Return Predictability in the Treasury Market: Real Rates, Inflation, and Liquidity

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Abstract

Estimating the liquidity differential between inflation-indexed and nominal bond yields, we separately test for time-varying real rate risk premia, inflation risk premia, and liquidity premia in U.S. and U.K. bond markets. We find strong, model independent evidence that real rate risk premia and inflation risk premia contribute to nominal bond excess return predictability to quantitatively similar degrees. The estimated liquidity premium between U.S. inflation-indexed and nominal yields is systematic, ranges from 40 bps in 2014 to over 200 bps during 2008-2009, and contributes to return predictability in inflation-indexed bonds.

I Introduction

There is wide consensus among financial economists that returns on nominal U.S. Treasury bonds in excess of Treasury bills are predictable at different investment horizons or, equivalently, that the expected excess return on nominal goverment bonds is time varying. Predictor variables include forward rates (Fama and Bliss, 1987), the slope of the yield curve (Campbell and Shiller, 1991), and a linear combination of forward rates (Cochrane and Piazzesi, 2005).

However, the question of whether the expected excess returns on inflation-indexed bonds is time varying remains relatively unexplored. This is partly due to the short history of inflation-indexed bonds in the U.S. and in other countries (Campbell, Shiller, and Viceira, 2009). Answering this question is important on its own, since inflation-indexed bonds are widely used by institutional and retail investors and a significant source of government funding.

It is also important because it can help understand the economic determinants of predictability in nominal bond excess returns (Campbell, Pflueger, and Viceira, 2014). Research in financial economics has proposed several theories to explain predictability in excess nominal bond returns. One hypothesis is that excess return predictability results from time variation in the aggregate price of risk. Building on the habit preferences model of Campbell and Cochrane (1999), Wachter (2006) shows that a model with time-varying real interest rates can generate nominal bond excess return predictability.

Another hypothesis is that excess return predictability could result from time variation in expected aggregate consumption growth or its volatility. The long-run consumption risk model of Bansal and Yaron (2004) and Bansal, Kiku, and Yaron (2010) emphasizes this possibility. Bansal and Shaliastovich (2013) show that this, combined with time-varying inflation volatility, can explain nominal bond predictability.

If excess bond return predictability is entirely due to time-varying habit or long-run consumption risk, then excess returns of real bonds should be predictable, since prices of both real and nominal government bonds change with the economy-wide real interest rate. Prices of nominal, but not real, government bonds also vary with expected inflation, so excess returns on nominal bonds over real bonds should not be predictable.

A third hypothesis is that the nominal nature of bonds is an important source of time-varying risk premia. In this case, the wedge between nominal and real bond returns should be predictable. Time-varying inflation risk premia are an important source of bond risks in Buraschi and Jiltsov (2005), Piazzesi and Schneider (2007), Gabaix (2012), Bansal and Shaliastovich (2013), Campbell, Sunderam, and Viceira (2013), and Campbell, Pflueger, and Viceira (2014).

We present in this chapter a joint empirical analysis of the sources of excess bond return predictability in nominal and inflation-indexed bonds in the U.S. and the U.K. This analysis establishes four main stylized facts or empirical findings. The first fact is that the yields of inflation-indexed bonds incorporate an economically significant time-varying liquidity premium with respect to the yields of nominal bonds of similar maturity. The second fact is that, adjusting yields and returns for this liquidity premium, inflation-indexed bonds exhibit excess return predictability which we can attribute to a time-varying real interest rate risk premium. The third fact is that both a time-varying real interest rate risk premium and a time-varying inflation risk premium are quantitatively important in explaining time variation in excess returns on nominal bonds.

The fourth fact is that the liquidity component in the yield differential between nominal and inflation-indexed bonds of similar maturity–also known as breakeven inflation–also predicts the return differential between nominal and inflation-indexed bonds. The estimated U.S. return differential due to liquidity exhibits a significantly positive stock market CAPM beta, suggesting that investors in U.S. inflation-indexed bonds (Treasury Inflation Protected Securities or TIPS) bear systematic liquidity risk and should be compensated in terms of a positive return premium. While the return differential due to liquidity is not directly tradable, this result is relevant to investors who may differ in terms of their exposure to liquidity crises.

The analysis starts by proposing an empirically flexible approach to estimate the liquidity differential between inflation-indexed and nominal bond yields. This approach consists in regressing breakeven inflation onto bond market liquidity proxies while controlling for inflation expectation proxies. Liquidity proxies explain almost as much variation in U.S. breakeven as do inflation expectation proxies. We estimate that the sample average ten year U.S. TIPS yield would have been 64 basis points (bps) lower if TIPS had been as liquid as nominal Treasury bonds. Liquidity variables have smaller, but still significant, explanatory power for U.K. breakeven. We find no evidence that residuals from liquidity regressions are non-stationary, alleviating concerns that results might be spurious.

Conditional on estimates of liquidity-adjusted returns, we find strong evidence that returns on nominal bonds in excess of real bonds are predictable from the breakeven term spread. We find that real bond excess returns are predictable from the real term spread. Time-varying liquidity risk contributes statistically and economically significantly to predictability in inflation-indexed bond excess returns. Our results suggest that a well specified model of bond return predictability should match substantial predictability in liquidity-adjusted real bond excess returns and in the liquidity-adjusted differential between nominal and real bond excess returns.

Interpreting expected real bond excess returns as real rate risk premia and expected returns on nominal bonds in excess of real bonds as inflation risk premia, we find that both are similarly variable and strongly correlated with the nominal term spread. Therefore, both inflation and real rate risk appear quantitatively important in explaining the predictability of nominal bond excess returns documented by Campbell and Shiller (1991). Moreover, we find that real rate risk premia and inflation risk premia can contribute either positively or negatively to expected nominal bond excess returns. These empirical findings are consistent across the U.S. and the U.K.

II Brief Literature Review

There is a limited body of academic research that explores excess return predictability in inflation-indexed bonds. Early work includes the studies of Barr and Campbell (1997) and Evans (1998) for the U.K., one of the first countries to issue inflation-indexed bonds in modern times (Campbell, Shiller, and Viceira, 2009). The study of Barr and Campbell (1997) tests for the expectations hypothesis of the term structure of interest rates in inflation-indexed bonds, or equivalently the hypothesis that the expected excess return on inflation-indexed bonds is constant, and it does not reject the hypothesis at short horizons. By contrast, Evans (1998) finds evidence of predictability at long horizons.

Recent work by Pflueger and Viceira (2011) shows that the slope of the real term structure forecasts positively excess returns on inflation-indexed bonds in both the U.K. and the U.S., consistent with the existing evidence of excess return predictability for nominal bonds (Campbell and Shiller 1991). The study also shows evidence that breakeven inflation forecasts positively the return differential between nominal and inflation-indexed bonds in both markets. Huang and Shi (2012) show that macroeconomic indicators also forecast inflation-indexed bond excess returns.

None of these studies controls for the impact of liquidity on the pricing of inflation-indexed bonds. Yet Campbell, Shiller, and Viceira (2009) and Gurkaynak, Sack, and Wright (2010) suggest that historically the market for TIPS has not been as liquid as the market for nominal Treasury bonds.[2] Liquidity could potentially explain part or all of the estimated predictability of excess returns on inflation-indexed bonds or the return differential between nominal and inflation-indexed bonds,[3] complicating interpretations of this predictability in terms of time-varying risk premia related to fundamentals such as real interest rate risk or inflation risk.

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[2] For additional evidence of relatively lower liquidity in U.S. TIPS, see Fleming and Krishnan (2009), Dudley, Roush, and Steinberg Ezer (2009), or Christensen and Gillan (2011).

[3] For example, the study of Fontaine and Garcia (2012) shows that liquidity predicts excess returns on nominal bonds, although it does not provide evidence on inflation-indexed bonds.

The question of what explains bond excess return predictability also arises in the context of the literature in fixed income that investigates the determinants of interest rates. This literature specifies no-arbitrage models of the term structure of interest rates to decompose nominal bond yields into components due to expected inflation, expected real rates, and risk premia related to fundamentals. Before pricing data on inflation-indexed bonds was rich enough to be of use in empirical research, studies estimated the models using nominal bond yield data combined with macroeconomic data on variables such as realized inflation or survey measures of expected inflation (Campbell and Shiller, 1996, Campbell and Viceira, 2001, Ang, Bekaert and Wei, 2008). Model estimates were then used to back out the unobserved term structure of real interest rates conditional on the specific parameterization of the model.

As the data on U.S. TIPS have become richer in both the time series dimension and in the cross-sectional dimension (Gurkaynak, Sack, and Wright, 2010), studies of the term structure of interest rates have started to make use of such data for model estimation and testing. Some examples include Chen, Liu, and Cheng (2010), Christensen, Lopez, and Rudebusch (2010), D'Amico, Kim, and Wei (2010), and Campbell, Sunderam, and Viceira (2013). With the exception of Campbell, Sunderam, and Viceira (2013), these studies do not focus explicitly on bond return predictability. But they produce estimates of the time series of real interest and inflation risk premia implied by their models.

A potential issue with these studies is that model-implied estimates of expected inflation, real interest rates, and real interest rate and inflation risk premia can be distorted if liquidity is an important determinant of bond yields and the model does not account for that possibility. D'Amico, Kim, and Wei (2010) is the only study that allows for the potential existence of a liquidity premium in inflation-indexed bond yields and shows that indeed model-implied estimates of the inflation risk premium and inflation expectations change significantly after accounting for such premium. Along these lines, Haubrich, Pennacchi, and Ritchken (2012) use nominal bond yields and inflation swap rates instead of TIPS yields to estimate a model of the nominal and real term structure of interest rates arguing that the inflation swap market is more liquid than the TIPS market. Fleckenstein, Longstaff, and Lustig (2013) show evidence of price discrepancies between U.S. inflation swap and TIPS markets which they attribute to mispricing of TIPS. We are not aware of any prior estimates of liquidity differentials between U.K. inflation-indexed and nominal bond markets.

This handbook chapter proposes a decomposition of nominal bond risk premia that does not rely on a specific parameterization of the stochastic discount factor. Thus it can provide guidance for a much wider range of asset pricing models. This chapter also uses a well-developed array of tools to address identification concerns in the presence of persistent variables, which can plague both ordinary least squares and affine term structure models (Bauer, Rudebusch, and Wu, 2012).

III Bond Data and Definitions

A Bond Notation and Definitions

Let $y_{n,t}^{\$}$ and $y_{n,t}^{TIPS}$denote nominal and inflation-indexed log (or continuously compounded) yields with maturity n. We use the superscript $TIPS$ for both U.S. and U.K. inflation-indexed bonds. Breakeven inflation is the difference between nominal and inflation-indexed bond yields:

$$b_{n,t} = y_{n,t}^{\$} - y_{n,t}^{TIPS}. \tag{1}$$

Log excess returns on nominal and inflation-indexed zero-coupon n-period bonds held for one period before maturity are given by:[4]

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

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

Inflation-indexed bonds are commonly quoted in terms of *real* yields, but since $xr^{TIPS}_{n,t+1}$ is an excess return over the *real* short rate it can be interpreted as a real or nominal excess return.

We define the log excess one-period breakeven return as the log return on a portfolio long one nominal bond and short one inflation-indexed bond with maturity n. This portfolio will have positive returns when breakeven inflation declines:

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

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

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

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

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

B Yield Data

We obtain zero-coupon off-the-run U.S. yields from the smoothed yield curves by Gurkaynak, Sack, and Wright (2007) and Gurkaynak, Sack, and Wright (2010, GSW henceforth). Using yields derived

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[4] These expressions follow directly from the fact that the log return on a one-period bill is given by its log yield $y_{1,t}$, and that the one-period log return on an n-period zeron coupon bond is given by the change in its log price, $p_{n-1,t+1} - p_{n,t}$, where $p_{n,t} = -ny_{n,t}$ by definition. See Campbell, Lo, and Mackinlay (1997), Chapter 10, p. 298.

from a smoothed yield curve is likely to reduce non-fundamental fluctuations in yields and therefore to bias downward the volatility of the estimated liquidity premium. We focus on 10-year nominal and real yields, because this maturity has the longest sample period. We compute quarterly log returns by substituting 10-year and 9.75-year zero coupon log yields into (2) and (3). Our sample period is 1999.3-2014.12 for yields and 1999.6-2014.12 for quarterly excess returns. We measure U.S. inflation with the all-urban seasonally adjusted Consumer Price Index (CPI), computed by the Bureau of Labor Statistics. The U.S. 3-month nominal interest rate is from the Fama-Bliss riskless interest rate file available on CRSP and Bloomberg.[5]

We use U.K. constant-maturity zero-coupon yield curves from the Bank of England, which are estimated with spline-based techniques (Anderson and Sleath, 2001). We use 20-year yields because those have the longest history. We compute quarterly log returns on 20-year nominal and real bonds using 20-year and 19.75-year zero coupon log yields.[6] Our sample covers 1999.11-2014.12 for U.K. yields and 2000.2-2014.12 for U.K. quarterly excess returns because liquidity variables only become available at the end of 1999. We use the non seasonally adjusted Retail Price Index, which is also used to calculate inflation-indexed bond payouts. U.K. three month Treasury bill rates are from the Bank of England (IUMAJNB).

The nominal principal value of U.S. TIPS adjusts with the CPI, but it can never fall below its original nominal face value. Consequently, a recently issued TIPS whose nominal face value is close to its original nominal face value contains a potentially valuable deflation option (Wright, 2010, Grishchenko, Vanden, and Zhang, 2011). The 10-year TIPS yield used for our empirical analysis is based on off-the-run TIPS issuances, which typically have high nominal face values relative to the deflation floor. Our empirical measure of the 10-year TIPS yield therefore likely does not contain

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[5] We use the CRSP 3-month T-bill for 1999.3-2013.12. We extend the data using month-end T-bill rates from Bloomberg (USGG3M) for 2014.1-2014.12. Monthly 3-month T-bill rates from CRSP and Bloomberg are 99.99% correlated for the period 1999.3-2013.12.

[6] The Bank of England only publishes 19.5 and 20-year zero coupon yields. We approximate the 19.75-year zero coupon log yield with the arithmetic average of 19.5 and 20-year log yields.

a significant deflation option. U.K. inflation-indexed bonds do not contain a deflation option.[7]

Since neither the U.S. nor the U.K. governments issue inflation-indexed bills, we build a hypothetical short-term real interest rate following Campbell and Shiller (1996) as the predicted real return on the nominal three month T-bill.[8] We use this real rate to construct excess returns on inflation-indexed bonds. Finally, although our yield data is available monthly, we focus on quarterly overlapping bond returns to reduce the influence of high-frequency noise in observed inflation and short-term nominal interest rate volatility in our tests.

IV Estimating the Liquidity Differential Between Inflation-Indexed and Nominal Bond Yields

Breakeven inflation should reflect investors' inflation expectations plus any compensation for bearing inflation risk. However, if the inflation-indexed bond market is not as liquid as the nominal bond market, inflation-indexed bond prices might reflect a liquidity discount relative to nominal bonds, or equivalently a liquidity premium in yields. This liquidity differential will impact breakeven inflation negatively.

We pursue an empirical approach to identify the liquidity differential between inflation-indexed and nominal bond markets in the U.S. and the U.K. We estimate the liquidity differential by regressing breakeven inflation on measures of liquidity as in D'Amico, Kim, and Wei (2008) and Gurkaynak, Sack, and Wright (2010), while controlling for inflation expectation proxies. We capture different notions of liquidity through three different liquidity proxies: the nominal off-the-run

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[7] 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), Campbell, Shiller, and Viceira (2009) and Gurkaynak, Sack, and Wright (2010). Campbell and Shiller (1996) offer a discussion of the taxation of inflation-indexed bonds.

[8] We predict the real return on a nominal T-bill using the lagged real return on the nominal three month T-bill, the lagged nominal T-bill, and lagged four quarter inflation over the sample 1982.1-2014.12. For simplicity we assume a zero liquidity premium on one-quarter real bonds.

spread, relative transaction volume of inflation-indexed bonds and nominal bonds, and proxies for the cost of funding a levered investment in inflation-indexed bonds.

Time-varying market-wide desire to hold only the most liquid securities, such as “flight to liquidity” episodes, might drive part of the liquidity differential between nominal and inflation-indexed bonds. We capture this notion of liquidity by the nominal U.S. off-the-run spread. The Treasury regularly issues new 10 year nominal notes and the newest “on-the-run” note is considered the most liquidly traded security in the Treasury bond market. The older “off-the-run”bond typically trades at a discount – i.e., at a higher yield – despite offering almost identical cash flows (Krishnamurthy, 2002).[9] The U.K. Treasury market does not have on-the-run and off-the-run bonds in a strict sense, since the Treasury typically reopens existing bonds to issue additional debt. We capture liquidity in the U.K. nominal government bond market with the difference between a fitted par yield and the yield on the most recently issued 10 year nominal bond, similarly to Hu, Pan, and Wang (2013). Hu, Pan, and Wang (2013) argue that such a measure captures market-wide liquidity and the availability of arbitrage capital. We refer to this U.K. measure as the “off-the-run spread” for simplicity.

Liquidity developments specific to inflation-indexed bond markets might also generate liquidity premia. When U.S. TIPS were first issued in 1997, investors might have had to learn about them and the TIPS market might have taken time to get established. More generally, following Duffie, Garleanu and Pedersen (2005, 2007) and Weill (2008), one can think of the transaction volume of inflation-indexed bonds as a measure of illiquidity due to search frictions.[10] We proxy for this idea with the transaction volume of inflation-indexed bonds relative to nominal bonds for the U.S. and the U.K., a measure previously used by Gurkaynak, Sack, and Wright (2010) for U.S. TIPS.

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[9] In the search model with partially segmented markets of Vayanos and Wang (2007) 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.

[10] See Duffie, Garleanu, and Pedersen (2005, 2007) and Weill (2008) for models of over-the-counter markets, in which traders need to search for counter parties and incur opportunity or other costs while doing so.

Fleming and Krishnan (2009) also provide evidence that trading activity is a good measure of cross-sectional TIPS liquidity.

Finally, we want to capture the cost of arbitraging between inflation-indexed and nominal bond markets for levered investors, and more generally the availability of arbitrage capital and the shadow cost of capital (Garleanu and Pedersen, 2011). In the U.S. and the U.K., a non-levered investor who perceives inflation-indexed bonds to be under priced relative to nominal bonds can enter a zero price portfolio long one dollar of inflation-indexed bonds and short one dollar of nominal bonds. If held to maturity, this position will effectively pay the investor cumulative inflation over the remaining life of the bonds, in exchange for paying breakeven inflation—or the yield differential between the nominal and inflation-indexed bonds—plus any funding costs of the position. The investor can effectively fund the long position in inflation-indexed bonds by borrowing against his nominal bond in the repo market.

A levered investor with no nominal bonds to borrow against in the repo market can replicate this position by entering into an inflation swap. A zero-coupon inflation swap is a contract where at maturity one party pays cumulative CPI inflation in exchange for a pre-determined fixed rate. The fixed rate is often referred to as synthetic breakeven inflation. A zero-coupon inflation swap does not require any initial capital. An inflation-swap position paying fixed and receiving floating is functionally equivalent to being long inflation-indexed bonds and short nominal bonds.

In practice, synthetic breakeven inflation and cash breakeven inflation are not equal, and the difference between the two varies over time reflecting variation in funding costs, or the cost of arbitraging between the cash market and the inflation-swap market (Viceira, 2011). The synthetic-cash breakeven inflation spread and the off-the-run spread in the U.S. are likely related to specialness of nominal Treasuries in the repo market and the lack of specialness of TIPS, which can vary over time.[11] Differences in specialness might be the result of variation in the relative liquidity of

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[11] A Treasury instrument is considered "on special" when its holders can use it as collateral to borrow at rates

securities, which make some securities easier to liquidate and hence more attractive to hold than others.

The spread between synthetic and cash breakeven inflation could potentially reflect mispricing or arbitrage opportunities between the two markets (Fleckenstein, Longstaff, and Lustig, 2013). When inflation-indexed bonds and inflation derivatives are not traded by the same marginal investor and investors face borrowing constraints, derivatives may not reflect all non-fundamental related fluctuations in inflation-indexed bond prices. However, the spread has historically tracked very closely the funding differentials between Treasury bonds and TIPS. We therefore control for investors' ability to finance a levered bond position, as reflected by mispricing between derivatives and bond markets, as an important but not the only potential source of non-payoff related fluctuations. We use the cash-synthetic breakeven inflation spread as our benchmark variable in the U.S., since it most closely captures the relative financing cost and specialness of TIPS over nominal Treasuries.

U.K. inflation swap data is not available. We use the LIBOR-general collateral (GC) repo interest-rate spread, as suggested by Garleanu and Pedersen (2011), to proxy for arbitrageurs' shadow cost of capital. In contrast to the cash-synthetic breakeven inflation spread, this measure cannot capture time-varying margin requirements of inflation-indexed bonds relative to nominal bonds.[12]

The estimated liquidity premium likely represents a combination of current ease of trading and

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significantly below prevailing market rates in the market for repurchase (or "repo") agreements. The prices of Treasury bonds "on special" tend to be larger than the prices of comparable bonds, reflecting their ability to produce interest rate savings when used in collateralized repo loans (Duffie, 1996, Buraschi and Menini, 2002). The repo "specialness" is the difference between the repo rate quoted for Treasury bonds that are not "on special" and the repo rate quoted for bonds that are "on special." In private email conversations Michael Fleming and Neel Krishnan report that for the period Feb. 4, 2004 to the end of 2010 average repo specialness was as follows. On-the-run coupon securities: 35 bps; off-the-run coupon securities: 6 bps; T-Bills: 13 bps; TIPS: 0 bps.

[12] We obtain the 3-month London Interbank Offered Rate (LIBOR), based on British Pound from the St. Louis Fed Fred data base http://research.stlouisfed.org/fred2/series/GBP3MTD156N. The General Collateral (GC) 3-month repo rate is from the Bank of England (IUDGR3M).

the risk that liquidity might deteriorate: If the liquidity of inflation-indexed bonds deteriorates during periods when investors would like to sell, as in “flight to liquidity” episodes, risk averse investors will demand a liquidity risk premium (Amihud, Mendelson, and Pedersen, 2005, Acharya and Pedersen, 2005). While the relative transaction volume of inflation-indexed bonds likely only captures the current ease of trading, the off-the-run spread, the smoothness of the nominal yield curve, the asset-swap spread and the LIBOR-GC spread are likely to represent both current liquidity and liquidity risk.

A Estimation Strategy

Let $b_{n,t}$ be breakeven inflation, X_t a vector of liquidity proxies, and π_t^e a vector of inflation expectation proxies. We estimate:

$$b_{n,t} = a_1 + a_2 X_t + a_3 \pi_t^e + \varepsilon_t, \tag{8}$$

Let $\hat{a}_2$ denote the vector of slope estimates in (8). The estimated liquidity premium in inflation-indexed yields over nominal yields is the negative of the variation in $b_{n,t}$ explained by the liquidity variables:

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

Variables indicating less liquidity in the inflation-indexed bond market, such as the off-the-run spread, the smoothness of the nominal yield curve, the asset-swap spread, and the LIBOR-GC spread, should enter negatively in (8). The relative transaction volume of the inflation-indexed bonds should enter positively.

We normalize liquidity variables to equal zero in a world of perfect liquidity. With perfect liquidity, the off-the-run spread, the smoothness of the nominal yield curve, the asset-swap spread, and the LIBOR-GC spread should be zero. U.S. and U.K. relative transaction volumes are normalized to a maximum of zero. This assumption might bias the estimated liquidity differential downward and does not affect the liquidity differential's estimated variability.

In order to obtain consistent liquidity estimates, the regression residual ε_t needs to be uncorrelated with liquidity proxies, controlling for inflation expectations. We do not include inflation risk proxies in the liquidity estimation (8) so as not to not preclude the outcome of our analysis. Not controlling for inflation risk premia is conservative in the following sense: If the estimated liquidity premium also happens to pick up on inflation risk premia in nominal bonds, then this should bias us against finding predictability in liquidity-adjusted breakeven returns.

If our liquidity proxies contain information on inflation expectations not already captured by included inflation variables, our estimate of the liquidity premium may be biased. We think that this is unlikely given that we control comprehensively for inflation expectations. In any case, changes in inflation expectations are not predictable if agents are rational. In that case, even if our estimate of the liquidity premium is correlated with inflation expectations, this type of potential mis-estimation will not introduce return predictability in either liquidity or liquidity-adjusted bond returns.

While our liquidity estimate most likely reflects liquidity fluctuations in both nominal bonds and in inflation-indexed bonds, we have to make an assumption in computing liquidity-adjusted inflation-indexed bond yields. We could assume that all of the liquidity premium is in nominal bonds, in which case we would not need to correct inflation-indexed bond yields. Here, we make the alternative assumption and adjust inflation-indexed assuming that the relative liquidity premium is entirely attributable to inflation-indexed bond illiquidity.[13] We refer to the following variables

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[13] See Pflueger and Viceira (2011) for evidence on predictability of TIPS excess returns with no liquidity adjustment.

as liquidity-adjusted inflation-indexed bond yields and liquidity-adjusted breakeven:

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

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

B Data on Liquidity and Inflation Expectation Proxies

The U.S. off-the-run spread is the difference between the 10 year GSW off-the-run par yield and the 10 year on-the-run nominal bond yield from Bloomberg (USGG10YR). For the U.K., we use the difference between the fitted 10 year nominal par yield available from the Bank of England (IUMMNPY) and the 10 year nominal on-the-run yield from Bloomberg.

We calculate U.S. and U.K. relative transaction volume as $\log\left(Trans_t^{TIPS}/Trans_t^{\$}\right)$ smoothed over the past three months. Here, $Trans_t^{TIPS}$ and $Trans_t^{\$}$ denote average monthly transaction volume for inflation-indexed and long-term nominal bonds. We use transaction volume for long-term nominal coupon bonds to capture the liquidity differential between inflation-indexed and equivalent maturity nominal bonds.[14]

[FIGURE 1 ABOUT HERE]

Data on 10 year zero-coupon inflation swaps are available from Bloomberg (USDSW10Y) from July 2004 onwards. The U.K. LIBOR-GC spread is the difference between three month British Pound LIBOR and three month British Pound GC rates.

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[14] For the U.S., we use Primary Dealers' transaction volumes from the New York Federal Reserve FR-2004 survey. We are grateful to the U.K. Debt Management Office for providing us with U.K. turnover data. In 2001 the Federal Reserve changed the maturity cutoffs. 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.

Figures 1A and 1B plot the time series of the U.S. and U.K. liquidity variables. The U.S. off-the-run spread was high during the late 1990s, declined during 2005-2007, jumped to over 50 bps during the financial crisis, and continued its decline afterwards. U.S. relative transaction volume rises linearly through 2004 and then stabilizes.[15] The differential between synthetic and cash breakeven inflation varies within a relatively narrow range of 15 to 45 bps during our sample period excluding the financial crisis period. Therefore, during our sample period it has always been more expensive to finance a long position in TIPS than in nominal Treasury bonds. This cost differential rose sharply during the financial crisis, reaching 113 bps in December 2008. Campbell, Shiller, and Viceira (2009) argue that the Lehman bankruptcy significantly affected TIPS liquidity because Lehman Brothers had been very active in the TIPS market. The unwinding of its large TIPS inventory, combined with a sudden increase in the cost of financing long positions in TIPS appears to have induced unexpected downward price pressure in the TIPS market.

Figure 1B shows a steady increase in the U.K. relative transaction volume. Greenwood and Vayanos (2010) argue that the U.K. pension reform of 2004, which required pension funds to discount future liabilities at long-term real rates, increased demand for inflation-indexed gilts and it seems plausible that the same reform also increased trading volume. Figure 1B shows that the LIBOR-GC spread peaked during the financial crisis, consistent with the notion that arbitrageurs' capital was scarce during this period. The smoother U.K. off-the-run spread might indicate that during flight-to-liquidity episodes investors have a preference for U.S. on-the-run nominal Treasuries.

We proxy for U.S. inflation expectations with the median 10 year CPI inflation forecast from the Survey of Professional Forecasters (SPF), consistent with bond maturities. We also include the Chicago Fed National Activity Index (CFNAI) to account for the possibility that shorter-term

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[15] Interestingly, the U.S. Treasury's renewed commitment to the TIPS issuance program (Bitsberger, 2003) and the development of synthetic markets occurred at a similar time.

inflation expectations enter into breakeven (Stock and Watson, 1999).[16] We proxy for U.K. inflation expectations using the median response to the question "How much would you expect prices in the shops generally to change over the next 12 months?" from the Bank of England Public Attitudes survey. Unfortunately, no longer forecasting horizon is available for our sample.

[TABLE I ABOUT HERE]

Summary statistics in Table I suggest that there was a substantial liquidity premium in U.S. TIPS yields relative to nominal yields, or a substantial negative inflation risk premium in nominal yields. Over our sample, U.S. average breakeven was 2.25% per annum (p.a.), average TIPS yields were 1.87% p.a., and average U.S. survey inflation was 2.43% p.a. If breakeven exclusively reflected investors' inflation expectations, the negative gap between U.S. breakeven and survey inflation would be surprising, especially given that the SPF tends to under predict inflation in low inflation environments (Ang, Bekaert, and Wei, 2007). In contrast, average U.K. breakeven exceeded survey inflation over the similar period 1999.11-2014.12.

Table I shows that realized log excess returns on U.S. Treasury bonds averaged 5.57% p.a. and exceeded average log excess returns on U.S. TIPS by 71 bps over our sample. This differential reverses in the U.K. At 4.14% p.a., average log excess returns on U.K. inflation-indexed bonds exceeded U.K. nominal log excess returns by 82 bps p.a.

C Estimating Differential Liquidity

Table IIA and IIB estimate the relation (8) for the U.S. and the U.K., respectively. We add liquidity proxies one at a time. For both panels, column (4) presents our benchmark estimate with

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[16] SPF survey expectations are available at a quarterly frequency and are released towards the end of the middle month of the quarter. We create a monthly series by using the most recently released inflation forecast.

all liquidity proxies and inflation expectation controls. The last two columns verify that results are robust to excluding the financial crisis.

[TABLE II ABOUT HERE]

Table IIA column (1) shows that inflation expectation proxies jointly explain 31% of the variability in U.S. breakeven. CFNAI enters positively and significantly, suggesting that short-run inflation expectations influence investors' long-run inflation expectations. Table I shows that SPF inflation expectations exhibit very little time variation. Table II suggests that this variation is unrelated to breakeven, after controlling for liquidity proxies and CFNAI.

Panel A shows that liquidity measures explain significant variation in U.S. breakeven inflation. The regression R^2 increases with the inclusion of every additional liquidity variable and reaches 59% in column (4). Column (2) shows that the off-the-run spread alone increases the regression R^2 by 17 percentage points. Column (5) adds a time trend to the regression, which enters significantly but does not impact the magnitude and statistical significance of the other variables, suggesting that our estimates of liquidity are not driven by a time trend, particularly in relative TIPS trading volume.

The coefficients in Table IIA are consistent with intuition and they are statistically significant. Breakeven inflation decreases in the off-the-run spread, suggesting that TIPS yields reflect a strong market-wide liquidity component. A one standard deviation move in the off-the-run spread of 12 bps tends to go along with a decrease in breakeven of 11.2 bps in our benchmark estimation (0.93×12 bps). These magnitudes are substantial relative to average breakeven of 225 bps. This empirical finding indicates that during flight-to-liquidity episodes, investors prefer nominal on-the-run U.S. Treasuries over U.S. TIPS, even though both types of bonds are fully backed by the U.S. Treasury.

Relative TIPS trading volume enters positively and significantly, indicating that search frictions impacted inflation-indexed bond prices during the early period of inflation-indexed bond issuance. As TIPS trading volume relative to nominal Treasury trading volume increased, TIPS yields fell relative to nominal bond yields. Our empirical estimates suggest that an increase in relative trading volume from its minimum in 1999 to its maximum in 2014 was associated with a decrease in the TIPS liquidity premium of 29 bps.

When the marginal investor in TIPS is levered, we would expect breakeven to fall one for one with the synthetic minus cash breakeven inflation spread. The estimated slope on the synthetic-cash breakeven inflation spread is at -1.32 just one standard deviation away of the theoretical value of -1. This slope estimate suggests that disruptions to securities markets and constraints on levered investors were important in explaining the sharp fall in breakeven during the financial crisis, when the synthetic-cash breakeven inflation differential spikes up.

We also find a strong relation between breakeven and liquidity proxies during the pre-crisis period. Column (6) in Panel A shows that before 2007, proxies for inflation expectations explain 28% of the variability of breakeven inflation. Column (7) shows that adding liquidity proxies more than doubles the regression R^2 to 58% and that the off-the-run spread enters with a strongly negative and significant coefficient.

Since some liquidity variables are persistent, one might be concerned about spuriousness. If there is no slope vector so that the regression residuals are stationary, Ordinary Least Squares is quite likely to produce artificially large R^2s and t-statistics (Granger and Newbold, 1974, Phillips, 1986, Hamilton, 1994). Table II shows that the augmented Dickey-Fuller test rejects the presence of a unit root in regression residuals for all regression specifications at conventional significance levels, including those specifications that include a time trend.

Table IIB shows that U.K. survey inflation explains a significant 46% of the variability in U.K.

breakeven inflation. Liquidity proxies enter with the predicted signs and increase the regression R^2 substantially to 61%. However, column (5) shows that introducing a time trend in the regression reduces both the magnitude and statistical significance of the coefficients survey inflation expectations and relative transaction volume, while it has the opposite effect on the LIBOR-GC spread, suggesting that market-wide liquidity conditions are an important determinant of high frequency variation in the yield differential between nominal and inflation-indexed bonds in the in U.K.

Columns (6) and (7) show that prior to the financial crisis, liquidity variables have somewhat greater explanatory power of the variability in U.K. breakeven inflation. In the pre-2007 sample, including the liquidity variables increases the regression R^2 to 67%. Interestingly, while in the full sample only relative transaction volume is individually statistically significant, in the pre-2007 sample the smoothness of the nominal yield curve also becomes statistically significant. Again, the augmented Dickey-Fuller tests reject the presence of a unit root for all regression specifications in the panel. Overall these results suggest that liquidity factors are important for understanding the time series variability of breakeven inflation both in the U.S. and the U.K.

[FIGURES 2A AND 2B ABOUT HERE]

Figures 2A and 2B plot estimated U.S. and U.K. liquidity premia from Table IIA (4) and Table IIB (4). The estimated U.S. liquidity premium averages 64 bps with a standard deviation of 26 bps over our sample. This high average reflects periods of very low liquidity in this market. Figure 2A shows a high liquidity premium in the early 2000's (about 70-100 bps), but a much lower liquidity premium between 2004 and 2007 (35-70 bps). The premium shoots up again beyond 200 bps during the crisis, and finally comes down to 40 bps at the end of our sample.

The estimated U.S. liquidity time series is consistent with previous estimates (D'Amico, Kim, and Wei (2008), Dudley, Roush, and Steinberg Ezer (2009), Gurkaynak, Sack, Wright (2010), Christensen and Gillan (2011), Haubrich, Pennacchi, and Ritchken (2012), Fleckenstein, Longstaff, and Lustig (2013)). However, we consider a more comprehensive set of liquidity proxies and estimate U.S. liquidity over a longer time period. We are not aware of any previous estimates of the liquidity differential between U.K. inflation-indexed and nominal bond yields.

The large liquidity premium in TIPS is puzzling given narrow TIPS bid-ask spreads. Haubrich, Pennacchi, and Ritchken (2012) report TIPS bid-ask spreads of at most 10 bps during the financial crisis. It seems implausible that the liquidity premium in TIPS yields simply serves to amortize transaction costs of a long-term investor.[17] If TIPS are held by buy-and-hold investors, as previously argued, then transaction costs of 10 bps can only justify a 1 bp liquidity premium for 10-year TIPS (Amihud, Mendelson, and Pedersen (2005)).

A simple calculation shows that the estimated liquidity premium in U.S. TIPS, though puzzlingly large when compared to bid-ask spreads, gives rise to liquidity returns in line with those on off-the-run nominal Treasuries. The on-the-run off-the-run liquidity differential converges in 6 months, when the new on-the-run nominal 10-year bond is issued. Thus, an average U.S. off-the-run spread of 17 bps yields an annualized return on the liquidity differential of 340 bps (annualized yield differential, 17× 2 bps, times the maturity of the bonds, 10 years). In contrast, the 10-year U.S. TIPS liquidity premium might take as long as 10 years to converge, yielding an average annualized return on U.S. TIPS liquidity of only 64 bps.

The estimated U.K. liquidity premium has a lower average (50 bps) but a similar standard deviation (25 bps) compared to U.S. liquidity. Figure 2B shows that the estimated U.K. liquidity premium was initially similar to the U.S. liquidity premium (around 100 bps), but declined to 10 bps towards the end of our sample. It even became briefly negative during the financial crisis,

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[17] See also Wright (2009).

reflecting extremely high relative transaction volume in U.K. inflation-indexed bonds.

[FIGURE 3 ABOUT HERE]

Figure 3A shows that liquidity-adjusted U.S. breakeven was substantially more stable than raw U.S. breakeven. Estimated liquidity-adjusted U.S. breakeven averaged 2.90% with a standard deviation of 25 bps over our sample. Adjusting breakeven for liquidity suggests that while investors' U.S. long-term inflation expectations fell during the crisis, there was never a period when investors feared substantial long-term deflation in the U.S.

Figure 3B partly attributes the strong upward trend in U.K. breakeven inflation to liquidity. However, even after adjusting for liquidity U.K. breakeven has trended upwards from around 3% to 3.5% over our sample. In contrast to the U.S., U.K. breakeven does not exhibit a pronounced drop during the financial crisis. Both raw and liquidity-adjusted U.K. breakeven become highly volatile during 2008-2010, potentially reflecting inflation uncertainty.

V Bond Excess Return Predictability

This section decomposes government bond excess returns into returns due to real interest rates, changing inflation expectations, and liquidity. We test for predictability in each component separately: Predictability in liquidity-adjusted real bond excess returns would indicate a time-varying real interest rate risk premium, while predictability in liquidity-adjusted breakeven returns would indicate a time-varying inflation risk premium. Predictability in the liquidity component of inflation-indexed returns would indicate a time-varying liquidity risk premium.[18]

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[18] Relative supply shocks and market segmentation of the type implied by the preferred habitat hypothesis of Modigliani and Sutch (1966) as formalized by Vayanos and Vila (2009) can also generate bond excess return predictability from the relative supply of inflation-indexed bonds (Greenwood and Vayanos, 2008, Hamilton and Wu, 2012). However, in unreported results we find that relative bond supply measures do not explain variation in breakeven

We adjust inflation-indexed and breakeven excess returns for liquidity and compute inflation-indexed bond returns due to illiquidity:

$$xr^{TIPS-L}_{n,t+1} = ny^{TIPS,adj}_{n,t} - (n-1)\, y^{TIPS,adj}_{n-1,t+1} - y^{TIPS}_{1,t}, \tag{12}$$

$$xr^{b+L}_{n,t+1} = xr^{\$}_{n,t+1} - xr^{TIPS-L}_{n,t+1}, \tag{13}$$

$$r^{L}_{n,t+1} = -(n-1)\, L_{n-1,t+1} + nL_{n,t}. \tag{14}$$

Table III regresses quarterly excess returns (12), (13), and (14) onto the lagged liquidity-adjusted real term spread $\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$, the lagged liquidity-adjusted breakeven term spread $(b_{n,t} + L_{n,t}) - b_{1,t}$, and the lagged estimated liquidity differential between inflation-indexed and nominal yields $L_{n,t}$. Intuitively, the three right-hand-side variables decompose the nominal term spread, used by Campbell and Shiller (1991) to predict nominal bond excess returns, into real term structure, inflation, and liquidity components. The table reports Newey-West standard errors with three lags and one-sided bootstrap p-values accounting for generated regressors.[19]

Ordinary least squares can overstate return-predictability in small samples, when the regressor is persistent and innovations are negatively correlated with returns (Stambaugh, 1999). In contrast, this correlation is typically negative for bond return predictability regressions (Bekaert, Hodrick, and Marshall, 1997). Therefore, the same small sample bias should bias us towards finding no predictability in real bond excess returns and breakeven returns.

[TABLE III ABOUT HERE]

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inflation nor predict bond excess returns. Thus we rule out this potential channel of excess return predictability for the remaining analysis.

[19] We use a non-parametric block bootstrap with block length 24 months and 2000 replications. We re-sample the data on inflation-indexed and nominal yields, liquidity variables, and inflation expectation proxies from non-overlapping blocks of length 24 with replacement. See Horowitz (2001) for a survey of bootstrap methods with serially dependent data.

Columns (1) and (2) in Table III show that the real term spread forecasts real bond excess returns positively, even controlling for liquidity, in the U.S. and the U.K. Bootstrap p-values in Columns (1) and (2) in Table III indicate that these positive coefficients are not statistically significant at conventional significance levels, even though Newey-West standard errors would indicate statistical significance. Of course, the relatively short sample may make it hard to detect predictability and bias our results towards finding no predictability. The liquidity-adjusted breakeven term spread and lagged liquidity do not enter significantly in columns (1) or (2) either in the U.S. or the U.K., as one might expect if those variables are unrelated to real interest rate risk.

Columns (3) and (4) in Tables IIIA and IIIB show that liquidity-adjusted breakeven term spreads predict breakeven excess returns with coefficients that are large, statistically significant, and similar across both countries. This empirical finding indicates that that time-varying inflation risk premia are a source of predictability in nominal bond excess returns and that the nominal term spread partly reflects time-varying inflation risk premia.

Remarkably, liquidity does not predict liquidity-adjusted real bond or breakeven excess returns in the U.S. or the U.K. The estimated liquidity differential does not appear related to fundamental bond cash-flow risk, alleviating concerns that estimated liquidity might capture time-varying inflation risk premia as a result of our estimation strategy.

The last two columns in Tables IIIA and IIIB show that liquidity $L_{n,t}$ predicts liquidity returns $r^{L}_{n,t+1}$ with large positive and highly significant coefficients. Time-varying and predictable liquidity premia are a source of inflation-indexed bond excess return predictability both in the U.S. and the U.K. Equivalently, the liquidity component in breakeven exhibits mean reversion. When liquidity in the inflation-indexed bond market is scarce, inflation-indexed bonds enjoy a higher expected return relatively to nominal bonds, rewarding investors who are willing to invest into a temporarily less liquid market.

A Economic Significance of Bond Risk Premia

[TABLE IV ABOUT HERE]

Table IV evaluates the economic significance of time-varying real rate risk premia, inflation risk premia, and liquidity risk premia. For simplicity we refer to the expected liquidity excess return as a liquidity risk premium, the expected liquidity-adjusted breakeven return as an inflation risk premium and expected liquidity-adjusted TIPS returns as a real rate risk premium. We note that our average return calculations are based on log returns with no variance adjustments for Jensen's inequality.

By construction, the average excess return on inflation-indexed bonds equals the sum of the liquidity risk premium plus the real rate risk premium. Column (1) of Panel A shows that, at 92 bps, the liquidity risk premium accounts for one-fifth of the average realized U.S. TIPS excess return over this period. Although the average estimated inflation risk premium is economically significant at 163 bps, it is substantially smaller than the average real interest rate risk premium of 394 bps over the same time period. Panel B shows that at 156 bps, the average estimated U.K. liquidity risk premium is even more substantial. The estimated inflation risk premium in U.K. nominal bonds is much lower at 74 bps, helping to explain low average log excess returns on nominal U.K. bonds.

Column (2) of Table IVA shows that the CAPM beta on U.S. liquidity-adjusted breakeven excess returns is negative, small, and not significant. But contrast, the CAPM beta on liquidity-adjusted TIPS excess returns is negative, large in absolute value, and and significant, and the CAPM beta on U.S. liquidity returns is positive and significant. The positive liquidity beta implies that TIPS tend to become illiquid relative to nominal Treasury bonds – or conversely, nominal bonds become liquid relative to TIPS – during stock market drops.[20] The strong positive covariation between

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[20] We compute CAPM betas using the stock market as the proxy for the wealth portfolio. The U.S. excess stock return is the log total return on the S&P 500 in excess of the log 3-month interest rate. The U.K. excess stock return is the log quarterly total return on the FTSE in excess of the log 3-month interest rate.

U.S. estimated liquidity returns and stock returns suggests that investors should earn a premium on TIPS for bearing systematic variation in liquidity.

In contrast, Table IVB shows that the U.K. liquidity beta is indistinguishable from zero. The CAPM beta of U.K. liquidity-adjusted breakeven returns is large, negative, and statistically significant, indicating pro-cyclical inflation expectations and nominal interest rates during our sample. Both procyclical nominal interest rates and low inflation risk premia are consistent with a view that nominal Treasuries were safe assets and provided investors with sizable diversification benefits over our sample.

The last two columns in Table IV tie our results back to the initial motivation and theory. Column (3) of Table IV reports roughly similar standard deviations for estimated real rate risk premia, inflation risk premia, and liquidity risk premia. The estimated components of bond excess returns therefore contribute quantitatively similarly to the predictability in standard Campbell and Shiller (1991) bond return forecasting regressions.

Column (4) of Table IV shows that the nominal term spread, shown by Campbell and Shiller (1991) to forecast nominal bond excess returns, is highly correlated with estimates of both inflation risk premia and real rate risk premia. The correlations between the nominal term spread and inflation risk premia range from 65% to 71%, while the correlations with real rate risk premia range from 88% to 92%.

[FIGURE 4 ABOUT HERE]

Figure 4 shows predicted 3-month excess returns or real rate risk premia, inflation risk premia, and liquidity risk premia. While magnitudes may appear large, Figure 4 shows predicted 3-month returns in annualized units and not predicted 12-month returns. Figure 4A shows a negative U.S.

inflation risk premium in the early part of the sample which turns positive in 2003. The inflation risk premium became highly positive during the period of high oil prices in 2008 and fell to almost -10% at the beginning of 2009, just when the U.S. real rate risk premium increased sharply.

A large and positive U.S. real interest rate risk premium during the crisis indicates that real bonds were considered risky, so a deepening of the recession was considered likely to go along with high long-term real interest rates. The liquidity risk premium on real bonds relative to nominal bonds spiked in the U.S., but not in the U.K. during the financial crisis. The U.K. liquidity risk premium even declined, suggesting that investors did not consider U.K. real bonds risky due to illiquidity.

U.S. and U.K. inflation risk premia present a contrasting picture during the financial crisis, mirroring contrasting inflation experiences. In contrast to the U.S., the U.K. inflation risk premium shot up during the financial crisis. This high inflation risk premium likely reflected the high level and volatility of U.K. inflation during the financial crisis.

VI Conclusion

This chapter explores the sources of time variation in bond risk premia in nominal and inflation-indexed bonds in the U.S. and the U.K. We find strong empirical evidence in both markets that nominal bond excess return predictability is related to time variation in inflation risk premia. Inflation risk premia exhibit significant time variation, are low on average, and take both positive and negative values in our sample. We find strong evidence in U.K. data that predictability in nominal bond excess returns is also related to time-varying real interest rate risk premia.

We find strong empirical evidence for both time-varying real rate and time-varying liquidity risk premia in inflation-indexed bonds in both markets. Liquidity risk premia in U.S. TIPS account for

92 bps of TIPS excess returns over our sample. Our results suggest that bond investors receive a liquidity discount for holding inflation-indexed bonds. However, this time-varying discount exposes them to systematic risk as measured by a positive and statistically significant CAPM beta.

The estimated liquidity premium in U.S. TIPS yields relative to nominal yields is economically significant and strongly time-varying. We estimate a large premium early in the life of TIPS, a decline after 2004, and a sharp increase to over 200 bps during the height of the financial crisis in the fall of 2008 and winter of 2009. Since then, the premium has declined to much lower levels of 40 to 50 bps. The estimated relative liquidity premium might partly reflect a convenience yield on nominal bonds (Krishnamurthy and Vissing-Jorgensen, 2012), rather than a liquidity discount specific to TIPS. In this case, TIPS are not undervalued securities, but instead investors may be willing to pay a liquidity premium on nominal Treasury bonds.

Estimated inflation risk premia, real rate risk premia and liquidity risk premia are roughly equally quantitatively important as sources of bond excess return predictability. Inflation risk premia and real rate risk premia are strongly correlated with the nominal term spread, while liquidity risk premia are not. The empirical results in this paper have important implications for modeling and understanding predictability in bond excess returns. We find an important role for time-varying real interest rate risk, which can be modeled either in a model of time-varying habit (Wachter, 2006) or in a model of time variation in expected aggregate consumption growth or its volatility (Bansal and Yaron, 2004, Bansal, Kiku, and Yaron, 2010). However, our results indicate that time-varying inflation risk is equally important for understanding the time-varying risks of nominal government bonds. A model that aims to capture predictability in nominal government bond excess returns therefore has to integrate sources of real interest rate risk and inflation risk.

Our results suggest directions for future research. Different classes of investors have different degrees of exposure to time-varying liquidity risk, real interest rate risk and inflation risk. Exposures may vary with shares of real and nominal liabilities and time horizons. Understanding the sources of bond return predictability can therefore have potentially important implications for investors' portfolio management and pension investing.

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Table I: Summary Statistics.

Nominal and inflation-indexed bond yields, excess returns, inflation expectation proxies and liquidity proxies. U.S. 10 year nominal and TIPS yields from Gurkaynak, Sack, and Wright (2010). U.K. 20 year nominal and inflation-indexed yields from Anderson and Sleath (2001). U.S. three-month log excess returns (1999.6-2014.12) and U.K. three-month log excess returns (2000.2-2014.12) are computed using zero-coupon log yields. U.S. survey inflation is the median 10 year CPI inflation forecast from the Survey of Professional Forecasters. The Chicago Fed National Activity Index (CFNAI) is as in Stock and Watson (1999). U.K. survey inflation reflects Bank of England Public Attitudes Survey 12 month inflation expectations. U.S. difference between synthetic and cash breakeven (2004.7-2014.12), and U.K. 3-month GBP LIBOR minus general collateral (GC) spread capture cost of arbitraging between nominal and inflation-indexed bonds. We normalize the maxima of relative transaction volumes to zero. The U.K. off-the-run spread reflects the spread between a fitted 10 year nominal par yield and the generic 10 year nominal U.K. bond yield from Bloomberg. Spreads and zero-coupon yields continously compounded in annualized percent.

Panel A: U.S. (1999.3-2014.12)		Mean	Std	Min	Max
Nominal Yields	$y^{\$}_{n,t}$	4.12	1.26	1.55	6.70
Inflation-Indexed Yields	$y^{TIPS}_{n,t}$	1.87	1.30	-0.79	4.29
Breakeven	$b_{n,t}$	2.25	0.36	0.39	2.87
Nominal Excess Ret.	$xr^{\$}_{n,t+1}$	5.57	8.74	-40.11	58.56
Infl.-Indexed Excess Ret.	$xr^{TIPS}_{n,t+1}$	4.86	7.64	-64.78	58.58
Breakeven Excess Ret.	$xr^{b}_{n,t+1}$	0.71	6.79	-41.26	76.74
Survey Inflation	π^E	2.43	0.10	2.20	2.55
Chicago Fed Nat. Activity	CFNAI	-0.27	0.89	-4.57	1.16
Off-the-Run Spr.		0.17	0.12	-0.01	0.63
Log Transaction Vol.		-0.66	0.47	-1.68	0.00
Synthetic - Cash		0.29	0.15	0.10	1.13

Panel B: U.K. (1999.11-2014.12)		Mean	Std	Min	Max
Nominal Yields	$y^{\$}_{n,t}$	4.14	0.57	2.45	5.01
Inflation-Indexed Yields	$y^{TIPS}_{n,t}$	1.14	0.82	-0.79	2.44
Breakeven	$b_{n,t}$	3.00	0.45	2.14	3.95
Nominal Excess Ret.	$xr^{\$}_{n,t+1}$	3.31	11.32	-49.72	77.67
Infl.-Indexed Excess Ret.	$xr^{TIPS}_{n,t+1}$	4.14	8.93	-67.51	45.25
Breakeven Excess Ret.	$xr^{b}_{n,t+1}$	-0.82	8.48	-49.34	68.35
Survey Inflation	π^E	2.77	0.68	1.50	4.40
Off-the-Run Spr.		0.05	0.06	-0.06	0.32
Log Transaction Vol.		-0.79	0.37	-1.64	0.00
LIBOR-GC Spr.		0.30	0.32	0.04	2.19

Table II: Estimating Differential Liquidity.

We regress the difference between nominal and inflation-indexed bond yields (breakeven inflation) onto liquidity proxies. The variables are as described in Table I. Newey-West standard errors with three lags in parentheses. * and ** denote significance at the 5% and 1% level, respectively.

Panel A: U.S. (1999.3-2014.12)

$y^{\$}_{n,t} - y^{TIPS}_{n,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Off-the-Run Spr.		-1.69**	-1.44**	-0.93**	-0.98**		-1.56**
		(0.29)	(0.28)	(0.32)	(0.30)		(0.44)
Synthetic-Cash			-1.13**	-1.32**	-1.31**		-0.68
			(0.29)	(0.30)	(0.29)		(0.61)
Transaction Vol.				0.17*	0.35**		0.10
				(0.07)	(0.09)		(0.08)
Month$\times 10^{-2}$					-0.25*		
					(0.11)		
Survey Inflation	0.25	1.10**	0.92**	1.06**	0.47	0.77	0.55
	(0.32)	(0.36)	(0.32)	(0.33)	(0.46)	(1.65)	(0.63)
CFNAI	0.23**	0.12**	0.04	0.07*	0.06	0.27**	0.18**
	(0.05)	(0.04)	(0.03)	(0.03)	(0.03)	(0.05)	(0.04)
Adjusted R-squared	0.31	0.48	0.57	0.59	0.60	0.28	0.58
ADF of Residuals	−4.43**	−4.75**	−4.29**	−4.84**	−4.91**	−4.54**	−3.22*
Period	Full	Full	Full	Full	Full	1999.3 – 2006.12	

Panel B: U.K. (1999.11-2014.12)

$y^{\$}_{n,t} - y^{TIPS}_{n,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Off-the-Run Spr.		0.19	0.10	-0.52	0.02		-3.11**
		(0.65)	(0.76)	(0.72)	(0.61)		(0.60)
LIBOR-GC Spr.			0.05	0.19	0.20*		0.32
			(0.15)	(0.14)	(0.10)		(0.31)
Transaction Vol.				0.68**	-0.07		0.47**
				(0.12)	(0.21)		(0.13)
Month$\times 10^{-2}$					0.64**		
					(0.16)		
Survey Inflation	0.45**	0.45**	0.44**	0.20**	0.11	0.54**	0.22**
	(0.06)	(0.07)	(0.07)	(0.06)	(0.09)	(0.12)	(0.08)
Adjusted R-squared	0.46	0.46	0.46	0.61	0.71	0.28	0.64
ADF of Residuals	−2.62	−2.64	−2.66	−3.67**	−3.45*	−2.79*	−3.03*
Period	Full	Full	Full	Full	Full	1999.11 – 2006.12	

Table III: Liquidity-Adjusted Bond Return Predictability.

We predict 3-month overlapping liquidity-adjusted excess log returns of inflation-indexed bonds and of nominal bonds in excess of inflation-indexed bonds using the liquidity-adjusted inflation-indexed term spread, the liquidity-adjusted breakeven term spread, and the liquidity differential $L_{n,t}$. $L_{n,t}$ is estimated as the negative of the variation explained by liquidity variables in Table II(4). $r^L_{n,t+1}$ is the return on inflation-indexed bonds due to illiquidity. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. We show one-sided bootstrap p-values from 2000 replications to account for the fact that liquidity is estimated. We use block bootstrap with block length 24 months.

Panel A: U.S. (1999.6-2014.12)

		(1) $xr^{TIPS-L}_{n,t+1}$	(2) $xr^{TIPS-L}_{n,t+1}$	(3) $xr^{b+L}_{n,t+1}$	(4) $xr^{b+L}_{n,t+1}$	(5) $r^{L}_{n,t+1}$	(6) $r^{L}_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$		3.00	2.60		-0.41		0.45
	Newey-West SE	(1.24)	(1.31)		(1.11)		(0.65)
	Bootstrap p-value	7.45%	14.85%		30.40%		42.00%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			1.76	4.14	4.02		-0.49
	Newey-West SE		(2.80)	(1.69)	(1.91)		(1.82)
	Bootstrap p-value		38.75%	0.00%	0.00%		40.00%
$L_{n,t}$			2.59		-3.65	12.60	11.91
	Newey-West SE		(8.79)		(5.91)	(3.51)	(4.26)
	Bootstrap p-value		22.05%		30.75%	0.00%	0.00%
Const.		-0.00	-0.01	-0.00	0.00	-0.02	-0.02
	Newey-West SE	(0.01)	(0.02)	(0.00)	(0.01)	(0.01)	(0.01)
	Bootstrap p-value	74.00%	15.75%	7.30%	46.20%	0.00%	0.25%
p-value		0.02	0.12	0.02	0.04	0.00	0.00
Adjusted R-squared		0.04	0.04	0.06	0.07	0.17	0.16
Sample				1999.6 − 2014.12			

Panel B: U.K. (2000.2-2014.12)

		(1) $xr^{TIPS-L}_{n,t+1}$	(2) $xr^{TIPS-L}_{n,t+1}$	(3) $xr^{b+L}_{n,t+1}$	(4) $xr^{b+L}_{n,t+1}$	(5) $r^{L}_{n,t+1}$	(6) $r^{L}_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$		4.80	3.32		-0.82		-0.49
	Newey-West SE	(1.72)	(2.43)		(2.62)		(1.23)
	Bootstrap p-value	14.60%	14.70%		28.80%		40.90%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			-3.62	5.46	6.48		3.17
	Newey-West SE		(2.93)	(3.02)	(3.38)		(1.86)
	Bootstrap p-value		6.35%	0.10%	0.05%		11.50%
$L_{n,t}$			-21.04		7.42	13.08	13.64
	Newey-West SE		(13.43)		(15.71)	(4.73)	(6.40)
	Bootstrap p-value		36.40%		35.75%	0.00%	0.00%
Const.		0.00	0.04	-0.01	-0.02	-0.01	-0.02
	Newey-West SE	(0.01)	(0.02)	(0.01)	(0.03)	(0.01)	(0.01)
	Bootstrap p-value	67.50	33.65	2.30%	19.50%	6.70%	6.75%
p-value		0.01	0.00	0.07	0.27	0.00	0.01
Adjusted R-squared		0.08	0.12	0.04	0.04	0.09	0.12
Sample				2000.2 − 2014.12			

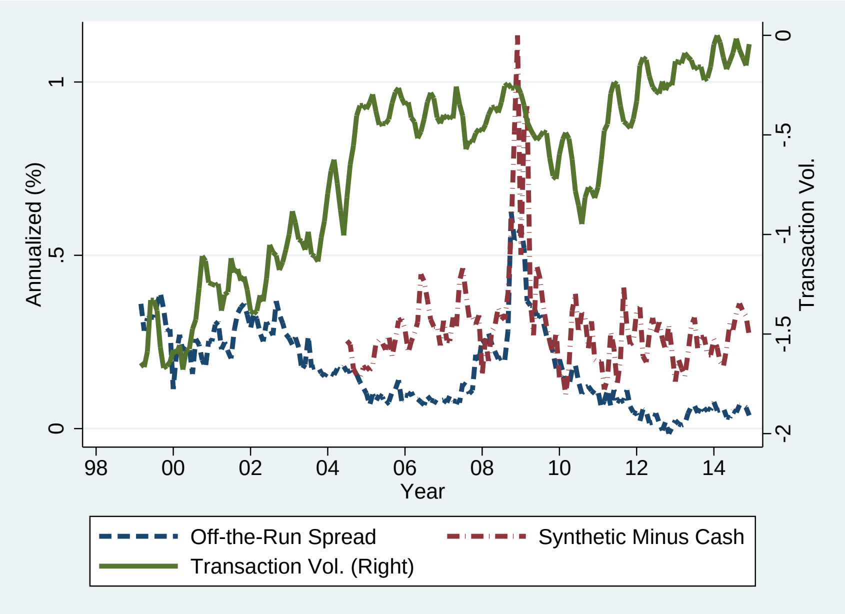
Table IV: Decomposing Bond Risk Premia.

We show statistics for realized and predicted 3-month overlapping log excess returns on real bonds and breakeven, and average log liquidity returns. Realized log excess returns are denoted $xr_{n,t}$, while predicted log excess returns are denoted $E_t\left(xr_{n,t+1}\right)$. We report the average log excess return $\hat{E}\left(xr_{n,t}\right)$, stock market beta $\hat{\beta}\left(xr_{n,t}\right)$, standard deviation of predicted log excess returns $\hat{\sigma}\left(E_t xr_{n,t+1}\right)$, and the correlation between predicted log excess return and the nominal term spread $\widehat{corr}\left(E_t xr_{n,t+1}, y_{n,t}^{\$} - y_{1,t}^{\$}\right)$. Betas are with respect to excess log stock returns on the S&P 500 (U.S.) and the FTSE (U.K.). We obtain predicted excess returns as fitted values from the regressions shown in Tables III(1), III(3) and III(5). Numbers shown are annualized (%). Newey-West standard errors for $\hat{\beta}$ are computed with three lags. * and ** denote significance at the 5% and 1% level for $\hat{\beta}$, respectively.

Panel A: U.S. (1999.6-2014.12)	$\hat{E}\left(xr_{n,t}\right)$	$\hat{\beta}\left(xr_{n,t}\right)$	$\hat{\sigma}\left(E_t xr_{n,t+1}\right)$	$\widehat{corr}\left(E_t xr_{n,t+1}, y_{n,t}^{\$} - y_{1,t}^{\$}\right)$
Liquidity-Adjusted Breakeven	1.63	-0.07	1.33	0.65
Liquidity-Adjusted Inflation-Indexed	3.94	-0.16*	1.52	0.88
Log Return Liquidity	0.92	0.12**	1.62	0.13

Panel B: U.K. (2000.2-2014.12)	$\hat{E}\left(xr_{n,t}\right)$	$\hat{\beta}\left(xr_{n,t}\right)$	$\hat{\sigma}\left(E_t xr_{n,t+1}\right)$	$\widehat{corr}\left(E_t xr_{n,t+1}, y_{n,t}^{\$} - y_{1,t}^{\$}\right)$
Liquidity-Adjusted Breakeven	0.74	-0.27^{**}	2.15	0.71
Liquidity-Adjusted Inflation-Indexed	2.58	0.15	3.32	0.92
Log Return Liquidity	1.56	-0.04	1.60	-0.54

Panel A: U.S. (1999.3-2014.12)



Panel B: U.K. (1999.11-2014.12)

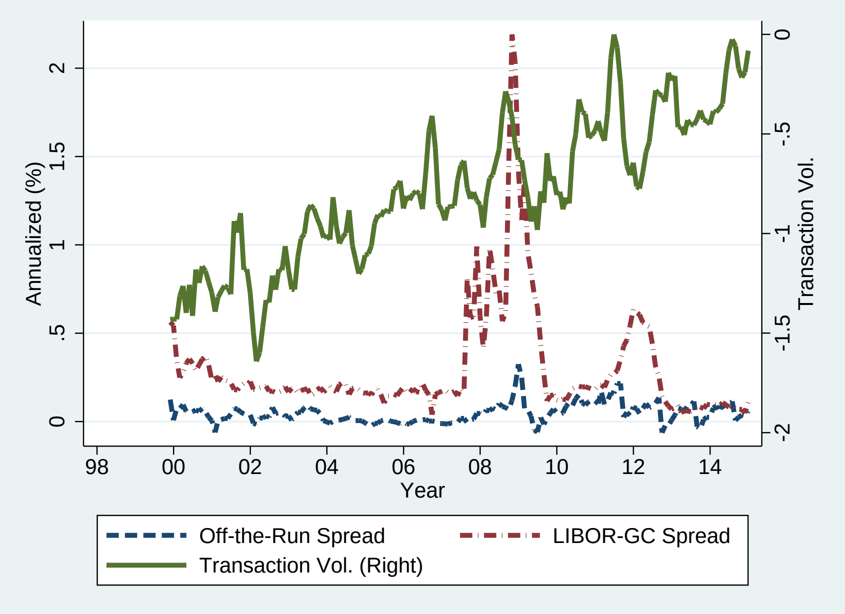
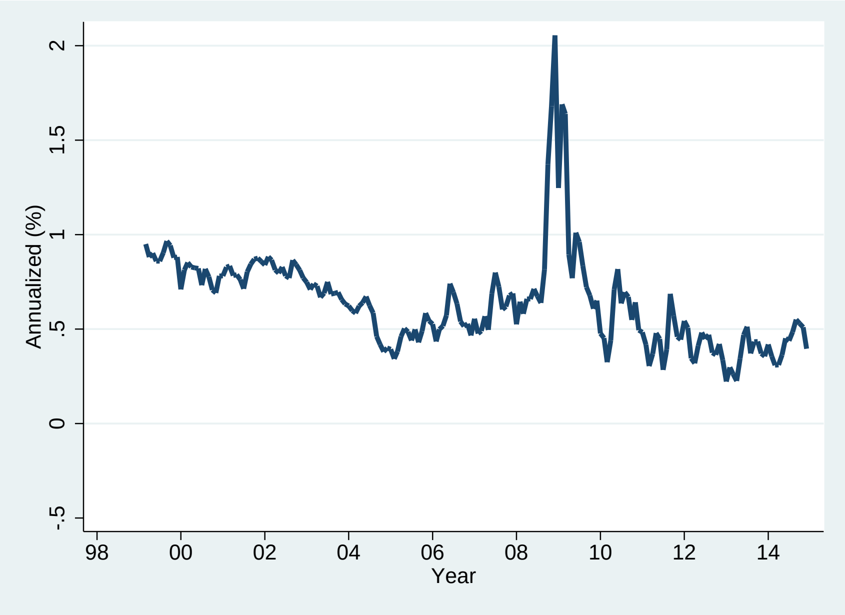


Figure 1: U.S. and U.K. Liquidity Proxies.

We use liquidity proxies to estimate differential liquidity between inflation-indexed and nominal government bonds. For the U.S., we use the spread between off-the-run and on-the-run 10 year nominal bond yields, the relative inflation-indexed bond log transaction volume, the difference between synthetic and cash breakeven. For the U.K., we use the difference between a 10 year nominal fitted par yield and the 10 year nominal generic Bloomberg yield, denoted “off the run”. We normalize the maxima of relative transaction volumes to zero. The asset-swap spread differential, synthetic minus cash breakeven, and the GBP three-month LIBOR-GC spread proxy for the cost of funding a levered investment in inflation-indexed bonds.

Panel A: U.S. (1999.3-2014.12)



Panel B: U.K. (1999.11-2014.12)

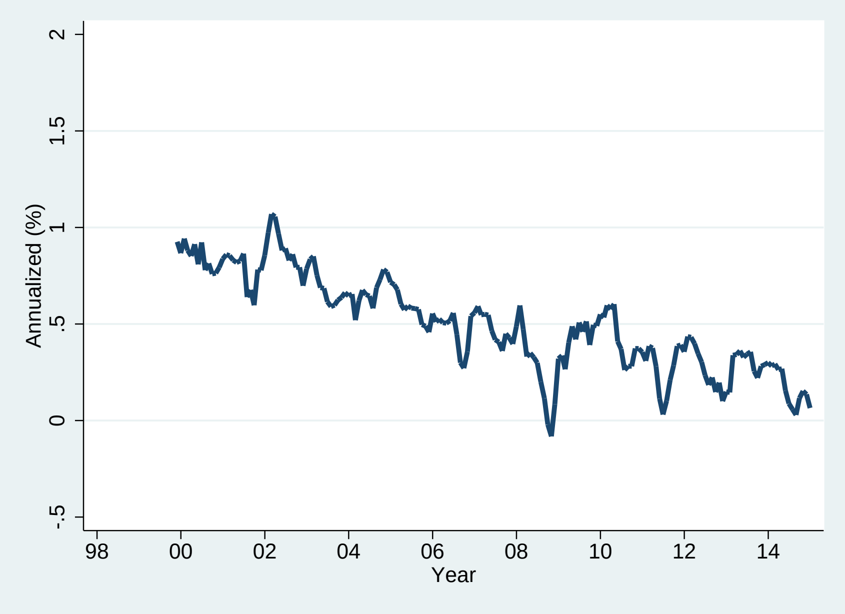
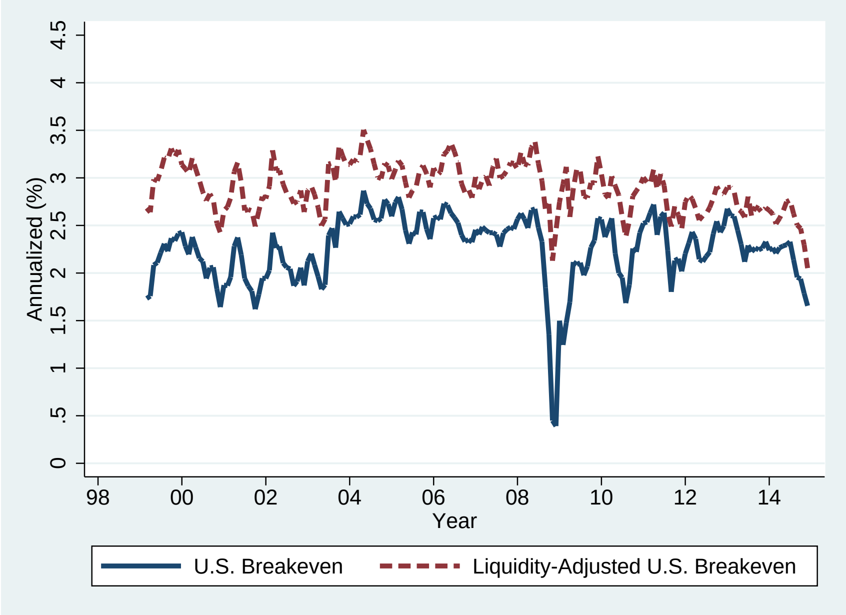


Figure 2: Estimated U.S. and U.K. Liquidity Premia.

We estimate liquidity premia as the negative of the variation in breakeven explained by liquidity proxies. Formally, $\hat{L}_{n,t} = -\hat{a}_2 X_t$, where X_t is the vector of liquidity variables and $\hat{a}_2$ is the vector of corresponding estimated coeffcients in Table II(4), Panels A and B.

Panel A: U.S. (1999.3-2014.12)



Panel B: U.K. (1999.11-2014.12)

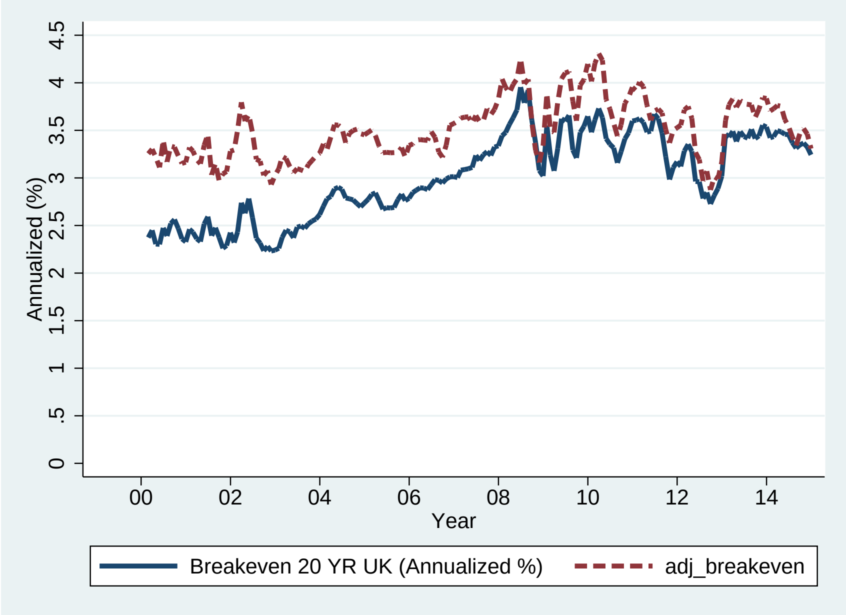
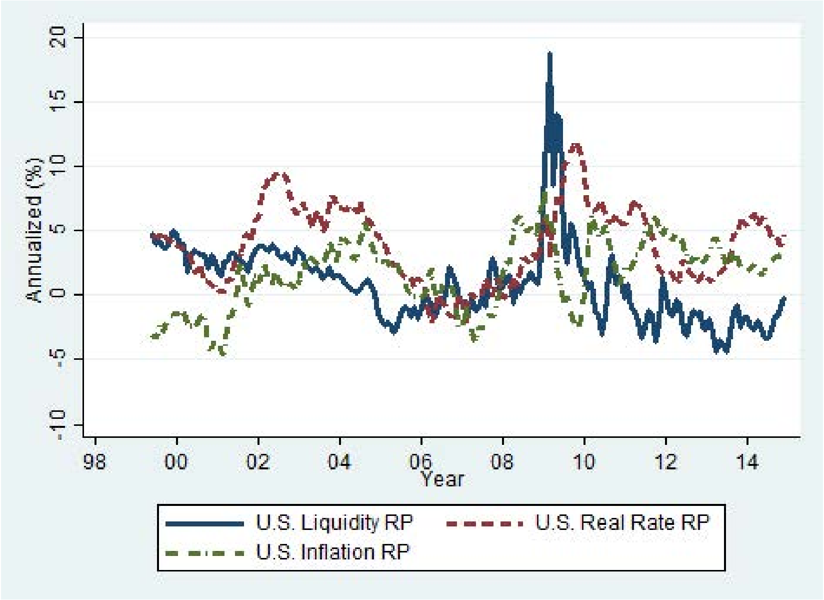


Figure 3: Liquidity-Adjusted U.S. 10 Year Breakeven and U.K. 20 Year Breakeven.

Liquidity-adjusted breakeven equals breakeven plus the liquidity premium shown in Figure 2.

Panel A: U.S. (1999.6-2014.12)



Panel B: U.K. (2000.2-2014.12)

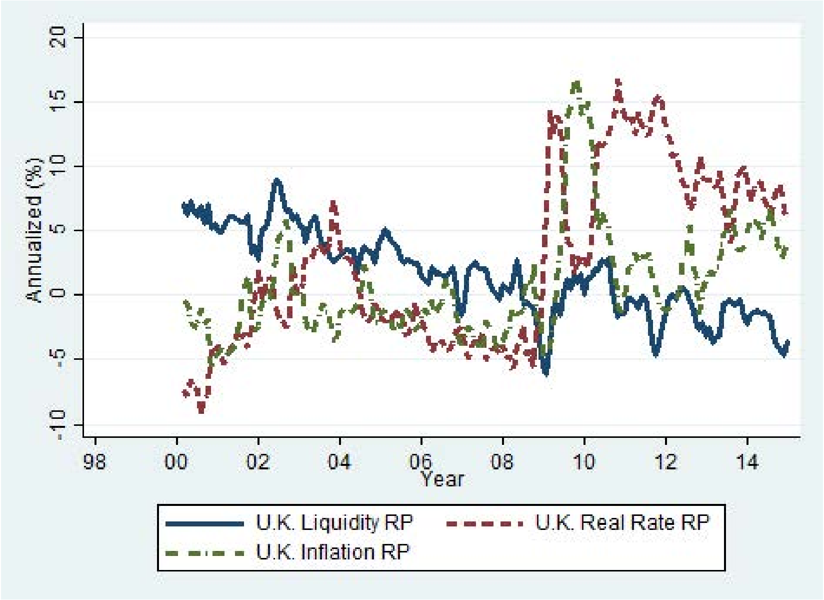


Figure 4: U.S. and U.K. Estimated Risk Premia.

Predicted 3-month excess returns in annualized units, labeled real rate risk premia, inflation risk premia, and liquidity risk premia. We obtain predicted excess returns as fitted values from the regressions shown in Tables III(1), III(3) and III(5), Panels A and B.