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Carolin E. Pflueger
Luis M. Viceira

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ABSTRACT

This paper decomposes the excess return predictability in inflation-indexed and nominal government bonds into effects from liquidity, market segmentation, real interest rate risk and inflation risk. We estimate a large and variable liquidity premium in US Treasury Inflation Protected Securities (TIPS) from the co-movement of breakeven inflation with liquidity proxies. The liquidity premium is around 70 basis points in normal times, but much larger during the early years of TIPS issuance and during the height of the financial crisis in 2008-2009. The liquidity premium explains the high excess returns on TIPS as compared to nominal Treasuries over the period 1999-2009. Liquidity-adjusted breakeven inflation appears stable, suggesting stable inflation expectations over our sample period. We find predictability in both inflation-indexed bond excess returns and in the spread between nominal and inflation-indexed bond excess returns even after adjusting for liquidity, providing evidence for both time-varying real interest rate risk premia and time-varying inflation risk premia. Liquidity appears uncorrelated with real interest rate and inflation risk premia. We test whether bond return predictability is due to segmentation between nominal and inflation-indexed bond markets but find no evidence in either the US or in the UK.

Carolin E. Pflueger
Harvard Business School
Boston MA 02163
cpflueger@hbs.edu

Luis M. Viceira
George E. Bates Professor
Harvard Business School
Baker Library 367
Boston, MA 02163
and NBER
lviceira@hbs.edu

1 Introduction

The yields on US Treasury Inflation Protected Securities (TIPS) have declined dramatically since they were first issued in 1997. Over the 10 year period starting in 1999 the average annualized excess log return on 10 year TIPS equalled a substantial 4.16%, almost a full percentage point higher than that on comparable nominal US government bonds. These differential returns are notable, because both nominal and inflation-indexed bonds are fully backed by the US government. Moreover, the real cash flows on nominal bonds are exposed to surprise inflation while TIPS coupons and principal are inflation-indexed. This paper asks to what extent the returns on nominal and inflation-indexed bonds in both the US and the UK can be attributed to differential liquidity and market segmentation or to real interest rate risk and inflation risk.

There is strong empirical evidence that the excess return on US nominal government bonds over the return on Treasury bills exhibits predictable variation over time (Campbell and Shiller 1991, Fama and Bliss 1987, Cochrane and Piazzesi 2005). In recent work, Pflueger and Viceira (2011) provide strong empirical evidence that the excess return on inflation-indexed (or real) bonds and the return differential between nominal and inflation-indexed bonds are also time varying both in the US and in the UK.

Although government bonds in large and stable economies are generally considered default-free, their real cash flows are exposed to other risks. The prices of both inflation-indexed and nominal government bonds change with the economy-wide real interest rate. Consequently, bond risk premia will reflect investors' perception of real interest rate risk, which may vary over time. The prices of nominal government bonds, but not inflation-indexed government bonds, also vary with expected inflation, so that inflation risk will impact their risk premia (Campbell and Viceira 2001). Campbell, Sunderam, and Viceira (2010) provide a model, in which inflation risk and real interest rate risk vary over time and lead to predictable variation in bond excess returns.

In addition to cash flow risk, institutional factors and trading frictions might also impact bond prices and bond risk premia. For any investor the riskless asset is an inflation-indexed bond whose cash flows match his consumption plan (Campbell and Viceira 2001, Wachter 2003), so that inflation-indexed bonds should typically be held by buy-and-hold investors. This suggests that even in normal times one might expect a liquidity premium in the yield of inflation-indexed bonds. While US nominal Treasury bonds are among the most liquid investments in the world, TIPS empirically 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).

If liquidity differences are time-varying, liquidity can make returns risky and induce an additional liquidity risk premium. For example, if the liquidity of inflation-indexed bonds deteriorates during periods when investors would like to sell, risk averse investors will demand a liquidity risk premium for holding these bonds (Amihud, Mendelson and Pedersen 2005, Acharya and Pedersen 2005). Our research aims to understand how much of the observed variation in the expected excess return on inflation-indexed bonds and of the expected return differential between inflation-indexed and nominal bonds can be explained by liquidity premia, which we argue reflect both the level and the risk of liquidity.

We adopt an empirically flexible approach to estimating the liquidity differential between inflation-indexed bonds and nominal 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 TIPS, the 10-year nominal off-the-run spread and the Ginnie Mae (GNMA) spread. We then use these estimates to adjust bond yields and returns for liquidity, and test for predictable variation in liquidity-adjusted nominal and inflation-indexed bond excess returns. Our approach contrasts with the approach of D'Amico, Kim and Wei (2008), who model nominal and real interest rates using a tightly parameterized affine term structure model and then measure the liquidity premium as the difference between model-implied and observed TIPS yields.

We estimate a statistically significant and economically important time-varying liquidity component in breakeven inflation in the US. We find that the yield on TIPS is about 106 basis points larger on average over our sample period than it would be if TIPS were as liquid as nominal Treasury bonds of equivalent maturity. This high average reflects extraordinary events associated with very low liquidity in this market. We find a high liquidity discount in the years following the introduction of TIPS (about 120 bps), which we attribute to learning and low trading volume, and during the fall of 2008 at the height of the financial crisis (beyond 200 bps). We estimate a much lower liquidity discount of about 70 bps between 2004 and 2007 and after the crisis in 2009.

The yield differential between nominal and inflation-indexed bonds is often used as a gauge of long-term inflation expectations. Breakeven inflation, as this yield differential is popularly known among practitioners, might reflect not only inflation expectations and possibly an inflation risk premium, but also a liquidity premium due to differential liquidity of inflation-indexed bonds relative to nominal bonds. We obtain a liquidity-adjusted measure of breakeven inflation which suggests that breakeven inflation has been fairly stable between three and four percent during our sample period.

Our analysis also sheds light on the sources of the differential liquidity premium in TIPS relative to nominal government bonds.[2] Following Weill (2007) and others one can interpret the TIPS transaction volume as a measure of illiquidity due to search frictions.[3] Our findings suggest that the impact of search frictions on inflation-indexed bond prices might have been exacerbated during the early period of inflation-indexed bond issuance, when the amount of bonds outstanding was relatively low and perhaps only a small number of sophisticated investors had a good understanding of the mechanics and pricing of these new bonds. In fact, TIPS transaction volume was very low relative to nominal Treasuries during this early period. As TIPS trading volume increased relative to US Treasury trading volume between 1999 and 2004, TIPS yields came down from their dramatically high levels of up to 4% to under 2%.

While arguably search frictions and learning specific to the novelty of TIPS drive part of the liquidity differential between nominal and inflation-indexed bonds, "flight-to-liquidity" episodes might also help explain this differential. In a flight to liquidity episode some market participants suddenly prefer highly liquid securities, such as on-the-run nominal Treasury securities, rather than less liquid securities.[4] Longstaff (2004) finds evidence for flight-to-liquidity episodes by looking at the spread between government agency bonds and US Treasury bonds. Krishnamurthy (2002) documents a similar liquidity effect by comparing the most recently issued on-the-run nominal Treasury bond with an older off-the-run nominal Treasury bond, whose payoffs are almost identical.

[2] There exists a wide literature on the relationship between liquidity and asset prices, see Amihud, Mendelson and Pedersen (2005) for a survey.

[3] See Duffie, Garleanu and Pedersen (2005, 2007) and Weill (2007) for models of over-the-counter markets, in which traders need to search for counterparties and incur opportunity or other costs while doing so.

[4] In the search model with partially segmented markets of Vayanos and Wang (2001) short-horizon traders endogenously concentrate in one asset, making it more liquid. Vayanos (2004) presents a model of financial intermediaries and exogenous transaction costs, where preference for liquidity is time-varying and increasing with volatility.

We find that breakeven inflation moves negatively with both the on-the-run versus off-the-run spread in Treasury bonds and the GNMA-Treasury spread in our sample period. This empirical finding indicates that while during a flight-to-liquidity episode investors rush into nominal US Treasuries, they do not buy US TIPS to the same degree. This is especially interesting given that both types of bonds are fully backed by the same issuer, the US Treasury, which is generally considered the safest borrower.

Controlling for liquidity allows us to disentangle the effects of liquidity, real interest rate risk and inflation risk on expected returns and to shed further light on the results in Pflueger and Viceira (2011), who find that inflation-indexed bond returns in both the US and the UK exhibit predictable time-variation. We find that liquidity is a large contributor to return predictability in inflation-indexed bonds, but that real rate risk and inflation risk are also statistically and economically significant contributors to return predictability in both inflation-indexed and nominal bonds. 17% of the variance of TIPS realized excess returns can be explained by a time-varying liquidity premium, and 6% of the variance by a time-varying real interest rate risk premium. We find that both inflation risk premia and real rate risk premia are present in nominal bond returns and explain 3% and 5% of the variance of their realized excess returns, respectively.

We also investigate the hypothesis that the markets for nominal and inflation-indexed debt are segmented, leading to relative price fluctuations and returns predictability. Recent research has emphasized the role of limited arbitrage and bond investors habitat preferences to explain predictability in nominal bond returns. By 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) empirically explore 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. We cannot find any evidence for bond supply effects either in the US or in the UK. One potential interpretation for this finding could be that governments understand investor demand for the different types of securities and adjust their issuance accordingly, effectively acting as an arbitrageur between the two markets.

The structure of this article is as follows. Section 2 estimates the liquidity premium in US TIPS versus nominal bonds using our liquidity proxies. Section 3 tests the market segmentation hypothesis in the US and in the UK, and section 4 considers time-varying real interest rate risk and inflation risk premia. Finally, section 5 offers some concluding remarks.

2 Estimating the Liquidity Component of Breakeven Inflation

Our approach to modelling liquidity premia is empirical. We estimate the US TIPS liquidity premium by regressing inflation compensation on measures of liquidity, following authors such as Gurkaynak, Sack, and Wright (2010). We use four liquidity proxies: the nominal off-the-run spread, the GNMA spread, relative TIPS transaction volume and the difference between TIPS asset-swap-spreads and nominal US Treasury asset-swap spreads. Since 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 and we cannot conduct a similar study for UK bonds.

We interpret relative TIPS transaction volume as a measure of TIPS-specific liquidity. One might think that when TIPS were first issued in 1997, the market needed to learn about TIPS and the market for TIPS took some time to get established. This should be reflected in initially low trading volumes in TIPS and high yields during the early period. The off-the-run spread and the GNMA spread are thought to capture flight-to-liquidity events in the US Treasury bond market (Krishnamurthy 2002). Finally, the asset swap spread variable captures extraordinary events during the financial crisis. (See Campbell, Shiller, and Viceira (2009) for an account of liquidity events during the Fall of 2008.)

While the relative transaction volume of TIPS likely only captures the current ease of trading TIPS and therefore a liquidity premium, the off-the-run spread, the GNMA spread and the asset-swap-spread are likely to represent both the level of liquidity and liquidity risk. Our estimated liquidity premium is therefore likely to represent a combination of current ease of trading TIPS versus nominal US Treasuries and the risk that the liquidity of TIPS might deteriorate.

2.1 Bond Notation and Definitions

We denote by $y^{\$}_{n,t}$ and $y^{TIPS}_{n,t}$ the log (or continuously compounded) yield with n periods to maturity for nominal and inflation-indexed bonds, respectively. We use the superscript $TIPS$ to denote this quantity for both US and UK inflation-indexed bonds.

We define breakeven inflation as the difference between nominal and inflation-indexed bond yields:

$$b_{n,t} = y^{\$}_{n,t} - y^{TIPS}_{n,t} \tag{1}$$

Log excess returns on nominal and inflation-indexed zero-coupon n-period bonds held for one period before maturity are given by

$$xr^{\$}_{n,t+1} = ny^{\$}_{n,t} - (n-1)\, y^{\$}_{n-1,t+1} - y^{\$}_{1,t}, \tag{2}$$

$$xr^{TIPS}_{n,t+1} = ny^{TIPS}_{n,t} - (n-1)\, y^{TIPS}_{n-1,t+1} - y^{TIPS}_{1,t}. \tag{3}$$

Therefore, the log excess one-period holding return on breakeven inflation is equal to

$$xr^{b}_{n,t+1} = xr^{\$}_{n,t+1} - xr^{TIPS}_{n,t+1}. \tag{4}$$

The yield spread is the difference between a long-term yield and a short-term yield:

$$s^{\$}_{n,t} = y^{\$}_{n,t} - y^{\$}_{1,t}, \tag{5}$$

$$s^{TIPS}_{n,t} = y^{TIPS}_{n,t} - y^{TIPS}_{1,t}, \tag{6}$$

$$s^{b}_{n,t} = b_{n,t} - b_{1,t}. \tag{7}$$

Inflation-indexed bonds are commonly quoted in terms of *real* yields, but since $xr_{n,t+1}^{TIPS}$ is an excess return over the *real* short rate it can be interpreted as a real or nominal excess return. In all regressions we approximate $y_{n-1,t+1}^{\$}$ and $y_{n-1,t+1}^{TIPS}$ with $y_{n,t+1}^{\$}$ and $y_{n,t+1}^{TIPS}$.

2.2 Estimation Strategy

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 increase relative to nominal yields. To account for this premium, we estimate the following regression for breakeven inflation:

$$b_{n,t} = a_1 + a_2 X_t + \varepsilon_t, \tag{8}$$

where 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. Section 2.3.2 gives a detailed description of the data sources and construction of these variables.

In (8) 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 one.

The asset-swap spread reflects the financing costs that a levered investor incurs from holding TIPS instead of a similar maturity nominal bonds. If the marginal investor in TIPS is such a levered investor, 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 negligible during the period of 2004-2007.

We obtain liquidity-adjusted TIPS yields by assuming that the liquidity premium estimated from the breakeven regression (8) is entirely attributable to time-varying liquidity in TIPS rather than in nominal bonds. The estimated liquidity component in TIPS yields then equals

$$\hat{L}_{n,t} = -\hat{a}_2 X_t, \tag{9}$$

where $\hat{a}_2$ is the vector of slope estimates in (8). Thus an increase in $\hat{L}_{n,t}$ reflects a reduction in the liquidity of TIPS relative to nominal Treasury bonds. Liquidity-adjusted TIPS yields and breakeven inflation then equal

$$y_{n,t}^{TIPS,adj} = y_{n,t}^{TIPS} - \hat{L}_{n,t}, \tag{10}$$

$$b_{n,t}^{adj} = b_{n,t} + \hat{L}_{n,t}. \tag{11}$$

That is, the observed yield on TIPS is larger than the liquidity-adjusted yield during times of low liquidity and accordingly the observed breakeven inflation will be smaller than the liquidity-adjusted breakeven inflation. For simplicity we assume that the liquidity premium on one-quarter real bonds is constant.

2.3 Data

2.3.1 Yield Data

We use data on constant-maturity inflation-indexed and nominal yields both in the US and in the UK. Inflation-indexed bonds have been available in the UK since 1983 and in the US since 1997. Inflation-indexed bonds are bonds whose principal adjusts automatically with the evolution a consumer price index, which in the US 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 adjust with inflation.[5]

[5] There are further details such as in inflation lags in principal updating and tax treatment of the coupons that slightly complicate the pricing of these bonds. 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.

For the US we use an expanded version of the Gurkaynak, Sack, and Wright (2007) and Gurkaynak, Sack, and Wright (2010, GSW henceforth) data set. GSW have constructed a zero-coupon yield curve starting in January 1961 for nominal bonds and for TIPS starting in January 1999 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 US 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. We use the 20-year maturity in our tests because 20-year nominal and real yields are available from 1985, while for instance 10-year real yields are available only since 1991.[6] Inflation is measured by the non seasonally adjusted Retail Price Index, which serves as the measure of inflation for inflation-indexed bond payouts.

Since 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 follow the procedure described in Pflueger and Viceira (2011). 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.

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

2.3.2 Data on Liquidity Proxies

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 a very similar 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. Market participants attribute this spread to 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. We obtain the 10 year off-the-run spread from the Federal Reserve and from Bloomberg.[7]

A second type of government-backed bond that is also less liquidly traded than on-the-run Treasuries is 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 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). We obtain a GNMA spread adjusted for prepayment risk from Bloomberg.[8]

Our third measure of liquidity aims to capture 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

[7] The on the run data is from Bloomberg (USGG10YR), and the off the run is from the Federal Reserve publication H.15 "Interest Rates".

[8] Ticker 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.

the late 1990's carried unusually high real yields. Campbell, Shiller, and Viceira (2009) and others have argued that perhaps TIPS were not well understood initially and may therefore have traded at a discount. In their study of the TIPS market microstructure Fleming and Krishnan (2009) conclude that trading activity is a good measure of cross-sectional TIPS liquidity. We follow Gurkaynak, Sack, and 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 $\log\left(Trans_t^{TIPS}/Trans_t^{\$}\right)$, 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 $Trans^{\$}$ we use the transaction volume of government coupon securities with at least 6 (before 2001) or 7 (from 2001) years to maturity.

We choose 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. We then smooth the measure of relative transaction volume over the past 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 accurate to have liquidity-adjusted TIPS yields that were more volatile than raw TIPS yields. Our computations are complicated by the fact that in 2001 the Federal Reserve changed the maturity cutoffs for which the transaction 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 capture the cost that levered investors would incur when holding TIPS. Such investors looking for TIPS exposure can either borrow by putting the TIPS on repo or they might consider entering into an asset swap, which requires no initial capital. 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. For a levered investor a widening of the spread can be considered 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 (ASW) 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 versus 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 40 bps 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 1 shows our four liquidity variables. 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 exhibits high frequency variation. 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 rises linearly through 2004 and then to stabilize. This is consistent with the idea that it took time for TIPS to become well-established relative to familiar nominal Treasuries. It also suggests that the liquidity premium due to the novelty of TIPS should have been modest in the period since 2004.

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 130 bps in December 2008. That is, before the crisis financing a long position in TIPS was about 40 basis more expensive than 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.

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. This led to a liquidity-induced sharp tightening of breakeven inflation associated with a widening of the TIPS asset-swap-spread.

2.4 Estimation Results

Table 1 reports OLS estimates of (8). Column 1 estimates only the impact of the off-the-run spread on breakeven inflation. 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 were 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. Column 5 estimates (8) for the pre-crisis time-period 1999-2006, including the off-the-run spread, the GNMA spread and transaction volume but not the asset-swap spread.

Table 1 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 transaction 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 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 5 is still 47% when the sample period ends in June 2007. Moreover, the signs and magnitudes of the regression coefficients do not depend on the inclusion of the financial crisis.

Column 4 in Table 1 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 work with the freely estimated version from column 4 for its flexibility.

Figure 2 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 2 shows a high liquidity premium in the early 2000's (about 120 bps), but a much lower liquidity premium between 2004 and 2007 (70 bps). The premium shoots up again beyond 200 bps during the crisis, and finally comes down to 70 bps after the crisis. 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 higher. 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.

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.

Figures 3 and 4 show liquidity-adjusted breakeven inflation and TIPS yields, respectively. Figure 3 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. Figure 4 shows that if TIPS had remained as liquid as nominal Treasuries their yields would have dropped dramatically in the fall of 2008. This has important implications for the interpretation of the dramatic reduction in breakeven inflation observed during the financial crisis as an indicator of massive expected deflation among bond market participants. We discuss this point in detail in section 4.

3 Testing For Market Segmentation Effects

Before using liquidity-adjusted yields and returns to explore the relevance of real interest rate risk and inflation risk in explaining the estimated predictable variation in bond excess returns, we consider first if institutional factors can explain this variability. In particular, 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) states 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 bond 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 to be even 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.[9] 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 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.[10] 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

[9] The 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 at http://www.gpoaccess.gov/eop/download.html.

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

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 $\Delta Supply_t = \left(D_t^{TIPS} - D_{t-1}^{TIPS}\right)/D_{t-1}^{TIPS} - \left(D_t - D_{t-1}\right)/D_{t-1}$. Figure 5A plots the relative supply of TIPS, D_t^{TIPS}/D_t, and 10 year breakeven inflation in the US, while Figure 5B plots the relative supply of UK inflation-linked gilts and 20 year breakeven inflation in the UK.

Figure 5A illustrates a 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 5B 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 accelerated 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 2 shows regressions of breakeven inflation onto the relative supply and the change in supply of inflation-indexed bonds. Panel A shows results for US bonds. Neither the relative supply nor $\Delta Supply_t$ appear to be related to breakeven inflation. Column 4 in the panel shows a regression of breakeven inflation 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 controlling for the supply of TIPS, shown in Table 1, while the supply variables remain statistically not significant.

Panel B in Table 2 shows 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. The results are very similar to the US results, 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 5B 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 and Vayanos (2009).

If markets are segmented we would expect increases in the relative supply of inflation-indexed bonds to predict excess returns on inflation-indexed bonds. Table 3 explores whether our bond supply variables and liquidity variables predict bond excess returns. Panel A shows results for the US. Our left-hand-side variables are the nominal, inflation-indexed and breakeven returns as defined in (2), (3) and (4). Pflueger and Viceira (2011) show that nominal, TIPS and breakeven term spreads are significant predictors of the corresponding excess returns. We therefore control for these spreads in our regressions.

Panel A in Table 3 shows that the TIPS and breakeven term spreads still enter significantly and predict TIPS excess returns and breakeven excess returns, respectively, after controlling for liquidity and supply effects. The liquidity premium enters significantly and in particular helps predict the breakeven return. By contrast, the supply variables are not statistically significant.[11] 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, but we do find evidence that liquidity helps predict the

[11] Arguably $\Delta Supply_t$ 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.

excess return on nominal bonds over TIPS.

Panel B in Table 3 shows similar return-predictability regressions for the UK, using $Supply_t$ and $\Delta Supply_t$ as additional explanatory variables. Both variables are generally not statistically significant. Hence it seems that the markets for nominal and inflation-indexed bonds are not subject to exogenous differential supply shocks. One would expect this result if the government accommodates demand pressures from investors for nominal or inflation-indexed bonds.

In summary, there is very little evidence of bond supply effects in either the UK or US bond markets. Moreover, the return predictability results in Pflueger and Viceira (2011) generally appear to hold up to the inclusion of liquidity and supply variables. The inflation-indexed bond spread still predicts inflation-indexed bond excess returns and the breakeven spread predicts breakeven excess returns. Panel A in Table 2 shows that liquidity is also a very strong predictor of breakeven excess returns. We therefore proceed to decompose breakeven inflation into a liquidity component and a liquidity-adjusted breakeven inflation and examine the predictability of these two components separately.

4 Time-Variation of Real Interest Rate and Inflation Risk Premia

4.1 Predictive regressions with liquidity-adjusted yields and returns

Pflueger and Viceira (2011) find that the real term spread predicts excess returns on inflation-indexed bonds and the breakeven inflation spread predicts breakeven returns in the US and the UK, similarly to the return predictability in US nominal government bonds documented in Campbell and Shiller (1991) and Fama and Bliss (1987). They also show that the evidence on predictability in nominal bond excess returns holds for the most recent historical period.

Inflation-indexed bond return predictability could be the result of either a time-varying real interest rate risk premium, a time-varying liquidity premium, or a combination of both—since supply effects do not seem to matter. Breakeven and nominal bond excess return predictability could be the result of a time-varying inflation-risk premium, but this finding may again partly be due to time-varying liquidity. We can use our estimates of liquidity effects on inflation-indexed bond prices and returns to disentangle these effects.

We start by running return predictability regressions, similar to those in Pflueger and Viceira (2011), replacing the TIPS yield by the liquidity-adjusted TIPS yield (10) and breakeven by liquidity-adjusted breakeven (11). Evidence of predictability in liquidity-adjusted TIPS excess returns and breakeven returns would suggest that a time-varying real interest rate risk premium and a time-varying inflation risk premium help explain the estimated predictable variation in inflation-indexed and nominal bond excess returns, conditional on our measure of liquidity.

We also examine whether there is evidence of a time-varying liquidity risk premium, by looking at the predictability of the liquidity return. We define the liquidity return as

$$r^L_{n,t+1} = -\left(n-1\right) L_{n-1,t+1} + nL_{n,t}. \tag{12}$$

We can think of $r^L_{n,t+1}$ as the return on TIPS return due to time-varying liquidity.

Our estimates for the liquidity premium $L_{n,t}$ are based on the full-period regression allowing for a flexible regression coefficient on the asset-swap spread, reported in Table 1, column 4. We also include $L_{n,t}$ as an additional control in our predictive regressions.

Table 4 shows the estimates of the liquidity-adjusted predictive regressions. Since we do not adjust the nominal yields for liquidity, the nominal expectations hypothesis regression is omitted from the table. Overall, Table 4 provides support for the hypothesis that real and nominal bond yields reflect time-varying real interest rate and inflation risk premia. Conditional on our estimates of liquidity-adjusted yields and returns, the real yield spread positively forecasts inflation-indexed bond returns, and the breakeven inflation spread forecasts breakeven returns—or the return on nominal bonds in excess of the return on inflation-indexed bonds. The coefficient on the liquidity-adjusted real term spread in the real bond predictive regression is large and significant, and the coefficient on the liquidity-adjusted breakeven inflation spread is also large and significant when the real term spread is added in as an additional control.

Remarkably, Table 4 shows that the liquidity variable does not predict real bond excess returns or breakeven excess returns. Hence, it appears that the current level of the liquidity premium is not related to fundamental cash-flow risk as represented by the real interest rate risk premium or the inflation risk premium.

The last column of Table 4 reports a regression of the liquidity return $r^L_{n,t+1}$ onto the liquidity-adjusted real term premium, the liquidity-adjusted breakeven inflation spread, and $L_{n,t}$. Table 4 shows that the liquidity return is predictable from the liquidity premium with a large and highly significant regression coefficient. Thus this table suggests the presence of a time-varying and predictable liquidity premium in TIPS.

The results shown in Table 4 strongly suggest that the rejection of the real and nominal expectations hypotheses in Pflueger and Viceira (2011) is not solely driven by liquidity factors. Instead our results offer support for the hypothesis of a time-varying real interest rate risk premium and a time-varying inflation risk premium. Table 4 also offers support for the hypothesis of the existence of a time-varying liquidity premium in TIPS.

4.2 Historical Fitted Risk Premia

We next look at the fitted bond risk premia and their components in order to better understand the economic significance of bond return predictability. Specifically, we now compare the means and variances of predicted excess log returns on real and nominal bonds, and discuss the historical behavior of fitted risk premia and their components extracted from our return predictability regressions. Thus our risk premium calculations are based on log returns with no variance adjustments for Jensen's inequality.

Table 5 shows the means and standard deviations of risk premia. We obtain the nominal risk premium, the risk premium on TIPS and the risk premium on breakeven as in Pflueger and Viceira (2011). They specify the nominal risk premium at any point in time as the expected excess log return on nominal bonds predicted by the nominal term spread. They similarly obtain TIPS and breakeven risk premia as fitted values of expected excess log return regressions. We obtain the inflation risk premium, the real rate risk premium and the liquidity premium as the fitted values from our liquidity-adjusted return predictability regressions shown in Table 4. The real rate risk premium is given by the expected liquidity-adjusted excess log return on TIPS fitted in column 1. The inflation risk premium is given by the fitted values for the expected liquidity-adjusted log return differential between TIPS and nominal bonds as reported in column 3. Finally, we obtain our liquidity return premium as the expected liquidity return in column 4.

Due to data constraints we were not able to compute a liquidity-adjustment for the UK. However, arguably liquidity-adjustments in the UK bond market are likely to be less significant than in the US bond market. UK inflation-linked bonds have been issued for a significantly longer period and therefore it appears plausible that initial learning should affect only a small portion of their time series. Moreover, neither UK nominal nor inflation-indexed bonds are likely to enjoy the same extraordinary liquidity benefits as US nominal Treasury bonds so arguably the liquidity premium between inflation-indexed and nominal UK bonds should be less significant.

Panel A in Table 5 shows the annualized fitted US risk premia. The average excess log return is 3.26% per annum (p.a.) for nominal Treasury bonds and 4.16% p.a. for TIPS over our sample period. The average log return on breakeven, or the difference between nominal log excess returns and TIPS log excess returns, is negative at -91 bps p.a. before adjusting for liquidity.

The estimated average liquidity return premium on TIPS is large at 1.38% p.a.. This premium is the average return due to liquidity over the period and equals the average liquidity premium in yields plus a term adjusting for the change in liquidity over our sample period. At the same time our estimates imply that a significant fraction of the total bond premium is attributable to the real interest rate risk premium, which at 2.86% p.a. on average is large even after adjusting for liquidity.

Our estimates attribute the negative risk premium on breakeven over our sample period to liquidity effects in TIPS. After adjusting for liquidity, we obtain an inflation risk premium of 75 bps p.a., which is positive but smaller than the real interest rate risk premium.

Another way to understand the economic significance of the estimated risk premia is by calculating their variabilities and comparing them to the variability of realized returns. From the second column of Panel A in Table 5 we see that the liquidity premium is the most volatile bond risk premium component. Its annual volatility is 3.15%, compared to 1.90% for the real rate risk premium and 1.38% for the inflation risk premium. The estimated inflation and real rate risk premia explain 3% and 5% of the sample variability of realized nominal bond returns, respectively. Liquidity appears to be an important driver of time-variation in TIPS returns. It explains 17% of the variance of realized TIPS returns, while the real rate risk premium explains

6% of the variance of realized TIPS returns.

Panel B in Table 5 shows the corresponding statistics for the UK for the longer sample period 1985-2009. Assuming that the liquidity premium in UK inflation-indexed bonds relative to nominal bonds is small, so that the risk premium on inflation-indexed bonds reflects the real rate risk premium and the risk premium on breakeven inflation reflects the inflation risk premium, our estimates imply that an average real rate risk premium of 1.66% p.a., and an average inflation risk premium of 1.81% per annum in UK bonds. Both components of bond risk premia are highly economically significant. In particular, we estimate a much larger inflation risk premium for UK bonds than for US bonds. In the estimation of the inflation risk premium we are relying on the simplifying assumption that UK inflation-indexed bonds are as liquid as nominal UK bonds. If instead UK inflation-indexed bonds were less liquid than nominal UK bonds then the actual inflation risk premium might be even higher. The high inflation risk premium might be explained by the longer sample period available for the UK, which spans a period in the late 1980's and early 1990's when arguably inflation uncertainty was more important than in the late 1990's and 2000's. It might also reflect a structurally larger inflation risk premium in the UK due to investors' perceptions of UK monetary and fiscal policy.

Figure 6A illustrates the time series of the fitted US risk premia. It shows that during the period of 2000 to 2006 the inflation risk premium was small or negative. 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, precisely at a time when the real rate risk premium increased sharply. The liquidity risk premium on TIPS was large in the early 2000's, but declined steadily during the decade, with the exception of a pronounced spike during the financial crisis in the Fall of 2008.

We can compare these estimates to the time series of real interest rate risk premia and inflation risk premia in the UK, shown in Figure 6B. 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.

5 Conclusion

This paper explores the sources, magnitude, and time variation in bond risk premia in US and UK inflation-indexed and nominal bonds. We find strong empirical evidence for two different potential sources of excess return predictability in inflation-indexed bonds: real interest rate risk and liquidity risk. We also provide empirical evidence that nominal bond return predictability is related not only to time variation in the real interest rate risk premium, but also to time variation in the inflation risk premium.

A high liquidity premium can explain why US TIPS have exhibited higher excess returns than nominal Treasuries over the 1999-2009 period. We estimate a large average real interest rate risk premium in US bonds, and a smaller inflation risk premium over this period. Our estimates for UK bonds suggest a much larger inflation risk premium for UK bonds for the period 1985-2009, and in particular during the financial crisis of 2008 and 2009.

We estimate the liquidity premium on TIPS yields relative to nominal Treasury bond yields using a variety of indicators of liquidity in the bond market. We show that the liquidity premium in TIPS yields exhibits strong time-variation, 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 to 70 bps after 2004, and a sharp increase to 250 bps during the height of 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. Once we adjust breakeven inflation for liquidity effects, we find it to be rather stable over our sample period, suggesting that bond investors long-term inflation expectations in the US have not moved significantly.

In our analysis of price pressures due to supply shocks in the inflation-indexed bond market we find no evidence for a supply channel in either the US or in the UK. Breakeven inflation does not appear to move with the relative supply of inflation-indexed debt. The relative supply of indexed debt does not enter significantly into predictive regressions of nominal and inflation-indexed bond returns, again offering no support for a market-segmentation hypothesis. If anything, our results are consistent with the government trying to accommodate shifts in the demand for nominal bonds, relative to inflation-indexed bonds.

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.

If real interest rate risk were the only source of time variation in bond risk premia, the difference between nominal bond excess returns and liquidity-adjusted real bond excess returns should not be predictable. However, we find empirical evidence that this difference is predictable, suggesting that a time-varying inflation risk premium is an additional determinant of nominal bond risk premia. Given that the liquidity premium in TIPS over our sample period was driven by some extraordinary events, such as the first introduction of TIPS and the financial crisis, one might expect real interest rate risk and inflation risk to play an even larger role for bond return predictability in the future.

Our results suggest several directions for future research. First, our results suggest that neither liquidity-adjusted real bond returns nor nominal bond returns in excess of liquidity-adjusted real bond returns are predicted by our proxies of liquidity. This indicates that liquidity premia may bear no relationship to real cash flow risks, a conclusion that should be important in guiding models of liquidity. 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 understand 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. Fourth, our analysis of supply effects in the inflation-indexed market suggests to further explore strategic behavior by the government in accommodating shifts in the demand for nominal and real bonds.

6 References

Acharya, Viral V., and Lasse Heje Pedersen, 2005, "Asset Pricing with Liquidity Risk", *Journal of Finance*, 77:375–410

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

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

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

Duffie, Darrel, Nicolae Gârleanu, and Lasse Heje Pedersen, 2005, "Over-the-Counter Markets", *Econometrica* 73(6):1815-1847

Duffie, Darrel, Nicolae Gârleanu, and Lasse Heje Pedersen, 2007, "Valuation in Over-the-Counter Markets", *Review of Financial Studies* 20(5):1865-1900

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.

Pflueger, Carolin E., and Luis M. Viceira, 2011, "Inflation-Indexed Bonds and the Expectations Hypothesis" forthcoming *Annual Review of Financial Economics*

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

Roll, Richard, 2004, "Empirical TIPS", Financial Analysts Journal 60: 31-53.

Vayanos, Dimitri, 2004, "Flight to Quality, Flight to Liquidity and the Pricing of Risk", *NBER Working Paper Series*, No. 10327

Vayanos, Dimitri, and Jean-Luc Vila, 2009, "A Preferred-Habitat Model of the Term Structure of Interest Rates", *NBER Working Paper Series*, No. 15487

Vayanos, Dimitri, and Tan Wang, 2007, "Search and endogenous concentration of liquidity in asset markets", *Journal of Economic Theory* 136:66 -104

Wachter, Jessica A., 2003, "Risk Aversion and Allocation to Long-Term Bonds", *Journal of Economic Theory* 112:325–333

Weill, Pierre-Olivier, 2007, "Liquidity premia in dynamic bargaining markets", *Journal of Economic Theory* 140:66-96

Table 1
Breakeven onto Liquidity Proxies US

$y^{\$}_{n,t} - y^{TIPS}_{n,t}$	(1)	(2)	(3)	(4)	(5)
Off-the-run	-0.56^{*}	-0.42^{*}	-0.53^{**}	-0.59^{**}	-0.56^{**}
	(0.25)	(0.21)	(0.18)	(0.17)	(0.15)
$GNMA$		-0.47^{**}	-0.37^{**}	-0.19	-0.21
		(0.08)	(0.12)	(0.11)	(0.16)
Transaction Volume			0.16	0.27^{**}	0.32^{**}
			(0.09)	(0.08)	(0.12)
$ASW^{spread}_{n,t}$	set -1	set -1	set -1	-1.59^{**}	
				(0.20)	
$p-value$	0.03	0.00	0.00	0.00	0.00
R^2	0.45	0.56	0.64	0.67	0.47
Sample Period	1999.1 – 2009.12		1999.3 – 2009.12		1999.3 – 2006.12

Newey-West standard errors with 3 lags in brackets.
$p-value$ of the F test for no predictability.
* and ** denote significance at the 5% and 1% level.

Table 2

$y^{\$}_{n,t} - y^{TIPS}_{n,t}$ **onto Relative Supply**

Panel A: US					**Panel B: UK**				
$Supply_t$	0.014		−0.012	−0.018	-0.27^{**}		0.29^{**}		0.29^{**}
	(0.023)		(0.054)	(0.018)	(0.06)		(0.05)		(0.05)
$\Delta Supply_t$		0.013	0.022	0.004		0.011		0.001	−0.014
		(0.019)	(0.017)	(0.006)		(0.014)		(0.011)	(0.010)
Off-the-run				-0.57^{**}					
				(0.17)					
$GNMA$				-0.18^{*}					
				(0.11)					
Transaction Volume				0.39^{**}					
				(0.15)					
$ASW^{spread}_{n,t}$				-1.55^{**}					
				(0.21)					
$month$			7×10^{-6}				$-3 \times 10^{-5**}$	$-2 \times 10^{-5**}$	$-3. \times 10^{-5**}$
			(1×10^{-5})				(3×10^{-6})	(2×10^{-6})	(3×10^{-6})
$p - value$	0.54	0.50	0.07	0.00	0.00	0.42	0.00	0.00	0.00
R^2	0.01	0.01	0.04	0.68	0.26	0.00	0.65	0.58	0.66
Sample Period	1999.1 − 2009.12		1999.3 − 2009.12				1985.1 − 2009.12		

Newey-West standard errors with 3 lags in brackets. $p - value$ of the F-test for no predictability.
* and ** denote significance at the 5% and 1% level.

Table 3
Return Predictability Controlling for Supply and Liquidity

	Panel A: US				**Panel B: UK**			
	$xr^{\$}_{n,t+1}$	$xr^{TIPS}_{n,t+1}$	$xr^{b}_{n,t+1}$	$xr^{b}_{n,t+1}$	$xr^{\$}_{n,t+1}$	$xr^{TIPS}_{n,t+1}$	$xr^{b}_{n,t+1}$	$xr^{b}_{n,t+1}$
$y^{\$}_{n,t} - y^{\$}_{1,t}$	2.35				3.23			
	(1.52)				(1.76)			
$y^{TIPS}_{n,t} - y^{TIPS}_{1,t}$		3.30**		−1.81		2.17		−3.02
		(1.23)		(1.19)		(1.41)		(1.95)
$b_{n,t} - b_{1,t}$			5.67*	6.44**			7.39**	8.97**
			(2.88)	(2.75)			(2.27)	(2.65)
$L_{n,t}$	−3.27	9.61	−13.10**	−9.78**			−0.51	−1.75
	(6.49)	(6.02)	(3.78)	(4.65)			(2.25)	(2.18)
$Supply_t$	0.26	0.14	−0.01	−0.21	−2.98	−2.72	0.00	−0.05
	(0.70)	(0.75)	(0.62)	(0.61)	(2.30)	(1.78)	(0.39)	(0.41)
$\Delta Supply_t$	0.17	0.10	0.17	0.04	−0.14	−0.12		
	(0.45)	(0.36)	(0.28)	(0.25)	(0.49)	(0.34)		
$month$					7×10^{-5}	2×10^{-4}**	-2×10^{-4}	-1×10^{-4}
					(1×10^{-4})	(9×10^{-5})	(1×10^{-4})	(1×10^{-4})
$p-value$	0.60	0.01	0.00	0.00	0.09	0.01	0.01	0.01
R^2	0.04	0.16	0.21	0.22	0.06	0.07	0.10	0.11
Sample Period		1999.3 − 2009.12				1985.4 − 2009.12		

Overlapping quarterly returns.
Newey-West standard errors with 3 lags in brackets. $p-value$ of the F-test for no predictability.
* and ** denote significance at the 5% and 1% level.

Table 4
Return Predictability Liquidity US

	$xr^{TIPS-L}_{n,t+1}$	$xr^{b+L}_{n,t+1}$	$xr^{b+L}_{n,t+1}$	$xr^{L}_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$	3.53^{*}		-1.66	-0.03
	(1.41)		(1.12)	(0.77)
$(b_{n,t} + L_{n,t}) - b_{1,t}$		2.94	3.42^{*}	-2.62
		(1.57)	(1.53)	(3.09)
$L_{n,t}$	-6.05	0.73	2.00	19.81^{**}
	(11.09)	(6.23)	(6.86)	(6.18)
$p-value$	0.05	0.17	0.11	0.02
R^2	0.06	0.04	0.07	0.26
Sample Period		$1999.6 - 2009.12$		

$-L_{n,t}$ is obtained as the fitted value from Table 1, Column 4.
$r^{L}_{n,t+1} = -(n-1)\,L_{n-1,t+1} + nL_{n,t}$ is the return on liquidity.
$xr^{TIPS-L}_{n,t+1}$ and $xr^{b+L}_{n,t+1} = xr^{b}_{n,t+1}$ are liquidity-adjusted excess returns. Overlapping quarterly returns.
Newey-West standard errors with 3 lags in brackets.
$p-value$ of the F-test for no predictability.
* and ** denote significance at the 5% and 1% level.

Table 5
Moments of Fitted Bond Risk Premia

Panel A: US

	$E(\widehat{y})$	$\sigma(\hat{y})$	$\sigma^2(\hat{y})/\sigma^2\left(xr_{n,t}^{\$}\right)$	$\sigma^2(\hat{y})/\sigma^2\left(xr_{n,t}^{TIPS}\right)$
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 Risk Premium	0.75	1.38	3%	
Real Rate Risk Premium	2.86	1.90	5%	6%
Liquidity Return Premium	1.38	3.15		12%

Panel B: UK

	$E(\widehat{y})$	$\sigma(\hat{y})$	$\sigma^2(\hat{y})/\sigma^2\left(xr_{n,t}^{\$}\right)$	$\sigma^2(\hat{y})/\sigma^2\left(xr_{n,t}^{TIPS}\right)$
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 (%). Risk premium $, risk premium TIPS and risk premium breakeven are obtained as in Pflueger and Viceira (2011) over 1999.4-2009.12 (US) and 1985.4-2009.12 (UK).
Real rate risk premium, inflation risk premium and liquidity return premium are obtained over 1999.6-2009.12 as fitted values from Table 4, columns 1, 3 and 4, respectively.

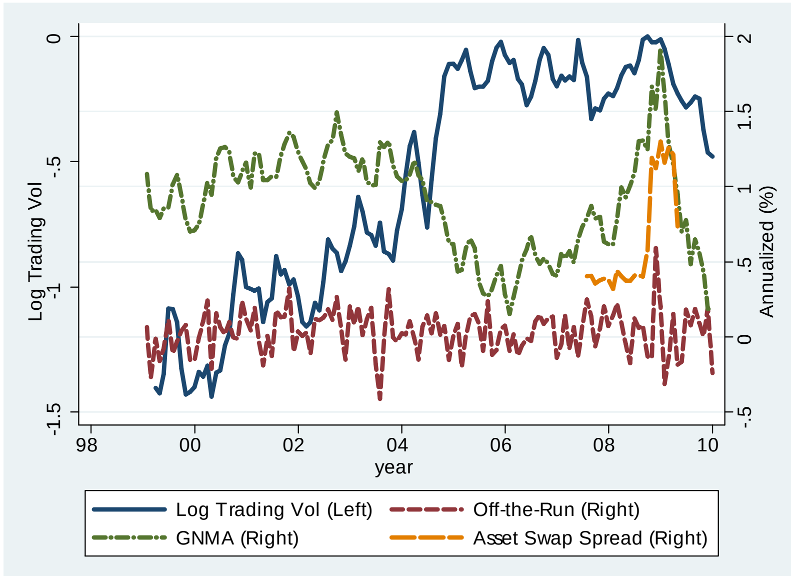

Figure 1: Liquidity Variables

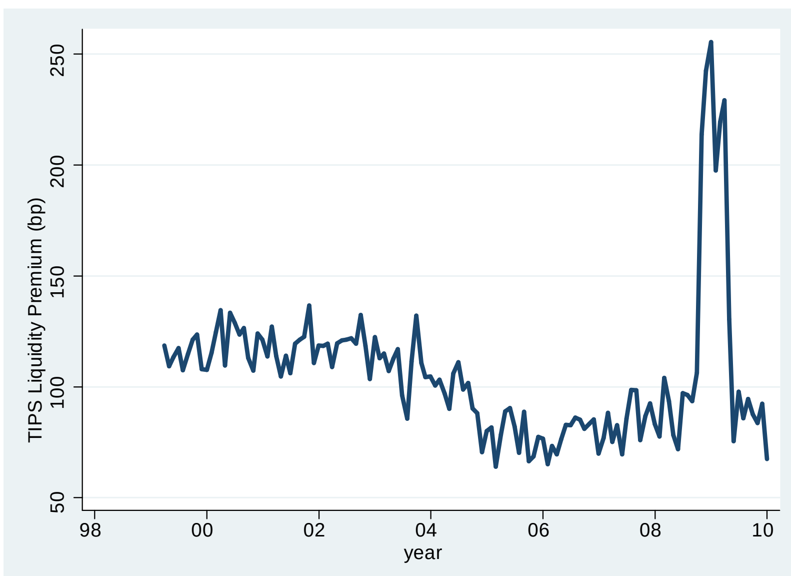

Figure 2: Estimated US Liquidity Premium

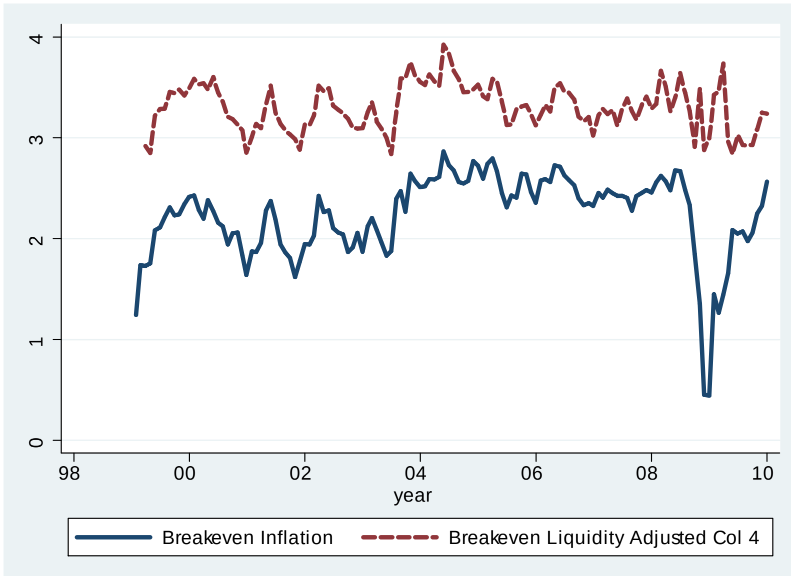

Figure 3: Liquidity-Adjusted US Breakeven Inflation

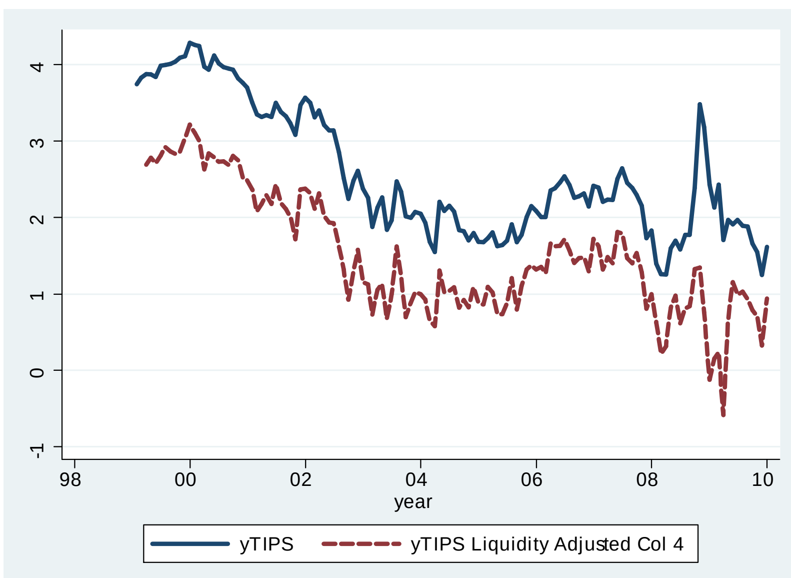

Figure 4: Liquidity-Adjusted US TIPS

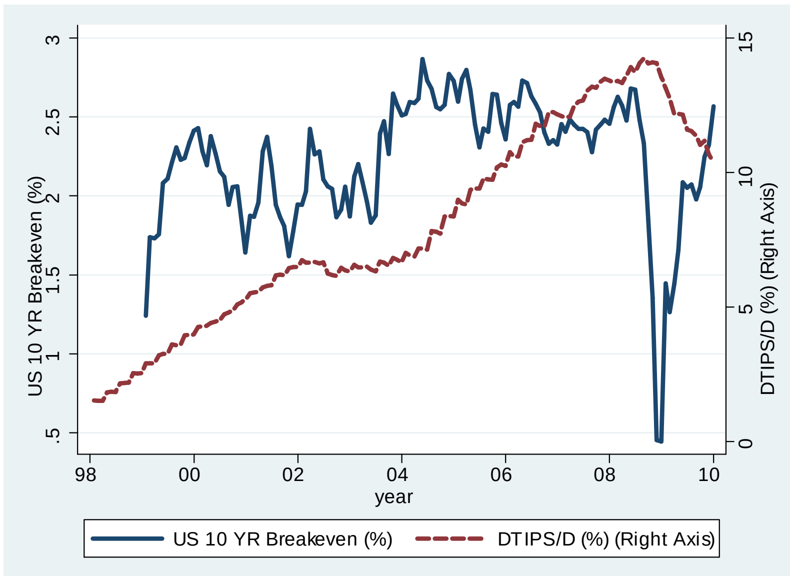

Figure 5A: US Relative Supply and 10 YR Breakeven

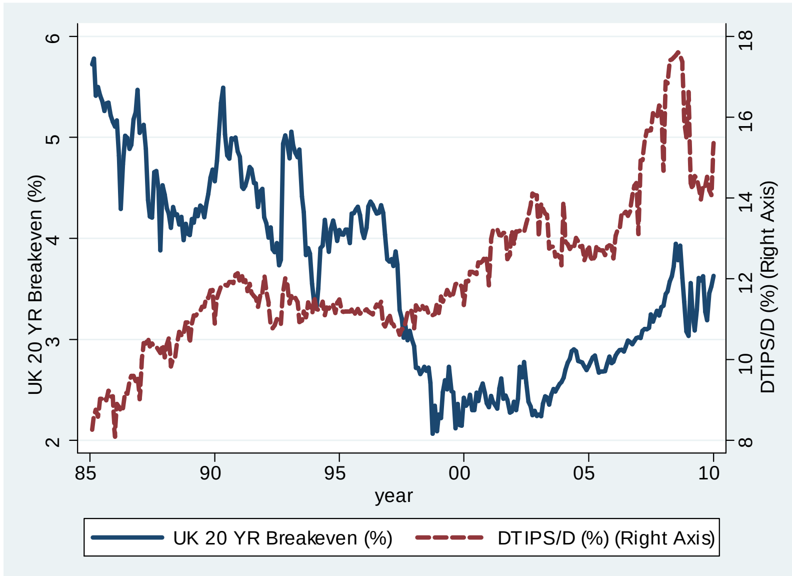

Figure 5B: UK Relative Supply and 20 YR Breakeven UK

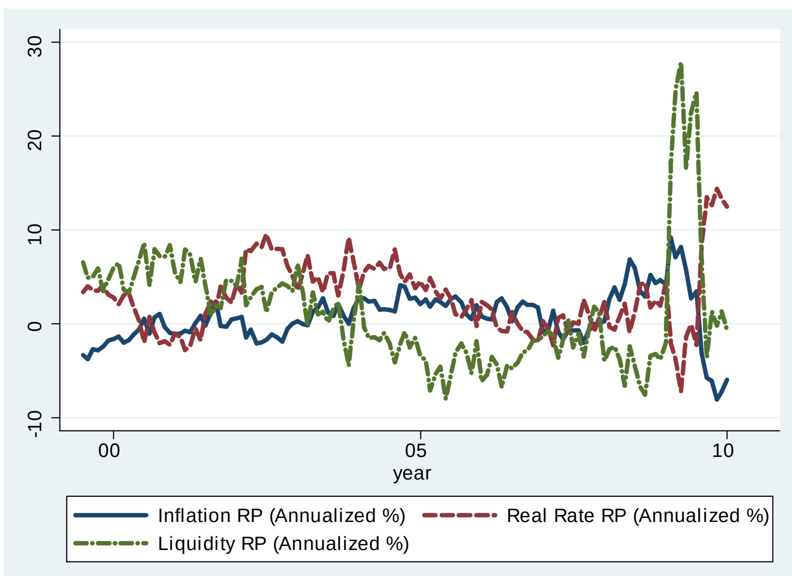

Figure 6A: Estimated US Risk Premia

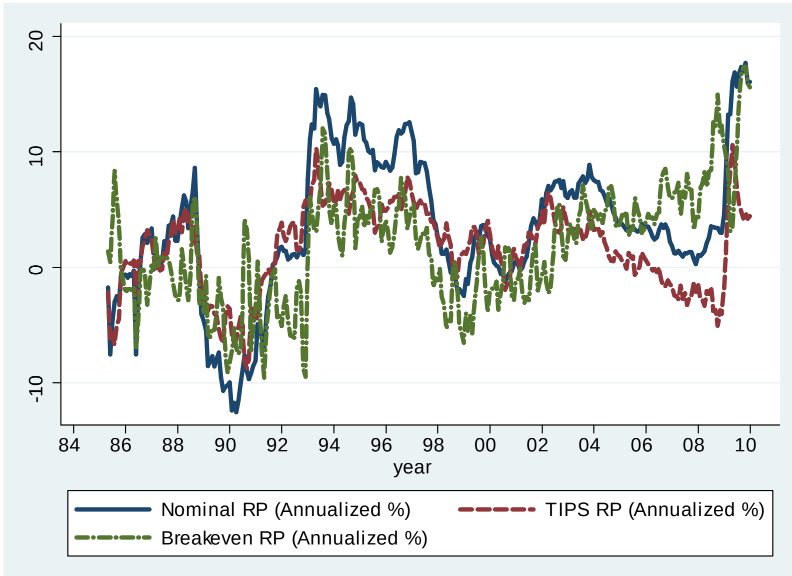

Figure 6B: Estimated UK Bond Risk Premia