira, 2010). By contrast, inflation-indexed bonds are not exposed to inflation risk, since their coupons and principal adjust automatically with inflation.²

In our analysis we adopt a flexible empirical approach that does not rely on a tightly parameterized model³. This allows us to analyze real interest rate risk and inflation risk together with liquidity premia and supply effects in the spirit of the preferred-habitat hypothesis of Modigliani and Sutch (1966). The starting point of our empirical investigation is the expectations hypothesis of interest rates. The expectations hypothesis postulates that the total risk premium on long-term bonds, or the expected excess return on long-term bonds over short-term bonds, should be constant over time. If the EH holds for inflation-indexed bonds, this implies that the real interest rate risk premium is constant. In that case the yield on long-term inflation-indexed bonds is equal to the average expected short-term real interest rate over the life of the bond plus a constant. Investors cannot earn predictable returns by shifting between long-maturity and short-maturity real bonds.

The implications of the expectations hypothesis for nominal bonds are stronger. If it holds, both the inflation risk premium and the real interest rate risk premium are constant⁴. In that case the yield on long-term nominal bonds is equal to the average

²Tax regulations in some countries, including the US, make the after-tax income and capital gains from inflation-indexed bonds not fully inflation indexed. This effect can be exacerbated at times of high accelerating inflation. See Section 2.

³See Adrian and Wu (2009), Buraschi and Jiltsov (2004), Campbell, Sunderam, and Viceira (2010), Christensen, Rudebusch and Wu (2010) and Evans (2003) for formal models of the term structure of interest rates that analyze and estimate inflation and real interest rate risk premia using data on both real and nominal bonds.

⁴Unless we are in the unlikely case where time-variation in the inflation risk premium and the

expected future short-term nominal interest rate up to a constant. A rejection of the nominal expectations hypothesis can be the result of a time-varying inflation risk premium, a time-varying real interest rate risk premium, or both. Without independent observation of real bond prices it is hard to distinguish between those sources of time variation in nominal bond risk premia.

The expectations hypothesis has been tested and rejected on U.S. nominal Treasury bonds numerous times, but previous tests for inflation-indexed bonds only had significantly shorter samples at their disposal and were not able to reject the expectations hypothesis (Barr, Campbell 1997). Campbell and Shiller (1991) present regression results for different combinations of maturities and holding periods and resoundingly reject the expectations hypothesis for U.S. nominal bonds. Fama and Bliss (1987), Cochrane and Piazzesi (2005) and others have also presented robust empirical evidence that nominal Treasury bond risk premia vary over time. However, Campbell (1999) presents evidence that the expectations hypothesis is harder to reject on nominal government bonds in a cross-section of other developed economies.

Two potential complicating factors in this empirical exploration of the expectations hypothesis are the differing liquidity of the market for inflation-indexed bonds and the market for nominal bonds, and the potential segmentation of both markets. First, although both nominal and inflation-indexed bonds are fully backed by their respective governments, inflation-indexed bonds tend to be less liquid. US nominal Treasury bonds are among the most liquid investments in the world, but TIPS have a significantly smaller and less liquid market (Campbell, Shiller, and Viceira 2009, Gurkaynak, Sack, and Wright 2010, Fleming and Krishnan 2009, Dudley, Roush, and Steinberg Ezer 2009).

This raises the issue of whether investors might demand a liquidity premium on TIPS relative to Treasuries, and whether this premium might be time-varying. For example, as the supply of TIPS has increased over time since they were first issued in 1997 and investors have learnt about these new securities, one might expect the liquidity of the inflation-indexed bond market to have increased. During the financial crisis in the Fall of 2008, TIPS experienced a sudden increase in yields relative to Treasuries. This might have been the result of a “flight to liquidity” by investors seeking the comfort and liquidity of well understood nominal US Treasury bonds, not the result of a sudden change in investors’ inflation expectations or real interest rates, as documented by Campbell, Shiller, and Viceira (2009).

real interest rate risk premium exactly cancel.

These events strongly suggest that it is important to control for liquidity when testing the expectations hypothesis in inflation-indexed bonds. In our exercise we explicitly proxy for the liquidity premium inherent in inflation-indexed US bonds using the transaction volume of TIPS, the financing cost for buying a TIPS, the 10 year nominal off-the-run spread and the Ginnie Mae (GNMA) spread. Modelling liquidity with these measures of market wide and TIPS-specific liquidity, we find evidence for a time-varying liquidity premium. When liquidity dries up in the TIPS market TIPS offer higher expected returns relative to nominal bonds. However, this liquidity premium appears largely orthogonal to the real interest rate risk premia and inflation risk premia identified before.

Second, building on the preferred-habitat hypothesis of Modigliani and Sutch (1966), Vayanos and Vila (2009) show that investors' preference for certain types of bonds, combined with risk aversion by bond market arbitrageurs, can result in bond return predictability not directly attributable to real interest rate risk or inflation risk but to market segmentation. This segmentation is the result of bond market arbitrageurs not fully offsetting the positions of "habitat investors" in response to shocks in the bond market. Greenwood and Vayanos (2008) and Hamilton and Wu (2010) explore empirically market segmentation across different maturities in the US Treasury nominal bond market using the maturity structure of outstanding government debt as a proxy for supply shocks, and find that it predicts bond returns.

In the context of real versus nominal bonds, it seems plausible that the preference of certain investors—such as pension funds with inflation-indexed liabilities—for real bonds, and the preference of others—such as pension funds with nominal liabilities—for nominal bonds might lead to imperfect market integration between both markets and this could generate return predictability. Following Greenwood and Vayanos (2008) we use the outstanding supply of real bonds relative to total government debt as a proxy for supply shocks in the inflation-indexed bond market. In the UK we find some evidence for bond supply effects, but they do not appear to drive our main results.

The structure of this article is as follows. Section 2 describes the mechanics of inflation-indexed bonds. Section 3 formalizes the expectations hypothesis of interest rates and expected inflation. Section 4 tests the expectations hypothesis in real and nominal bonds without controlling for liquidity or supply effects. Section 5 adds liquidity factors to our tests of the expectations hypothesis, and section 6 considers bond supply effects. Section 7 provides evidence on real and nominal bond return

predictability from the tent-shaped linear combination of nominal interest rates proposed by Cochrane and Piazzesi (2005). Finally, section 8 offers some concluding remarks.

2 Inflation-Indexed Bonds

Inflation-indexed bonds have been available in the UK since 1983 and in the US since 1997. US inflation-indexed bonds are called Treasury Inflation Protected Securities (TIPS). They are designed to approximate real bonds with payouts that are constant despite inflation surprises. They are quoted in terms of a real interest rate and are issued mostly at long maturities greater than 10 years. The principal on these bonds grows with a pre-specified price index, which in the U.S. is the Consumer Price Index (CPI-U) and in the UK is the Retail Price Index (RPI). The coupons are equal to the inflation-adjusted principal on the bond times a fixed coupon rate. Thus the coupons on these bonds also fluctuate with inflation.

Of course, the price index might not grow over time. For instance the CPI decreased by almost 4% between September 2008 and December 2008. In the US, the final payment of principal on a TIPS is protected against deflation and it can never be smaller than the stated nominal value at issuance. However, its coupons are not: the inflation-adjusted value of the principal for coupon computation purposes can fall below the initial value at issuance. In contrast, neither the principal nor the coupons on inflation-linked gilts in the UK are protected from deflation.

Further details complicate the pricing of these bonds. Since inflation figures in the US and in the UK are published with a lag, the principal value of inflation-indexed bonds adjusts with a 3 month lag. UK inflation-linked gilts that were issued prior to the financial year 2005-06 follow an 8 month lagged indexing procedure while more recent issues follow a 3 month lagged methodology. The tax treatment of these bonds also differs. In the UK principal adjustments of inflation-linked gilts are not taxed. This gives inflation-linked gilts a tax advantage over nominal gilts, a larger share of whose cash flows come in the form of taxable nominal coupon payments. In the US, on the other hand, inflation-adjustments of principal are considered ordinary income for tax purposes. As a result the tax obligations associated with holding a TIPS increase when inflation is high so that on an after-tax basis U.S. TIPS are not fully indexed to inflation. More details on TIPS can be found in Viceira (2001), Roll

(2004) and Gurkaynak, Sack, and Wright (2010). Campbell and Shiller (1996) offer a discussion of the taxation of inflation-indexed bonds. Campbell, Shiller, and Viceira (2009) provide an overview of the history of inflation-indexed bonds in the US and the UK.

3 The Expectations Hypothesis

The expectations hypothesis of the term structure of interest rates says that the excess return on an n -period bond over a 1-period bond should be constant over time. There should not be any particularly good time to hold short-term or long-term bonds. Equivalently, the expectations hypothesis says that if short yields are anticipated to rise in the future then this should already be reflected in current long yields. The expectations hypothesis is usually stated for nominal bonds. We formulate expectations hypotheses for nominal bonds, real bonds and for inflation expectations. We show that these different interpretations of the expectations hypothesis are closely related to real interest rate risk, inflation risk and liquidity premia and derive empirical predictions that we will test subsequently.

3.1 Bond Notation and Definitions

We start by establishing some notation and definitions that will be used throughout the article. We denote by $p_{n,t}^{\$}$ the log price of a zero-coupon n -period nominal bond, and by $y_{n,t}^{\$}$ the bond's log (or continuously compounded) yield. For zero-coupon bonds, log price and yield are related according to

$$y_{n,t}^{\$} = - \left(\frac{1}{n} \right) p_{n,t}^{\$}. \quad (1)$$

The yield spread is the difference between a long-term yield and a short-term yield, $s_{n,t}^{\$} = y_{n,t}^{\$} - y_{1,t}^{\$}$.

The log return on a zero-coupon n -period bond if it is held for one period and sold before maturity is given by the change in its price, i.e.

$$\begin{aligned} r_{n,t+1}^{\$} &= p_{n-1,t+1}^{\$} - p_{n,t}^{\$} \\ &= ny_{n,t}^{\$} - (n-1)y_{n-1,t+1}^{\$}, \end{aligned} \quad (2)$$

where the second equality follows immediately from (1).

We use the superscript *TIPS* to denote the corresponding quantities for both US and UK inflation-indexed bonds. Inflation-indexed bonds are commonly quoted in terms of *real* yields. That is $p_{n,t}^{TIPS}$ is the *real* log price of an indexed bond, $y_{n,t}^{TIPS}$ is the *real* yield and $r_{n,t+t}^{TIPS}$ is the *real* one-period log return. The nominal one-period log return on an inflation-indexed bond is then given by $r_{n,t+1}^{TIPS} + \pi_{1t}$, where π_{1t} denotes the 1-period log inflation rate from period t to period $t + 1$.

3.2 Nominal Expectations Hypothesis

The nominal expectations hypothesis (EH) states that the expected log excess return on long-term nominal bonds over short-term nominal bonds, or bond risk premium, is constant over time:

$$\text{Et} [r_{n,t+1}^{\$} - y_{1,t}^{\$}] = \mu_n^{\$}, \quad (3)$$

where the constant bond risk premium $\mu_n^{\$}$ can depend on maturity n . The advantage of formulating the expectations hypothesis in logs is that the log expectations hypothesis for one holding period is consistent with the log expectations hypothesis for any other holding period.⁵

The EH can be represented in a number of different ways that obtain by simple algebraic manipulation of (2) and (3).⁶ A popular equivalent representation of the nominal EH relates the yield on a n -period zero-coupon nominal bond at time t to expected future short-term nominal interest rates:

$$y_{n,t}^{\$} = \theta_n^{\$} + \frac{1}{n} \text{Et} \sum_{i=0}^{n-1} y_{1,t+i}^{\$}. \quad (4)$$

Equation (4) says that the current n -period yield should be equal to the expected average short yields over its maturity up to a time-invariant constant $\theta_n^{\$}$. The constant

⁵Another version of the expectations hypothesis, the so-called pure expectations hypothesis (PEH), considers a formulation of (3) in terms of *simple* returns as opposed to *log* returns, and sets expected excess simple returns to zero (Campbell, Lo, and MacKinlay, 1997). The intuition of the PEH is that if investors are risk neutral then they should adjust positions until the expected one-period returns for short nominal bonds and long nominal bonds are equalized. The log EH (3) is less constraining in that it allows for a non-zero bond risk premium.

⁶For a detailed discussion of equivalent formulations of the expectations hypothesis see Campbell, Lo, and MacKinlay (1997, Chapter 10) or Cochrane (2005, Chapter 19).

$\theta_n^\$$ is simply the average of bond risk premia for maturities up to n periods, i.e., $\theta_n^\$ = \sum_{i=2}^n \mu_i^\$/n$. A second equivalent representation of the nominal EH relates changes in long-term yields to the yield spread

$$E_t [y_{n-1,t+1}^\$ - y_{n,t}^\$] = \left(\theta_{n-1}^\$ - \frac{n}{n-1} \theta_n^\$ \right) + \frac{1}{n-1} s_{n,t}^\$. \quad (5)$$

Although these alternative equivalent representations of the EH provide useful intuition to understand the meaning and implications of the EH, we choose to work with the return-based definition (3) in our empirical exploration of the EH. This approach allows for transparent interpretation of empirical results in terms of return predictability, and it is flexible enough to easily accommodate a complementary analysis of liquidity premia and supply pressures in the bond market.

The EH says that $r_{n,t+1}^\$ - y_{1,t}^\$$ cannot be predicted. However, early tests of the EH based on (5) found robust evidence that the nominal term spread—or an equivalent combination of forward rates—predicts nominal excess returns positively (Campbell and Shiller 1991, Fama and Bliss 1987). That is, whenever the term spread is high the risk premium on long nominal bonds is higher.⁷ Building on this prior work, we test in our data whether the term spread contains a time-varying risk premium by running the regression test

$$r_{n,t+1}^\$ - y_{1,t}^\$ = \alpha^\$ + \beta^\$ s_{n,t}^\$ + \varepsilon_{t+1}^\$, \quad (6)$$

where $\beta^\$ = 0$ under the null that the EH holds. Of course, failing to reject $\beta^\$ = 0$ in (6) does not imply that we fail to reject the EH, as other state variables might forecast bond excess returns. Thus we also include in (6) other variables that have been shown to forecast bond excess returns in our empirical analysis.

3.3 Real Expectations Hypothesis

The EH has traditionally been formulated and tested in terms of nominal bonds but it appears at least as plausible to formulate the expectations hypothesis in terms of real bonds. The nominal EH supposes that the bond risk premium on nominal bonds, consisting of both inflation risk and real interest rate risk, is constant over time. The

⁷This is equivalent to finding a negative slope in a regression of changes in the yield on long-term bonds on $s_{n,t}^\$/(n-1)$.

EH for inflation-indexed bonds is strictly weaker in that it only supposes that real interest rate risk is constant.

Expressed in terms of returns the EH for inflation-indexed zero-coupon bonds says that

$$E_t [r_{n,t+1}^{TIPS} - y_{1,t}^{TIPS}] = \mu_n^{TIPS}, \quad (7)$$

Analogously to the nominal EH we test the real EH by testing whether the real term spread predicts excess returns on real bonds:

$$r_{n,t+1}^{TIPS} - y_{1,t}^{TIPS} = \alpha^{TIPS} + \beta^{TIPS} s_{n,t}^{TIPS} + \varepsilon_{t+1}^{TIPS} \quad (8)$$

where $s_{n,t}^{TIPS} = y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$ is the TIPS bond spread. The real EH hypothesis implies that the coefficient of real excess log returns of inflation-indexed bonds on the real term spread should be zero. If $\beta^{TIPS} \neq 0$ then we can infer that the real yield reflects time-varying real risk premia and μ_n^{TIPS} is time-varying. The TIPS bond spread is a natural candidate regressor due to its similarity to the nominal bond spread. Since TIPS are not exposed to inflation surprises the TIPS yield spread should not reflect inflation risk but it might reflect other risk premia such as real interest rate risk and liquidity premia. Hence, if any of these premia are important in driving the rejection of the nominal expectations hypothesis they would be likely to be reflected in terms of a nonzero coefficient β^{TIPS} .

3.4 Breakeven Inflation and the Inflation Expectation Hypothesis

We now look at the difference between nominal and indexed yields, known by bond market participants as “breakeven inflation:”

$$b_{n,t} = y_{n,t}^{\$} - y_{n,t}^{TIPS} \quad (9)$$

Most simply n -period breakeven inflation is the inflation rate over the next n periods that would make a nominal bond and an indexed bond of maturity n earn the exact same buy-and-hold return. The nominal bond outperforms the inflation-indexed bond if realized inflation over the life of the bonds turns out to be smaller than breakeven inflation, and underperforms it if realized inflation turns out to be larger.

Bond market participants often use breakeven inflation as a measure of expected inflation. However, the identification of breakeven inflation with expected inflation is not entirely correct. In order to understand this point, it is useful to think about the components of bond yields, both nominal and inflation-indexed. Economic logic, formally corroborated by models of the term structure of interest rates,⁸ suggests that we can decompose the yield on an inflation-indexed bond into a component that reflects current expectations of future real interest rates, a component that reflects a real interest rate risk premium, and another that reflects all other factors affecting the yield on the bond, such as liquidity:

$$y_{n,t}^{TIPS} = y_{n,t} + L_{n,t}^{TIPS}, \quad (10)$$

where $L_{n,t}^{TIPS}$ denotes the liquidity premium specific to the inflation-indexed bond, and $y_{n,t}$ embeds the components of bond yields related to expectations of future interest rates and the real interest rate risk premium. This premium arises if the real interest rate is correlated with macroeconomic conditions or risk-aversion and can be positive or negative depending on the sign of the correlation. We can interpret $y_{n,t}$ as the yield on an inflation-indexed bond in a perfectly liquid market.

Similarly, we can think of the yield on a nominal bond as composed of the yield on a perfectly liquid real bond $y_{n,t}$ plus additional components reflecting expected inflation, an inflation risk premium, and a liquidity component:

$$y_{n,t}^{\$} = y_{n,t} + \pi_{n,t}^e + \psi_{n,t} + L_{n,t}^{\$}, \quad (11)$$

where $\pi_{n,t}^e$ denotes n-period expected inflation and $\psi_{n,t}$ denotes the inflation risk premium. $L_{n,t}^{\$}$ denotes the nominal bond market liquidity premium for long nominal bonds over short nominal bonds.

We allow for time variation in all of these components. Inflation expectations can change over time, and the inflation risk premium on nominal bonds can also change over time if the correlation of inflation with economic conditions changes over time. Viceira (2010) provides robust empirical evidence of significant time-variation in the total risk of US nominal Treasury bonds, and Campbell, Sunderam, and Viceira (2010) show further evidence that this partly reflects a time-varying inflation risk premium that reflects a changing correlation of inflation with economic conditions. They estimate a negative or low inflation risk premium in the 1950's and 1960's

⁸See, for example, the term structure models in Adrian, Wu (2009), Campbell and Viceira (2001), Campbell, Sunderam, and Viceira (2010) and Christensen, Lopez, Rudebusch (2010).

period of stable tradeoff between inflation and growth, a large positive premium in the stagflation period of the late 1970's and early 1980's, and a negative premium again since the late 1990's. Finally, nominal bonds can also trade at a liquidity premium or discount that can change over time.

Subtracting (10) from (11) and using the definition of breakeven inflation we obtain

$$b_{n,t} = \pi_{n,t}^e + \psi_{n,t} + (L_{n,t}^{\$} - L_{n,t}^{TIPS}). \quad (12)$$

Thus breakeven inflation reflects not only expectations about future inflation. It also reflects an inflation risk premium on the nominal bond, which might be time-varying, and any liquidity differential between the nominal and the inflation-indexed bond markets. We think of the liquidity premium on nominal bonds as being typically smaller than the liquidity premium on inflation-indexed bonds, so the difference $L_{n,t}^{\$} - L_{n,t}^{TIPS}$ is typically negative. But the magnitude of the liquidity differential can potentially vary over time.

An important insight that emerges from (12) is that the EH may hold for inflation-indexed bonds but fail for nominal bonds, if either the inflation risk premium or the differential bond liquidity premium are time-varying. Equation (12) also implies that if both the inflation risk premium and the liquidity differential are constant, and bond market inflation expectations are rational, the expected excess return on breakeven inflation should be constant. We call the joint hypothesis of rational inflation expectations and a constant inflation risk premium the inflation expectations hypothesis.

The excess return on breakeven inflation is given by $nb_{n,t} - (n-1)b_{n-1,t+1} - b_{1,t}$, which is mechanically identical to the difference between the excess return on nominal bonds and the excess return on inflation-indexed bonds of identical maturity:

$$nb_{n,t} - (n-1)b_{n-1,t+1} - b_{1,t} = (r_{n,t+1}^{\$} - y_{1,t}^{\$}) - (r_{n,t+1}^{TIPS} - y_{1,t}^{TIPS}). \quad (13)$$

Under the assumption of constant inflation and liquidity risk premia, the left-hand side of equation (13) equals a constant plus $n\pi_{n,t}^e - (n-1)\pi_{n-1,t+1}^e - \pi_{1,t}$, which is zero when inflation expectations are rational. To see this, note that

$$n\pi_{n,t} - (n-1)\pi_{n-1,t+1} - \pi_{1,t} = 0, \quad (14)$$

since both $n\pi_{n,t+1}$ and $(n-1)\pi_{n-1,t+1} + \pi_{1,t}$ denote cumulative inflation from time t to time $t+n$. Therefore under rational expectations equation (14) must also hold ex-ante.

By analogy with our tests of the nominal and real EH, we run the regression

$$(r_{n,t+1}^{\$} - y_{1,t}^{\$}) - (r_{n,t+1}^{TIPS} - y_{1,t}^{TIPS}) = \alpha^b + \beta^b s_{n,t}^b + \varepsilon_{t+1}^b, \quad (15)$$

where $s_{n,t}^b = b_{n,t} - b_{1,t}$ is the breakeven inflation spread, and test whether $\beta^b = 0$. If the slope is positive, it means that when breakeven inflation at the long end of the yield curve is large, nominal bonds tend to outperform inflation-indexed bonds of similar maturity. If inflation risk premia are important in the return predictability of nominal bonds then we would expect them to show up in terms of a nonzero regression coefficient in (15), particularly if the expected change in the liquidity differential is constant or if we can control for this differential appropriately. The breakeven spread $s_{n,t}^b$ should likely reflect the inflation risk premia contained in the nominal yield spread $s_{n,t}^{\$}$.

Since the breakeven inflation spread, the nominal term spread, and the real term spread are mechanically related by $s_{n,t}^{\$} = s_{n,t}^b + s_{n,t}^{TIPS}$, it also makes sense to test whether both the real term spread and the breakeven inflation spread forecast the return on breakeven inflation. Thus we also run regressions of the type

$$(r_{n,t+1}^{\$} - y_{1,t}^{\$}) - (r_{n,t+1}^{TIPS} - y_{1,t}^{TIPS}) = \alpha^b + \beta_1^b s_{n,t}^b + \beta_2^b s_{n,t}^b + \varepsilon_{t+1}^b. \quad (16)$$

It is important to note that neither (15) nor (16) are redundant with respect to the standard EH regressions (8) and (6) except of course in the trivial case where the spreads do not forecast bond excess returns and thus all slope coefficients are zero.

4 Testing the Expectations Hypothesis in Real and Nominal Government Bonds

4.1 Data

We conduct tests of the real and nominal EH using government bond data from both the US and UK. For the US we use an expanded version of the Gurkaynak, Sack, Wright (2007) and Gurkaynak, Sack, Wright (2010, GSW henceforth) data set. GSW have constructed a zero-coupon yield curve starting in January 1961 for nominal bonds and starting in January 1999 for TIPS by fitting a smoothed yield curve. We expand their data back to 1951 using the McCulloch, Houston, and Kwon (1993)

data for US nominal zero coupon yields from January 1951 through December 1960. The GSW data set contains constant maturity yields for maturities of 2 to 20 years. Our empirical tests will focus on the 10-year nominal and real yields, because this maturity bracket has the longest and most continuous history of TIPS outstanding. We measure U.S. inflation with the all-urban seasonally adjusted CPI, and the short-term nominal interest rate with the 3 month T-bill rate from the Fama-Bliss riskless interest rate file from CRSP. TIPS payouts are linked to the all-urban non seasonally adjusted CPI and our results become slightly stronger when using the non seasonally adjusted CPI instead.

For the UK we use zero-coupon yield curves from the Bank of England. Anderson and Sleath (2001) describe the spline-based techniques used to estimate the yield curves. Nominal yields are available starting in 1970 for 0.5 to 20 years to maturity. Real yields are available starting in 1985 for 2.5 to 25 years to maturity. We focus on the 20-year nominal and real yields and, for comparability with the US, on the 10-year nominal and real yields. We use the 20-year maturity in our tests because 20-year nominal and real yields are available from 1985, while 10-year real yields are available only since 1991.⁹ Inflation is measured by the non seasonally-adjusted Retail Price Index, which serves as the measure of inflation for inflation indexed bond payouts.

In all regressions we approximate $y_{n-1,t+1}^{\$}$ and $y_{n-1,t+1}^{TIPS}$ with $y_{n,t+1}^{\$}$ and $y_{n,t+1}^{TIPS}$. Because neither the US nor the UK governments issue inflation-indexed bills, we need to resort to an empirical procedure to build a hypothetical short-term real interest rate. We describe this procedure in Section 4.2. Finally, although our yield data sets are available at a monthly frequency, we sample our data at a quarterly frequency in order to reduce the influence of high-frequency noise in observed inflation and short-term nominal interest rate volatility in our tests.

4.2 Construction of the Short-Term Real Interest Rate

While three-month nominal T-bills are issued in the US and in the UK, there exists no equivalent short-term instrument with fixed real payoffs. Apart from technical difficulties, the demand would probably not exist simply because inflation risk in both countries has been historically negligible over such a short horizon. However, we

⁹For some months the 20 year yields are not available and instead we use longest maturity available. The maturity used for the 20 year yield series drops down to 16.5 years for a short period in 1991.

need a proxy for a short-term real rate for our tests of the expectations hypothesis. We follow Campbell and Shiller’s (1996) analysis of hypothetical TIPS to construct an ex-ante measure of the short-term real interest rate.

We start by assuming zero inflation risk and liquidity premium over 1 quarter. Therefore, the ex-ante short-term real interest rate is given by

$$y_{1,t}^{TIPS} = y_{1,t}^{\$} - \pi_{1,t}^e.$$

Next we assume that inflation expectations over the next quarter are rational and proxy for the ex-ante real short rate as the fitted value from the regression of this quarter’s realized real rate $y_{1,t}^{\$} - \pi_{1,t+1}$ onto last quarter’s realized real rate $y_{1,t-1}^{\$} - \pi_{1,t}$, the nominal short rate $y_{1,t}^{\$}$, and annual inflation up to time t .

Table 1 shows the monthly predictive regressions for the U.S. and the UK. It reports the point estimates of the slope coefficients as well as Newey-West heteroskedasticity and autocorrelation consistent (h.a.c.) standard errors with four lags in parenthesis. The table shows that the main determinant of the ex-ante real rate is the nominal rate, with a positive coefficient of about 0.5 in both the US and the UK. The regressions can explain 44% of the real interest rate variation in the US and 18% of the real interest rate variation in the UK, respectively, and the regressors are jointly significant in both regressions.

Figure 1 shows the predicted and realized US real short rate together with the nominal short rate. It shows that the predicted real short rate very much just follows the nominal short rate and smooths out fluctuations in the ex-post real rate caused by short-term volatility in realized inflation. The estimate is conservative in the sense that it barely relies on lagged realized inflation and it does not attempt to predict high-frequency fluctuations in inflation.

Tables 2A, 2B and 2C present summary statistics for the short-term real interest rate together with bond returns and yield spreads for the US and UK. Because the sample period in each table is different, it is hard to attribute the differences across tables to bond maturity or country differentials. Nonetheless, we estimate the average ex-ante short-term real interest rate, the average real term spread, and the average excess return on TIPS to be considerably higher in the US than in the UK. Bond return volatilities are generally comparable across both countries controlling for maturity, and increase with maturity. It is interesting that both countries exhibit very similar return correlation patterns. The returns on nominal bonds and on inflation-indexed bonds are highly positively correlated, while the returns on inflation-indexed

bonds and on breakeven inflation are significantly negatively correlated at the 10-year maturity.

4.3 The Nominal Expectations Hypothesis in the U.S.

Tables 3A and 3B report tests of the nominal EH in the US using our preferred return-based regression test (6). Thus we test whether nominal log excess returns are predictable from the nominal term spread.

The objective of Tables 3A and 3B is to analyze changes in the predictability of nominal bond returns since Campbell, Shiller (1991) reported tests of the nominal EH. Campbell, Shiller (1991) found that they were able to clearly reject the expectations hypothesis for almost all of their maturity combinations for the sample period 1952-1987. Table 3 reruns those same regressions for our full sample period (1951.12-2009.12) with 5-year and 10-year constant maturity zero-coupon bonds. For comparison we also report them for the Campbell-Shiller sample period and the sample period from 1987 until present.¹⁰ The table reports the point estimates of the slope coefficients and Newey-West standard errors with 3 lags¹¹.

Table 3A shows that the full time period 1952-2009 yields an even stronger rejection of the expectations hypothesis than the earlier sample period 1952-1987. At the same time, using the second part of the sample only it is harder to reject the expectations hypothesis at conventional significance levels. Stock and Watson (2002) documented a break in the mid-1980s in a number of macroeconomic time series. If the predictability of bond returns is linked to macroeconomic processes, it is conceivable that bond return predictability also experienced a break at the same time.

Following this intuition, Table 3B examines more closely whether there was a structural change in bond return predictability in 1987. We add the term spread interacted with a dummy for the second sub period, $s_{n,t}^{\$} \times d_{1987-2008}$ to the regression in order to allow for different slope coefficients before 1987 and after 1987. The interaction term does not enter significantly the regression, indicating that we cannot reject the hypothesis of a stable relationship across sub samples. This evidence agrees with the observation in Table 3A. The full sample period and the Campbell-Shiller

¹⁰Campbell, Shiller (1991) used the McCulloch, Huston, Kwon (1993) data of zero coupon yields for their entire period so that our results differ slightly from theirs due to our different data source.

¹¹Our results are unchanged if instead we use Newey-West standard errors with 12 lags.

sample period yield very similar regression coefficients and the coefficient is more accurately measured using the full sample period.

Thus the addition of the 1987-2009 period to the early sample period contributes to reinforce the empirical evidence towards rejection of the nominal EH. It also emphasizes the difficulty of detecting this type of bond return predictability in smaller sample sizes, even if the sample comprises more than 20 years of data. This qualification is particularly important for our subsequent analysis of the real EH, because even our longest series of inflation-indexed bonds only spans a 24 year period from 1985 to 2009.

4.4 Expectations Hypothesis Real and Nominal

Tables 4A, 4B, and 4C present our main regression tests for the nominal, real and inflation expectations hypothesis in the US and in the UK. Columns 1 through 4 in each table report coefficients from the return-based regressions (6), (8), (15) and (16), respectively. The data consists of monthly data of overlapping quarterly returns. Newey-West standard errors are based on 3 lags to adjust for overlapping returns.

Table 4A reports the regression tests for the US data from 1999 to 2009. According to the nominal EH the coefficient in column 1 should be zero. We cannot reject the nominal EH over this particular time period. However, the rejection of the nominal EH is somewhat marginal—the significance level is 15%. Moreover, the results in Tables 3A and 3B indicate that this may well be related to the short sample size rather than a change in the predictive relationship.

Column 2 of Table 4A tests whether real returns on inflation-indexed bonds are predictable. The real EH says that the regression coefficient should be 0. We previously argued that the real EH could hold even if the nominal EH fails. In light of this the rejection of the real EH in column 2 is particularly striking. The coefficient on the real spread is large compared to the coefficients on the nominal spread reported in Table 4 and column 1. It is also significant at the 1% level.

Column 3 of Table 4A tests the inflation EH in the US. We find that the breakeven spread predicts the difference in nominal and inflation-indexed bond excess returns and interpret this as evidence against the inflation EH. Assuming that bond market participants' inflation expectations are rational and that liquidity premia are con-

stant, this result is consistent with a time-varying inflation risk premium. Column 4 adds the TIPS spread as an additional regressor and shows it does not affect the predictive power or the coefficient estimate of the breakeven spread. These results suggest that when the breakeven spread increases, inflation risk also increases and investors demand a higher inflation risk premium from nominal bonds. Interestingly, the inflation-indexed bond spread appears to predict breakeven returns negatively in the US. Thus a widening of the real term spread forecasts a decrease in the spread between nominal bond risk premia and inflation-indexed bond risk premia. One might expect that if the real term spread proxies for the real interest rate risk premium, its coefficient should be zero; that is, increases in the real interest rate risk premium should affect approximately in the same proportion the prices of both inflation-indexed bonds and nominal bonds. We show evidence below that the effect of the real term spread on breakeven inflation returns might be related to liquidity factors.

Taken together, the results in Table 4A suggest that the risk premium on inflation-indexed bonds and the risk premium on nominal bonds both vary over time in the US. In the absence of time-varying liquidity premia or some other time-varying institutional factors that predict bond returns, this evidence implies that the real interest rate risk premium and the inflation risk premium are both time-varying.¹²

Tables 4B and 4C report the corresponding results for the UK 10-year (1991-2009) and 20-year bonds (1985-2009). The pattern of results in both tables are remarkably consistent with the results shown in Table 4A for the US bond market. The regression coefficients for the UK 10-year bonds in Table 4B are relatively less precisely estimated. Table 4C reports the same regression tests for 20 year bonds over the longer sample period 1985-2009 and shows that over this longer sample period we can reject the nominal, real and inflation EH at the 5% significance level. Moreover in column 4 the real term spread does not appear to predict breakeven returns, especially for the UK 20 year bonds.

Overall, the results in Table 4 provide strong support for the predictability of nominal and real bond returns and for the predictability of their difference in US and UK bond data. These results provide support for the hypothesis that the risk

¹²It is important to note that our results for the real EH and the inflation EH are not sensitive to the use of an estimated short-term real interest rate series to compute real bond excess returns. For example, the inflation EH regression results hold if we use the return differential between long-term nominal bonds and inflation-indexed bonds instead of the excess return differential.

premium on nominal bonds is driven by both a time-varying inflation risk premium and a time-varying real interest rate risk premium. An increase in breakeven inflation forecasts positively an increase in nominal bond risk premia relative to inflation-indexed bond risk premia. The US results also show the striking result that the real term spread forecasts negatively the spread between the nominal bond risk premium and the inflation-indexed bond risk premium. This could indicate that the prices of long-term inflation-indexed bonds are influenced by factors other than the level of real interest rates and the real interest rate risk premium. In order to distinguish between liquidity, inflation and real interest rate premia more clearly we proceed to model liquidity premia in TIPS.

5 Disentangling Liquidity, Real Interest Rate Risk, and Inflation Risk Premia

So far we have attributed the time variation in expected bond excess returns to time-varying real interest rate risk and inflation risk premia, ignoring liquidity and institutional factors that might also affect the prices and returns on bonds. In particular, if the inflation-indexed bond market is less liquid than the nominal bond market, inflation-indexed bonds might trade at a discount reflecting the compensation investors demand for holding them relative to nominal bonds. This liquidity premium might vary over time, thus clouding our tests of the expectations hypothesis. In particular the wedge between nominal and inflation-indexed bond yields could contain a large and time-varying liquidity premium, and this could bias upwards the coefficients reported in columns 4 and 5 of Table 4. It would also be plausible to think that this liquidity premium would induce predictable time-variation in TIPS yields and bias upwards the coefficients of the TIPS return predictability regression reported in column 2 of Table 4.

If we had a model for liquidity we could draw more precise conclusions about the predictability of inflation risk premia. Conversely, if we had a model for inflation risk premia we could draw conclusions about liquidity premia. These conclusions would be of course conditional on the validity of the model for either liquidity premia or inflation risk premia we use. Since we want to impose as few conditions as possible on the inflation process and inflation risk premia on the data, we opt for modelling liquidity premia.

Our approach to modelling liquidity premia is empirical. We use a number of reasonable proxies for market-wide and TIPS market liquidity and interpret the part of breakeven inflation that comoves with them as the liquidity premium $L_{n,t}$. We then obtain a measure of breakeven inflation and TIPS yields that is free from the effects of differential liquidity of TIPS versus nominal bonds. Of course, this measure is conditional on our estimate of $L_{n,t}$. Because we have data for liquidity proxies only for the US in the most recent period, our analysis is restricted to the last 10 years of US experience.

5.1 Empirical Measures of Liquidity

Our first proxy for liquidity in the Treasury market is the spread between the on-the-run and off-the-run 10 year nominal Treasury yields. The Treasury regularly issues new 10 year nominal notes, and the newest 10 year note is considered the most liquidly traded security in the Treasury bond market. The most recent Treasury note (or bond) is known as the “on-the-run note” by market participants. After the Treasury issues a new 10-year note, the prior note goes “off-the-run.”

The off-the-run bond typically trades at a discount over the on-the-run bond—i.e., it trades at a higher yield—, despite the fact that it offers almost identical cash flows with an identical remaining time to maturity. Similarly, older bonds with longer maturities at issuance that have almost the same cash flows and remaining time to maturity as the on-the-run bond also trade at a discount. The on-the-run off-the-run spread is also observed at other maturity points on the Treasury yield curve. Market participants attribute this spread to the lower liquidity of the off-the-run bond relative to the on-the-run bond. Treasury bonds are typically held by buy-and-hold investors, and older bonds are more difficult to find and to trade than more recently issued bonds. This spread varies over time, suggesting a time-varying premium. We obtain the 10 year off the run spread from the Federal Reserve and from Bloomberg.¹³

A second type of government-backed bond that is also less liquidly traded than on-the-run Treasury bonds are GNMA bonds. The Government National Mortgage Association (GNMA) guarantees the timely payment of interest and principal on residential mortgage backed securities. As such GNMA bonds do not contain any

¹³The on the run data is from Bloomberg (USGG10YR), and the off the run is from the Federal Reserve publication H.15 “Interest Rates”.

default risk, although they do contain prepayment risk, because mortgage holders can prepay without penalty. We use the spread between GNMA bond yields and on-the-run Treasury yields as a proxy for a market-wide desire to hold and trade only the most liquid securities. Spreads between agency bonds and Treasury bonds have previously been used as indicators of the liquidity premium in the TIPS and Treasury markets by Gurkaynak, Sack and Wright (2008) and by Longstaff (2004). The GNMA spread is obtained from Bloomberg and is adjusted for prepayment risk.¹⁴

Our third measure of liquidity aims at capturing liquidity developments specific to the TIPS market. There is evidence suggesting that the TIPS market might have been subject to specific liquidity events. For example, the first issues of TIPS in the late 1990's carried unusually high real yields. Campbell, Shiller, and Viceira (2009) and others have argued that perhaps initially TIPS were not well understood and may therefore have traded at a discount. In their study of the TIPS market microstructure Fleming, Krishnan (2009) conclude that trading activity is a good measure of cross-sectional TIPS liquidity. We follow Gurkaynak, Sack, Wright (2010) in using the transaction volume of TIPS relative to the transaction volume of Treasuries as an indicator for time-varying TIPS liquidity.

We obtain Primary Dealers' transaction volumes for TIPS and nominal Treasury securities from the New York Federal Reserve FR-2004 survey. We construct our measure of relative transaction volume as $\log (Trans_t^{TIPS} / Trans_t^{\$})$, where $Trans_t^{TIPS}$ denotes the average weekly transactions volume over the past 3 months and $Trans_t^{\$}$ the corresponding figure for nominal bonds. We normalize the relative transaction volume so that its maximal value is equal to zero. For $Trans_t^{\$}$ we use the transaction volume of government coupon securities with at least 6 (before 2001) or 7 (from 2001) years to maturity. We chose the transaction volume series for coupon bonds with a long time to maturity because we are aiming at capturing the differential liquidity of TIPS with respect to 10 year nominal bonds. Including all maturities or even T-bills would also reflect liquidity of short-term instruments versus long-term instruments. Additionally we smooth the measure of relative transaction volume over three months because we think of it as capturing secular learning effects. This smoothing also helps avoid introducing more volatility into TIPS yields in the process of adjusting for liquidity. It would not seem desirable that liquidity adjusted TIPS yields are more volatile than raw TIPS yields. The computations are complicated by the fact that in 2001 the Federal Reserve changed the maturity cutoffs for which the transaction

¹⁴Ticker GNSF060. This is the prepayment-option adjusted spread based on a 6% coupon 30 year GNMA generic bond. It is adjusted for prepayment risk using the Bloomberg prepayment model.

volumes are reported. This means that before 6/28/2001 we use the transaction volume of Treasuries with 6 or more years to maturity while starting 6/28/2001 we use the transaction volume of Treasuries with 7 or more years to maturity. The series after the break is scaled so that the growth in $Trans^{\$}$ from 6/21/2001 to 6/28/2001 is equal to the growth in transaction volume of all government coupon securities.

Finally, we want to account for the extraordinary liquidity events that took place during the financial crisis during the fall of 2008. Campbell, Shiller, and Viceira (2009) argue that the bankruptcy of Lehman Brothers in September of 2008 had a significant effect on liquidity in the TIPS market, because Lehman Brothers had been very active in the TIPS market. The unwinding of its large TIPS inventory in the weeks following its bankruptcy, combined with a sudden increase in the cost of financing long positions in TIPS appears to have induced an unexpected downward price pressure in the TIPS market that lead to a liquidity-induced sharp tightening of breakeven inflation. In particular, Campbell, Shiller and Viceira (2009) show a strong negative correlation between the evolution of breakeven inflation and a measure of the cost of financing a long position in TIPS, the TIPS asset-swap spread, during the Fall of 2008.

An asset swap is a derivative contract between two parties where one party pays the cash flows on a particular government bond (e.g. TIPS or nominal) and receives *LIBOR* plus a spread, which can be positive or negative. The payer of the bond cash flows can hedge itself by holding the bond and financing the position in the short term debt market. Therefore the asset swap spread (ASW) reflects the current and expected financing costs of holding the long bond position. The initial net value of an asset swap spread is set to zero. A widening of the spread is equivalent to an increase in the cost of financing a long position in the bond.

Accordingly, our fourth measure of liquidity is the difference between the asset swap spread for TIPS and the asset swap spread for nominal Treasuries, $ASW_{n,t}^{spread} = ASW_{n,t}^{TIPS} - ASW_{n,t}^{\$}$. This is a measure of the relative cost of financing a long position in the TIPS market and in the nominal Treasury market. A widening of this relative spread indicates that the cost of financing a long position in the TIPS market has increased relative to the cost of financing a long position in the nominal Treasury market.

We only have data on $ASW_{n,t}^{spread}$ from July 2007 until April 2009, and set it to its July 2007 value of 40bp when the asset swap spread series is not available. The

data source for the Asset Swap Spreads is Barclays Capital. For the 10 year TIPS Asset Swap Spread we use the July 2017 Asset Swap and for the 10 year nominal Asset Swap we use the generic 10 Year On-the-Run Par Asset Swap Spread.

Figure 2 shows our four liquidity variables. For easier comparability the sign of log relative transaction volume is flipped. The dissimilar time-series patterns of the variables suggest that each one represents a different aspect of market liquidity, although the spread variables all jump during the financial crisis of 2008-2009. The on-the-run off-the-run spread varies with high frequency. The GNMA spread on the other hand moves relatively slowly. One reason for the difference in the two spreads could be that they have a different investor base. The GNMA spread pattern of a lower spread between 2002 and 2007 agrees with anecdotes of long-term investors who were particularly willing to invest into less liquid securities in order gain yield during that period. The relative transaction volume can be seen to be rising linearly through to 2004 and then to stabilize. This captures the idea that it took a while for TIPS to become well-established and moreover that in the period since 2004 the liquidity premium due to the novelty of TIPS should have been modest.

Finally the asset swap spread variable $ASW_{n,t}^{spread}$ varies within a relatively narrow range of 35 basis point to 41 basis points from July 2007 through August 2008, and it rises sharply during the financial crisis, reaching 130bp in December 2008. That is, before the crisis the average cost of financing a long position in TIPS was about 40 basis more expensive than the cost of financing a long position in nominal Treasury bonds, but this cost differential rose to more than 120 basis points after the Lehman bankruptcy in September 2008.

5.2 Estimating the Liquidity Premium

At times when TIPS are relatively less liquid than nominal bonds we would expect TIPS to trade at a discount and the TIPS yield to widen relative to nominal yields. Empirically we estimate this as a linear relationship between breakeven inflation and our liquidity variables with the regression

$$b_{n,t} = a_1 + a_2 X_t + \varepsilon_t, \tag{17}$$

X_t is a vector containing our four liquidity proxies: the off-the-run spread, the GNMA spread, the relative TIPS transactions volume and the difference between TIPS and

nominal asset swap spreads. In (17) we would expect variables that indicate less liquidity in the TIPS market to enter negatively and variables that indicate higher liquidity in the TIPS market to enter positively. That is, the off-the-run spread, the GNMA spread and the asset swap spread should enter negatively. On the other hand higher transaction volume in the TIPS market indicates that TIPS are easily traded and therefore it should enter positively. Since the off-the-run spread and GNMA spread capture the liquidity premium in different but related securities we would expect the magnitude of the regression coefficients on these spreads to be less than 1. As argued before, we would expect breakeven inflation to fall approximately one for one with the asset swap spread.

Our liquidity variables are normalized in such a way that they go to zero in a world of perfect liquidity. When liquidity is perfect the off-the-run spread, the GNMA spread and the asset-swap spread should equal zero. The transaction volume is normalized so that its maximum is equal to zero. That is, we assume that the liquidity premium attributable to low transaction volume was close to zero during the period of 2004-2007.

Next, we will obtain liquidity adjusted TIPS yields by assuming that the liquidity premium is entirely attributable to time-varying liquidity in TIPS rather than in nominals. The estimated liquidity component in TIPS yields then equals

$$\hat{L}_{n,t} = -\hat{a}_2 X_t, \quad (18)$$

where \hat{a}_2 is the vector of slope estimates in (17). Thus an increase in $\hat{L}_{n,t}$ reflects a reduction in the liquidity of TIPS relative to nominal Treasury bonds. We then subtract this estimated liquidity component from TIPS yields to obtain liquidity-adjusted TIPS yields and breakeven as

$$y_{n,t}^{TIPS,adj} = y_{n,t}^{TIPS} - \hat{L}_{n,t} \quad (19)$$

$$b_{n,t}^{adj} = b_{n,t} + \hat{L}_{n,t}. \quad (20)$$

The liquidity premium on 1 quarter real bonds is assumed to be constant.

Table 5 reports OLS estimates of (17). Column 1 presents estimates with the off-the-run spread included in the regression. Column 2 adds the GNMA spread, and column 3 adds TIPS transactions volume. Columns 1 through 3 always include $ASW_{n,t}^{spread}$, but with a slope set to its theoretical value of -1 . Column 4 presents estimates with freely estimated coefficients for all four liquidity proxies. During the

financial crisis securities markets got severely disrupted and the buyers and sellers of asset swaps may not have acted as the marginal buyers and sellers of TIPS. Estimating a_2 freely accounts for the possibility that the asset swap spread only represents a fraction of the financing cost for the marginal holder of TIPS.

Table 5 shows coefficients whose signs are consistent with expectations and generally statistically significant. Breakeven inflation is decreasing in the off-the-run spread and in the GNMA spread, and increasing in the transactions volume of TIPS relative to nominal Treasuries. Interestingly, our liquidity measures explain a very large fraction of the variability of breakeven inflation, from 45% in column 1 to 67% in column 4. The adjusted R^2 increases with every additional liquidity control introduced, indicating that each of the controls helps explain the liquidity premium on TIPS. These results are not sensitive to the inclusion of the financial crisis in the sample period. The R^2 of the regression in column 4 is still 47% when the sample period ends in June 2007.

Column 4 in Table 5 shows that the freely estimated coefficient on the asset swap spread differential is at -1.59 somewhat larger in absolute value than -1 . The standard error on the regression coefficient indicates that it is precisely estimated. The large size of this parameter estimate suggests that the asset swap spread differential might represent only a fraction of the financing cost for the marginal holder of TIPS, particularly during the financial crisis. It also suggests the relevance of liquidity factors in explaining the sharp fall in breakeven during the financial crisis, since the swap spread differential behaves almost like a dummy variable that spikes up during the financial crisis. However, due to the significant macroeconomic and financial markets events it is possible that inflation expectations fell at the same time that liquidity in the TIPS market became scarce. Nonetheless, the difference between the liquidity component estimated in columns 3 and 4 appears small as indicated by the very similar R^2 . We will continue to work with the freely estimated version from column 4 for its flexibility.

Figure 3A shows our estimated liquidity premium. We find an average spread due to liquidity of around 106 bps. Although this average is high, one must take into account that it reflects periods of very low liquidity in this market. Figure 3A shows a high liquidity premium in the early 2000's (about 120 bps), a much lower liquidity premium between 2004-2007 (70 bps). The premium then shoots up again beyond 200 bps during the crisis, and finally comes down to 70 bps after the crisis.

Fleckenstein, Longstaff and Lustig (2010) present a measure of average TIPS

mispricing by comparing breakeven inflation to synthetic zero-coupon inflation swaps. Their series of average TIPS-Treasury mispricing resembles our series of differential financing costs $ASW_{n,t}^{spread}$ both in terms of level and time series variation. We allow for additional variables that help us identify sources of illiquidity operating at different frequencies. We find that these variables drive strong time variation in the liquidity premium, and also result in an even higher average liquidity premium than previously estimated.

The time series of our liquidity premium is consistent with the findings in D’Amico, Kim and Wei (2008) but the level of our liquidity premium is again higher. D’Amico, Kim and Wei model nominal and real interest rates using an affine term structure model and measure the liquidity premium as the difference between the model-implied and observed TIPS yields. They find a large liquidity premium during the early years of TIPS of around 100 bps and then a much lower liquidity premium during the period 2004-2007.

Figures 3B and 3C show liquidity-adjusted breakeven inflation and TIPS yields, respectively. Figure 3B shows that liquidity-adjusted breakeven inflation moves between 3% and 3.5% for much of the sample period. Moreover our liquidity adjustment attributes most of the drop in breakeven inflation during the fall of 2008 to liquidity. Moreover, Figure 3C shows that if TIPS had remained as liquid as nominal Treasuries their yields would have dropped dramatically in the fall of 2008.

5.3 The Real and Nominal Expectations Hypothesis with Liquidity-Adjusted Breakeven and Real Interest Rates

Table 6A includes estimated liquidity (18) as an additional control in our EH regressions. We use the estimates reported in the last column of Table 5 to compute $L_{n,t}$.¹⁵ The liquidity variable enters significantly into the breakeven regressions in columns 3 and 4 and reduces the coefficients on the breakeven spread slightly. Thus an increase in the relative liquidity of TIPS, which corresponds to a decrease in $L_{n,t}$, is associated with a widening of the return spread. As TIPS become more liquid, their expected excess return declines relative to the expected excess return on nominal Treasury

¹⁵A measure of $L_{n,t}$ based on the values of a_2 reported in column 3 of Table 5, which restricts the coefficient on the swap spread differential to -1 produce very similar results. These results are available upon request.

bonds. Estimated liquidity does not enter significantly into either the nominal or real expectations hypothesis regression and real bond returns remain predictable from the real term spread.

Table 6A shows that the real and nominal EH regression results shown in Table 4 are largely robust to the inclusion of liquidity controls. Inclusion of liquidity controls makes the coefficient on the breakeven inflation spread in the inflation expectations regressions marginally insignificant but does not affect its sign or magnitude. The inclusion of the liquidity variable in the inflation expectations regression in column 4 reduces the absolute value of the coefficient on the real term spread and renders it insignificant. This result suggests that the result in Table 4, where we found that the real term spread could forecast the excess return spread between nominal Treasuries and TIPS, is related to liquidity factors.

Overall, Table 6A provides support for the hypothesis that there is a time-varying liquidity premium built into TIPS yields but it also appears that real and nominal bond yields reflect time-varying real interest rate and inflation risk premia.

We have expressed TIPS yields as the sum of real yields and a liquidity premium, and breakeven inflation as the sum of expected inflation, an inflation risk premium and a liquidity premium. To separate these factors better we rerun the regressions in Table 6A replacing the TIPS yield by the liquidity-adjusted TIPS yield (19) and breakeven by liquidity-adjusted breakeven (20). We also include $L_{n,t}$ as an additional control. These results are reported in Table 6B. Since we do not adjust the nominal yields for liquidity the nominal EH regression is omitted from the table. Instead we report in column 2 a regression of the return on the liquidity spread $r_{n,t+1}^L$ onto the liquidity adjusted real term premium, the liquidity-adjusted breakeven inflation spread, and $L_{n,t}$. $r_{n,t+1}^L$ can be thought of as the TIPS return due to time-varying liquidity.¹⁶

Table 6B shows that the liquidity return is predictable from the liquidity premium with a large and highly significant regression coefficient. It also reinforces the evidence for a time-varying liquidity premium in TIPS returns. After adjusting the real term spread and breakeven spread for liquidity, the coefficient on $L_{n,t}$ is much larger in size and statistically significant. An increase in $L_{n,t}$, or equivalently a reduction in liquidity, is associated with an increase in the expected excess return on TIPS and a decrease in the spread between nominal bond excess returns and inflation-

¹⁶We define $r_{n,t+1}^L$ as $-(n-1)L_{n-1,t+1} + nL_{n,t}$.

indexed bond excess returns. At the same time the magnitude and significance of the coefficients on the real and breakeven spreads remain unchanged from Table 6A. Thus this table presents strong evidence of a time-varying liquidity risk premium in TIPS.

Finally, we re-run the EH regressions using both liquidity-adjusted spreads and liquidity-adjusted excess log returns. Since we have adjusted yields and returns for liquidity, we are now running EH regressions on data that should contain no liquidity premium. Table 6C presents these regression results. Remarkably Table 6C shows that the liquidity variable is no longer statistically significant, with small coefficients and very large standard errors in all regressions. Furthermore, the coefficient on the liquidity-adjusted real term spread in the real EH is large and significant and the coefficient on the liquidity-adjusted breakeven inflation spread is also large and statistically significant. The coefficient on the real term spread is unchanged in magnitude and becomes marginally insignificant.

The results shown in Table 6 strongly suggest that the rejection of the real and nominal EH shown in Table 4 are not driven by liquidity factors, and offer support for the hypothesis of a time-varying real interest rate risk premium and a time-varying inflation risk premium. At the same time the results in Table 6B offer strong support for the hypothesis of the existence of a time-varying liquidity premium in TIPS.

6 Bond Supply and the Expectations Hypothesis

In this section we explore whether the relative supply of nominal and inflation-indexed Treasury bonds is correlated with their relative yield—i.e., breakeven inflation—and whether it forecasts excess bond returns.

The preferred-habitat hypothesis of Modigliani and Sutch (1966) emphasizes that the preference of certain types of investors for specific bond maturities might result in supply imbalances and price pressure in the bond market. In recent work Vayanos and Vila (2009) formalize this hypothesis in a theory where risk averse arbitrageurs do not fully offset the price imbalances generated by the presence of preferred-habitat investors in the bond market. Greenwood and Vayanos (2008) and Hamilton and Wu (2010) find statistically significant correlation between the relative supply of nominal Treasury bonds at different maturities and the behavior of nominal interest rates.

Arguably the inflation-indexed bond market is a natural candidate to look for segmentation effects in the bond market. Just as investors might differ in their preference for bond maturities, they might also differ in their preference for holding inflation-indexed or nominal bonds. For example, some investors such as traditional defined-benefit pension funds in the US with a mature liability structure have liabilities which are mostly nominal, while other investors such as less mature defined-benefit pension funds or individuals investing for retirement face liabilities which are mostly indexed.

Following Greenwood and Vayanos (2008) we try to control for the potential segmentation between both markets and supply effects using the outstanding supply of real bonds relative to total government debt as a control variable. If supply is subject to exogenous shocks while clientele demand is stable over time we would expect increases in the relative supply of inflation-indexed bonds to be correlated with contemporary decreases in breakeven inflation, as the price of inflation-indexed bonds falls in response to excess supply. Subsequently we would expect to see positive returns on inflation-indexed bonds as their prices rebound.

Alternatively it could be the case that demand changes over time, and the government tries to accommodate changes in demand. This would be consistent with a debt management policy that tries to take advantage of interest rate differentials across both markets. In this case we would expect the relative supply of inflation-indexed bonds to be unrelated to subsequent returns and possibly positively correlated with contemporaneous breakeven inflation.

We measure the relative supply of inflation-indexed bonds in the US as the nominal amount of TIPS outstanding relative to US government TIPS, notes and bonds outstanding.¹⁷ The face value of TIPS outstanding available in the data is the original face value at issuance times the inflation incurred since then and therefore it increases with inflation. The numbers include both privately held Treasury securities and Federal Reserve and intragovernmental holdings. This is similar to the supply measure used by Greenwood and Vayanos (2008).

We also look at bond supply effects in the UK bond market. The relative supply variable for the UK is computed similarly as the total amount of inflation-linked gilts relative to the total amount of conventional gilts outstanding. Conventional gilts

¹⁷The economic report of the president reports US Treasury securities by kind of obligation and reports T-bills, Treasury notes, Treasury bonds and TIPS separately. The data can be found in Table 85 for the reports until 2000 and in Table 87 in subsequent reports on <http://www.gpoaccess.gov/eop/download.html>.

exclude floating-rate and double-dated gilts but include undated gilts. The face value of index-linked gilts does not include inflation-uplift and is reported as the original nominal issuance value.¹⁸ Our results are not sensitive to including or excluding the inflation uplift.

Let D_t^{TIPS} denote the face value of inflation-indexed bonds outstanding and D_t the combined face value of nominal and inflation-indexed bonds outstanding at time t for either the US or the UK. We define $Supply_t$ as D_t^{TIPS}/D_t . We also consider the change in supply $\Delta Supply_t$, which we compute as the relative change in D_t^{TIPS} minus the relative change in D_t so that $\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS})/D_{t-1}^{TIPS} - (D_t - D_{t-1})/D_{t-1}$. Figure 4A plots the relative supply of TIPS, D_t^{TIPS}/D_t , and 10 year breakeven inflation in the US, while Figure 4B plots the relative supply of UK inflation-linked gilts and 20 year breakeven inflation in the UK.

Figure 4A illustrates rapid increase in the relative amount of TIPS outstanding. Starting from less than 2% in 1997 TIPS increased to represent over 14% of the US notes, bonds and TIPS portfolio in 2008. Subsequently to the financial crisis the US government issued substantial amounts of nominal notes and bonds, leading to a drop in the relative TIPS share in 2009. At the same time the level of breakeven inflation remained relatively steady over this 11 year period with a large drop in the fall of 2008, as discussed earlier.

Figure 4B illustrates the history of the relative share of UK inflation-linked gilts outstanding. The relative share of linkers has increased over the period from about 8% in 1985 to over 17% in 2008. At the same time 20 year UK breakeven inflation has fallen in the period 1985-2009, reaching a low of 2.1% in 1998. The increase in inflation-linked bonds outstanding accelerates noticeably after 2004. Greenwood and Vayanos (2009) analyze this episode in light of the UK Pensions Act of 2004, which provided pension funds with a strong incentive to buy long-maturity and inflation-linked government bonds and subsequently led the government to increase issuance of long-maturity and inflation-linked bonds.

Table 7 shows regressions of US breakeven inflation onto the relative supply and the change in supply of TIPS in the US. Neither the relative supply nor $\Delta Supply_t$ appear to be related to breakeven inflation. Column 4 regresses breakeven onto $Supply_t$, $\Delta Supply_t$ and our liquidity proxies. The magnitude and statistical significance of the coefficients on these proxies is very similar to the results that obtain without con-

¹⁸We are deeply grateful to the UK Debt Management Office for providing us with the UK data.

trolling for the supply of TIPS, shown in Table 5, while the supply variables remain statistically not significant.

Table 8 explores if our bond supply variables predict bond excess returns in the US. This table is similar to Table 6A, excepts that it adds our supply variables to the EH regressions. The supply variables are not statistically significant, and do not change the magnitude or significance of the other variables previously included in these regressions.¹⁹ Overall, we find little evidence of supply effects explaining either the spread between nominal and real interest rates in the US or bond risk premia. Our results about the drivers of bond excess return predictability appear to be robust to the inclusion of bond supply controls in EH regressions.

Table 9A and Table 9B show regressions of UK breakeven inflation onto the relative supply and the change in supply of inflation linkers. Due to data constraints we are not able to control for liquidity. To control for possible spurious correlation between breakeven inflation and bond supply, we run these regressions with and without including a time trend. In both tables the results are very similar, even though the maturities of the bonds and the sample periods are different: The supply variable is significant but it switches sign as we include a time trend in the regression, while the change in supply does not enter significantly. The time trend is statistically significant and increases the R^2 from 26% (column 1) to 65% (column 3).

Figure 4B helps understand this sign change. Since the mid-1980's the supply of inflation linkers in the UK has risen, while breakeven inflation has been generally declining. This secular decline in breakeven inflation likely reflects for the most part changes in monetary policy and declines in both realized and expected inflation (Campbell, Shiller, and Viceira 2009), rather than changes in bond supply. This explains why a simple regression of UK breakeven regression on the supply of inflation linkers gives a negative slope. Introducing a time trend takes care of this common inverse trend, and switches the sign of the slope on the supply variable to positive. This positive partial correlation suggests that at the margin periods of low breakeven inflation are associated with relatively more issuance of nominal bonds by the UK government. One could interpret these results as the government reacting to increased demand for inflation-linked bonds by issuing more inflation-indexed bonds. This interpretation is consistent with the episode described in Greenwood, Vayanos (2009).

¹⁹Arguably $\Delta Supply_t$ is more appropriate than $Supply_t$ for use in excess return regressions, since $Supply_t$ exhibits a time trend. However, our results do not change if we consider $Supply_t$ and $\Delta Supply_t$ in isolation instead of simultaneously.

Table 10A and Table 10B show our UK EH regressions adding $Supply_t$ and $\Delta Supply_t$ as additional explanatory variables. Both variables are generally not statistically significant in most regressions for both maturities. There is some evidence in Table 10A that changes in the relative supply of inflation linkers forecast negatively the excess return on 10-year UK nominal bonds. The sign of the coefficient is consistent with the hypothesis of exogenous supply shocks. We do not observe this effect in the 20-year bonds or in inflation-indexed bonds. Hence it seems that nominal bonds, but not inflation-indexed bonds, are subject to shocks to exogenous shocks to supply. One would expect to observe this effect if the government accommodates expenditure shocks by raising nominal but not inflation-indexed debt at inopportune times.

Overall, our EH results both in the US and in the UK are robust to controlling for bond supply variables. The bond return predictability documented in Sections 4 and 5 does not appear to be driven by temporary price pressure due to supply effects but instead appears to be related to changes in bond risk premia. There is some evidence of bond supply effects in the UK bond market, but those do not weaken the evidence about time variation in real interest rate risk premia and inflation risk premia.

7 Cochrane and Piazzesi Bond Return Predictability and the Inflation Risk Premium

In recent work Cochrane and Piazzesi (2005, CP) show that a tent-shaped linear combination of nominal forward rates is a good predictor of excess nominal bond returns for a wide range of bond maturities. Their findings imply that nominal bond risk premia are high when intermediate-term nominal interest rates are high relative to both shorter-term and longer-term rates. In the context of a non-linear model of the term structure of interest rates, Campbell, Sunderam, and Viceira (2010) interpret their findings as reflecting a time-varying transitory inflation risk premium.

We explore this interpretation by examining whether the CP tent-shaped combination of nominal forward rates forecasts inflation-indexed bond excess returns in addition to nominal bond excess returns. If the Cochrane Piazzesi factor reflects inflation risk premia it should not predict returns on inflation-indexed bonds.

We construct the Cochrane Piazzesi factor from one- to five-year Fama-Bliss zero coupon nominal bond yields, available from CRSP. Let $f_{n,t}^s$ denote the log 1 year

nominal forward rate at time t for loans between $n - 1$ and n years in the future. We obtain the Cochrane-Piazzesi factor using the optimal weights found in Cochrane, Piazzesi (2005) as $CP_t = -2.14f_{1,t}^{\$} + 0.81f_{2,t}^{\$} + 3.00f_{3,t}^{\$} + 0.80f_{4,t}^{\$} - 2.08f_{5,t}^{\$}$. Unfortunately we do not have enough richness in the term structure of TIPS rates to construct a CP variable based on TIPS yields. We also limit our analysis to the US.

Table 11 reproduces the CP predictability results for our data set, using the 1952-2009 sample period and a one-quarter forecasting horizon. Column 1 in the table shows that CP is significant and forecasts nominal bond excess returns with a respectable R^2 of 4% at a quarterly horizon. However, column 3 in the table shows that the variable loses its statistical significance once we control for the yield spread.

Table 12 explores the ability of CP to forecast bond excess returns over our 1999-2009 sample period. The variable is not statistically significant in columns 1 to 3, although it produces an R^2 of 2% in the nominal bond excess returns, suggesting that perhaps the lack of statistical significance in this regression is related to the short-sample period. The variable does not seem to have forecasting power for inflation-indexed bond returns.

Columns 4, 5, and 6 run our basic EH regressions adding CP as an additional forecasting variable. The inclusion of CP does not change our basic results in the nominal and real EH regressions. It enters significantly and with a positive sign only in the last column. Comparing this to column 4 of Table 4A shows that CP also increases the R^2 from 20% to 27%. When CP is high, nominal bond excess returns are expected to be larger than inflation-indexed bond excess returns. This result is consistent with Campbell, Sunderam, and Viceira (2010)'s interpretation of CP as a proxy for a time-varying inflation risk premium.

8 Historical Fitted Risk Premia

We look at the fitted risk premia in order to better understand the economic significance of the bond return predictability examined in this article. In this section we will compare the means and variances and discuss the historical behavior of fitted risk premia.

Tables 13 and 14 show the means and standard deviations of risk premia obtained from our preferred regression specifications reported in Tables 4A, 6B, 6C for the US

and 4C for the UK. The top panel of Table 13 shows the fitted US risk premia obtained with the non liquidity-adjusted data. These fitted values correspond to nominal, real and inflation risk premia only if liquidity is constant over time. The lower panel reports fitted values from the regressions that explicitly adjust for liquidity and we interpret these fitted values as inflation, real and liquidity risk premia.

Column 1 in Table 13 shows that TIPS have had a high risk premium over our sample period with about 2.86% due to real interest rate risk and 1.38% due to liquidity. The liquidity premium in Table 13 is the average return due to liquidity over the period and equals the average liquidity component in yields plus a term adjusting for its average drift. The inflation risk premium on average has been just below one percent but it is positive after adjusting for liquidity.

The inflation and real rate risk premia can explain 3% and 5% of nominal bond returns, respectively, while the nominal bond spread by itself can explain 3% of nominal bond returns. Liquidity appears to be an important driver of TIPS returns and can explain 17% of the variance in TIPS returns. The real rate risk premium can explain 6% of the variance in TIPS returns. The TIPS risk premium and the breakeven risk premium reported in rows 2 and 3 contain a liquidity component, as discussed before. Since we find a large variance of the liquidity risk premium, it is not surprising to see that the TIPS risk premium and breakeven risk premium are also variable with standard deviations of 2.7% and 3.24% annualized. This variability is greatly reduced once we control for liquidity and this emphasizes the importance of controlling for liquidity.

Figures 5A and 5B illustrate the time series of the fitted risk premia. Figure 5A shows that the nominal and TIPS risk premia have moved together over time. Moreover the breakeven risk premium has dropped sharply during the financial crisis in the fall of 2008. Figure 5B shows that during the period of 2000 to 2006 the inflation risk premium was small or negative. At the same time the liquidity risk premium was declining. During the period of high oil prices in 2008 and during the peak of the financial crisis in late 2008 the inflation risk premium was positive but subsequently fell to almost -10% at the end of 2009. The liquidity risk premium experienced a pronounced spike during the fall of 2008.

For the UK we can similarly look at the size and variability of fitted risk premia. Due to their longer sample period we concentrate on 20 year gilts. Table 14 shows that the expected nominal return has been 3.47% annualized and the nominal yield spread can explain about 5% of the variance in nominal bond returns. The risk premium on

inflation-indexed gilts has on average been positive and the breakeven risk premium has also on average been positive, indicating that investors consider nominal gilts riskier than inflation-linked gilts. The variances of the fitted real interest rate risk premia and inflation risk premia are similar, explaining 2% and 3% of nominal bond returns, respectively. Unlike in the US the risk premia for inflation-linked gilts and breakeven inflation show a smaller variance than the nominal bond risk premium. This somewhat alleviates the concern that liquidity should be a major driver of UK inflation-linked gilt returns.

Figure 6 shows the time series of the fitted UK risk premia. The nominal, TIPS and breakeven risk premia have moved together over the period 1985 to 2009. In contrast to the US observation the UK breakeven risk premium shot up during the financial crisis and has remained high. In the framework of Campbell, Sunderam and Viceira (2010) this could indicate that while investors in the UK fear that further economic deterioration will go along with inflation, US investors are concerned about low growth accompanied by low inflation or even deflation.

9 Conclusion

This paper documents predictability of excess returns in inflation-indexed bonds and in the spread between nominal bond returns and inflation-indexed bond returns. While return predictability in US Treasury nominal bonds has been well-documented, to our knowledge this is the first paper to provide direct empirical evidence for predictability of returns in real bonds, or a rejection of the expectations hypothesis in inflation-indexed bonds in both the US and the UK. We find strong empirical evidence for two different potential sources for excess return predictability in inflation-indexed bonds: real interest rate risk and liquidity. Additionally we also update the existing empirical evidence rejecting the nominal expectations hypothesis in both the US and the UK, and more substantively we provide empirical evidence that this rejection is related not only to time variation in the real interest rate risk premium, but also to time variation in the inflation risk premium.

Our flexible empirical approach allows us to estimate the liquidity risk premium on TIPS and its variation over time using a variety of indicators of liquidity in the bond market. We show that the liquidity risk premium exhibits strong variation over time, with a large premium (in the vicinity of 120 bps) early in the life of TIPS, which

arguably was driven by learning effects, a significant decline after 2004 to 70 bps, and a sharp increase to 250 bps during the financial crisis in the Fall of 2008 and Winter of 2009. Since then, the premium has declined back to its normal level of 70 bps.

We find that for US TIPS the real term spread predicts real excess returns even after controlling for liquidity, and therefore appears to proxy for a real interest rate risk premium. The effect of the liquidity premium on returns is such that when liquidity in the TIPS market is scarce TIPS enjoy a higher expected return relatively to nominal bonds, rewarding investors who are willing to invest into a temporarily less liquid market. Liquidity explains up to 17% of the observed variation in TIPS returns, and more than 54% of the variation in breakeven inflation, or the yield differential between nominal and inflation-indexed bonds. The liquidity premium does not predict liquidity-adjusted returns on TIPS so that it does not seem to proxy for any real interest rate risk. We also find strong evidence rejecting the real expectations hypothesis in UK inflation-linked bonds, although we are unable to control for liquidity factors.

If real interest rate risk were the only source of time variation in bond risk premia, we would expect that the difference between nominal bond excess returns and liquidity-adjusted real bond excess returns should not be predictable. However, we find strong empirical evidence that this difference is predictable, suggesting that a time-varying inflation risk premium is an additional determinant of nominal bond risk premia even after controlling for liquidity differentials between the nominal bond market and the inflation-indexed bond market. We also find evidence that the tent-shaped linear combination of nominal forward rates proposed by Cochrane and Piazzesi (2005) might be related to changes in the inflation risk premium in nominal bonds, consistent with the interpretation and the empirical evidence reported in Campbell, Sunderam, and Viceira (2010).

In our analysis of price pressures due to supply shocks in the inflation-indexed bond markets we find weak and mixed evidence for a supply channel, and only in the UK. Our results are consistent with the government trying to accommodate shifts in the demand for nominal bonds, relative to inflation-indexed bonds. Moreover, supply shocks in the nominal bond market cause temporary but predictable changes in the prices of nominal bonds. We do not find any evidence for supply channel effects in the US bond market but the short US sample size may reduce the power of our tests. Including the relative supply of indexed debt as an additional control leaves our expectations hypothesis regressions for the US and the UK unchanged, adding to

the evidence for time-varying real rate and inflation-risk premia.

Our results suggest several directions for future research. First, our results suggest that the inflation-indexed bond returns related to liquidity are not predicted by our proxies for real interest rate risk or inflation risk. Using a similar liquidity adjustment in a more tightly parametrized model of the term structure of interest rates could help to better model the drivers of real interest rate risk. Second, inflation expectations are a major input into monetary policy. One could adjust breakeven inflation for the forms of inflation risk premia and liquidity premia found in this paper to obtain a measure of long-term expected inflation. It would be informative to see whether this is a good predictor of future inflation and other macroeconomic variables. Third, different classes of investors have different degrees of exposure to time-varying liquidity, real interest rate risk and inflation risk. It would be interesting to explore the implications for portfolio management and pension investing and how these implications vary by investment horizon and the investor's share of real and nominal liabilities.

10 References

- Adrian, Tobias, and Hao Z.Wu, 2009, "The Term Structure of Inflation Expectations", Working paper, Federal Reserve Bank of New York.
- Anderson, Nicola and John Sleath, 2001, "New estimates of the UK real and nominal yield curves", Bank of England 2001, ISSN 1368-5562, available at www.bankofengland.co.uk/workingpapers/index.htm
- Barr, David G., and John Y. Campbell, 1997, "Inflation, Real Interest Rates, and the Bond Market: A Study of UK Nominal and Index-Linked Government Bond Prices." *Journal of Monetary Economics* 39:361-383.
- Buraschi, Andrea and Alexei Jiltsov, 2005, "Inflation risk premia and the expectations hypothesis", *Journal of Financial Economics* 75:429-490
- Campbell, John Y., 1999, "Asset Prices, Consumption, and the Business Cycle", Chapter 19 in John B. Taylor and Michael Woodford eds., *Handbook of Macroeconomics*, North-Holland: Amsterdam, 1231-1303
- Campbell, John Y., and John H. Cochrane, 1999, "By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior", *Journal of Political*

Economy 107:205–251

- Campbell, John Y., Andrew W. Lo, and A. Craig MacKinlay, 1997, *The Econometrics of Financial Markets*, Princeton University Press, Princeton, NJ
- Campbell, John Y. and Robert J. Shiller, 1991, “Yield Spreads and Interest Rate Movements: A Bird’s Eye View”, *Review of Economic Studies* 58, 495–514
- Campbell, John Y., and Robert J. Shiller, 1996, “A Scorecard for Indexed Government Debt”, In *National Bureau of Economic Research Macroeconomics Annual 1996*, edited by Ben S. Bernanke and Julio Rotemberg. MIT Press
- Campbell, John Y., Robert J. Shiller, and Luis M. Viceira, 2009, "Understanding Inflation-Indexed Bond Markets", In *Brookings Paper on Economic Activity*, April 2009, edited by David Romer and Justin Wolfers
- Campbell, John Y., Adi Sunderam, and Luis M. Viceira, 2010, “Inflation Bets or Deflation Hedges? The Changing Risks of Nominal Bonds”, Manuscript, Harvard University
- Campbell, John Y., and Luis M. Viceira, 2001, “Who Should Buy Long-Term Bonds?”, *American Economic Review* 91:99–127
- Campbell, John Y., and Luis M. Viceira, 2005, “The Term Structure of the Risk-Return Tradeoff”, *Financial Analysts Journal* 61(1):34–44
- Cochrane, John H., 2005, *Asset Pricing*, revised ed., Princeton University Press, Princeton, NJ
- Cochrane, John H., and Monika Piazzesi, 2005, “Bond Risk Premia”, *American Economic Review* 95, 138–160
- Christensen, Jens E., Jose A. Lopez, and Glenn D. Rudebusch, 2010, "Inflation Expectations and Risk Premiums in an Arbitrage-Free Model of Nominal and Real Bond Yields", *Journal of Money, Credit and Banking*, 42(6):143-178
- D’Amico, Stefania, Don H. Kim, and Min Wei, 2008, "Tips from TIPS: the informational content of Treasury Inflation-Protected Security prices", *BIS Working Papers*, No 248

- Dudley, William C., Jennifer Roush, and Michelle Steinberg Ezer, 2009, "The Case for TIPS: An Examination of the Costs and Benefits", *Economic Policy Review* 15(1): 1-17
- Evans, Martin D.D., 2003, "Real Risk, Inflation Risk and the Term Structure", *The Economic Journal* 113(487):345-389
- Fama, Eugene F., and Robert R. Bliss, 1987, "The Information in Long-Maturity Forward Rates", *American Economic Review* 77, 680-692
- Fleckenstein, Matthias, Francis A. Longstaff, and Hanno Lustig, 2010, "Why does the Treasury Issue TIPS? The TIPS-Treasury Bond Puzzle", *NBER Working Paper Series*, No. 16358
- Fleming, Michael J., and Neel Krishnan. 2009. "The Microstructure of the TIPS Market", Federal Reserve Bank of New York.
- Gürkaynak, Refet S., Brian Sack, and Jonathan H. Wright, 2007, "The U.S. Treasury yield curve: 1961 to the present." *Journal of Monetary Economics* 54(8):2291-2304
- Gürkaynak, Refet S., Brian Sack, and Jonathan H. Wright, 2010, "The TIPS Yield Curve and Inflation Compensation", *American Economic Journal: Macroeconomics* 2(1):70–92
- Greenwood, Robin, and Dimitri Vayanos, 2008, "Bond Supply and Excess Bond Returns", *NBER Working Paper Series*, No. 13806
- Greenwood, Robin, and Dimitri Vayanos, 2009, "Price pressure in the government bond market", *American Economic Review*, 100(2):585–90
- Hamilton, James D., and Jing (Cynthia) Wu, 2010, "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment", University of California, San Diego
- Longstaff, Francis A., 2004, "The Flight-to-Liquidity Premium in U.S. Treasury Bond Prices", *Journal of Business*, 77(3): 511–26.
- McCulloch, J. Huston, and H. Kwon, 1993, "US Term Structure Data, 1947–1991", Working Paper 93-6, Ohio State University

- Modigliani, Franco, and Richard Sutch, 1966, "Innovations in Interest-Rate Policy", *American Economic Review* 56:178-197
- Piazzesi, Monika and Martin Schneider, 2007, "Equilibrium Yield Curves", *NBER Working Paper Series*, No. 12609
- Roll, Richard, 2004, "Empirical TIPS", *Financial Analysts Journal* 60: 31-53.
- Stock, James H., and Mark W. Watson, 2002, "Has the Business Cycle Changed and Why?", In *National Bureau of Economic Research Macroeconomics Annual 2002*
- Vayanos, Dimitri, and Jean-Luc Vila, 2009, "A Preferred-Habitat Model of the Term Structure of Interest Rates", *NBER Working Paper Series*, No. 15487
- Viceira, Luis M., 2001, "The Harvard Management Company and Inflation-Protected Bonds", HBS Case # 201-053
- Viceira, Luis M., 2010, "Bond Risk, Bond Return Volatility, and the Term Structure of Interest Rates", forthcoming *International Journal of Forecasting*
- Wachter, Jessica A., 2003, "Risk Aversion and Allocation to Long-Term Bonds", *Journal of Economic Theory* 112:325-333
- Wachter, Jessica A., 2006, "A Consumption-Based Model of the Term Structure of Interest Rates", *Journal of Financial Economics* 79:365-399

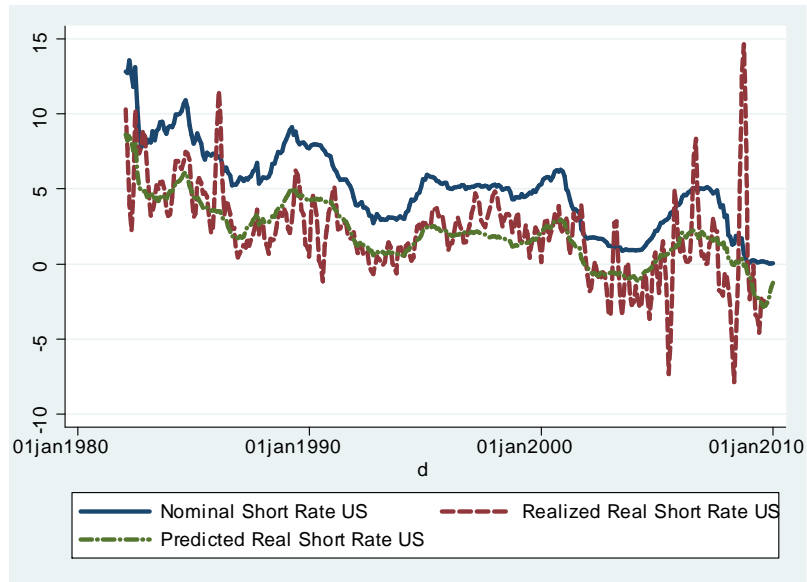


Figure 1: US Realized and Predicted Real Short Rate

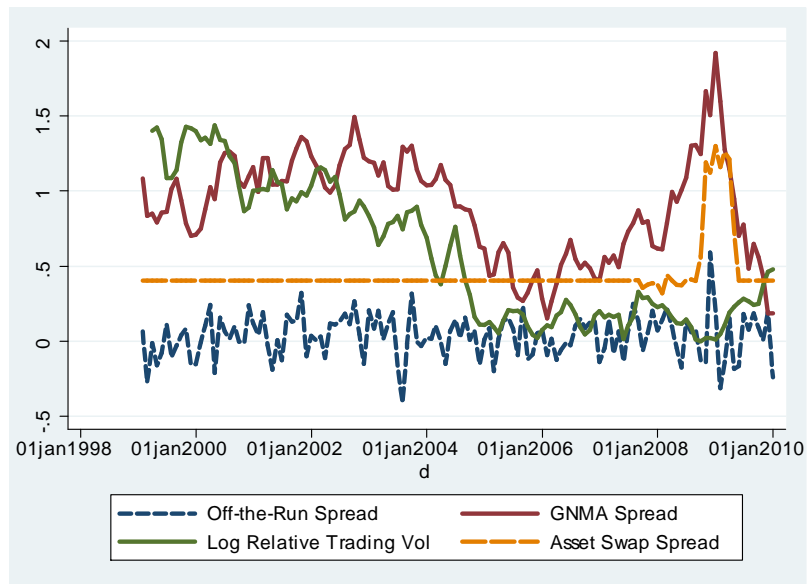


Figure 2: Liquidity Variables

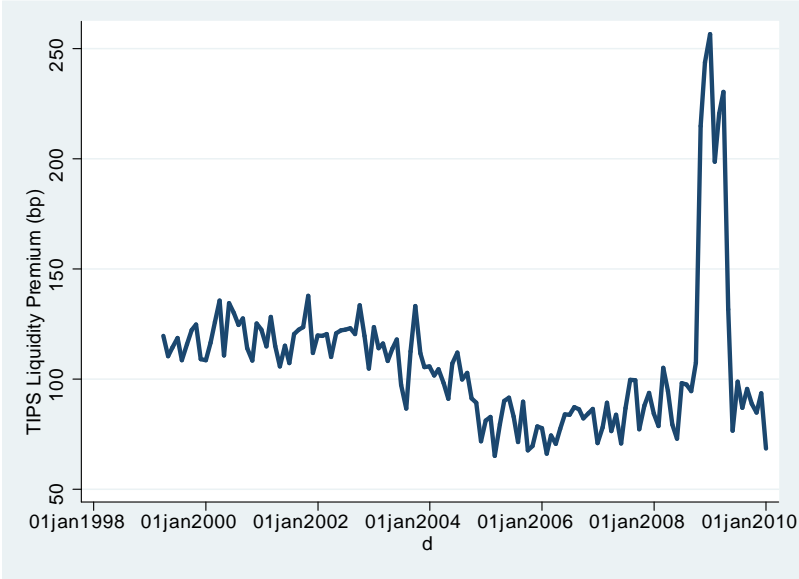


Figure 3A: Liquidity Premium on US TIPS

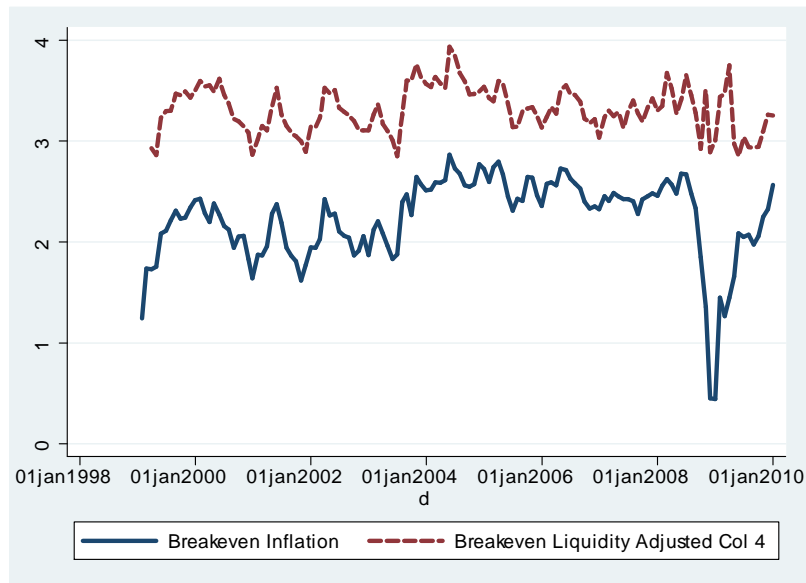


Figure 3B: US Breakeven Liquidity Adjusted

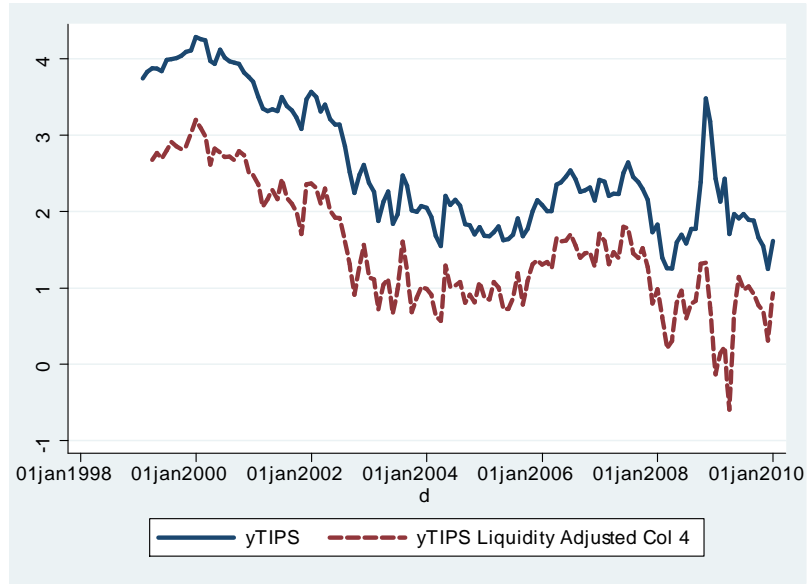


Figure 3C: US TIPS Liquidity Adjusted

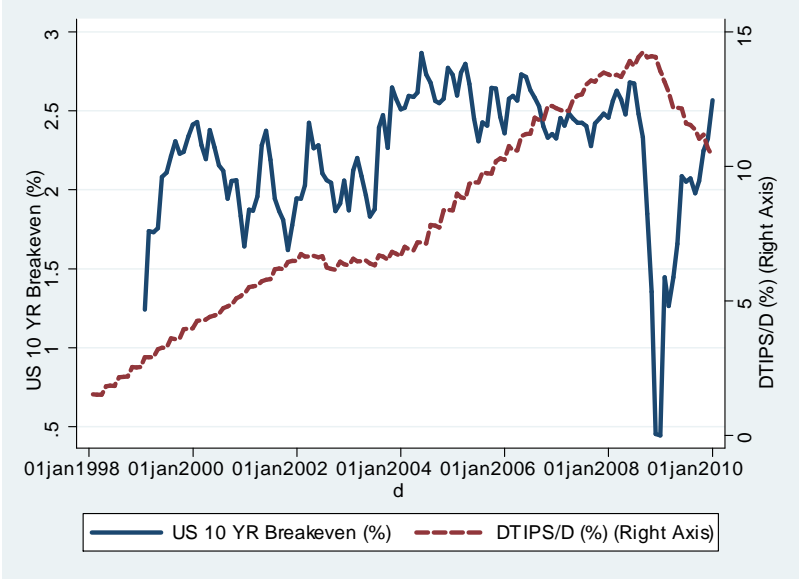


Figure 4A: US Relative Supply and 10 YR Breakeven

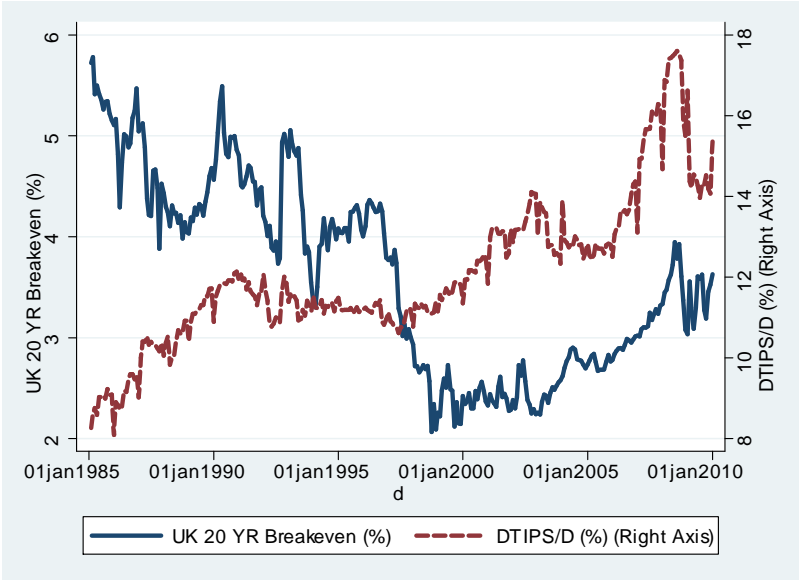


Figure 4B: UK Relative Supply and 20 YR Breakeven UK

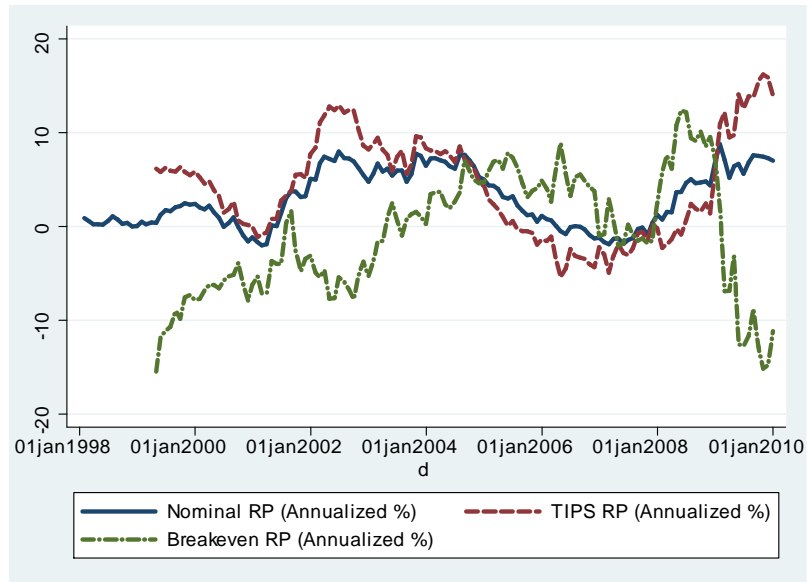


Figure 5A: US Risk Premia Estimated in Table 4A

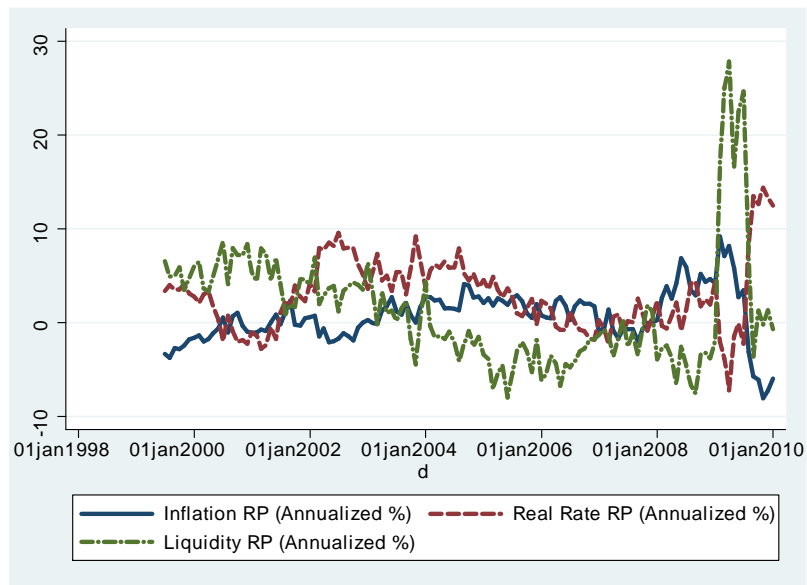


Figure 5B: US Risk Premia Estimated in Table 6B and 6C

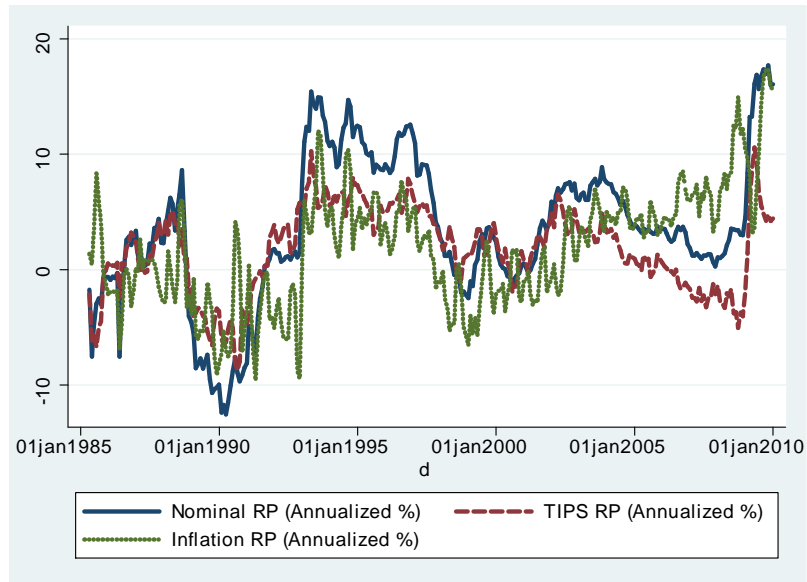


Figure 6: UK 20 Year Bond Risk Premia

Table 1
Forecasted Real Short Rate

$y_{1,t}^{\$} - \pi_{t+1}$	US	UK
$y_{1,t}^{\$}$	0.57**	0.46
	(0.22)	(0.29)
$y_{1,t-1}^{\$} - \pi_t$	0.08	-0.11
	(0.08)	(0.07)
$(\pi_{t-3} + \pi_{t-2} + \pi_{t-1} + \pi_t) / 4$	0.08	0.03
	(0.09)	(0.09)
<i>p - value</i>	0.00	0.00
R^2	0.44	0.18

Overlapping quarterly real short rate returns onto the nominal short rate, last quarter's real short rate return and inflation over the past year. Monthly data 1982.1-2009.12.

Newey-West standard errors with 4 lags in brackets.

Regressions contain constant term.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability. and the non-adjusted R^2 .

Table 2A
Summary Statistics US 10YR

	Mean	Standard Deviation
$y_{1,t}^{\$}$	2.87	0.96
π_t	2.56	1.50
$y_{1,t}^{TIPS}$	0.50	0.72
$y_{n,t}^{\$} - y_{1,t}^{\$}$	1.86	0.72
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$	2.04	0.61
$b_{n,t} - b_{1,t}$	-0.17	0.37
$r_{n,t+1}^{\$}$	3.26	8.57
$r_{n,t+1}^{TIPS}$	4.16	7.67
$r_{n,t+1}^b$	-0.91	7.22

Return Correlations

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$
$r_{n,t+1}^{\$}$	1	0.61	0.54
$r_{n,t+1}^{TIPS}$	.	1	-0.34
$r_{n,t+1}^b$	.	.	1

Annualized (%). Monthly data 1999.4-2009.12.

Monthly data of quarterly overlapping returns and inflation.

Table 2B
Summary Statistics UK 10YR

	Mean	Standard Deviation
$y_{1,t}^{\$}$	5.03	0.84
π_t	2.62	1.52
$y_{1,t}^{TIPS}$	2.40	0.43
$y_{n,t}^{\$} - y_{1,t}^{\$}$	0.54	0.64
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$	0.05	0.42
$b_{n,t} - b_{1,t}$	0.49	0.43
$r_{n,t+1}^{\$}$	3.37	7.66
$r_{n,t+1}^{TIPS}$	1.84	6.58
$r_{n,t+1}^b$	1.53	7.04

Return Correlations

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$
$r_{n,t+1}^{\$}$	1	0.52	0.60
$r_{n,t+1}^{TIPS}$	.	1	-0.37
$r_{n,t+1}^b$	.	.	1

Annualized (%). Monthly data 1991.12-2009.12.
Monthly data of quarterly overlapping returns.

Table 2C
Summary Statistics UK 20YR

	Mean	Standard Deviation
$y_{1,t}^{\$}$	6.55	1.52
π_t	3.47	1.84
$y_{1,t}^{TIPS}$	3.14	0.77
$y_{n,t}^{\$} - y_{1,t}^{\$}$	-0.24	0.97
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$	-0.37	0.58
$b_{n,t} - b_{1,t}$	0.13	0.57
$r_{n,t+1}^{\$}$	3.47	14.67
$r_{n,t+1}^{TIPS}$	1.66	9.25
$r_{n,t+1}^b$	1.81	11.97

Return Correlations

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$
$r_{n,t+1}^{\$}$	1	0.58	0.78
$r_{n,t+1}^{TIPS}$	.	1	-0.06
$r_{n,t+1}^b$	.	.	1

Annualized (%). Monthly data 1985.4.12-2009.12.
Monthly data of quarterly overlapping returns.

Table 3A
Nominal Expectations Hypothesis US Before and After 1987

	1952.1-2009.12	1952.1-1987.2	1987.3-2009.12
5 Year	2.44** (0.90)	2.85* (1.32)	1.46 (1.03)
10 Year	3.57** (1.12)	4.85* (1.95)	1.81 (1.18)

Overlapping quarterly returns $r_{n,t+1}^{\$}$ onto $y_{n,t}^{\$} - y_{1,t}^{\$}$. Monthly data.
 Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

Table 3B
Nominal Expectations Hypothesis Dummy Interaction

$r_{n,t+1}^{\$}$	5 Year	10 Year
$(y_{n,t}^{\$} - y_{1,t}^{\$})$	2.85* (1.32)	4.85* (1.95)
$(y_{n,t}^{\$} - y_{1,t}^{\$}) \times d_{1987-2009}$	-1.39 (1.68)	-3.04 (2.28)
$d_{1987-2009}$	0.01 (0.01)	0.01 (0.01)
<i>p - value</i>	0.04	0.01
R^2	0.05	0.06

Overlapping quarterly returns $r_{n,t+1}^{\$}$ onto $y_{n,t}^{\$} - y_{1,t}^{\$}$.
 Monthly data 1952.1-2009.12.

$d_{1987-2009}$ equals 1 in 1987.3-2009.12 and zero otherwise.

Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability.
 and the non-adjusted R^2 .

Table 4A
Real and Nominal Expectations Hypothesis US

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$	2.17			
	(1.49)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		4.45**		-3.10*
		(1.37)		(1.22)
$b_{n,t} - b_{1,t}$			7.24*	7.43*
			(3.13)	(2.45)
$p - value$	0.15	0.00	0.02	0.01
R^2	0.03	0.12	0.13	0.20

$$r_{n,t+1}^{\$} = -(n-1)y_{n,t+1}^{\$} + ny_{n,t}^{\$} - y_{1,t}^{\$}$$

$$r_{n,t+1}^{TIPS} = -(n-1)y_{n,t+1}^{TIPS} + ny_{n,t}^{TIPS} - y_{1,t}^{TIPS}$$

$$r_{n,t+1}^b = r_{n,t+1}^{\$} - r_{n,t+1}^{TIPS}$$

$$b_{n,t} - b_{1,t} = (y_{n,t}^{\$} - y_{1,t}^{\$}) - (y_{n,t}^{TIPS} - y_{1,t}^{TIPS})$$

Overlapping quarterly returns. Monthly data 1999.4-2009.12.

Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability.

and the non-adjusted R^2 .

Table 4B
Real and Nominal Expectations Hypothesis UK 10 Year Bonds

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$	0.55			
	(1.29)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		4.67*		-3.74
		(1.99)		(2.36)
$b_{n,t} - b_{1,t}$			2.75	3.21
			(1.96)	(1.95)
$p - value$	0.67	0.02	0.16	0.17
R^2	0.00	0.10	0.03	0.08

$$r_{n,t+1}^{\$} = -(n-1)y_{n,t+1}^{\$} + ny_{n,t}^{\$} - y_{1,t}^{\$}$$

$$r_{n,t+1}^{TIPS} = -(n-1)y_{n,t+1}^{TIPS} + ny_{n,t}^{TIPS} - y_{1,t}^{TIPS}$$

$$r_{n,t+1}^b = r_{n,t+1}^{\$} - r_{n,t+1}^{TIPS}$$

$$b_{n,t} - b_{1,t} = (y_{n,t}^{\$} - y_{1,t}^{\$}) - (y_{n,t}^{TIPS} - y_{1,t}^{TIPS})$$

Overlapping quarterly returns. Monthly data 1991.12-2009.12.

Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability.
and the non-adjusted R^2 .

Table 4C
Real and Nominal Expectations Hypothesis UK 20 Year Bonds

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$	3.21*			
	(1.53)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		3.16*		-1.31
		(1.30)		(2.05)
$b_{n,t} - b_{1,t}$			4.31*	4.89*
			(1.99)	(2.33)
<i>p</i> - value	0.04	0.02	0.03	0.10
R^2	0.05	0.04	0.04	0.05

$$r_{n,t+1}^{\$} = -(n-1)y_{n,t+1}^{\$} + ny_{n,t}^{\$} - y_{1,t}^{\$}$$

$$r_{n,t+1}^{TIPS} = -(n-1)y_{n,t+1}^{TIPS} + ny_{n,t}^{TIPS} - y_{1,t}^{TIPS}$$

$$r_{n,t+1}^b = r_{n,t+1}^{\$} - r_{n,t+1}^{TIPS}$$

$$b_{n,t} - b_{1,t} = (y_{n,t}^{\$} - y_{1,t}^{\$}) - (y_{n,t}^{TIPS} - y_{1,t}^{TIPS})$$

Overlapping quarterly returns. Monthly data 1985.4-2009.12

Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability.

and the non-adjusted R^2 .

Table 5
Breakeven onto Liquidity Proxies

$y_{n,t}^{\$} - y_{n,t}^{TIPS}$	(1)	(2)	(3)	(4)
Off-the-run	-0.56*	-0.42*	-0.53**	-0.59**
	(0.25)	(0.21)	(0.18)	(0.17)
<i>GNMA</i>		-0.47**	-0.37**	-0.19
		(0.08)	(0.12)	(0.11)
Transaction Volume			0.16	0.27**
			(0.09)	(0.08)
$ASW_{n,t}^{spread}$	set -1	set -1	set -1	-1.59**
				(0.20)
<i>p</i> - value	0.03	0.00	0.00	0.00
R^2	0.45	0.56	0.64	0.67

(1) and (2) are from 1999.1-2009.12. (3) and (4) are from 1999.3-2009.12.

Continuously compounded yields annualized and in %. Transaction volume in logs.

Regressions contain constant term.

Newey-West Standard Errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the

non-adjusted R^2 .

Table 6A
Return Predictability Liquidity US

	$r_{n,t+1}^s$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^s - y_{1,t}^s$	2.29 (1.49)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		3.16* (1.31)		-1.63 (1.30)
$b_{n,t} - b_{1,t}$			5.57 (3.40)	6.04 (3.40)
$L_{n,t}$	-3.82 (6.03)	9.50 (6.09)	-13.49** (3.67)	-10.14* (5.13)
$p - value$	0.28	0.00	0.00	0.00
R^2	0.03	0.16	0.21	0.22

$L_{n,t}$ is obtained as minus the fitted value from Table 5 (4).

Overlapping quarterly returns. Monthly data 1999.6-2009.12.

Regressions contain constant terms.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 6B
Return Predictability Liquidity US

	$r_{n,t+1}^L$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$(y_{n,t}^{TIPS} - L_{n,t}) - y_{1,t}^{TIPS}$	-0.03 (0.77)	3.16* (1.31)		-1.63 (1.30)
$(b_{n,t} + L_{n,t}) - b_{1,t}$	-2.62 (3.09)		5.57 (3.40)	6.04 (3.40)
$L_{n,t}$	19.81** (6.18)	12.66* (5.80)	-19.06** (4.93)	-17.81** (5.37)
$p - value$	0.02	0.00	0.00	0.00
R^2	0.26	0.16	0.21	0.22

$-L_{n,t}$ is obtained as the fitted value from Table 5 (4).

$r_{n,t+1}^L = -(n-1)L_{n-1,t+1} + nL_{n,t}$ is the return on the liquidity spread.

$r_{n,t+1}^{TIPS-L} = r_{n,t+1}^{TIPS} - r_{n,t+1}^L$ and $r_{n,t+1}^{b+L} = r_{n,t+1}^b + r_{n,t+1}^L$ are liquidity-adjusted returns on TIPS and breakeven.

Overlapping quarterly returns. Monthly data 1999.6-2009.12.

Regressions contain constant terms.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 6C
Return Predictability Liquidity US

	$r_{n,t+1}^{TIPS-L}$	$r_{n,t+1}^{b+L}$	$r_{n,t+1}^{b+L}$
$(y_{n,t}^{TIPS} - L_{n,t}) - y_{1,t}^{TIPS}$	3.53* (1.41)		-1.66 (1.12)
$(b_{n,t} + L_{n,t}) - b_{1,t}$		2.94 (1.57)	3.42* (1.53)
$L_{n,t}$	-6.05 (11.09)	0.73 (6.23)	2.00 (6.86)
$p - value$	0.05	0.17	0.11
R^2	0.06	0.04	0.07

$-\bar{L}_{n,t}$ is obtained as the fitted value from Table 5 (4).

$r_{n,t+1}^L = -(n-1)L_{n-1,t+1} + nL_{n,t}$ is the return on the liquidity spread.

$r_{n,t+1}^{TIPS-L} = r_{n,t+1}^{TIPS} - r_{n,t+1}^L$ and $r_{n,t+1}^{b+L} = r_{n,t+1}^b + r_{n,t+1}^L$ are liquidity-adjusted returns on TIPS and breakeven.

Overlapping quarterly returns. Monthly data 1999.6-2009.12.

Regressions contain constant terms.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 7
 $y_{n,t}^{\$} - y_{n,t}^{TIPS}$ onto Relative Supply of TIPS US

$Supply_t$	0.014 (0.023)		-0.012 (0.054)	-0.018 (0.018)
$\Delta Supply_t$		0.013 (0.019)	0.022 (0.017)	0.004 (0.006)
Off-the-run				-0.57** (0.17)
GNMA				-0.18* (0.11)
Transaction Volume				0.39** (0.15)
$ASW_{n,t}^{spread}$				-1.55** (0.21)
$month$			7×10^{-6} (1×10^{-5})	
$p - value$	0.54	0.50	0.07	0.00
R^2	0.01	0.01	0.04	0.68

Standard errors in Brackets. Newey-West Standard Errors with 3 lags. Monthly data
Columns 1-3 are from 1999.1-2009.12. Column 4 is from 1999.3-2009.12.

$Supply_t = D_t^{TIPS} / D_t$ denotes relative quantity of TIPS outstanding.

$\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS}) / D_{t-1}^{TIPS} - (D_t - D_{t-1}) / D_{t-1}$ denotes change in TIPS
outstanding relative to change in all bonds outstanding.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability
and the non-adjusted R^2 .

Table 8
Return Predictability US Controlling for Supply and Liquidity

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$	2.35 (1.52)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		3.30** (1.23)		-1.81 (1.19)
$b_{n,t} - b_{1,t}$			5.67* (2.88)	6.44** (2.75)
$L_{n,t}$	-3.27 (6.49)	9.61 (6.02)	-13.10** (3.78)	-9.78** (4.65)
$Supply_t$	0.26 (0.70)	0.14 (0.75)	-0.01 (0.62)	-0.21 (0.61)
$\Delta Supply_t$	0.17 (0.45)	0.10 (0.36)	0.17 (0.28)	0.04 (0.25)
$p - value$	0.60	0.01	0.00	0.00
R^2	0.04	0.16	0.21	0.22

$L_{n,t}$ is obtained as minus the fitted value from Table 4 (4).

$Supply_t = D_t^{TIPS}/D_t$ denotes relative quantity of TIPS outstanding.

$\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS})/D_{t-1}^{TIPS} - (D_t - D_{t-1})/D_{t-1}$ denotes change in TIPS outstanding relative to change in all bonds outstanding.

Overlapping quarterly returns. Monthly data 1999.6-2009.12.

Regressions contain constant terms.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 9A
 $y_{n,t}^{\$} - y_{n,t}^{TIPS}$ onto Relative Supply UK 10 YR

<i>Supply_t</i>	-0.21** (0.06)		0.25** (0.05)		0.27** (0.05)
$\Delta Supply_t$		-0.006 (0.013)		-0.002 (0.009)	-0.02** (0.008)
<i>month</i>			$-4 \times 10^{-5**}$ (4×10^{-6})	$-2. \times 10^{-5**}$ (3×10^{-6})	$-4 \times 10^{-5**}$ (4×10^{-6})
<i>p - value</i>	0.00	0.64	0.00	0.00	0.00
<i>R²</i>	0.19	0.00	0.60	0.51	0.60

Standard errors in Brackets. Newey-West Standard Errors with 3 lags. Monthly data
Monthly data 1991.9-2009.12

$Supply_t = D_t^{TIPS} / D_t$ denotes relative quantity of inflation-linked gilts outstanding.

$\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS}) / D_{t-1}^{TIPS} - (D_t - D_{t-1}) / D_{t-1}$ denotes change in inflation-linked gilts outstanding relative to change in all gilts outstanding.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 9B
 $y_{n,t}^{\$} - y_{n,t}^{TIPS}$ onto Relative Supply UK 20 YR

<i>Supply_t</i>	-0.27** (0.06)		0.29** (0.05)		0.29** (0.05)
$\Delta Supply_t$		0.011 (0.014)		0.001 (0.011)	-0.014 (0.010)
<i>month</i>			$-3 \times 10^{-5**}$ (3×10^{-6})	$-2 \times 10^{-5**}$ (2×10^{-6})	$-3. \times 10^{-5**}$ (3×10^{-6})
<i>p - value</i>	0.00	0.42	0.00	0.00	0.00
<i>R²</i>	0.26	0.00	0.65	0.58	0.66

Standard errors in Brackets. Newey-West Standard Errors with 3 lags.
Monthly data 1985.1-2009.12.

$Supply_t = D_t^{TIPS} / D_t$ denotes relative quantity of inflation-linked gilts outstanding.

$\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS}) / D_{t-1}^{TIPS} - (D_t - D_{t-1}) / D_{t-1}$ denotes change in inflation-linked gilts outstanding relative to change in all gilts outstanding.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 10A
Return Predictability UK 10 YR Controlling for Supply and Time Trend

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$	-0.03 (1.12)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		5.57** (2.04)		-6.36** (1.97)
$b_{n,t} - b_{1,t}$			2.61 (1.72)	3.87** (1.57)
$Supply_t$	1.38 (1.65)	-0.88 (1.68)	2.16 (2.60)	1.61 (2.27)
$\Delta Supply_t$	-0.74** (0.26)	-0.10 (0.23)	-0.38 (0.25)	-0.55 (0.30)
$month$	-1.4×10^{-4} (1.0×10^{-4})	1.2×10^{-4} (1.0×10^{-4})	-1.9×10^{-4} (1.3×10^{-4})	$-2.6 \times 10^{-4**}$ (1.3×10^{-4})
$p - value$	0.03	0.11	0.16	0.00
R^2	0.04	0.11	0.07	0.17

$Supply_t = D_t^{TIPS} / D_t$ denotes relative quantity of inflation-linked gilts outstanding.
 $\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS}) / D_{t-1}^{TIPS} - (D_t - D_{t-1}) / D_{t-1}$ denotes change in inflation-linked gilts outstanding relative to change in all gilts outstanding.

Overlapping quarterly returns. Monthly data 1991.12-2009.12.

Regressions contain constant terms.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 10B
Return Predictability UK 20 YR Controlling for Supply and Time Trend

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$	3.23 (1.76)			
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		2.17 (1.41)		-3.02 (1.95)
$b_{n,t} - b_{1,t}$			7.39** (2.27)	8.97** (2.65)
$Supply_t$	-2.98 (2.30)	-2.72 (1.78)	-0.51 (2.25)	-1.75 (2.18)
$\Delta Supply_t$	-0.14 (0.49)	-0.12 (0.34)	0.00 (0.39)	-0.05 (0.41)
<i>month</i>	7×10^{-5} (1×10^{-4})	$2 \times 10^{-4**}$ (9×10^{-5})	-2×10^{-4} (1×10^{-4})	-1×10^{-4} (1×10^{-4})
<i>p - value</i>	0.09	0.01	0.01	0.01
R^2	0.06	0.07	0.10	0.11

$Supply_t = D_t^{TIPS}/D_t$ denotes relative quantity of inflation-linked gilts outstanding.
 $\Delta Supply_t = (D_t^{TIPS} - D_{t-1}^{TIPS})/D_{t-1}^{TIPS} - (D_t - D_{t-1})/D_{t-1}$ denotes change in inflation-linked gilts outstanding relative to change in all gilts outstanding.
 Overlapping quarterly returns. Monthly data 1985.4-2009.12.
 Regressions contain constant terms.
 Newey-West standard errors with 3 lags in brackets.
 * and ** denote significance at the 5% and 1% level respectively.
 The last row reports the the p-value of the F-test for no predictability.

Table 11
Return Predictability Cochrane-Piazzesi US 1952-2009

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{\$}$
$y_{n,t}^{\$} - y_{1,t}^{\$}$		2.74*
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$		(1.23)
$b_{n,t} - b_{1,t}$		
CP_t	0.41** (0.13)	0.23 (0.13)
$p - value$	0.00	0.00
R^2	0.04	0.06

$$CP_t = -2.14f_{1,t}^{\$} + 0.81f_{2,t}^{\$} + 3.00f_{3,t}^{\$} + 0.80f_{4,t}^{\$} - 2.08f_{5,t}^{\$}$$

Overlapping quarterly returns. Monthly data 1952.9-2009.12.

Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 12
Return Predictability Cochrane-Piazzesi US 1999-2009

	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$	$r_{n,t+1}^{\$}$	$r_{n,t+1}^{TIPS}$	$r_{n,t+1}^b$
$y_{n,t}^{\$} - y_{1,t}^{\$}$				1.88 (1.69)		
$y_{n,t}^{TIPS} - y_{1,t}^{TIPS}$					5.06* (1.54)	-4.33** (1.20)
$b_{n,t} - b_{1,t}$						7.65* (3.09)
CP_t	0.31 (0.37)	0.01 (0.37)	0.29 (0.26)	0.20 (0.38)	-0.29 (0.29)	0.57* (0.22)
$p - value$	0.41	0.97	0.27	0.27	0.00	0.00
R^2	0.02	0.00	0.02	0.04	0.14	0.27

$$CP_t = -2.14f_{1,t}^{\$} + 0.81f_{2,t}^{\$} + 3.00f_{3,t}^{\$} + 0.80f_{4,t}^{\$} - 2.08f_{5,t}^{\$}$$

Overlapping quarterly returns. Monthly data 1999.4-2009.12.

Regressions contain constant term.

Newey-West standard errors with 3 lags in brackets.

* and ** denote significance at the 5% and 1% level respectively.

The last two rows report the p-value of the F-test for no predictability and the non-adjusted R^2 .

Table 13
Fitted Risk Premia US

	$E(\hat{y})$	$\sigma(\hat{y})$	$\sigma^2(\hat{y})/\sigma^2(r_{n,t}^{\$})$	$\sigma^2(\hat{y})/\sigma^2(r_{n,t}^{TIPS})$
Risk Premium \$	3.26	1.56	3%	
Risk Premium TIPS	4.16	2.70	10%	12%
Risk Premium Breakeven	-0.91	3.24	14%	
Inflation RP	0.75	1.38	3%	
Real Rate RP	2.86	1.90	5%	6%
Liquidity RP	1.38	3.15		17%

Annualized (%). Columns 1 and 2 show mean and standard deviation of fitted values.

Rows 1, 2 and 3 correspond to regressions in columns 1, 2 and 4 of Table 4A.

Rows 4 and 5 correspond to regressions in columns 3 and 1 of Table 6C.

Row 6 corresponds to regression in column 1 of Table 6B.

Table 14
Fitted Risk Premia UK 20YR

	$E(\hat{y})$	$\sigma(\hat{y})$	$\sigma^2(\hat{y})/\sigma^2(r_{n,t}^{\$})$	$\sigma^2(\hat{y})/\sigma^2(r_{n,t}^{TIPS})$
Risk Premium \$	3.47	3.13	5%	
Risk Premium TIPS	1.66	1.84	2%	4%
Risk Premium Breakeven	1.81	2.55	3%	

Annualized (%). Columns 1 and 2 show mean and standard deviation of fitted values.

Rows 1, 2 and 3 correspond to regressions in columns 1, 2 and 4 of Table 4C.