NBER WORKING PAPER SERIES

AN EMPIRICAL DECOMPOSITION OF RISK AND LIQUIDITY IN NOMINAL AND INFLATION-INDEXED GOVERNMENT BONDS

Carolin E. Pflueger
Luis M. Viceira

Working Paper 16892
http://www.nber.org/papers/w16892

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 2011

We thank Tom Powers for excellent research assistance. We are grateful to John Campbell, Kent Daniel, Graig Fantuzzi, Michael Fleming, Josh Gottlieb, Robin Greenwood, Arvind Krishnamurthy, George Pennacchi, Michael Pond, Matthew Richardson, Jeremy Stein, to seminar participants at the NBER Summer Institute 2011, the Econometric Society Winter Meeting 2011, the Federal Reserve Board, the European Central Bank, the New York Federal Reserve, the Foster School of Business at the U. of Washington, the HBS-Harvard Economics Finance Lunch and the HBS Finance Research Day for helpful comments and suggestions. We are also grateful to Martin Duffell and Anna Christie from the UK Debt Management Office for their help providing us with UK bond data. This material is based upon work supported by the Harvard Business School Research Funding. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

An Empirical Decomposition of Risk and Liquidity in Nominal and Inflation-Indexed Government Bonds
Carolin E. Pflueger and Luis M. Viceira
NBER Working Paper No. 16892
March 2011, Revised April 2012
JEL No. G12

ABSTRACT

This paper decomposes inflation-indexed and nominal government bond excess return predictability into liquidity, real interest rate risk and inflation risk. We estimate a systematic liquidity premium in Treasury Inflation Protected Securities (TIPS) yields relative to nominal yields. The liquidity premium is around 30 bps during normal times but larger during the early years of TIPS and during the financial crisis 2008-2009. We find that time-varying liquidity premia in TIPS and time-varying inflation risk premia in nominal bonds generate return predictability. We find no evidence that shocks to relative issuance generate bond return predictability in the US or 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

Since their first issuance in 1997, inflation-indexed bonds in the U.S. have gained wide acceptance among investors and they now constitute a significant fraction of the stock of U.S. Treasury debt. Yet many academics and Treasury market pundits argue that these bonds, known as Treasury Inflation Protected Securities (TIPS), have a smaller and less liquid market than their nominal counterparts, U.S. Treasury notes and bonds.[2] This paper conducts an empirical investigation of the sources and magnitude of illiquidity in the TIPS market. Conditional on a measure of the liquidity discount on TIPS relative to nominal Treasury bonds, it asks to what extent liquidity risk and to what extent time-varying inflation risk and time-varying real interest rate risk generate excess return predictability in government bonds.

Understanding the liquidity differential between TIPS and Treasury bonds is important for several reasons. First, it is well-known that the Expectations Hypothesis of the term structure of interest rates does not hold for U.S. nominal government bonds (Campbell and Shiller 1991, Fama and Bliss 1987, Cochrane and Piazzesi 2005). Equivalently, excess returns on U.S. nominal government bonds are predictable. Explanations of return predictability in government bond returns emphasize either a time-varying real interest rate risk premium, or a time-varying inflation risk premium, or a combination of those two (Wachter 2006, Campbell, Sunderam, and Viceira 2010). Pflueger and Viceira (2011) have highlighted that inflation-indexed bonds can be very helpful in disentangling inflation risk and real interest rate risk as the fundamental sources of government bond return predictability. But such an exercise requires identifying price and return differentials between the two bond markets

[2] For evidence of relatively lower liquidity in TIPS see D'Amico, Kim, and Wei (2008), Campbell, Shiller, and Viceira (2009), Fleckenstein, Longstaff, and Lustig (2010), Fleming and Krishnan (2009), Dudley, Roush, and Steinberg Ezer (2009), Gurkaynak, Sack, and Wright (2010), and Haubrich, Pennacchi, and Ritchken (2011).

which are due to liquidity and not due to sources of fundamental risk.

Second, over the 11 year period starting in 1999 the average annualized excess log return on 10 year TIPS equalled a substantial 4.7%, almost half a percentage point higher than that on comparable nominal U.S. government bonds. This significant return differential is puzzling because both nominal and inflation-indexed bonds are fully backed by the U.S. government. Moreover, the real cash flows on nominal bonds are exposed to surprise inflation while TIPS coupons and principal are inflation protected. Is all or part of this return differential compensation to TIPS investors for holding a less liquid form of U.S. Treasury debt?

Third, investors and policy makers use the yield differential between nominal bonds and inflation-indexed bonds, popularly known among practitioners as "breakeven inflation," as a gauge of bond market long-term expectations of inflation and its variation over time. But if TIPS trade at a discount over nominal Treasury bonds due to differential liquidity, breakeven inflation will underestimate inflation expectations. Moreover, variation in this liquidity discount over time might get confused with changes in inflation expectations. For instance, breakeven inflation fell to almost zero during the financial crisis and, for some maturities, was even negative. Did this reflect a sudden and large change in inflation expectations towards a long period of sustained deflation? Or was this caused by a sudden episode of illiquidity in the TIPS market with no significant change in long-term inflation expectations?

It is natural to expect that TIPS might have been less liquid than nominal Treasury bonds in their early years, when issuance of these securities was small, and investors might have had to learn about them. However, there are reasons to believe that liquidity differentials between the nominal bond market and the inflation-indexed bond market might persist beyond an initial stage of learning and supply buildup. 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. Thus the return differential might have been the result of a liquidity discount demanded by investors that has diminished—but not necessarily disappeared—over time with the growth in TIPS trading and adoption among investors.

We examine these questions adopting an empirically flexible approach. We estimate the liquidity differential between inflation-indexed bonds and nominal bonds using a variety of proxies for liquidity. We find a statistically significant and economically important time-varying liquidity component in breakeven inflation. While controlling for time-varying inflation expectations, liquidity variables can explain more than half the time-variation in U.S. breakeven inflation. After adjusting for liquidity, our findings suggest that liquidity-adjusted breakeven inflation has been quite stable and close to three percent over our sample period. Liquidity-adjusted breakeven inflation remained above 1.7% during the financial crisis, while realized breakeven inflation was close to zero or even negative for some maturities, suggesting that low realized breakeven inflation may not have been a reflection of investors' long-term deflationary fears but instead an increase in the relative illiquidity of TIPS.

Over our sample period the yield on TIPS has been about 65 basis points larger on average than it would have been if TIPS had been as liquid as nominal Treasury bonds. 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 70 to 100 bps), which we attribute to learning and low trading volume, and during the fall of 2008 at the height of the financial crisis (beyond 150 bps). We estimate a much lower but still significant liquidity discount of between 30 to 70 bps between 2004 and 2007 and after the crisis.

Our estimated liquidity differential exhibits a highly significantly positive CAPM beta with respect to the stock market. This suggests that investors in TIPS bear systematic risk due to time-varying liquidity and should be compensated in terms of a return premium.

We next disentangle bond return predictability due to liquidity, due to time-varying real interest rate risk and due to time-varying inflation risk. 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, nominal and inflation-indexed 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 inflation risk will impact their risk premia.[3] Our empirical estimates indicate that time-varying inflation risk is a large contributor to return predictability in nominal bonds, and that time-varying liquidity contributes statistically and economically significantly to return predictability in TIPS. We don't find robust evidence for time-varying real interest rate risk premia as a source of predictability in government bond returns in the US over our sample period. However, empirical results for the UK over a longer sample period indicate time-varying real interest rate risk premia.

We finally investigate the hypothesis that the markets for nominal and inflation-indexed debt are segmented, leading to relative price fluctuations and return predictability. Recent

[3] For models of real cash flow risks in nominal government bonds see Campbell and Viceira (2001), Campbell, Sunderam, and Viceira (2010), and Christensen, Lopez, and Rudebusch (2010).

research has emphasized the role of limited arbitrage and bond investors' habitat preferences to explain predictability in nominal bond returns (Modigliani and Sutch, 1966, Vayanos and Vila, 2009). 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 nominal and inflation-indexed markets and might explain generate return predictability.

We use the outstanding supply of real bonds relative to total government debt as a proxy for supply shocks in the inflation-indexed bond market in an empirical setup similar to Greenwood and Vayanos (2008) and Hamilton and Wu (2010). We cannot find any evidence for bond supply effects either in the U.S. 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 arbitrageurs between the two markets.

This paper relates to a number of recent papers that estimate liquidity premia in TIPS. In recent work, Fleckenstein, Longstaff and Lustig (2010) show that inflation-swaps, which allow investors to trade on a synthetic measure of breakeven inflation, appear to be mispriced relative to breakeven inflation in the cash market for TIPS and nominal Treasury bonds. This significant mispricing appears to be related to financing costs to levered investors (Campbell, Shiller, and Viceira, 2009, and Viceira, 2011), and raises the question why unlevered investors have not taken advantage of it. We estimate the liquidity differential between the cash TIPS market and the cash nominal Treasury bond market over a significantly longer time period. Consequently, we find an even higher pricing differential due to liquidity.

Our estimates for the liquidity premium are consistent with the magnitudes estimated in other recent papers. D'Amico, Kim and Wei (2009) estimate a liquidity premium in a structural model of nominal and real government bonds. Christensen and Gillan (2011) derive a set of bounds for the liquidity premium in TIPS yields. Haubrich, Pennacchi, and Ritchken (2011) estimate a term structure model using nominal bond yields, inflation derivatives and survey inflation expectations. Our approach is new in that we focus on the empirical excess return predictability in government bonds and to what extent this predictability is driven by time-varying liquidity versus real cash flow risks. Moreover, we estimate the liquidity differential between TIPS and nominal Treasury bonds using a transparent empirical methodology, which allows for an intuitive interpretation of the time-variation in TIPS liquidity.

The structure of this paper is as follows. Section I estimates the liquidity premium in U.S. TIPS versus nominal bonds using our liquidity proxies. Section II tests the market segmentation hypothesis in the U.S. and in the UK, and section III tests for time-varying real interest rate risk and inflation risk premia. Finally, section IV offers some concluding remarks.

I Estimating the Liquidity Component of Breakeven Inflation

In perfectly liquid markets, breakeven inflation, or the spread between the yield on a nominal bond and the yield on an inflation-indexed bond with identical timing of cash flows, will reflect investors' inflation expectations plus any compensation for bearing inflation risk.

However, if the market for inflation indexed bonds is not as liquid as the markets for nominal bonds, the yield on inflation-indexed bonds might reflect a liquidity premium relative to the yield on nominal bonds which narrows observed breakeven inflation.

We pursue an empirical approach to identify the liquidity differential between the market for nominal Treasury bonds and TIPS. We estimate the liquidity differential by regressing breakeven inflation on measures of liquidity as in Gurkaynak, Sack, and Wright (2010), while controlling for inflation expectations using different proxies. We capture different notions of liquidity through three different liquidity proxies: the nominal off-the-run spread, relative TIPS transaction volume and the difference between TIPS asset-swap spreads and nominal U.S. Treasury asset-swap spreads. Since we have data for liquidity proxies only for the U.S. in the most recent period, this part of our estimation is restricted to the last 10 years of U.S. experience.

A time-varying market-wide desire to hold only the most liquid securities might drive part of the liquidity differential between nominal and inflation-indexed bonds. 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. We measure this market wide desire to hold only the most liquid securities by the nominal off-the-run spread. The Treasury regularly issues new 10 year nominal notes, and the newest 10 year note, also known as the "on-the-run" note or bond, is considered the most liquidly traded security in the Treasury bond market. 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 (Krishnamurthy, 2002).[4]

Liquidity developments specific to the TIPS market might also generate a liquidity premium in TIPS. When TIPS were first issued in 1997, investors might have had to learn about TIPS and the market for TIPS took some time to get established. We proxy for this idea by using the transaction volume of TIPS relative to the transaction volume of Treasuries, a measure previously used by Gurkaynak, Sack, and Wright (2010). Fleming and Krishnan (2009) previously found that trading activity is a good measure of cross-sectional TIPS liquidity, lending credibility to relative transaction volume as a liquidity proxy in our time series setup. Following Weill (2007) and others one can also think of TIPS transaction volume as a measure of illiquidity due to search frictions[5].

Finally, we want to capture the cost of arbitraging between TIPS and nominal markets for a levered investor. Such investors looking for TIPS exposure can either borrow by putting the TIPS on repo or they can enter into an asset-swap, which requires no initial capital. An asset-swap is a derivative contract between two parties where one party receives the cash flows on a particular government bond (e.g. TIPS or nominal) and pays $LIBOR$ plus the asset-swap spread (ASW), which can be positive or negative. We use the difference between the asset-swap spread for TIPS and the asset-swap spread for nominal Treasuries,

$$ASW_{n,t}^{spread} = ASW_{n,t}^{TIPS} - ASW_{n,t}^{\$}. \tag{1}$$

[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.

[5] 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.

A non-levered investor who perceives TIPS to be underpriced relative to nominal Treasuries might consider entering a zero price portfolio, which is long one dollar of TIPS and short one dollar of nominal Treasuries. A levered investor could take a similar position by entering one TIPS asset-swap and going short one nominal Treasury asset-swap. This levered investor pays the relative spread (1), which is typically positive, for the privilege of not having to put up any initial capital. Since the levered investor holds a portfolio with a theoretical price of zero, this spread reflects the current and expected relative financing costs of holding the bond position. Empirically, the asset-swap spread variable captures extraordinary events during the financial crisis.[6]

As a robustness analysis, we also consider the spread between synthetic breakeven inflation and cash breakeven inflation. Synthetic breakeven inflation is the fixed rate in a zero-coupon inflation swap. Zero-coupon inflation swaps are contracts where one party pays the other cumulative CPI inflation at the end of maturity in exchange for a pre-determined fixed rate. Entering a zero-coupon inflation swap does not require any initial capital, similarly to entering a TIPS asset-swap and going short a nominal Treasury asset-swap. The difference between synthetic breakeven (or breakeven inflation in the inflation swap market) and cash breakeven is therefore the flip side of the asset-swap spread (Viceira 2011) and should be empirically similar to $ASW_{n,t}^{spread}$. We consider the asset-swap spread as our benchmark variable, since it most closely captures the relative financing cost and specialness of TIPS over nominal Treasuries.

The asset-swap spread is likely related to specialness of nominal Treasuries in the repo market and the lack of specialness of TIPS, which can vary over time[7]. These differences in

[6]See Campbell, Shiller, and Viceira (2009) for an account of liquidity events during the Fall of 2008.

[7]In private email conversations Michael Fleming and Neel Krishnan report that for the period Feb. 4,

specialness might be the result of variation in the relative liquidity of securities, which make some securities easier to liquidate and hence more attractive to hold than others.

The liquidity differential between the nominal bond market and the inflation-indexed bond market can also give rise to a liquidity risk premium: 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 for holding these bonds (Amihud, Mendelson and Pedersen 2005, Acharya and Pedersen 2005).

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, 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 U.S. Treasuries and the risk that the liquidity of TIPS might deteriorate.

In order to isolate the liquidity component in breakeven inflation, we consider the difference between breakeven inflation and survey long-term inflation expectations, which should in principle not reflect time-varying inflation expectations. Survey long-term inflation expectations are extremely stable over our sample period and in order to take into account the possibility that more short-term inflation expectations enter into breakeven, we also control for the Chicago Fed National Activity Index (CFNAI). The CFNAI is based on economic activity measures and provides a reliable inflation forecast over a 12 month horizon (Stock and Watson, 1999). The CFNAI should especially take into account fluctuations in inflation expectations that are related to the aggregate economy.

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.

A 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 U.S. and UK inflation-indexed bonds. We denote SPF survey inflation expectations by π^{SPF}.

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

$$b_{n,t} = y^{\$}_{n,t} - y^{TIPS}_{n,t} \tag{2}$$

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

$$\begin{aligned} xr^{\$}_{n,t+1} &= ny^{\$}_{n,t} - (n-1)\, y^{\$}_{n-1,t+1} - y^{\$}_{1,t}, & (3) \\ xr^{TIPS}_{n,t+1} &= ny^{TIPS}_{n,t} - (n-1)\, y^{TIPS}_{n-1,t+1} - y^{TIPS}_{1,t}. & (4) \end{aligned}$$

The log excess one-period holding return on breakeven inflation is equal to

$$xr^{b}_{n,t+1} = xr^{\$}_{n,t+1} - xr^{TIPS}_{n,t+1}. \tag{5}$$

Note that this is essentially the return on a portfolio long long-term nominal bonds and short long-term inflation-indexed bonds. This portfolio will have positive returns when breakeven inflation declines, and negative returns when it increases.

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

$$s_{n,t}^{\$} = y_{n,t}^{\$} - y_{1,t}^{\$}, \tag{6}$$

$$s_{n,t}^{TIPS} = y_{n,t}^{TIPS} - y_{1,t}^{TIPS}, \tag{7}$$

$$s_{n,t}^{b} = b_{n,t} - b_{1,t}. \tag{8}$$

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 $y_{n,t+1}^{TIPS}$.

B 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:

$$b_{n,t} - \pi^{SPF} = a_1 + a_2 X_t + a_3 CFNAI_t + \varepsilon_t, \tag{9}$$

where X_t is a vector containing our three liquidity proxies: the off-the-run spread, the relative TIPS transactions volume and the difference between TIPS and nominal asset-swap spreads.

In (9) we would expect variables that indicate less liquidity in the TIPS market, such as the off-the-run spread and the asset-swap spread, to enter negatively. Higher transaction volume in the TIPS market indicates that TIPS are easily traded and therefore it should enter positively.

The asset-swap spread reflects the financing costs that a levered investor incurs from holding TIPS instead of nominal bonds of similar maturity. 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 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. The CFNAI is constructed to have an average value of zero and a standard deviation of one.

We obtain the TIPS liquidity premium as the negative of the variation in $b_{n,t} - \pi^{SPF}$ explained by the liquidity variables, while controlling for the CFNAI as a proxy of short-term inflation expectations. The estimated relative liquidity premium in TIPS yields then equals

$$\hat{L}_{n,t} = -\hat{a}_2 X_t, \tag{10}$$

where $\hat{a}_2$ is the vector of slope estimates in (9). Thus an increase in $\hat{L}_{n,t}$ reflects a reduction in the liquidity of TIPS relative to nominal Treasury bonds.

While our liquidity estimate most likely reflects liquidity fluctuations in both nominal bonds and in TIPS, we have to make an assumption in computing liquidity-adjusted TIPS yields. We can either assume that all of the liquidity premium is in nominal bonds, in which case we do not need to correct TIPS yields at all. Or we can assume that all of the liquidity premium is due to TIPS, which yields our liquidity-adjusted TIPS yields. To allow comparison between these two possibilities, we construct liquidity-adjusted TIPS yields under the assumption that the liquidity premium $L_{n,t}$ is entirely attributable to time-varying liquidity in TIPS rather than in nominal bonds. We refer to the following variables as liquidity-adjusted TIPS yields and liquidity-adjusted breakeven

$$y_{n,t}^{TIPS,adj} = y_{n,t}^{TIPS} - \hat{L}_{n,t}, \tag{11}$$

$$b_{n,t}^{adj} = b_{n,t} + \hat{L}_{n,t}. \tag{12}$$

C Yield Data

We use data on constant-maturity inflation-indexed and nominal yields both in the U.S. and in the UK. Inflation-indexed bonds are bonds whose principal adjusts automatically with the evolution of a consumer price index, which in the U.S. is the Consumer Price Index (CPI-U) and in the UK is the Retail Price Index (RPI). The coupons are equal to the inflation-adjusted principal on the bond times a fixed coupon rate. Thus the coupons on these bonds also adjust with inflation.[8]

For the U.S. we use the Gurkaynak, Sack, and Wright (2007) and Gurkaynak, Sack, and Wright (2010, GSW henceforth) data set. GSW have constructed a zero-coupon off-the-run yield curve starting in January 1961 for nominal bonds and for TIPS starting in January 1999 by fitting a smoothed yield curve. Our empirical tests will focus on the 10-year nominal and real yields, because this maturity bracket has the longest and most continuous history

[8] 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.

of TIPS outstanding. We measure U.S. inflation with the all-urban seasonally adjusted CPI, and the short-term nominal interest rate with the 3 month T-bill rate from the Fama-Bliss riskless interest rate file from CRSP.

While the nominal principal value of TIPS increases with inflation, it is guaranteed to never fall below its original nominal face value. As a consequence of this a recently issued TIPS, whose nominal face value is close to its original nominal face values, has a deflation option built into it that is more valuable than that in a less recently issued TIPS with the same time to maturity remaining. Grishchenko, Vanden, and Zhang (2011) study the deflationary expectations reflected in the pricing of the TIPS deflation floor. During normal times the probability of a severe and prolonged deflation is negligible so that those bonds trade at identical prices, as discussed in Wright (2009). Wright (2009) also points out some of the dramatic price discrepancies between recently issued and seasoned five-year TIPS observed during the financial crisis and attributes them to the increased value of the deflation option during the financial crisis. In Appendix Figure A.1 we illustrate the GSW 10 year TIPS yield together with yields of 10 year TIPS issued at different reference CPI. A lower reference CPI indicates that the deflation option in a particular issuance is less valuable. Since the GSW yield is closest to TIPS yields with low reference CPI, we conclude that the GSW yield does not reflect a significant deflation option.

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 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.[9] Inflation is measured by the non seasonally adjusted Retail Price Index, which serves as the measure of inflation for inflation-indexed bond payouts. UK three month Treasury bill rates are from the Bank of England (IUMAJNB).

Since neither the U.S. 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 to compute excess returns. We follow the procedure described in Pflueger and Viceira (2011) and use the fitted ex-post real return on a nominal three month T-bill. The predictive regressions are reported in Appendix Table A.I. For simplicity we assume a zero liquidity premium on one-quarter real bonds. Appendix Table A.VI shows that our results are robust to replacing TIPS returns in excess of our estimated real interest rate with nominal TIPS returns in excess of the nominal T-bill rate.

Finally, although our yield data sets are available at a monthly frequency, we focus on quarterly overlapping bond returns in order to reduce the influence of high-frequency noise in observed inflation and short-term nominal interest rate volatility in our tests.

We use the median 10 year forecast of CPI inflation from the Survey of Professional Forecasters, consistent with the 10 year maturity of U.S. breakeven. SPF survey expectations are available at a quarterly frequency and are released towards the end of the middle month of the quarter. Our breakeven series is monthly and we create a monthly series of the differential between breakeven inflation and survey inflation expectations by subtracting the most recently released inflation forecast.

[9] 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.

D Data on Liquidity Proxies

We obtain the 10 year nominal off-the-run spread by subtracting a 10 year nominal on-the-run yield from Bloomberg from the GSW 10 year off-the-run yield.[10]

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 month and $Trans_t^{\$}$ the corresponding figure for nominal bonds. 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 to capture 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 rather than capturing short-term fluctuations in liquidity.[11] We normalize the relative transaction volume so that its maximal value is equal to zero.

[FIGURE 1 ABOUT HERE]

[10] The on-the-run data is from Bloomberg (USGG10YR). We subtract the on-the-run yield to maturity for a generic 10 year nominal Treasury bond from the GSW off-the-run par yield for a nominal 10 year Treasury bond.

[11] In 2001 the Federal Reserve changed the maturity cutoffs for which the transaction volumes are reported. 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.

We obtain asset-swap spread data from Barclays Live. We only have data on $ASW_{n,t}^{spread}$ from January 2004, and set it to its January 2004 value of 28 bps before that date. We obtain 10 year zero-coupon inflation-swap data from Bloomberg (USDSW10Y) from July 2004.

Figure 1 shows our liquidity variables. The on-the-run off-the-run spread was high during the late 1990s, declined during 2005-2007, and jumped to over 50 bps during the financial crisis. The relative transaction volume rises linearly through 2004, stabilizes and declines modestly after the financial crisis. This pattern suggests that the liquidity premium due to the novelty of TIPS should have been modest in the period since 2004. Interestingly, shortly after the Treasury reconfirmed its commitment to the TIPS issuance program in mid-2003 (Bitsberger, 2003) the relative TIPS trading volume increased substantially and synthetic markets developed.

Finally, the asset-swap spread variable $ASW_{n,t}^{spread}$ varies within a relatively narrow range of 21 basis point to 41 basis points from January 2004 through December 2006, 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 30 basis more expensive than financing a long position in nominal Treasury bonds, but this cost differential rose dramatically 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. The asset-swap spread $ASW_{n,t}^{spread}$ and the differential between synthetic and cash breakeven inflation track very closely, as expected.

[TABLE I ABOUT HERE]

Table I shows summary statistics for bond spreads and excess returns as well as liquidity variables. Over our sample period breakeven inflation has averaged 2.25% per annum (p.a.) and TIPS yields have averaged 2.41% p.a. At 2.47% p.a., survey inflation expectations have been higher than breakeven inflation on average. If breakeven inflation reflects only investors' inflation expectations plus perhaps an inflation risk premium, this is surprising unless the inflation risk premium has been substantially negative over this period. It is even more surprising in light of the finding in Ang, Bekaert, and Wei (2007) that the Survey of Professional Forecasters tends to under predict inflation when inflation is low, which makes breakeven inflation appear even lower relative to plausible inflation expectations. Simply comparing average breakeven inflation to average survey inflation expectations therefore suggests that there may have been a substantial liquidity premium in TIPS yields relative to nominal Treasury yields, or a substantive negative inflation risk premium.

The realized average annualized log excess returns on TIPS have been equal to 4.66% p.a., exceeding the log excess returns on nominal government bonds by 48 basis points (bps). The average log excess returns on UK inflation-indexed bonds, on the other hand, have been substantially smaller at only 2.14% p.a. over the longer sample period from 1985.4 to 2009.12.

E Estimation Results

We estimate the relative liquidity premium in TIPS yields in Table II according to regression (9). We add liquidity proxies one at a time. Table II(4) presents our benchmark estimate with all liquidity proxies and controlling for the CFNAI for our full sample period (1999.3-2010.12) and also for an early period that excludes the financial crisis (1993.3-2006.12).

[TABLE II ABOUT HERE]

Table II shows coefficients whose signs are consistent with intuition and statistically significant. The liquidity measures explain a significant portion of the variability of the spread between breakeven and survey inflation expectations. The off-the-run spread alone obtains an R^2 of 57%, as shown in Table II(1). The R^2 increases with the inclusion of every additional liquidity variable to 62% in Table II(3), indicating that each of the controls helps explain the liquidity premium on TIPS. Our proxy for short-term expected inflation, the CFNAI, enters as expected positively, and further increases the R^2 by another four percentage points. Appendix Table A.II shows that each variable alone also explains a significant fraction of the variation in breakeven inflation.

Breakeven inflation moves negatively with the off-the-run spread in Treasury bonds with a large coefficient, suggesting that TIPS yields reflect a strong market-wide liquidity component. A one standard deviation move in the off-the-run spread of 11 bps tends to go along with a decrease in breakeven of 13 bps in our benchmark estimation (1.19×11 bps). These magnitudes are substantial relative to average breakeven of 225 bps. This empirical finding indicates that while during a flight-to-liquidity episode investors rush into nominal on-the-run

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.

The negative and significant coefficient on relative TIPS trading volume indicates that the impact of search frictions on inflation-indexed bond prices were exacerbated during the early period of inflation-indexed bond issuance, when maybe only a small number of sophisticated investors had a good understanding of the mechanics and pricing of these new bonds. 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 2004 was associated with an economically significant decrease in the TIPS liquidity premium of 38 bps.

The freely estimated coefficient on the asset-swap spread differential at -0.64 is somewhat smaller in magnitude than the theoretical value of -1. The negative and economically significant coefficient on the asset-swap spread suggests the relevance of liquidity factors in explaining the sharp fall in breakeven during the financial crisis, since the asset-swap spread differential behaves almost like a dummy variable that spikes up during the financial crisis. 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. A regression coefficient with a smaller magnitude allows for the possibility that the marginal TIPS investor only faced a fraction of the financing costs reflected in asset-swap markets. When we estimate the regression with the synthetic minus cash breakeven spread instead of the asset swap spread, we obtain very similar results with a coefficient on the synthetic minus cash breakeven spread even closer to the theoretical value of -1.

The constant in Table II can be interpreted as the differential between liquidity-adjusted breakeven inflation and survey inflation forecasts over our sample period. In our benchmark specification, liquidity-adjusted breakeven exceeds survey inflation expectations by 50 bps on average but this differential varies between 21 bps and 61 bps depending on the regression specification. Ang, Bekaert, and Wei (2007) find that the SPF tends to under predict inflation when inflation is low, while the Michigan survey[12] of consumers' inflation expectations is on average unbiased. Unfortunately, the Michigan survey is designed to forecast inflation over the coming year, whereas we are interested in 10 year forecasts. The level of the Michigan forecast over our sample period is indeed higher by about 40 bps than the SPF survey, suggesting that our estimation procedure yields a plausible average level for the TIPS liquidity premium.

While bond market liquidity was especially variable during the financial crisis, we also find a strong relationship between breakeven and liquidity proxies during the pre-crisis period. In Table II(6) and II(7) we see that before 2007 liquidity variables explain 49% of the variation in the spread between breakeven inflation and survey inflation expectations and that the off-the-run spread enters with a strong negative and significant coefficient.

Since some of the liquidity variables are persistent, one might be concerned about spuriousness in Table II. If there does not exist a slope vector so that the regression residuals are stationary, Ordinary Least Squares is quite likely to produce spurious results with artificially large $R^{2\prime}s$ and t-statistics (Granger and Newbold, 1974, Phillips, 1986, Hamilton, 1994). To evaluate the potential importance of this problem, we test the regression residuals for a unit root using augmented Dickey-Fuller tests. Table II shows that we can reject the presence of a unit root for all regression specifications in Table II at conventional significance levels.

[12] Available at http://research.stlouisfed.org/fred2/series/MICH/downloaddata?cid=32455.

We also estimate the regression (9) with all variables expressed in quarterly changes. Table A.III in the Appendix shows that the regression results in quarterly changes are very similar to the regression results in levels, further alleviating spuriousness concerns.

Our estimation of the liquidity premium might rely on extrapolation outside the range of historically observed liquidity events. The effect of our liquidity proxies on the liquidity premium in TIPS might be nonlinear and this might especially matter during events of extreme liquidity or extreme illiquidity. Appendix Tables A.IV and A.V report additional results including interaction terms. We find that including interaction terms yields a very similar time series for liquidity at a slightly lower level, while the return predictability results remain unaltered.

We also report liquidity regressions including the TIPS bid-ask spread as an additional natural liquidity proxy in Appendix Table A.IV. We find that the bid-ask spread does not enter, suggesting that our other liquidity proxies already incorporate the time-varying round-trip cost of buying and selling a TIPS.[13]

[FIGURE 2 ABOUT HERE]

Figure 2 plots the liquidity premium as estimated in the benchmark regression in Table II (4), where we obtain the liquidity premium according to equation (10). Intuitively, the liquidity premium equals the negative of the fitted value after taking out the constant and the variation explained by the inflation forecasting variable CFNAI. We obtain an average spread due to liquidity of 65 bps with a standard deviation of 25bps (see Table IV). Although

[13] We are grateful to George Pennachi for making his proprietary data on TIPS bid-ask spreads avaialble to us.

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 70-100 bps), but a much lower liquidity premium between 2004 and 2007 (25-70 bps). The premium shoots up again beyond 150 bps during the crisis, and finally comes down to 50-70 bps after the crisis.

The time series of our liquidity premium is consistent with the findings in D'Amico, Kim and Wei (2008) but in addition we provide an estimate of the liquidity premium during and after the financial crisis. In recent work Fleckenstein, Longstaff and Lustig (2010) show evidence that inflation-swaps, which allow investors to trade on inflation without putting up any initial capital, appear to be mispriced relative to breakeven inflation in the cash market for TIPS and nominal Treasury bonds. Their series of average mispricing between synthetic and cash breakeven inflation is reflected in our "Synthetic-Cash" variable in Table II(5). The off-the-run spread and TIPS relative transaction volume enter in addition to the mispricing between synthetic and cash breakeven. Consequently, we estimate that the size of the liquidity differential in the cash market for TIPS and nominal Treasury bonds is even larger than the size of the mispricing in the inflation swap market.

The large liquidity premium in TIPS is puzzling given that bid-ask spreads on TIPS are small. Haubrich, Pennacchi and Ritchken (2010) report bid-ask spreads for TIPS between 0.5 bps up to a high of 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[14]. As argued before, TIPS should typically be held by buy-and-hold investors. In a simple model of liquidity, such as given in Amihud, Mendelson and Pedersen (2005), a

[14] See also Wright (2009).

transaction cost of 10 bps can only justify a liquidity premium of 1bp for a 10 year TIPS that is held by a buy-and-hold investor.

It is instructive to compare the liquidity premium for TIPS to the liquidity premium for off-the-run nominal Treasuries, adjusted for the likely time to convergence of the liquidity differential. Table I shows that the average off-the-run spread over our sample period is 21 bps. However, the on-the-run off-the-run liquidity differential can be expected to converge when the new on-the-run nominal 10 year bond is issued, that is within 6 months. Thus the average annualized return on the liquidity differential between 10 year on-the-run and off-the-run nominal Treasury bonds is 21×20 bps= 420 bps. On the other hand, the TIPS liquidity premium might converge significantly more slowly. An extreme assumption might be that the TIPS liquidity premium persists for 10 years for a 10 year TIPS, in which case the average annualized return on TIPS liquidity is 65 bps. These simple calculations show that the estimated liquidity premium in TIPS, though puzzlingly large when compared to bid-ask spreads, gives rise to liquidity returns which are not unreasonable when compared to those on off-the-run nominal Treasuries.

[FIGURE 3 ABOUT HERE]

Figure 3 shows liquidity-adjusted breakeven inflation. The benchmark estimation suggests an average liquidity-adjusted breakeven over our sample period of 2.90% with a standard deviation of 26bps (see Table IV). Figure 3 shows that liquidity-adjusted breakeven was substantially more stable during our sample period than raw breakeven. Both raw breakeven and liquidity-adjusted breakeven exhibited a drop during the financial crisis but this drop was significantly smaller for liquidity-adjusted breakeven. Our estimation therefore suggests that while investors' long-term inflation expectations fell during the financial crisis, there was never a period when investors feared massive deflation. Instead, we find that the extreme fall in raw breakeven inflation was partly due to market disruptions.

[FIGURE 4 ABOUT HERE]

Figure 4 plots liquidity-adjusted TIPS yields assuming that the estimated differential liquidity premium is entirely due to TIPS. The figure shows that if TIPS had remained as liquid as nominal Treasuries their yields would have remained relatively more stable during the financial crisis. Our estimation attributes the dramatic spike in TIPS yields to 3.5% in the fall of 2008 partly to liquidity and partly to a moderate increase in real long-term yields.

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

A Predictive regressions with liquidity-adjusted yields and returns

This section provides new empirical evidence on excess bond return predictability using liquidity-adjusted returns on TIPS and breakeven inflation, and returns on nominal Treasury bonds. We interpret our predictability regressions as evidence of time variation in real interest rate risk premia, inflation risk premia, and liquidity risk premia. The following section III investigates whether bond return predictability could instead be the result of the supply effects suggested in the preferred habitat model with limits to arbitrage of Greenwood and Vayanos (2009), but it does not find strong evidence of such effects in our sample period.

We decompose government bond excess returns into returns due to real interest rates, returns due to changing inflation expectations, and returns due to liquidity. We then test for predictability in each component separately. Predictability in real bond excess returns would indicate a time-varying real interest rate risk premium, while predictability in liquidity-adjusted breakeven returns should indicate a time-varying inflation risk premium. Predictability in the liquidity component of TIPS returns would indicate a time-varying liquidity risk premium.

Replacing the TIPS yield by the liquidity-adjusted TIPS yield (11)—assuming once again that the liquidity differential is entirely attributable to TIPS—and breakeven inflation by liquidity-adjusted breakeven (12) we compute liquidity-adjusted TIPS and breakeven excess returns according to

$$\begin{aligned} xr_{n,t+1}^{TIPS-L} &= ny_{n,t}^{TIPS,adj} - (n-1)\, y_{n-1,t+1}^{TIPS,adj} - y_{1,t}^{TIPS}, & (13) \\ xr_{n,t+1}^{b+L} &= xr_{n,t+1}^{\$} - xr_{n,t+1}^{TIPS-L}. & (14) \end{aligned}$$

The return on TIPS due to illiquidity is given by

$$r_{n,t+1}^{L} = -(n-1)\, L_{n-1,t+1} + nL_{n,t}. \quad (15)$$

Campbell and Shiller (1996) showed that the nominal term spread can predict excess returns on long-term nominal bonds. Pflueger and Viceira (2011) in addition found that

TIPS returns are predicted by the TIPS term spread and that breakeven inflation returns are predicted by the breakeven term spread but do not adjust for liquidity. Table III shows similar predictability regression for liquidity-adjusted returns. Table III reports Newey-West standard errors with three lags to control for time-series autocorrelation in the regression errors. We also report one-sided bootstrap p-values to account for the fact that liquidity is estimated and is therefore only known with error. We use a non-parametric block bootstrap with block length 24 months and 2000 replications. See Horowitz (2001) for a survey of bootstrap methods.

[TABLE III ABOUT HERE]

The first two columns in Table III show that after adjusting for liquidity, we cannot find any evidence for predictability in real bond excess returns. While Pflueger and Viceira (2011) found that the TIPS term spread predicts TIPS excess returns[15], we cannot reject the null hypothesis of no predictability in liquidity-adjusted TIPS excess returns at conventional significance levels. Said differently, we cannot reject the expectations hypothesis of the term structure of interest rates in real bonds. This finding of no predictability might of course partly be due to our short sample period in the US and only longer time series may be able to tell.

On the other hand, the evidence for predictability in liquidity-adjusted breakeven excess returns is strong. The liquidity-adjusted breakeven term spread predicts breakeven excess returns significantly with a large coefficient. This provides support for the hypothesis that nominal bond term spreads partly reflect time-varying inflation risk premia and that time-varying inflation risk premia are a source of predictability in nominal bond excess returns.

[15] Over our slightly updated sample period the evidence becomes marginally insignificant, see Table V.

Remarkably liquidity does not predict liquidity-adjusted real bond excess returns or breakeven excess returns and therefore does not appear to be related to fundamental cash-flow risk. This finding suggests that the liquidity premium does not capture time-varying inflation risk, even though we did not explicitly control for time-varying inflation risk when estimating the liquidity premium.

The last column of Table III shows that the liquidity return $r^L_{n,t+1}$ is highly predictable from lagged liquidity $L_{n,t}$ with a large and highly significant regression coefficient. Return-predictability in TIPS excess returns therefore is partly due to a time-varying and predictable liquidity 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.

Table III uses excess returns on TIPS over our hypothetical real short rate. However, the return predictability results in Table III hold up if instead we consider nominal returns on TIPS in excess of the nominal short rate, as shown in Appendix Table A.VI.

B Economic Significance of Risk Premia

Table IV shows statistics to illustrate the economic significance of different bond risk premia.[16] As discussed in the introduction, US TIPS enjoyed higher excess returns than US nominal bonds over our sample period, so US breakeven excess returns are negative on aver-

[16] Our average return calculations are based on log returns with no variance adjustments for Jensen's inequality. We compute CAPM betas using the stock market as the proxy for the wealth portfolio. The US excess stock return is the log quarterly return on the value-weighted CRSP index, rebalanced annually, in excess of our log 3 month interest rate. The UK excess stock return similarly is computed as the log quarterly total return on the FTSE in excess of our log 3 month interest rate.

age over our sample period. Our estimates explain the negative breakeven excess return with a positive return due to liquidity, which is large at 1.01% p.a.[17] After adjusting for liquidity, we obtain a positive breakeven inflation return of 53 bps p.a. on average. At the same time, our estimates imply that even controlling for liquidity the average return on TIPS has been positive at 3.66% p.a.

[TABLE IV ABOUT HERE]

The second column in the panel shows CAPM betas of raw and liquidity-adjusted bond excess returns. The positive and significant beta on liquidity implies that TIPS tend to become illiquid relative to nominal Treasury bonds—or conversely, Treasury bonds become more liquid relative to TIPS—at times when the stock valuations fall. The strong positive covariation of our liquidity estimate with stock returns suggests that investors should expect to earn a premium on TIPS for bearing systematic variation in liquidity.

Consistent with this notion, Appendix Table A.VII shows that the market alpha of liquidity returns is small and insignificant over our full sample period. This table also shows that while during the pre-crisis period liquidity returns appear to have no market exposure and substantial alpha, inclusion of the financial crisis shows that liquidity returns are highly systematic and do not offer significant alpha. It therefore seems that positive liquidity returns compensate TIPS holders for the risk that TIPS become less liquid during dramatic drops in the stock market. Appendix Table A.VIII also shows that TIPS liquidity returns are not related to innovations in the Pastor-Stambaugh liquidity factor, which captures liquidity in the stock market, or to the Fama-French factors.

[17] The average liquidity-adjusted excess log return on TIPS and the log return on liquidity add up to the average excess log return on TIPS up to rounding.

The CAPM betas of liquidity-adjusted breakeven excess returns and liquidity-adjusted TIPS returns are negative but insignificant at -0.09 and -0.11, respectively.[18] These negative betas imply that on average real interest rates and inflation expectations are pro-cyclical during our sample period. Procyclical behavior of real interest rates and low inflation risk makes all Treasury bonds, whether nominal or inflation-indexed, safe assets that provide investors with sizable diversification benefits relative to stocks in the framework of Campbell, Sunderam, and Viceira (2011).

In order to understand the economic significance of the estimated return predictability, we now calculate the volatilities of predicted excess returns and compare them to the variability of realized bond excess returns. The expected liquidity-adjusted breakeven returns, the expected liquidity-adjusted TIPS returns and expected liquidity returns are the fitted values from Table III(2), III(4), and III(5). We obtain the expected excess returns on nominal bonds, TIPS and breakeven inflation similarly as fitted values of the respective excess return onto the breakeven and TIPS term spreads.

The third column of Panel B in Table IV shows that liquidity-adjusted breakeven excess returns have the most volatile predictable component, followed by liquidity-adjusted TIPS excess returns and liquidity returns. Time-varying expected liquidity returns can account for 3% of the variance of realized TIPS returns, while expected returns on liquidity-adjusted TIPS are more variable, explaining 6% of the variance of realized TIPS returns. While we are not able to reject the null hypothesis of no predictability in liquidity-adjusted TIPS excess returns in Table III, the fitted time-varying real interest rate risk premium appears

[18] While raw breakeven returns have a large and negative CAPM beta, adjusting for liquidity reduces the magnitude and significance of this CAPM beta. These results suggest that the negative inflation risk premium estimated by Campbell, Sunderam and Viceira (2010) over our sample period might have been partly caused by systematic variation in the relative liquidity of TIPS and nominal Treasury bonds.

quantitatively more volatile than the fitted liquidity premium.

Time-variation in expected excess returns on liquidity-adjusted breakeven inflation and TIPS can account for 7% and 4% of the sample variability of realized nominal bond returns, respectively. These relative magnitudes suggest that the time-varying inflation risk premium is quantitatively important for nominal bond excess return predictability.

[FIGURE 5 ABOUT HERE]

Figure 5A illustrates the time series of the fitted US expected excess returns. We label 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. Figure 5A shows quarterly expected returns in annualized units. While the magnitudes may appear large, we need to bear in mind that Table III predicts quarterly returns and not returns over the next year. During the period of 2000 to 2006 the inflation risk premium was small or negative. During the period of high oil prices in 2008 the inflation risk premium was positive but subsequently fell to almost -10% at the beginning 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.

A negative inflation risk premium in 2009 indicates that investors considered the nominal component of bond returns safe, so further economic deterioration was anticipated to go along with low inflation rather than high inflation. A large and positive real interest rate risk premium during the same time period indicates that real bonds were considered risky, so a deepening of the recession was likely to go along with high long-term interest rates.

Panel C in Table IV shows similar statistics for UK excess bond returns over the longer sample period 1985-2010. Due to data constraints we are not able to compute a liquidity-adjustment for the UK. However, 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, suggesting that "flight-to-liquidity" effects should be less significant in generating a liquidity differential between inflation-indexed and nominal bonds in the UK.

We find an average excess return on UK inflation-indexed bonds of 2.15% p.a. Average breakeven excess returns were positive in the UK, just like liquidity-adjusted breakeven excess returns in the US.

The CAPM beta of UK inflation-indexed bonds at 0.14 is positive and statistically significant, while the CAPM beta of breakeven inflation is essentially zero over the full sample. The betas on UK bonds indicate that on average inflation-indexed bonds, and to some degree nominal bonds, have been risky over the time period under consideration. On the other hand, breakeven inflation has not exhibited any systematic risk. However, the UK breakeven betas hide important variation across sub-periods. In Appendix Table A.VII, we show that the beta of UK breakeven inflation was positive in the period prior to 1999 and turned negative and significant in the post-1998 period, suggesting that inflation risk in nominal bonds has varied over time and was much more pronounced in the first half of the sample.

Interestingly, Figure 5B suggests that the UK breakeven risk premium shot up during the financial crisis. In the framework of Campbell, Sunderam, and Viceira (2010) this could indicate that while investors in the UK feared that further economic deterioration would go along with inflation, US investors were concerned about low growth accompanied by low inflation or even deflation.

III Testing For Market Segmentation Effects in the US and UK Bond Markets

Sections I and II have presented evidence of the impact of liquidity on breakeven inflation and on TIPS and breakeven returns. In this section we explore the role of shocks to relative supply as a source of bond return predictability. 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, leading to excess bond return predictability. Greenwood and Vayanos (2008) and Hamilton and Wu (2010) find empirical support for this theory using the relative supply of nominal Treasury bonds at different maturities as a proxy for supply shocks.

We test whether segmentation between inflation-indexed and nominal bond markets induces relative price fluctuations and return predictability in an empirical setup similar to

Greenwood and Vayanos (2008). 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.[19] 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. [20]

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

[19] 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. 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 as in Greenwood and Vayanos (2008).

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

the US or the UK. We define the relative supply as

$$Supply_t = D_t^{TIPS}/D_t. \tag{16}$$

We also consider the relative issuance $\Delta Supply_t$, which we compute as

$$\Delta Supply_t = \left(D_t^{TIPS} - D_{t-1}^{TIPS}\right)/D_{t-1}^{TIPS} - \left(D_t - D_{t-1}\right)/D_{t-1}. \tag{17}$$

Finally, it could be that most bond issuance is predictable and it might therefore not lead to relative price fluctuations. We therefore construct a measure of unexpected relative issuance ε_t^{Supply}. In the Appendix we conduct Dickey-Fuller tests to find that in the US we cannot reject a unit root in $Supply_t$ or in $\Delta Supply_t$. However, the year-over-year change in relative issuance appears stationary and we construct a supply shock ε_t^{Supply} as the residual from an autoregression of $\Delta Supply_t - \Delta Supply_{t-12}$ with twelve lags. In the UK we can reject stationarity in relative issuance $\Delta Supply_t$, potentially reflecting the less regular issuance cycle in the UK, and we construct a supply shock ε_t^{Supply} as the residual from an autoregression of $\Delta Supply_t$ with twelve lags.

[FIGURE 6 ABOUT HERE]

Figure 6A plots the relative supply of TIPS, D_t^{TIPS}/D_t, and 10 year breakeven inflation in the US. Starting from less than 2% in 1997 TIPS increased to represent over 14% of the US Treasury coupon bond 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 to 9% in 2010. 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 6B illustrates that the relative share of UK linkers has increased over the period from about 9% in 1985 to 16% in 2010. At the same time 20 year UK breakeven inflation has fallen in the period 1985-2010, reaching a low of 2.1% in 1998. The increase in inflation-linked bonds outstanding accelerated noticeably after 2004.[21]

[TABLE V ABOUT HERE]

In Table V, we test whether the relative yields of inflation-indexed and nominal bonds are related to our measures of relative supply. If markets are segmented and subject to exogenous supply shocks we would expect a negative coefficient on measures of relative supply of inflation-indexed bonds. Table VA shows that in the US neither the relative supply nor relative issuance $\Delta Supply_t$ or the supply shock ε_t^{Supply}appear to be related to breakeven inflation, either individually or jointly. These results are robust to controlling for liquidity proxies and for a time trend.

Table VB shows similar empirical results for the UK over a significantly longer time period. Due to data constraints we are not able to control for liquidity. The supply variable is significant but it switches sign as we include a time trend in the regression, while the change in supply or the supply shock ε_t^{Supply} do not enter significantly. The time trend is

[21] 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.

highly statistically significant and increases the R^2 from 26% to 65%.

Figure 6B helps to interpret the supply coefficient's sign change when adding a time trend. 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 changes in monetary policy and declines in both realized and expected inflation (Campbell, Shiller, and Viceira 2009), rather than changes in bond supply. 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 might lend weight to the interpretation that the UK government reacts to increased demand for inflation-linked bonds by issuing more inflation-indexed bonds.

Fleckenstein, Longstaff, and Lustig (2010) argue that the supply of Treasury securities affects the relative mispricing of inflation-indexed and nominal bonds. Their empirical results can be reconciled with ours. We use the theoretically motivated relative supply of inflation-indexed bonds, while they include both the supply of TIPS and of Treasuries separately in their regressions. The sign of their results is such that TIPS become relatively more expensive, when the Treasury issues more TIPS and this result is again inconsistent with a market segmentation hypothesis.

If markets are segmented in the sense of Greenwood and Vayanos (2009) we would expect a positive shock in the relative supply of inflation-indexed bonds to predict lower excess returns on nominal bonds over inflation-indexed bonds. Table VI explores this prediction of the segmentation hypothesis. Our left-hand-side variables in Table VI are the nominal, inflation-indexed and breakeven returns as defined in (3), (4) and (5). Table VI shows that in the US and in the UK the supply variables do not help to predict bond excess returns.

Campbell and Shiller (1996) showed that the nominal term spread can predict excess returns on long-term nominal bonds. Moreover, Pflueger and Viceira (2011) show that TIPS term spreads and breakeven term spreads are significant predictors of the corresponding excess returns and therefore we control for these spreads in our regressions. We saw in Section II that liquidity predicts the liquidity component of bond excess returns and we therefore include it as an additional control.

[TABLE VI ABOUT HERE]

Table VI shows that even after including liquidity and supply effects, the nominal term spread enters positively for nominal bond excess returns and its slope coefficient is significant in the UK. The breakeven term spread predicts breakeven excess returns both in the US and in the UK. The TIPS term spread predicts TIPS excess returns both in the UK but is marginally insignificant in the US over our sample period. Relative supply shocks therefore cannot explain why term spreads predict excess returns on inflation-indexed bonds and on nominal bonds in excess of inflation-indexed bonds.

In summary, there is no evidence of relative supply shocks predicting bond excess returns in either the UK or the US. These results do not seem consistent with segmented markets that are subject to exogenous supply shocks. Instead they might indicate that US and UK governments accommodate demand pressures from investors for nominal or inflation-indexed bonds.[22]

[22] Anectodal evidence suggests that this is the case, at least for the UK. Unlike the US Treasury, the British Treasury has an irregular auction calendar and it appears to take into account bond demand when deciding the size and characteristics of bond issues.

The empirical evidence in Table IV suggests that raw TIPS excess returns and breakeven excess returns are predictable from their respective term spreads and that our return-predictability results in Table III also hold without adjusting for liquidity. Comparing Tables III(2) and Table VI(3), we see that the TIPS return-predictability regressions are not sensitive to the assumption that all variation in relative liquidity is due to variation in TIPS liquidity rather than liquidity in nominal Treasuries. Table VI(7) shows that in the UK over a longer time period the TIPS term spread significantly predicts TIPS excess returns, indicating a time-varying real interest rate risk premium.

IV Conclusion

This paper explores the sources of time variation in bond risk premia in inflation-indexed and nominal bonds in the US and in the UK. We find strong empirical evidence that nominal bond excess return predictability is related to a time-varying inflation risk premium. As also provide empirical evidence for liquidity as a source of return predictability in inflation-indexed bonds in the US.

Using a variety of liquidity indicators, we find that the liquidity premium on TIPS yields relative to nominal Treasury bond yields exhibits strong time-variation, with a large premium early in the life of TIPS, a significant decline to a lower premium after 2004, and a sharp increase to over 150 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 more normal levels of 50 to 70 bps.

Time-varying liquidity explains up to 66% of the time-series variance of breakeven inflation. Once we adjust breakeven inflation for liquidity effects, we find it to be stable over our sample period around 3%, suggesting that bond investors' long-term inflation expectations in the US have not moved significantly, even during the financial crisis.

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. If anything, our results are consistent with the government trying to accommodate shifts in the demand for nominal bonds, relative to inflation-indexed bonds.

Our liquidity premium is correlated with other liquidity spreads in fixed income markets, particularly the off-the-run spread (Krishnamurthy, 2002), and it exhibits an economically and statistically significant positive CAPM beta, suggesting that the liquidity premium is at least partly systematic in nature. A simple calculation also suggests that the liquidity returns on TIPS during normal times are comparable to the liquidity returns on off-the-run nominal Treasury bonds.

The liquidity premium does not predict liquidity-adjusted returns on TIPS or on breakeven, so that it does not seem to proxy for any real interest rate risk or inflation risk. Hence, while we find that the liquidity differential between nominal bonds and TIPS moves with the aggregate market, it bears no relationship to the real cash flow risks of the specific securities, a conclusion that should be important in guiding future models of liquidity.

A possible interpretation is that we partly identify a liquidity premium or convenience yield on nominal Treasury bonds (Krishnamurthy and Vissing-Jorgensen, 2010), rather than a liquidity discount specific to TIPS. Under this interpretation TIPS are not undervalued securities; instead investors appear to be willing to pay a liquidity premium on nominal Treasury bonds. The Treasury could take advantage of this premium by issuing more nominal

Treasury bonds, but it would still be issuing TIPS at their fair value. If investors appropriately value TIPS, taking them off the market might have adverse welfare consequences for investors in need of the real interest rate hedge and inflation hedge offered by TIPS (Campbell and Viceira 2002).

Our results suggest several directions for future research. First, 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 when a longer historical time series of TIPS becomes available. Second, 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. Third, 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.

References

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

Amihud, Yakov, Haim Mendelson, and Lasse Heje Pedersen, 2005, Liquidity and Asset Prices, *Foundations and Trends in Finance* 1(4), 269–364

Anderson, Nicola and John Sleath, 2001, New estimates of the UK real and nominal yield curves, Bank of England Working Paper, ISSN 1368-5562, available at www.bankofengland.co.uk/workingpapers/index.htm

Bitsberger, Timothy, 2003, Why Treasury Issues TIPS, Chart Presentation of Deputy Assistant Secretary for Federal Finance Timothy S. Bitsberger To the Bond Market Association's Inflation-Linked Securities Conference New York, NY, available at http://www.treasury.gov/press-center/press-releases/Pages/js505.aspx

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 Ben S. Bernanke and Julio Rotemberg, ed.: *National Bureau of Economic Research Macroeconomics Annual 1996* (MIT Press)

Campbell, John Y., Robert J. Shiller, and Luis M. Viceira, 2009, "Understanding Inflation-Indexed Bond Markets", in David Romer and Justin Wolfers, ed.: *Brookings Papers on Economic Activity: Spring 2009* (Brookings Institution Press)

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

Christensen, Jens E., and Gillan, James M., 2011, A Model-Independent Maximum Range for the Liquidity Correction of TIPS Yields, manuscript, Federal Reserve Bank of San Francisco.

Christensen, Jens E., Jose A. Lopez, and Glenn D. Rudebusch, 2010, Inflation Expectations and Risk Premiums in an Arbitrage-Free Model of Nominal and Real Bond Yields, *Journal of Money, Credit and Banking* 42(6), 143-178

D'Amico, Stefania, Don H. Kim, and Min Wei, 2008, Tips from TIPS: the informational content of Treasury Inflation-Protected Security prices, *BIS Working Papers*, No 248

Dudley, William C., Jennifer Roush, and Michelle Steinberg Ezer, 2009, The Case for TIPS: An Examination of the Costs and Benefits, *Economic Policy Review* 15(1), 1-17

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, *FRB of New York Staff Report,* No. 414

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

Granger, C.W.J., and P. Newbold, 1974, Spurious Regressions in Econometrics, *Journal of Econometrics* 2, 111-120

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

Grishchenko, Olesya V., Joel M. Vanden, and Jianing Zhang, 2011, The Informational Content of the Embedded Deflation Option in TIPS, Finance and Economics Discussion Series, Federal Reserve Board

Hamilton, James, 1994, "Time Series Analysis", Princeton University Press

Haubrich, Joseph G., George G. Pennacchi, and Peter H. Ritchken, 2010, Inflation Expectations, Real Rates, and Risk Premia: Evidence from Inflation Swaps, Working Paper, Federal Reserve Bank of Cleveland, available at SSRN: http://ssrn.com/abstract=1784067

Hamilton, James D., and Jing (Cynthia) Wu, 2010, The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment, Manuscript, University of California, San Diego

Horowitz, J.L., 2001,"The Bootstrap“, in J.J. Heckman and E.E. Leamer, ed: *Handbook of Econometrics Vol. 5* (Amsterdam: North-Holland Publishing Co.)

Krishnamurthy, Arvind, 2002, The Bond/Old-Bond Spread, *Journal of Financial Economics* 66(2), 463-506

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen, 2010, The Aggregate Demand for Treasury Debt, Working Paper, Kellogg School of Management at Northwestern University.

Longstaff, Francis A., 2004, The Flight-to-Liquidity Premium in U.S. Treasury Bond Prices, Journal of Business 77(3), 511–26.

Modigliani, Franco, and Richard Sutch, 1966, Innovations in Interest-Rate Policy, *American Economic Review* 56, 178-197

Pastor, Lubos, and Robert F. Stambaugh, 2003, Liquidity Risk and Expected Stock Returns, *Journal of Political Economy* 111, 642–685.

Phillips, P.C.B., 1986, Understanding Spurious Regressions in Econometrics, *Journal of Econometrics* 33(3), 311-340

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

Pond, Michael, and Chirag Mirani, 2011, Pouring cold water on liquidity, Barclays Capital

Roll, Richard, 2004, Empirical TIPS, *Financial Analysts Journal* 60, 31-53

Stock, James, and Mark Watson, 1999, Forecasting inflation, *Journal of Monetary Economics* 44, 293-335

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

Viceira, Luis M., 2011, Discussion of "Why Does The Treasury Issue TIPS? The TIPS-Treasury Bond Puzzle, slide presentation prepared for the NBER Asset Pricing Group Meeting of April 29, 2011, Chicago. Available upon request.

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

Wachter, Jessica A., 2006, A Consumption-Based Model of the Term Structure of Interest Rates,, *Journal of Financial Economics* 79, 365–399

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

Wright, Jonathan H., 2009, Comment on Understanding Inflation-Indexed Bond Markets, in David Romer and Justin Wolfers, ed.: *Brookings Papers on Economic Activity: Spring 2009* (Brookings Institution Press)

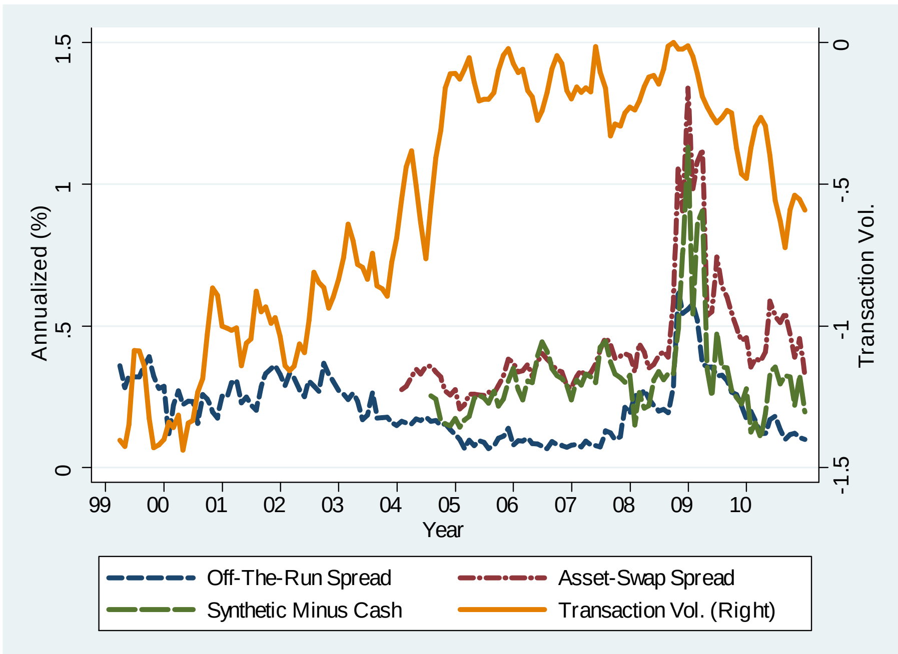

Figure 1. US Liquidity Proxies 1999-2010. Relative TIPS Trading Volume from New York Federal Reserve survey FR-2004; TIPS-Nominal Asset-Swap Spread from Barclays Live; Synthetic Breakeven from Bloomberg; 10 Year On-the-Run Off-The-Run spread from the Gurkaynak, Sack, and Wright (2010) and Bloomberg;

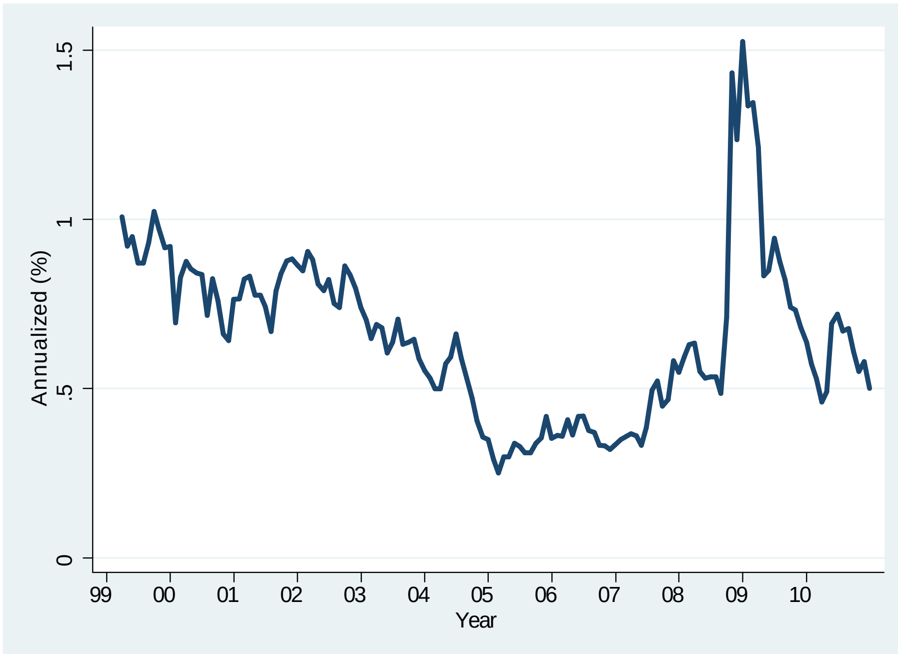

Figure 2. Estimated US Liquidity Premium. 10 Year TIPS liquidity premium estimated in Table II (4). The liquidity premium is estimated as $-\hat{a}_2 X_t$, where $\hat{a}_2$ as in Table II (4) and X_t is the vector $[\text{Off-the-Run}_t, ASW_t, \text{Transaction.Vol.}_t]$.

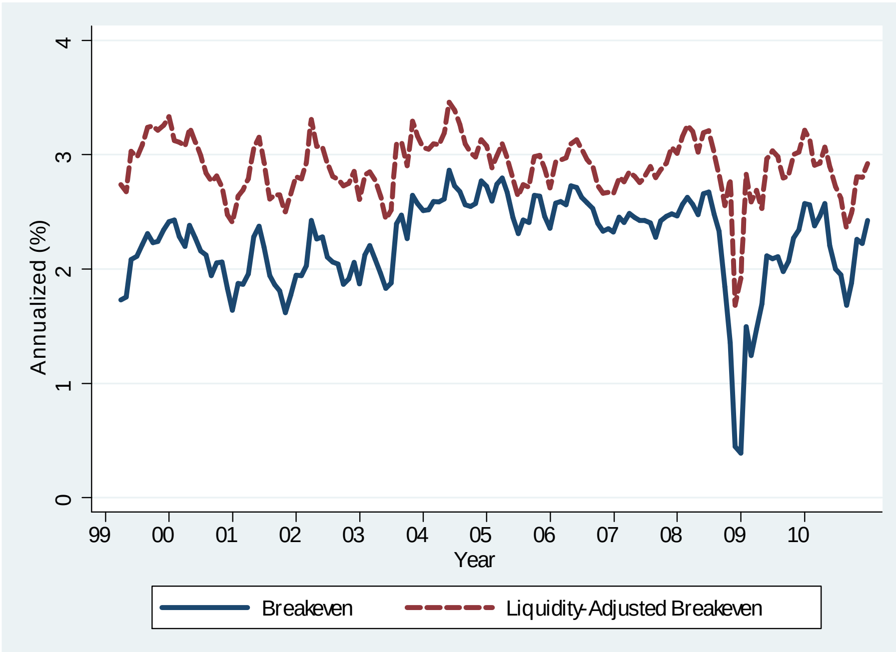

Figure 3. Liquidity-Adjusted US 10 Year Breakeven Inflation. We adjust breakeven inflation (the difference between nominal and TIPS yields) for the liquidity premium shown in Figure 2.

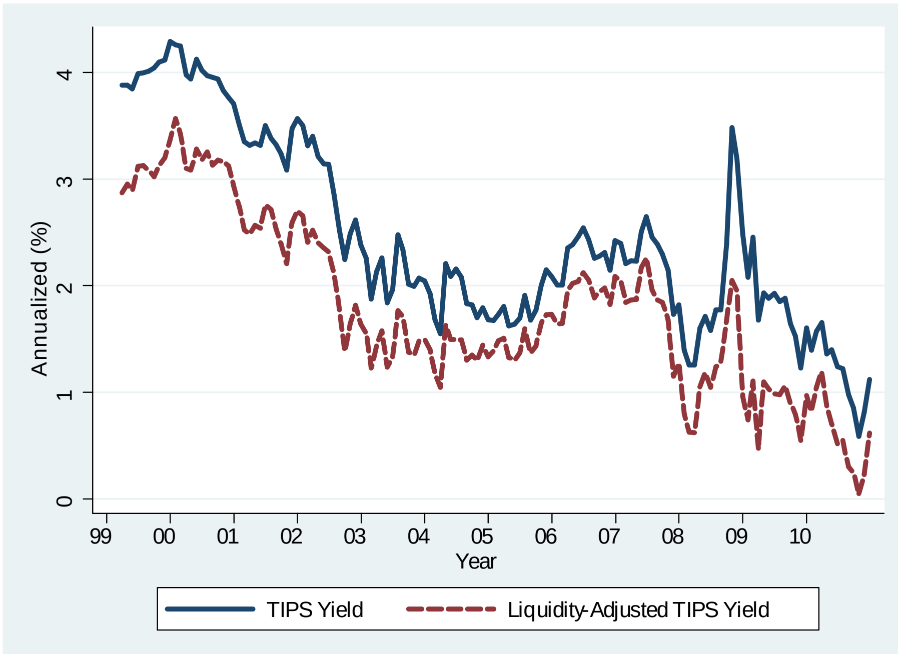

Figure 4. Liquidity-Adjusted US TIPS. We adjust US 10 Year TIPS yields for the liquidity premium shown in Figure 2.

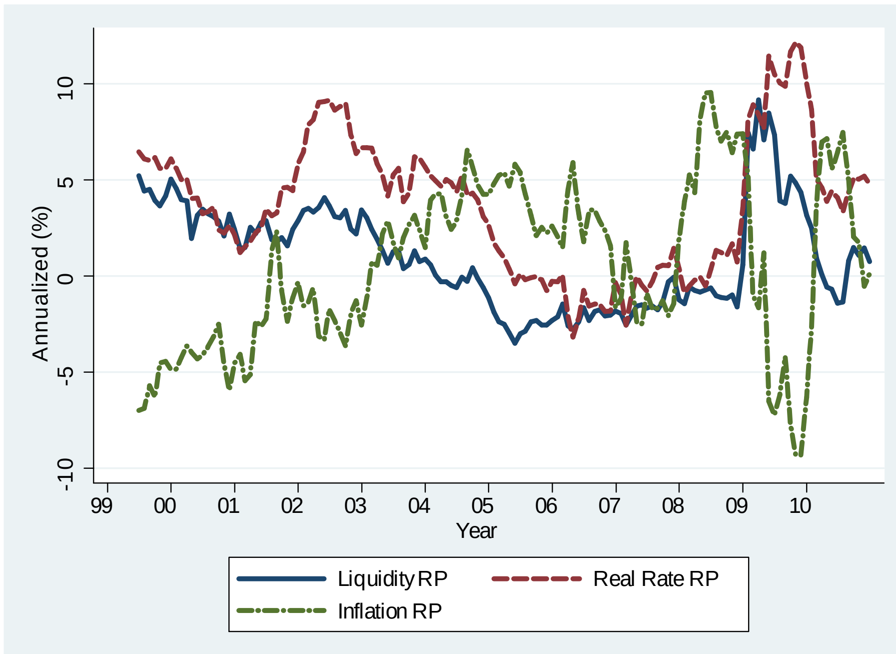

Figure 5A. Estimated US Risk Premia. The real rate risk premium, inflation risk premium and liquidity return premium are obtained as the fitted values in Tables III(2), III(4) and III(5).

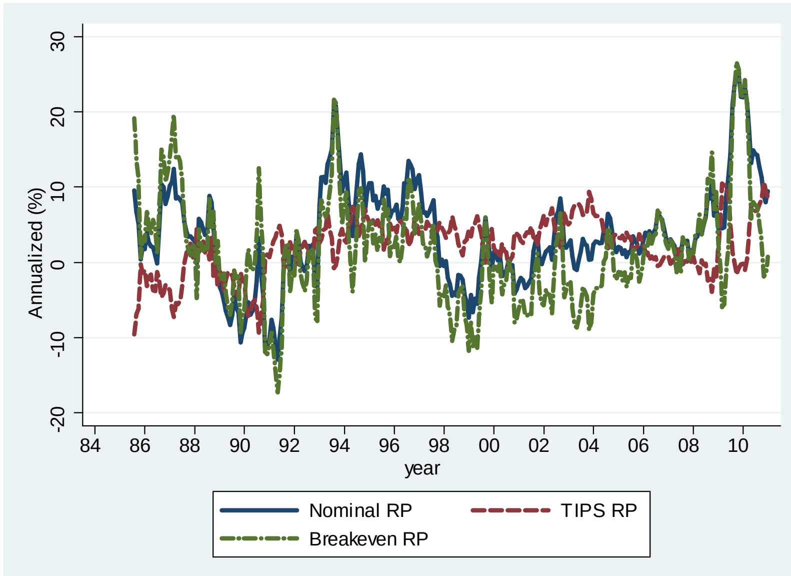

Figure 5B. Estimated UK Bond Risk Premia. The nominal risk premium, TIPS risk premium and breakeven risk premium are obtained for 1985.10-2010.12 similarly to Pflueger and Viceira (2011). We show fitted values for UK regressions of nominal excess returns, TIPS excess returns and breakeven exess returns onto TIPS and breakeven term spreads.

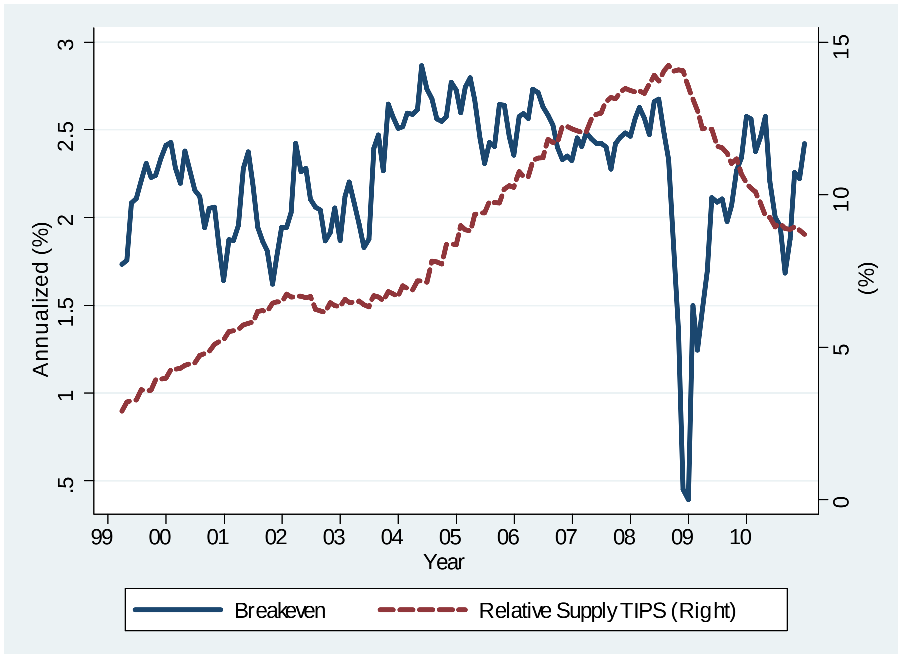

Figure 6A. US Relative Supply and 10 Year Breakeven Inflation. Relative supply shows the total amount of TIPS relative to the total amount of TIPS and nominal bonds outstanding.

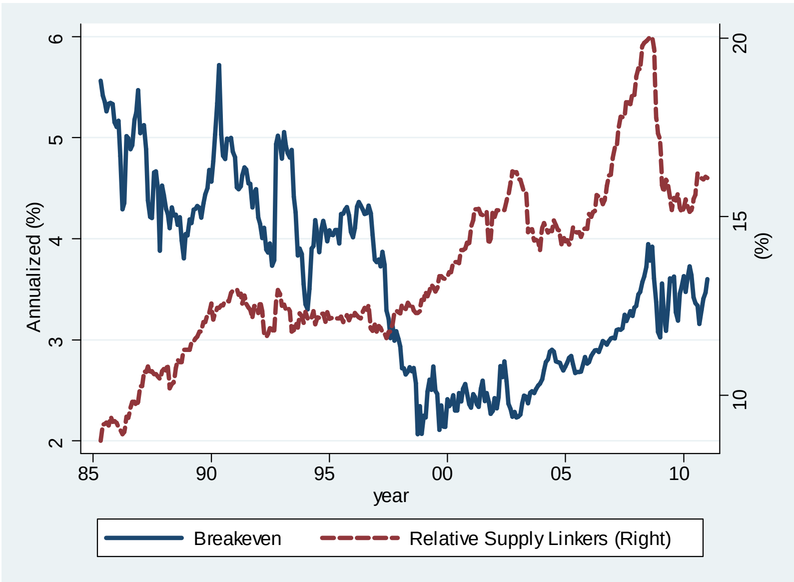

Figure 6B. UK Relative Supply and 20 Year Breakeven.
Relative supply shows the total amount of inflation-linked gilts relative to nominal and inflation-linked gilts outstanding.

Table I
Summary Statistics

US data is monthly 1999.6-2010.12 and UK data is monthly 1985.4-2010.12. The US asset-swap spread is monthly 2004.1-2010.12. “Synthetic - cash” is the difference between the inflation swap spread rate and cash breakeven inflation and runs from 2004.7-2010.12. “Transaction volume” is the log TIPS transaction volume relative to the log transaction volume of government coupon securities with at least 6 years to maturity. π^{SPF} denotes the median 10 year CPI-inflation forecast from the Survey of Professional Forecasters. π^{SPF} is released in the middle month. For each month end we report the most recent release. Yields and spreads are in annualized % units. Quarterly overlapping nominal excess log returns $xr^{\$}_{n,t+1}$, TIPS excess log returns $xr^{TIPS}_{n,t+1}$ and breakeven excess log returns $xr^{b}_{n,t+1}$ are also in annualized %. * and ** denote significance at the 5% and 1% levels.

	Panel A: US 10 YR				**Panel B: UK 20 YR**			
	Mean	Std	Min	Max	Mean	Std	Min	Max
$y^{\$}_{n,t}$	4.66	0.87	2.66	6.70	6.30	1.94	3.79	9.93
$y^{TIPS}_{n,t}$	2.41	0.89	0.59	4.29	2.72	1.18	0.57	4.57
$b_{n,t}$	2.25	0.39	0.39	2.87	3.59	0.93	2.07	5.72
$xr^{\$}_{n,t+1}$	4.19	8.75	-41.89	56.62	3.69	14.63	-104.94	109.35
$xr^{TIPS}_{n,t+1}$	4.66	7.63	-64.91	58.03	2.14	9.09	-65.78	63.67
$xr^{b}_{n,t+1}$	-0.48	7.30	-42.62	74.33	1.55	12.30	-102.40	84.86
π^{SPF}	2.47	0.07	2.2	2.55				
Off-the-Run Spr.	0.21	0.11	0.07	0.63				
Asset-Swap Spr.	0.55	0.24	0.33	1.34				
Transaction Vol.	-0.55	0.43	-1.44	0.00				
Synthetic - Cash	0.32	0.17	0.11	1.13				

Table II
Breakeven onto Liquidity Proxies US

We regress the difference between nominal bond yields and TIPS (breakeven inflation) less π^{SPF} onto liquidity proxies. π^{SPF} denotes the median 10 year CPI- inflation forecast from the Survey of Professional Forecasters. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level, respectively. The augmented Dickey-Fuller statistic (ADF) includes a trend and three lagged differences.

$y^{\$}_{n,t} - y^{TIPS}_{n,t} - \pi^{SPF}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Off-the-Run Spr.	-2.67^{**}	-2.34^{**}	-1.73^{**}	-1.19^{**}	-1.35^{**}	-1.97^{**}	-1.48^{**}
	(0.35)	(0.28)	(0.39)	(0.36)	(0.31)	(0.55)	(0.42)
Asset-Swap Spr.		-0.42^{*}	-0.84^{**}	-0.64^{*}			
		(0.21)	(0.26)	(0.27)			
Transaction Vol.			0.22^{*}	0.29^{**}	0.24^{**}	0.09	0.11
			(0.09)	(0.09)	(0.07)	(0.10)	(0.08)
CFNAI				0.12^{**}	0.10^{**}		0.19^{**}
				(0.03)	(0.03)		(0.04)
Synthetic - Cash					-1.10^{**}		
					(0.28)		
Const.	0.38^{**}	0.46^{**}	0.61^{**}	0.50^{**}	0.59^{**}	0.29^{**}	0.21^{**}
	(0.07)	(0.08)	(0.10)	(0.11)	(0.09)	(0.07)	(0.07)
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R^2	0.57	0.60	0.62	0.66	0.70	0.49	0.60
ADF of Residuals	-4.39^{**}	-4.22^{**}	-4.25^{**}	-4.82^{**}	-5.20^{**}	-4.48^{**}	-4.85^{**}
Sample			$1999.3 - 2010.12$			$1999.3 - 2006.12$	

Table III
Liquidity-Adjusted Return Predictability US

We regress liquidity-adjusted excess log bond returns of TIPS and of nominal bonds in excess of TIPS onto the liquidity-adjusted TIPS term spread, the liquidity-adjusted breakeven term spread and the liquidity premium on TIPS $L_{n,t}$. $L_{n,t}$ is estimated as the fitted value less the constant and less variation due to CFNAI in Table II (4). $r^L_{n,t+1}$is the return on TIPS due to liquidity. We use quarterly overlapping returns. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level with respect to Newey-West standard errors, respectively. We also show one-sided bootstrap p-values from 2000 replications. We use block bootstrap with block length 24 months. Bootstrap accounts for the fact that the liquidity premium is estimated.

		(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) $r^L_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$		2.35	2.52		-1.36	0.38
	Newey-West SE	(1.57)	(1.88)		(1.52)	(0.66)
	Bootstrap p-value	34.7%	27.1%		34.5%	43.7%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			-0.66	4.90**	5.49**	-0.77
	Newey-West SE		(2.90)	(1.72)	(1.76)	(1.66)
	Bootstrap p-value		16.7%	0.1%	0.0%	34.8%
$L_{n,t}$		6.02	5.69	-9.48	-6.58	9.92**
	Newey-West SE	(9.12)	(10.01)	(5.47)	(7.28)	(3.28)
	Bootstrap p-value	16.5%	22.1%	6.05%	16.35%	0.1%
p-value		0.09	0.16	0.01	0.01	0.00
R^2		0.06	0.07	0.13	0.14	0.16
Sample				$1999.6 - 2010.12$		

Table IV
Moments of Realized and Fitted Bond Returns

We show summary statistics for realized excess log returns $xr_{n,t}$ and historical fitted risk premia $E_t\left(xr_{n,t+1}\right)$. We show realized sample moments $\hat{E}\left(xr_{n,t}\right)$ and $\hat{\beta}\left(xr_{n,t}\right)$ for excess log returns on nominal bonds, TIPS, breakeven, liquidity-adjusted breakeven, liquidity-adjusted TIPS and liquidity returns. Betas are with respect to excess log stock returns including dividends. We obtain US expected excess log returns for liquidity-adjusted breakeven, liquidity-adjusted TIPS and liquidity over 1999.6-2010.12 as fitted values from Tables III(2), III(4) and III(5). Expected nominal, TIPS and breakeven excess log returns breakeven were obtained in Pflueger and Viceira (2011) from analogous return-predictive regressions using no liquidity-adjustment over 1999.6-2010.12 (US) and 1985.4-2010.12 (UK). Numbers shown are annualized (%). Newey-West standard errors for $\hat{\beta}$ are computed with 3 lags. * and ** denote significance at the 5% and 1% level for $\hat{\beta}$, respectively.

Panel A: US Liquidity	Mean	Std	Min	Max	
Liq. Premium	0.65	0.25	0.25	1.53	
Liq.-Adj. Breakeven	2.90	0.26	1.69	3.46	
Liq.-Adj. TIPS Yields	1.79	0.81	0.04	3.56	
Panel B: US Returns	$\hat{E}\left(xr_{n,t}\right)$	$\hat{\beta}\left(xr_{n,t}\right)$	$\sigma\left(E_t xr_{n,t+1}\right)$	$\frac{\sigma^2(E_t xr_{n,t+1})}{\sigma^2\left(xr^{\$}_{n,t}\right)}$	$\frac{\sigma^2(E_t xr_{n,t+1})}{\sigma^2\left(xr^{TIPS}_{n,t}\right)}$
Excess Log Return Nominal	4.19	-0.19^{**}	1.98	5%	
Excess Log Return TIPS	4.66	0.01	2.82	10%	14%
Excess Log Return BEI	-0.48	-0.21^{*}	3.14	13%	
Liq.-Adj. Exc. Log Ret. BEI	0.53	-0.09	2.16	6%	
Liq.-Adj. Exc. Log Ret. TIPS	3.66	-0.11	1.77	4%	5%
Log Return Liquidity	1.01	0.12^{**}	1.35		3%
Panel C: UK Returns	$\hat{E}\left(xr_{n,t}\right)$	$\hat{\beta}\left(xr_{n,t}\right)$	$\sigma\left(E_t xr_{n,t+1}\right)$	$\frac{\sigma^2(E_t xr_{n,t+1})}{\sigma^2\left(xr^{\$}_{n,t}\right)}$	$\frac{\sigma^2(E_t xr_{n,t+1})}{\sigma^2\left(xr^{TIPS}_{n,t}\right)}$
Excess Log Return Nominal	3.69	0.15	3.34	5%	
Excess Log Return TIPS	2.15	0.14^{**}	1.83	2%	4%
Excess Log Return BEI	1.52	0.01	3.67	6%	

Table V
Breakeven Inflation onto Relative Supply

We regress the difference between nominal bond yields and inflation-indexed yields (breakeven inflation) onto measures of relative supply. We control for liquidity measures as in Table II and a time trend. $Supply_t$ denotes the amount of inflation-indexed bonds outstanding relative to all nominal and inflation-indexed bonds outstanding. $\Delta Supply_t$ denotes the issuance of inflation-indexed bonds relative to all nominal and inflation-indexed bonds. ε_t^{Supply} is obtained as the residual in a 12-lag monthly autoregression of $\Delta Supply_t - \Delta Supply_{t-12}$ ($\Delta Supply_t$) in the US (UK). Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level, respectively.

	Panel A: US				**Panel B: UK**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Supply_t$	0.01			0.01	-0.20^{**}			0.15^{**}
	(0.03)			(0.02)	(0.04)			(0.07)
$\Delta Supply_t$		0.03		0.00		0.01		-0.15
		(0.02)		(0.01)		(0.03)		(0.13)
ε_t^{Supply}			0.03	0.01			0.00	0.13
			(0.02)	(0.01)			(0.03)	(0.12)
Off-the-run Spr.				-1.28^{**}				
				(0.43)				
Asset-Swap-Spr.				-1.27^{**}				
				(0.31)				
Transaction Vol.				0.20				
				(0.15)				
month				0.00				-0.01^{**}
				(0.00)				(0.00)
p-value	0.77	0.07	0.12	0.00	0.00	0.85	0.92	0.00
R^2	0.00	0.05	0.03	0.64	0.26	0.00	0.00	0.49
Sample		2000.2-2010.12				1986.1 – 2010.12		

Table VI
Excess Bond Returns onto Relative Supply of Inflation-Indexed Bonds

We regress log excess bond returns of TIPS, nominal bonds and nominal bonds over TIPS onto measures of relative supply as defined in Table V. We control for the nominal term spread, the TIPS term spread and the breakeven term spread as well as TIPS liquidity as estimated in Table II(4). We use quarterly overlapping returns. Newey-West standard errors with three lags are provided in parentheses. The p-value of the F-test of no predictability is shown. * and ** denote significance at the 5% and 1% level, respectively.

	Panel A: US				Panel B: UK			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$xr^{\$}_{n,t+1}$	$xr^{\$}_{n,t+1}$	$xr^{TIPS}_{n,t+1}$	$xr^{b}_{n,t+1}$	$xr^{\$}_{n,t+1}$	$xr^{\$}_{n,t+1}$	$xr^{TIPS}_{n,t+1}$	$xr^{b}_{n,t+1}$
$Supply_t$	-0.21	-0.36	0.09	-0.45	-1.26	-1.11	-0.24	-0.87
	(0.74)	(0.69)	(0.72)	(0.74)	(1.09)	(1.06)	(0.78)	(0.99)
$\Delta Supply_t$	0.25	0.20	0.23	-0.03	-3.05	-3.70	-3.79	0.09
	(0.56)	(0.55)	(0.41)	(0.31)	(5.78)	(5.92)	(3.23)	(5.39)
ε_t^{Supply}	0.00	0.00	0.00	0.00	2.46	2.94	3.73	-0.79
	(0.00)	(0.00)	(0.00)	(0.00)	(5.94)	(6.04)	(3.34)	(5.53)
$L_{n,t}$	1.06	6.05	15.86	-9.81				
	9.98	(11.90)	(10.78)	(10.06)				
$y^{\$}_{n,t} - y^{\$}_{1,t}$	2.14				3.02*			
	(1.43)				(1.52)			
$y^{TIPS}_{n,t} - y^{TIPS}_{1,t}$		0.88	2.76	-1.88		0.01	3.63*	-3.62
		(2.14)	(1.45)	(1.61)		(3.27)	(1.75)	(2.48)
$b_{n,t} - b_{1,t}$		4.03	-2.75	6.78*		6.70	-2.30	9.00**
		(3.17)	(2.48)	(2.71)		(3.73)	(2.00)	(3.01)
p-value	0.38	0.45	0.01	0.03	0.17	0.20	0.23	0.03
R^2	0.05	0.05	0.20	0.19	0.06	0.07	0.05	0.10
Sample	2000.5 – 2010.12				1986.4 – 2010.12			

Table A.I
Forecasted Real Short Rate

Overlapping quarterly realized real return on nominal 3 month T-bill onto the nominal 3 month T-bill, 3 month lagged realized real return on 3 month T-bill and inflation over the past year. Newey-West standard errors with 4 lags in parentheses. * and ** denote significance at the 5% and 1% level.

	(1)	(2)
$y^{\$}_{1,t} - \pi_{t+1}$	US	UK
$y^{\$}_{1,t}$	0.55**	0.79**
	(0.20)	(0.13)
$y^{\$}_{1,t} - \pi_t$	0.10	-0.08
	(0.08)	(0.05)
$(\pi_{t-3} + \pi_{t-2} + \pi_{t-1} + \pi_t)/4$	0.10	-0.07
	(0.08)	(0.04)
Const.	-0.52**	-0.26*
	(0.09)	(0.12)
p-value	0.00	0.00
R^2	0.48	0.48
Sample	1982.1-2010.12	

Table A.II
Univariate Liquidity Regressions

Variables as in Table II. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level.

$y^{\$}_{n,t} - y^{TIPS}_{n,t} - \pi^{SPF}$	(1)	(2)	(3)	(4)	(5)
Off-the-Run Spr.	-2.67**				
	(0.35)				
Asset-Swap Spr.		-1.15**			
		(0.33)			
TransactionVol.			0.22		
			(0.14)		
CFNAI				0.25**	
				(0.05)	
Synthetic-Cash					-1.81**
					(0.40)
const.	0.38**	0.23	-0.07	-0.10*	0.33**
	(0.07)	(0.13)	(0.13)	(0.04)	(0.12)
$p - value$	0.00	0.00	0.13	0.00	0.00
R^2	0.57	0.27	0.06	0.38	0.34
Sample			1999.3-2010.12		

Table A.III
Estimating Liquidity in Quarterly Changes

We replicate Table II using quarterly changes. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level.

$\Delta\left(y_{n,t}^{\$} - y_{n,t}^{TIPS} - \pi^{SPF}\right)$	(1)	(2)	(3)	(4)	(5)
Δ Off-the-Run Spr.	-2.76**	-1.38*	-1.36*	-1.27*	-1.82**
	(0.67)	(0.56)	(0.55)	(0.53)	(0.48)
Δ Asset-Swap Spr.		-1.18**	-1.18**	-1.13**	
		(0.34)	(0.36)	(0.35)	
Δ TransactionVol.			-0.19	-0.18	-0.23
			(0.19)	(0.19)	(0.19)
Δ CFNAI				0.07*	0.07*
				(0.03)	(0.03)
Δ Synthetic-Cash					-1.02**
					(0.19)
const.	0.00		0.01	0.02	0.01
	(0.03)		(0.03)	(0.03)	(0.03)
$p-value$					
R^2	0.34	0.42	0.44	0.45	0.45
Sample			1999.3-2010.12		

Table A.IV
Estimating Liquidity with Additional Controls

We replicate Table II including interaction terms and the TIPS bid-ask spread. The TIPS bid-ask spread is from Tradeweb and available 2005.3-2010.6. We set to its 2005.3 value before 2005.3 and to its 2010.6 value after 2010.6. Newey-West standard errors with three lags in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level.

$y^{\$}_{n,t} - y^{TIPS}_{n,t} - \pi^{SPF}$	(1)	(2)	(3)	(4)
Off-the-Run Spr.	1.17	1.31	1.06	-1.20**
	(0.92)	(1.06)	(1.04)	(0.35)
Asset-Swap Spr.	-0.38	-0.41	-0.17	-0.61*
	(0.27)	(0.29)	(0.61)	(0.30)
Transaction Vol.	0.35**	0.31	0.35**	0.28**
	(0.09)	(0.18)	(0.10)	(0.09)
CFNAI	0.14**	0.14**	0.14**	0.12**
	(0.04)	(0.03)	(0.04)	(0.03)
$(\text{Off-the-Run})^2$	-4.43**	-4.48**	-3.60	
	(1.63)	(1.64)	(3.11)	
Off-the-Run×Transaction Vol.		0.20		
		(0.77)		
Off-the-Run×Asset-Swap Spr.			-0.65	
			(1.78)	
TIPS Bid-Ask Spread				-0.03
				(0.31)
$const.$	0.20	0.20	0.16	0.50**
	(0.13)	(0.13)	(0.17)	(0.11)
$p - value$	0.00	0.00	0.00	0.00
R^2	0.67	0.67	0.67	0.66
Sample		1999.3-2010.12		

Table A.V
Return Predictability Liquidity US
Nonlinear Liquidity

Return-predictability regressions as in Table III. We adjust for nonlinear liquidity as estimated in Table A.IV (1). Newey-West standard errors with three lags appear in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level, respectively.

		$xr^{TIPS-L}_{n,t}$	$xr^{TIPS-L}_{n,t}$	$xr^{TIPS-L}_{n,t}$	$xr^{TIPS-L}_{n,t}$	$r^{L}_{n,t+1}$
$\left(y^{TIPS}_{n,t} - L_{n,t}\right) - y^{TIPS}_{1,t}$		2.71*	2.79		-1.72	-0.21
	Newey-West SE	(1.31)	(1.48)		(1.21)	(0.54)
	Bootstrap p-value	25.6%	19.5%		13.7%	29.1%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			-0.34	4.63**	5.37**	-0.38
	Newey-West SE		(2.83)	(1.60)	(1.53)	(1.81)
	Bootstrap p-value		18.7%	0.05%	0.0%	41.2%
$L_{n,t}$		4.06	3.93	-6.63	-3.74	15.43**
	Newey-West SE	(8.47)	(9.08)	(4.46)	(5.49)	(4.14)
	Bootstrap p-value	17.7%	27.0%	11.6%	23.8%	0.0%
$p-value$		0.06	0.12	0.02	0.01	0.00
R^2		0.07	0.07	0.11	0.13	0.22
Sample			1999.6-2010.12			

Table A.VI
Return Predictability Liquidity US
Tradeable Excess Returns

We run liquidity-adjusted return-predictive regressions as in Table III. We consider liquidity-adjusted log nominal bond returns on TIPS over nominal returns on the nominal T-bill rate $r_{n,t}^{TIPS-L} - r_t^{Tbill}$ as a tradeable version of liquidity-adjusted log excess returns of TIPS. We also consider liquidity-adjusted log nominal bond returns on TIPS over log nominal bond returns on nominal bonds $r_{n,t}^{TIPS-L} - r_{n,t}^{nom}$ as a tradeable version of liquidity-adjusted breakeven returns. Newey-West standard errors with three lags appear in parentheses. The p-value of the F-test for no predictability is shown. * and ** denote significance at the 5% and 1% level, respectively.

		$\left(r_{n,t}^{TIPS-L} - r_t^{Tbill}\right)$		$\left(r_{n,t}^{TIPS-L} - r_{n,t}^{nom}\right)$	
$\left(y_{n,t}^{TIPS} - L_{n,t}\right) - y_{1,t}^{TIPS}$		2.38	2.65		-1.49
	Newey-West SE	(1.55)	(1.75)		(1.66)
	Bootstrap p-value	36.2%	27.5%		30.5%
$(b_{n,t} + L_{n,t}) - b_{1,t}$			-1.02	5.20*	5.85**
	Newey-West SE		(2.50)	(2.12)	(2.23)
	Bootstrap p-value		12.7%	0.5%	0.1%
$L_{n,t}$		4.20	3.71	-7.77	-4.59
	Newey-West SE	(8.49)	(9.24)	(5.65)	(7.33)
	Bootstrap p-value	20.2%	24.9%	10.1%	21.4%
$p - value$		0.12	0.20	0.04	0.07
R^2		0.05	0.06	0.10	0.11
Sample		1999.6-2010.12			

Table A.VII
Sub-Period Betas US

We regress liquidity-adjusted and non liquidity-adjusted excess log government bond returns onto excess log stock returns. All variables are described in Table IV. Newey-West standard errors are computed with 3 lags. * and ** denote significance at the 5% and 1% level for $\hat{\alpha}$ and $\hat{\beta}$, respectively.

Panel A: US	1999.6-2010.12		1999.6-2006.12		2002.1-2010.12	
	$\widehat{\beta}$	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\alpha}$
Excess Log Return Nominal	-0.19**	4.21*	-0.23*	3.66	-0.19**	4.21*
Excess Log Return TIPS	0.01	4.66*	-0.16*	4.36**	0.03	4.89*
Excess Log Return BEI	-0.21*	-0.45	-0.07	-0.69	-0.22*	-0.01
Liq.-Adj. Exc. Log Ret. BEI	-0.09	0.54	-0.04	0.72	-0.09	0.71
Liq.-Adj. Exc. Log Ret. TIPS	-0.11	3.67*	-0.19**	2.94*	-0.10	4.16*
Log Return Liquidity	0.12**	0.99	0.03	1.41**	0.13**	0.72

Panel B: UK	1985.7-2010.12		1985.7-2006.12		1985.7-1998.12		1999.1-2010.12	
	$\widehat{\beta}$	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\alpha}$
Excess Log Return Nominal	0.15	3.16	0.19	3.45	0.31	4.26	-0.07	0.86
Excess Log Return TIPS	0.14**	1.63	0.13*	1.58	0.16*	0.53	0.13	2.77
Excess Log Return BEI	0.01	1.53	0.06	1.87	0.15	3.73	-0.20*	-1.91

Table A.VIII
Four Factor Regressions

US liquidity-adjusted and non liquidity-adjusted excess log government bond returns onto excess log stock returns xr_{t+1}^{equity}, the SMB factor , the HML factor, and innovations in the Pastor-Stambaugh liquidity factor. Annualized (%). Newey-West standard errors with 3 lags in brackets. * and ** denote significance at the 5% and 1% level.

Panel A: 1999.6-2010.12	$xr_{n,t+1}^{\$}$	$xr_{n,t+1}^{TIPS}$	$xr_{n,t+1}^{b}$	$xr_{n,t+1}^{TIPS-L}$	$xr_{n,t+1}^{b+L}$	$r_{n,t+1}^{L}$
xr_{t+1}^{equity}	-0.13*	0.08	-0.21*	-0.04	-0.09	0.12**
	(0.06)	(0.11)	(0.09)	(0.07)	(0.06)	(0.04)
HML	0.02	-0.03	0.05	-0.04	0.05	0.01
	(0.06)	(0.07)	(0.06)	(0.07)	(0.06)	(0.02)
SMB	-0.16*	-0.11	-0.05	-0.14*	-0.02	0.03
	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)	(0.02)
Pastor-Stambaugh	-0.07*	-0.08*	0.01	-0.07*	-0.00	-0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)
const.	5.00*	5.23**	-0.22	4.56**	0.45	0.67
	(1.99)	(1.81)	(1.60)	(1.50)	(1.31)	(0.64)

Table A.IX
Dickey-Fuller Unit Root Tests

We report Dickey-Fuller test for the null-hypothesis of a unit root with twelve lags. $Supply_t$ denotes the amount of inflation-indexed bonds outstanding relative to all nominal and inflation-indexed bonds outstanding. $\Delta Supply_t$ denotes the relative issuance of inflation-indexed bonds relative to all nominal and inflation-indexed bonds issuance.
$\Delta Supply_t - \Delta Supply_{t-12}$ is the change in relative issuance over the past 12 months.
* and ** denote significance at the 5% and 1% level respectively.

Panel A: US

	$Supply_t$	$\Delta Supply_t$	$\Delta Supply_t - \Delta Supply_{t-12}$
	-2.02	-2.12	-3.25^{*}
Sample	$1999.1 - 2010.12$	$1999.2 - 2010.12$	$2000.2 - 2010.12$

Panel B: UK

	$Supply_t$	$\Delta Supply_t$	$\Delta Supply_t - \Delta Supply_{t-12}$
	-1.96	-4.75^{**}	-2.65
Sample	$1986.1 - 2010.12$	$1986.1 - 2010.12$	$1987.1 - 2010.12$

Table A.X
Supply Autoregression

We regress relative issuance $\Delta Supply_t$, as described in Table V onto its own twelve lags. We also regress the 12-month change in relative issuance onto its own twelve lags. We report the sum of the twelve autoregressive coefficients.

	Panel A: US	**Panel B: UK**
	$\Delta Supply_t$ $-\Delta Supply_{t-12}$	$\Delta Supply_t$
Sum of Coeff.	0.44	0.23
const.	-0.25	0.00
	(0.21)	(0.00)
R^2	0.29	0.04
Sample	$2000.2 - 2010.12$	$1986.1 - 2010.12$

Table A.XI
Sample Correlations of Exess Returns and Spreads

Monthly data of quarterly overlapping returns and inflation 1999.6-2010.12. Annualized (%). All data are described in Table III.

Correlations Excess Returns

	$xr_{n,t+1}^{TIPS-L}$	$xr_{n,t+1}^{b+L}$	$r_{n,t+1}^{L}$
$xr_{n,t+1}^{TIPS-L}$	1	-0.07	-0.02
$xr_{n,t+1}^{b+L}$	.	1	-0.20
$r_{n,t+1}^{L}$	.	.	1

Correlations Spreads

	$\left(y_{n,t}^{TIPS}-L_{n,t}\right)-y_{1,t}^{TIPS}$	$(b_{n,t}+L_{n,t})-b_{1,t}$	$L_{n,t}$
$\left(y_{n,t}^{TIPS}-L_{n,t}\right)-y_{1,t}^{TIPS}$	1	0.31	0.37
$(b_{n,t}+L_{n,t})-b_{1,t}$	.	1	0.07
$L_{n,t}$	.	.	1

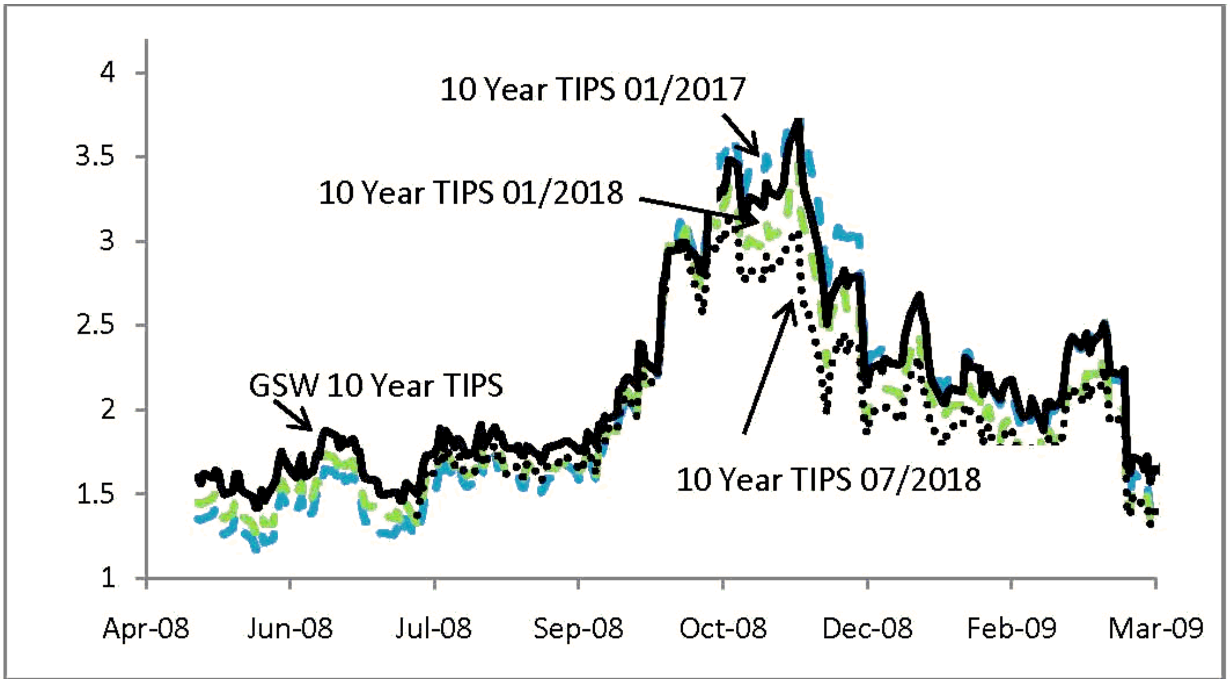

Figure A.1. Recently Issued and Less Recently Issued 10 Year TIPS. GSW 10 Year TIPS yields from Gurkaynak, Sack and Wright (2010); 10 Year TIPS maturing in 07/2018 (reference CPI 215.7), 01/2018 (reference CPI 209.5) and 01/2017 (reference CPI 201.7) from Bloomberg.