Inflation Risk Premium: Evidence from the TIPS Market*

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Abstract

We study the term structure of real interest rates, expected inflation and inflation risk premia using data on prices of Treasury inflation-protected securities (TIPS) over the period 2000-2007. Our study is motivated by the importance of the information inferred from TIPS securities. In particular, Bernanke (2004) emphasizes that *"inflation-indexed securities would appear to be the most direct source of information about inflation expectations and real interest rates"*. We find that inflation risk premium is time varying and more specifically, negative in the first half of the sample but is positive in the second half of the sample. The negative inflation risk premium during 2000-2003 appears to be due to liquidity problems in the TIPS market. We estimate that the mean inflation risk premium over the second half can be as low as six basis points and as high as 68 basis points depending on the inflation forecast measure and the maturity of the breakeven rate. We also find that the inflation risk premium is considerably less volatile during 2004-2007, a finding consistent with the observation that inflation expectations have been more stable during this period.

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Abstract

We study the term structure of real interest rates, expected inflation and inflation risk premia using data on prices of Treasury inflation-protected securities (TIPS) over the period 2000-2007. Our study is motivated by the importance of the information inferred from TIPS securities. In particular, Bernanke (2004) emphasizes that *"inflation-indexed securities would appear to be the most direct source of information about inflation expectations and real interest rates"*. We find that inflation risk premium is time varying and more specifically, negative in the first half of the sample but is positive in the second half of the sample. The negative inflation risk premium during 2000-2003 appears to be due to liquidity problems in the TIPS market. We estimate that the mean inflation risk premium over the second half can be as low as six basis points and as high as 68 basis points depending on the inflation forecast measure and the maturity of the breakeven rate. We also find that the inflation risk premium is considerably less volatile during 2004-2007, a finding consistent with the observation that inflation expectations have been more stable during this period.

1 Introduction

Treasury Inflation-Protected Securities (TIPS) were first issued by the U.S. Treasury department in 1997. Since then, the TIPS market has grown substantially to about 8% of the outstanding Treasury debt. One important feature of this indexed debt is that both the principal and coupon payments from TIPS are linked to the value of an official price index - the Consumer Price Index (CPI). Namely, both payments from TIPS are denominated in real rather than nominal terms. As such, TIPS can be considered to be free of inflation risk. The difference between nominal Treasury and TIPS yields of equivalent maturities is known as a breakeven inflation rate[1] and represents the compensation to investors for bearing the inflation risk. This compensation includes both the expected inflation and the *inflation risk premium* (due to inflation uncertainty). In a speech before the Investment Analysis Society of Chicago in 2004, Governor Ben Bernanke (2004) stressed that estimating the magnitude of the inflation risk premium is important for the purpose of deriving the correct measure of market participants' expected inflation. Indeed, having a good estimate of inflation risk premium is important for both demand and supply sides of the economy. On the demand side, such a measure would allow investors to hedge effectively against inflation risk. On the supply side, the measure would allow Treasury to tune the supply of the TIPS. As Greenspan (1985) stated, *"The real question with respect to whether indexed debt will save taxpayer money really gets down to an evaluation of the size and persistence of the so-called inflation risk premium that is associated with the level of nominal interest rates."*

However, inflation risk premium is not directly observable and is known to be difficult to be estimated accurately. The literature on estimating the magnitude and volatility of inflation risk premium is also rather limited. The usual way to estimate inflation risk premium in the literature is to use the difference between nominal long-term and short-term yields, so called term premium. In this paper, we take a different approach. We estimate the inflation risk premium using market prices of TIPS. Our use of TIPS market prices was motivated by the view of Bernanke (2004) who stated that *"...the inflation-indexed securities would appear to be the most direct source of information about inflation expectations and real rates"*. More specifically, in our empirical analysis we use monthly yields on zero-coupon TIPS with maturities of 5, 7, and 10 years from Barclays Capital, and monthly yields on zero-coupon nominal Treasury bonds from Federal Reserve over the period 2000-2007. As such, unlike those obtained in the existing studies, our estimates of

[1] More formally, we define *a breakeven inflation rate* as a difference between nominal and real yields and we call *a TIPS breakeven rate* the difference between nominal and TIPS yields of the same maturity.

the inflation risk premium are derived directly from TIPS trading data.

We estimate that the mean inflation risk premium is between six basis points and 68 basis points over 5- and 10-yr horizons, respectively. The variation in the estimates comes not only from the variation in maturity, but also depends on the proxies for the expected inflation. In addition, we find that the inflation risk premium is time varying and more specifically, is negative in the first half of the sample but is positive in the second half of the sample. The negative inflation risk premium during 2000-2003 appears to be due to liquidity problems in the TIPS market. We also find that inflation risk premium is considerably less volatile during 2004-2007, a finding consistent with the observation that inflation expectations were more stable during this period. We explicitly adjust the inflation risk premium for liquidity in TIPS which is proxied by the average trading volume and bid-ask spreads. Once we adjust the inflation risk premium for liquidity, its estimates drop to about 14 basis points. These estimates are not unreasonable given Bernanke's (2004) view that an inflation risk premium of 35 to 100 basis points is too large.

A study closely related to ours is the one by D'Amico, Kim, and Wei (2006), who estimate a three-factor term structure model with nominal Treasury security and TIPS data and conclude that the TIPS yields contain a substantial "liquidity" component. The long-run averages of inflation risk premium in their study can also be positive or negative depending upon the different nominal or TIPS series that they use to fit a three-factor term-structure model. Jarrow and Yildirim (2003) and Chen, Liu, and Cheng (2005) also use TIPS data to estimate term structure models but they do not focus on the estimation of the inflation risk premium.

A few studies obtain an estimate of the inflation risk premium without using the information from the TIPS market. For example, Campbell and Shiller (1996) estimate the inflation risk premium based on the (nominal) term premium (before the inception of the TIPS market) and find that inflation risk premium is between 50 and 100 basis points. Buraschi and Jiltsov (2005) analyze both nominal and real risk premia of the U.S. term structure of interest rates based on a structural monetary version of a real business cycle model. They find that inflation risk premium is time-varying, ranging from 20 to 140 basis points. Their estimate of the average 10-year inflation risk premium is roughly 70 basis points over a 40-year period. Ang, Bekaert, and Wei (2007b) consider a term structure model with regime switches and find that the unconditional five-year inflation risk premium is around 1.15%, but its estimates vary with regimes.

The estimates of the inflation risk premium that we obtain using the TIPS market prices are much lower than the ones obtained by Campbell and Shiller (1996), Buraschi and Jiltsov (2005), and Ang, Bekaert, and Wei (2007b). However, the results in these studies may not be directly comparable to ours due to different sample periods, estimation methods and data sets used.

The estimation methodology we use in this study is in the spirit of Evans (1998), where we employ equilibrium first order conditions to link the nominal and real term structures. Evans (1998) uses these equilibrium conditions in order to test the Fisher hypothesis using U.K. data. He strongly rejects Fisher hypothesis but he does not provide any estimates of the inflation risk premium in the U.K.

The rest of the paper is organized as follows. Section 2 describes data used in our empirical analysis and methodology. Section 3 presents estimation results for real yields, inflation risk premium and the correction for liquidity premium. Finally, Section 4 concludes.

2 Data and Methodology

In this section we first provide a brief review of the TIPS market and then describe data and methodology used in our empirical analysis.

A An Overview of the TIPS Market

TIPS were first introduced in 1997. This indexed debt was initially called Treasury Inflation Protected Securities (TIPS). Later on its official name was changed to Treasury Inflation Indexed Securities. Nevertheless, market participants keep calling these instruments TIPS, so we retain this abbreviation for our paper. The first inflation-indexed debt issue had a maturity of 10 years. Since 1997, Treasury has been issuing regularly additional 10-year debt, and 5-year, 10-year and 30-year debt irregularly. The TIPS market has been growing significantly since its inception, although the market had significant liquidity problems in the first few years. For instance, in September 2007, $450 billion TIPS were outstanding, representing roughly 10% of nominal Treasury debt, with $70 billion in new issuance every year, and over $8 billion in average turnover daily.[2]

The main advantage of TIPS over nominal Treasuries is that TIPS investors are almost hedged against inflation risk. The coupon rate of a TIPS is fixed in real terms, and the principal amount grows with inflation over the life of indexed debt. The real return (purchasing power) of TIPS does not vary with inflation. However, the real return of nominal

[2]See, for example, US Treasury press release on http://www.ustreas.gov/press/releases/hp570.htm.

Treasury declines as inflation increases. Therefore, nominal Treasury debt holders are not protected against inflation risk.

The following example illustrates how TIPS investors are protected against inflation fluctuations, but nominal debt holders are not. Suppose in January 2006 Treasury auctioned 5-year TIPS with a 2% coupon rate and 5-year nominal debt with a 4.5% coupon rate. If an investor buys the January TIPS and holds it to maturity, he will receive the real return to his investment equal to 2%. If an investor buys nominal Treasury with 4.5% coupon rate, his real return will depend on the level of the actual Consumer Price Index (CPI) inflation rate. If inflation rate turns out to be 2.5%, then the real return on nominal debt will be 2%. If instead, inflation rate turns out to be 3%, then the real return to nominal Treasury debt will be only 1.5%. Part of the purchasing power will be eroded by higher inflation against which nominal debtholders are not protected. To investors, the only relevant measure of return is real rate of return, or real yield, since it measures the result of the investment in terms of the purchasing power.

B Data

Due to the issue of low liquidity in the TIPS market prior to 2000, we limit our sample to the period from January 2000 to December 2007. For TIPS data, we use monthly yields on zero-coupon TIPS of 5, 7, and 10 year maturities from Barclays Capital Bank. For nominal data, we use monthly yields on zero-coupon nominal Treasury bonds from Federal Reserve. Panels A and B of Figure 1 plot monthly term structure of nominal Treasury bonds and TIPS, respectively. We can see from the graphs that both nominal and TIPS yields decrease steadily since the beginning of our sample perod until about mid 2003, and then increase with the volatility of both types of yields being apparently much lower in the second half of the sample. Panel C of Figure 1 presents a TIPS breakeven rate derived as a difference between 10-year nominal and TIPS zero-coupon yields. Clearly, the breakeven rate is relatively low and volatile in the first half of the sample and relatively high and less volatile in the second half.

To link the TIPS and nominal Treasury bond markets, we need information on the expected inflation. We consider four measures of the expected inflation in our analysis. Two of them are based on the historical average of realized inflation. One is the seasonally-unadjusted Consumer Price Index (CPI) and the other Core CPI (Consumer Price Index Less Food and Energy). We choose seasonally unadjusted CPI because TIPS are linked to this index (more precisely, the payments are linked to the 3-month lagged unadjusted

CPI). The remaining two measures of the expected inflation are based on surveys. One is from Survey of Professional Forecasters (SPF) conducted by Federal Reserve Bank of Philadelphia every quarter and the other measure is the Blue Chips Forecasts provided by Aspen Publishers.[3] Ang, Bekaert, and Wei (2007a) study various models of expected inflation and find that, after all, survey measures forecast inflation the best. SPF forecasts of 1-year ahead and 10-year ahead inflation are available on quarterly basis and while 1-year ahead Blue Chips forecasts are available monthly. Before presenting the summary statistics, we would like to describe the Blue Chip inflation forecasts in a little more detail because they are not reported in a conventional way.

Blue Chip Forecasts of Financial and Economic Indicators represent consensus forecasts of about 50 professional economists in the leading financial and economic advisory firms, and investment banks each month. The survey contains the forecasts of the key financial and macroeconomic indicators, including forecasts of CPI inflation (inflation hereafter).

In particular, Blue Chip Economic Indicators provide monthly estimates of one-year inflation forecast for both the current year and the next year. For instance, in January 1999, Blue Chip provides the expected inflation for both 1999 and 2000. In February 1999, they also provide inflation forecasts for 1999 and 2000 but the forecast horizon is actually 11 months. In December 1999, analysts again provide forecasts of the 1999 and 2000 year inflation albeit with a forecast horizon of one month only. This feature of the survey results in time-varying forecast horizon for any variable in question. In our empirical analysis we need monthly forecasts for a fixed horizon. For instance, in February 1999 we need a 1-year ahead inflation forecast, but Blue Chips Survey has only 11-month and 23-month ahead forecasts available. However, the 1-year ahead inflation forecast can be interpolated from two Blue Chips Survey data points.

In general, we obtain monthly fixed horizon forecast by doing linear interpolations as follows. Let $Y(t, T_1, T_2)$ be the forecast of inflation between T_1 and T_2 provided in the month t. At each month t we have 2 consensus forecasts: $Y(t, T_1, T_2)$ and $Y(t, T_2, T_3)$ forecasts, where $T_2 - T_1 \equiv T_3 - T_2 = 12$. This difference is always fixed in the survey. These forecasts are revised through a year. Thus, next month we are provided with revised forecasts of inflation between T_1 and T_2 as well as between T_2 and T_3. The forecast horizon $T_2 - \tau$, where $\tau = t, t+1, \ldots, t+11$, is time-varying. We extract the time series for the fixed horizon inflation forecast as a weighted average of 2 consensus forecasts:

[3] We do not use the Livingston Survey because it is conducted only twice a year and, unlike other surveys, participants of the Livingston survey are asked to provide their forecasts of non-seasonally-adjusted CPI levels six and twelve months in the future.

Month t	Interpolated value of the 1-year ahead forecast
1	$Y(t,t,t+12) = Y(t,T_1,T_2)$
2	$Y(t+1,t+1,t+13) = \frac{11}{12}Y(t+1,T_1,T_2) + \frac{1}{12}Y(t+1,T_2,T_3)$
3	$Y(t+2,t+2,t+14) = \frac{10}{12}Y(t+2,T_1,T_2) + \frac{2}{12}Y(t+2,T_2,T_3)$
...	...
11	$Y(t+10,t+10,t+22) = \frac{2}{12}Y(t+10,T_1,T_2) + \frac{10}{12}Y(t+10,T_2,T_3)$
12	$Y(t+11,t+11,t+23) = \frac{1}{12}Y(t+11,T_1,T_2) + \frac{11}{12}Y(t+11,T_2,T_3)$
13	$Y(t+12,t+12,t+24) = Y(t+12,T_2,T_3)$

We now proceed to summary statistics of the data used in our empirical analysis. Panel A of Table 1 reports the summary statistics on zero-coupon TIPS yields. We observe that on average TIPS yields in our sample are between 2.21% and 2.57% for 5 and 10-year index-linked bonds respectively.

Panel B reports sample statistics for nominal zero-coupon Treasuries. Nominal Treasuries yields are between 4.24% (5-year yields) and 4.89% (10-year yields) on average during our sample period. This indicates that the spread between nominal and inflation-linked bonds is between 2.03% and 2.32% depending on the maturity of the bonds. This spread is usually called the breakeven inflation rate. So, we present breakeven inflation statistics in Panel C.

Panel D reports the statistics of various realized and expected inflation measures. As shown in the table, the average realized CPI-based inflation is 2.77% with a 4.31% volatility during our sample period, while Core inflation is 2.2%, naturally, with a much lower volatility of 1.01% only. The measures of expected inflation reported in the panel include Michigan Consumer Survey forecast, SPF and Blue Chip inflation forecasts of the CPI over the same period. Michigan Consumer Survey forecast of 1-year ahead inflation available on monthly frequency, while SPF is available quarterly. Michigan Survey forecast of 1 year ahead inflation appears to be much more volatile with a volatility of 0.55% compare to the volatility of SPF forecast of 1 year inflation equal to 0.24%. Note that SPF 10-year CPI inflation rate forecast mean is 2.48% per year with a standard deviation of 0.04%. This allows us to proxy SPF expected inflation by a single number, 2.5%, at least at the 10-year horizon. The average Blue Chips one-year ahead forecast of the CPI-based inflation is 2.45% with .40% volatility. Note that this forecast is higher than the forecast reported by SPF, but lower than Michigan's one-year ahead inflation forecast. In sum, it is obvious from these numbers that these measures of realized and expected inflation far exceed the breakeven inflation, reported in Panel C. It follows then that either nominal rates were too low (which is probably not the case because nominal Treasury market is quite efficient and developed) or real yields were too high. We take the latter view, linking high real yields during our sample period to the liquidity problems that TIPS market has experienced.

C Methodology

First, we need to construct a yield curve of real interest rates. The reason is that TIPS rates do not equal real rates since TIPS payments are linked not to the current index level at the time of coupon and principal payments, but to the inflation index level which is lagged 3 months. This represents some additional difficulty in computing real rates, because there is a risk of inflation shock during three months that investors are not protected against. Therefore, we have to establish relationship between three term structures: term structure of nominal rates, index-linked (TIPS) term structure, and term structure of real rates. In order to construct a real yield curve from observed nominal and TIPS data, we follow Evans (1998).

Next, we examine inflation risk premium based on nominal yields, real yields, and expected inflation rates. In particular, we show first that the Fisher hypothesis does not hold, and therefore, reject a zero inflation risk premium. We then estimate the inflation risk premium. Below is the detailed description of our methodology.

C.1 Notation

Before proceeding with the description, we define some notation as follows:

Nominal Bonds. Let $Q_t(h)$ denote the nominal price of a zero-coupon bond at period t paying \$1 at period $t+h$. Then define the continuously compounded yield on a bond of maturity h as

$$y_t(h) \equiv -\frac{1}{h} lnQ_t(h). \tag{1}$$

Define k-period nominal forward rate h periods forward as

$$F_t(h,k) \equiv \left[\frac{Q_t(h)}{Q_t(h+k)}\right]^{1/k}. \tag{2}$$

Real Bonds. Let $Q_t^*(h)$ denote the nominal price of a zero-coupon bond at period t paying $\$\frac{P_{t+h}}{P_t}$ at period $t+h$, where P_t is the (known) price level at t. $Q_t^*(h)$ also defines the real price of one consumption bundle at $t+h$. By definition, such a bond completely indexes against future movements in price levels h periods ahead. Then define the continuously compounded real yield on a bond of maturity h and forward rates as

$$y_t^*(h) \equiv -\frac{1}{h} lnQ_t^*(h) \quad \text{and} \quad F_t^*(h,k) \equiv \left[\frac{Q_t^*(h)}{Q_t^*(h+k)}\right]^{1/k}. \tag{3}$$

Bonds with incomplete indexation. Let $Q_t^+(h)$ denote the nominal price of an index-linked (IL) zero-coupon bond at period t paying $\$\frac{P_{t+h-l}}{P_t}$ at period $t+h$, where $l > 0$ is the indexation lag. When $h = l$, then such a bond pays out \$1 at maturity. Therefore, we have $Q_t(l) = Q_t^+(l)$ in the absence of arbitrage. The yields and forward rates of IL bonds are defined as:

$$y_t^+(h) \equiv -\frac{1}{h} lnQ_t^+(h) \quad \text{and} \quad F_t^+(h,k) \equiv \left[\frac{Q_t^+(h)}{Q_t^+(h+k)}\right]^{1/k}. \tag{4}$$

In this paper, we study US Treasury-Inflation Protected Securities (TIPS) whose indexation lag is 3 months so $l = 3$ in our case.

C.2 Nominal, Real, and Index-Linked Term Structure

First, let's establish relationship between nominal, IL, and real prices: Q_t, Q_t^+, andQ_t^*. The expressions below are given in terms of the stochastic discount factor M_t. Also, we assume that the price index for the month t, P_t, is known in the end of the period t. This seems to be a reasonable approximation of the US data since the index is published with a 2-week delay only. Let M_{t+1} be a random variable that prices one-period state-contingent claims. In the absence of arbitrage opportunities, the one-period nominal returns for all traded assets, $i = 1, \ldots, N$, are given by

$$E_t[M_{t+1}R_{t+1}^i] = 1, \tag{5}$$

where R_{t+1}^i is the gross return on asset i between t and $t+1$, E_t is the expectation operator conditioned on the information set at time t. We use (5) to find prices of nominal, real and IL bonds. In the case of the nominal bonds, for $h > 0$ (5) becomes:

$$Q_t(h) = E_t[M_{t+1}Q_{t+1}(h-1)]. \tag{6}$$

In case of real bonds, the nominal return at $t+1$of a claim of $\$(P_{t+h}/P_t)$ at $t+h$ is given by:

$$\frac{Q^*_{t+1}(h-1)\frac{P_{t+1}}{P_t}}{Q^*_t(h)}. \tag{7}$$

Therefore, (5) becomes:

$$Q^*_t(h) = E_t[M^*_{t+1}Q^*_{t+1}(h-1)], \tag{8}$$

where $M^*_{t+1} = M_{t+1} \times \frac{P_{t+1}}{P_t}$.

In a similar way, we find the price of IL claims. We know that $Q_t(l) = Q^+_t(l)$, so need to find prices only for IL claims with maturities $h > l$. In a same way as for the case of real bonds, we can show that

$$Q^+_t(h) = E_t[M^*_{t+1}Q^+_{t+1}(h-1)]. \tag{9}$$

Log-linearizing equations and applying $Q_t(0) = Q^*_t(0) = 1$ we have:

$$q_t(h) = E_t\sum_{i=1}^{h} m_{t+i} + \frac{1}{2}V_t\left(\sum_{i=1}^{h} m_{t+i}\right), \tag{10}$$

$$q^*_t(h) = E_t\sum_{i=1}^{h} m^*_{t+i} + \frac{1}{2}V_t\left(\sum_{i=1}^{h} m^*_{t+i}\right), \tag{11}$$

$$\begin{aligned} q^+_t(h) \quad = \quad & E_t\textstyle\sum_{i=1}^{\tau} m^*_{t+i} + E_t q_{t+\tau}(l) + CV_t(\sum_{i=1}^{\tau} m^*_{t+i}, q_{t+\tau}(l)) \\ & +\tfrac{1}{2}\left[V_t\left(\textstyle\sum_{i=1}^{h} m^*_{t+i}\right) + V_t(q_{t+\tau}(l))\right], \end{aligned} \tag{12}$$

where $\tau \equiv h - l$, $V_t(\cdot)$ and $CV_t(\cdot,\cdot)$ represent the conditional variance and covariance given period t information, and the lowercase letters stand for natural logarithms. The equations are approximations in general, but hold exactly if the joint distribution for $\{M_{t+j}, P_{t+i+1}/P_{t+i}\}_{j>0,i>0}$ conditional on the period t information is log normal.

C.3 Term Structure of Real Interest Rates

Using (10), (11), (12), and definition of $m^*_t \equiv m_t + \Delta p_t$, we can link prices of nominal, real and IL bonds by the following formula:

$$q^+_t(h) = q^*_t(\tau) + [q_t(h) - q_t(\tau)] + \gamma_t(\tau), \tag{13}$$

where $\tau = h - l$ and

$$\gamma_t(\tau) \equiv CV_t(q_{t+\tau}(l), \Delta^\tau p_{t+\tau}). \tag{14}$$

Equation(13) shows that the log price of real bonds is not only a function of nominal prices and IL prices, but also depends on the covariance between future inflation and future nominal prices, measured by $\gamma_t(\tau)$. Note also, that (13) is not a function of stochastic discount factor. Last term in (13), $\gamma_t(\tau)$ represents the compensation for the risk of high inflation. By no-arbitrage condition, the IL bond prices depend on future nominal bond prices, $q_{t+\tau}(l)$, and this will affect the choice between real and IL bonds. In the periods of unexpectedly high inflation, nominal prices drop, causing negative $\gamma_t(\tau)$. Therefore, IL bond will sell at a discount (compare to real bonds) to compensate for this risk.

Equation (13) can be rewritten in terms of yields in order to derive the estimates of the real term structure. Let $y_t(h)$, $y_t^*(h)$, and, $y_t^+(h)$ be the continuously compounded yields for nominal, real, and IL bonds respectively. Then (13) can be rewritten:

$$y^*(\tau) = \frac{h}{\tau} y_t^+(h) - \frac{l}{\tau} f_t(\tau, l) + \frac{1}{\tau}\gamma_t(\tau). \tag{15}$$

Given (15), we can estimate real yields, y_t^* using IL yields, y_t^+, and log nominal forward rates, f_t that we observe in the data. The only variable that has to be estimated is $\gamma_t(\tau)$. To estimate $\gamma_t(\tau)$, we follow VAR methodology proposed by Evans (1998).

We consider first-order vector-autoregression:

$$z_{t+1} = Az_t + e_{t+1}, \tag{16}$$

where $z_t' \equiv [\Delta p_t, q_t(l), x_t]$, where x_t is a vector of conditioning variables that can potentially include relevant macro-variables which would affect the covariance between inflation and nominal bond prices. For now, we just use a unit vector, so $x_t = \mathbf{1}$. As a result of estimated (16), $\gamma_t(\tau)$ is given by:

$$\gamma_t(\tau) = i_1' \left[\sum_{i=1}^{\tau} A^{\tau-i} \left(\sum_{j=1}^{i} A^{i-j} V(e_{t+j}|z_t) A^{i-j'} \right) \right] i_2, \tag{17}$$

where i_k, $k = 1, 2$ is the selection vector such that $\Delta p_t = i_1' z_t$ and $q_t(l) = i_2' z_t$. The equation (17) shows how the covariance between $\Delta^\tau p_{t+\tau}$ and $q_{t+\tau}(l)$ conditioned on z_t defined through the coefficient matrix A and the innovation variances $V(e_{t+j}|z_t)$.[4] The VAR(1) results are presented in Table 2. We discuss the properties and magnitude of $\gamma_t(\tau)$ in more detail in Section 3.

[4]It seems that there is a typo in the derivation of $\gamma_t(\tau)$ in Evans (1998) and we present corrected formula.

C.4 Inflation Risk Premium

Consider the following equation that defines the inflation risk premium:

$$y_t(\tau) = y_t^*(\tau) + E_t\pi_{t+\tau}(\tau) + IRP_t(\tau), \tag{18}$$

where $\pi_{t+\tau} \equiv (1/\tau)\Delta^\tau p_{t+\tau}$, and $IRP_t(\tau)$ is the inflation risk premium. This equation can be also derived from log-linear pricing equations (10), (11), (12), and (15). Equation (18) presents a form of Fisher equation that equates the $\tau-$period nominal yield with the yield on a $\tau-$period real bond plus expected inflation and an inflation risk premium $IRP_t(\tau)$.

One method of estimating inflation risk premium is based on a specification of the real pricing kernel in a model with a representative agent. Examples of this approach include Fisher (1975), Benninga and Protopapadakis (1983), Evans and Wachtel (1992), and Buraschi and Jiltsov (2005).[5]

We use an alternative approach here that does not require any specification of the real pricing kernel.[6] This approach is based on the following regression:

$$y_t(\tau) - y_t^*(\tau) - E_t\pi_{t+\tau}(\tau) = \alpha_0 + \alpha_1 \left[y_t(\tau) - y_t^{real}(\tau)\right] + u_{t+\tau}. \tag{19}$$

By definition, the left-hand side of equation is $IRP_t(\tau)$. We can, therefore, examine to which extent the changes in the yield spread, $y_t(\tau) - y_t^{real}(\tau)$, are correlated with the inflation risk premium. Also, equation (19) can be used to estimate inflation risk premium. The empirical results for inflation risk premium are discussed in Section 3.

3 Empirical Results

In this section we present results from the empirical analysis. We present the estimates of real yields and the estimates of inflation risk premium. In addition, in the last subsection of the present section we control the estimates of inflation risk premium for liquidity. TIPS market experienced liquidity problems in the first years since its inception and especially in the first years of our sample. In this way, our estimates of inflation risk premium can be affected by a sound liquidity component.

[5] In general, inflation risk premium can be positive or negative depending on how the real pricing kernel covaries with inflation. See, for example, Evans (1998), page 211.

[6] This is in the spirit of Evans (1998). Even though he shows how the inflation risk premium depends on the real pricing kernel but he does not use any specification of the real pricing kernel in his empirical analysis.

A Estimates of Real Yields

In order to compute real yields, we first estimate the covariance between future inflation and future nominal bond prices given by $\gamma_t(\tau)$ in (14). We do this by estimating VAR given in (16) and computing $\gamma_t(\tau)$ given by (17) and present the results in the Table 2. In order to assess how $\gamma_t(\tau)$ affects the IL yields, we annualize these estimates by multiplying them by $-1200/\tau$. Although $\gamma_t(\tau)$ seems to manifest uniformly upward sloping term structure, its impact, even for 10-year yields, is not large resulting in .2075 per cent to the annualized yields.

The estimation of real yields is given in Table 3. We can see from the table that real yields (and TIPS yields) were quite high during the period 2000-2002. For example, real yields were as high as 3.8% in 2000. This finding is consistent with the fact that the TIPS market was quite illiquid in late 90s and early 00s. But as indicated in the table, real yields started to decrease over 2001-2005 period and then increased slightly again in 2006, with a consequent decrease in 2007.

Figure 2 illustrates how the dynamics of real yields contributes to the widening of the 10-year breakeven inflation rate. It also provides comparison between the breakeven rate and the expected inflation provided by the Survey of Professional Forecasters. The difference between the breakeven inflation rate and expected inflation is negative in the first half of the sample period but becomes positive in the second half of the sample period. It would be unreasonable to interpret this difference as a negative inflation risk premium given the fact that many studies find positive estimates of inflation risk premium (see, for example, Clarida and Friedman (1984), Campbell and Shiller (1996), Buraschi and Jiltsov (2005) and Ang, Bekaert, and Wei (2007b)).

Our conjecture that this difference is not entirely due to inflation risk premium, but part of it constitutes the liquidity premium. Due to illiquid nature of the TIPS market, the liquidity premium, it seems, comprised a substantial component in the TIPS yields. This factor seems to cause TIPS yields to be too high and a breakeven inflation rate to be lower than the SPF expected inflation in the first half of our sample. In the next section, we provide the estimates of inflation uncertainty, but they have to be treated cautiously with understanding that part of the $IRP_t(\tau)$ magnitude is due to liquidity problem. It remains to be determined how much of the difference between a breakeven rate and an expected inflation rate is due to inflation uncertainty and how big is the liquidity component. We show some preliminary results of computing liquidity premium in Section C but the effect of liquidity on TIPS yields and the inflation risk premium remains the focus of our ongoing research.

B Estimates of the Inflation Risk Premium (IRP)

In this section, we discuss the estimates of inflation risk premium that we have obtained using two types of measures of expected inflation. First, we compute the IRP based on the measure expected inflation as an average of past realized inflation. Second, we use inflation forecasts from the Survey of Professional Forecasters and Blue Chip Economic Indicators to compute IRP.

B.1 IRP Estimates Based on the Average Realized Inflation

We now proceed to estimate the inflation risk premium (IRP) using constructed real yield curves. In order to run regression (19) and estimate IRP, we need data on expected inflation, $E_t\pi_{t+\tau}(\tau)$. We proxy expected inflation by historical averages of realized inflation based on both seasonally unadjusted CPI and Core CPI. The average is estimated over five different windows, namely, over prior 1, 3, 5, 7, and 10 years.

Table 4 reports the estimates of expected inflation based on historical averages of realized inflation. The estimates of expected inflation based on seasonally unadjusted CPI are reported in Panel A. There are two distinguished features worth noting. First, $E_t\pi_{t+\tau}(\tau)$ exhibits upward-sloping term structure: that is, our estimates increase with horizon for every estimation period. For example, for one-year estimation period, expected inflation increases from 2.47% to 2.54% when τ changes from 57 months (roughly five years) to 117 months (roughly 10 years). For five-year estimation period these estimates vary from 2.45% and 2.73% depending on the horizon. These estimates are consistent with the ones obtained by other researchers. In particular, Carlstrom and Fuerst (2004) find that 10-year expected inflation is between 2.5% and 2.6%. Second, for longer estimation period our estimates are biased upward and closer to 3% per year but this reflects the fact that they encompass periods of high inflation.

The estimates of expected inflation based on Core CPI are reported in Panel B. As in panel A, we observe an upward sloping term structure for each estimation period, and upward bias of the estimates based on a longer estimation period. At the same time, estimates here are slightly lower than those based on the standard CPI index. On average, the estimates of expected inflation using 1, 3, and 5 years of past inflation rates based on Core CPI are around 2.5% and consistent with those provided by the Survey of Professional

Forecasters.

Regression (19) shows whether inflation risk premium (IRP) is correlated with yield spread, $y_t(\tau) - y_t^*(\tau)$. If it is, then Fisher hypothesis does not hold (if IRP is zero, it would not covary with yield spreads). We obtain two sets of estimation results of inflation risk premium using CPI and Core CPI as a proxy for inflation, and report the results in Tables 5 and 6, respectively. As can be seen from both tables, the estimates of α_1 are positive and significantly different from zero[7] for both tables, therefore, we conclude that the inflation risk premium is different from zero and time-varying. As such, the use of Fisher equation with $IRP_t(\tau) = 0$ is challenged, and inflation risk premium should be taken into account when computing real yields. Evans (1998) also documents a time-varying inflation risk premium in the UK market using UK index-linked bonds.

Next, we compute the sample average of inflation risk premium using (18) based on (1) historical average of seasonally unadjusted CPI, to which TIPS are linked; (2) historical average core CPI index.

Figure 3 shows the plot of inflation risk premium both as time series and in cross section. It reveals that inflation risk premium is visibly negative and relatively volatile in the first half of the sample but becomes positive and less volatile in the second half of the sample. Tables 7 and 9 report sample averages for inflation risk premium for two sets of expected inflation. Each table provides results for the whole sample, first and second halves of the sample, and for each year. For most estimation horizons of expected inflation measure, all the tables reveal consistently that inflation risk premium estimates are negative during 2000-2003 in the first half of the sample, and positive in the second half.[8] Recall from Table 3 that these years correspond mostly to the period of high real rates. For instance, when expected inflation is computed using one-year estimation horizon, we observe the highest inflation risk premium of 54 basis points in 2004 (for 10-year maturity bonds, see Table 7). Overall, during the second sub-period of the sample in 2004-2007, inflation risk premium ranges from 4 to 36 basis points (using one-year horizon to estimate expected inflation). It makes sense that we obtain that inflation uncertainty is lower on shorter maturities and higher on longer maturities. In Table 9 we report the estimates of the inflation risk premium based on Core CPI as an expected inflation proxy. Comparing these estimates with those in Table 7 we observe that Core CPI-based premia are positive in our sample while CPI-based premia are negative in our sample. The IRP varies from four to 11 basis

[7] $t-$stats are Newey-West corrected.

[8] Evans (1998) notes that inflation risk premium can be positive or negative depending on how the real pricing kernel covaries with inflation (see Evans (1998), page 211).

points in the whole sample, negative in the first half and positive in the second half. In 2004-2007 premium varies from 52 to 60 basis points, if we look at the one-year horizon for extimation of inflation proxy. We observe also that premia are positive in 2006 and 2007 regardless our choice of the horizon for inflation estimation. To summarize the discussion on the magnitudes of inflation premia, we find that a pattern of negative vs positive inflation risk premia in two subsamples is robust with respect to the choice of inflation proxy and its estimation horizon.

Tables 8 and 10 report volatility estimates for inflation risk premium. We observe that the volatility in the second half of the sample is considerably lower (across maturities) than in the first half of the sample. For example, Table 8 shows that the 10-year IRP volatility falls from 30 to 18 basis points when expected inflation is estimated using one-year horizon of past inflation rates. When expected inflation is estimated as a 5-year average of past inflation rates, the volatility of 10-year inflation risk premium falls from 36 basis points to 13 basis points. We observe similar pattern when we use past Core CPI rates as proxies of expected inflation.

B.2 IRP Estimates Based on the Survey Forecasts

In this subsection we discuss the estimates of inflation risk premium when we use inflation forecasts from the Survey of Professional Forecasters and Blue Chips Economic Indicators Survey. We compute IRP estimates from the Survey of Professional Forecasters (SPF) and Blue Chip Economic Indicators Survey as an alternative measures of the CPI-based inflation forecasts. Blue Chips forecasts are more volatile then SPF: the volatility of Blue Chips one-year ahead forecasts is 40 basis points while volatility of SPF forecasts is only 24 basis points. However, the advantage of using Blue Chips forecasts is that they are available on monthly basis while SPF forecasts are available quarterly. We do not report the Michigan Consumer Survey because Michigan's forecasts are obviously biased upward and, therefore, would bias inflation risk premium downward. In particular, its one-year ahead inflation forecasts seem to be consistently overestimated during 2000-2007 sample period, averaging 2.89%. Also, Michigan survey forecasts are much more volatile than one-year forecasts by SPF: 55 basis vs 24 basis points, respectively (see Table 1, Panel D for statistics).

In Table 11 we report sample averages and volatilities for inflation risk premium using three measures of inflation forecasts from SPF: one-year ahead forecast based on GDP price deflator, one-year ahead forecast based on CPI, and 10-year ahead forecast based on CPI. We also report Blue Chips one-year ahead CPI-based inflation forecast. We find that the inflation risk premium for 5-year bonds is the lowest among positive IRPs: only six basis points in the case of Blue Chips one-year ahead forecast. We also report that the inflation risk premium for 10-year bonds is the highest (48 basis points) when we use one-year ahead forecast of CPI reported by SPF.[9] These estimates are considerably lower than the ones reported by Campbell and Shiller (1996), Buraschi and Jiltsov (2005) and Ang, Bekaert, and Wei (2007b). In a related study, the long-run averages of inflation risk premium in D'Amico, Kim, and Wei (2006) can be positive or negative depending on the different series that they use to fit a three-factor term-structure model.[10] Essentially, Table 11 repeats the results of Tables 7 and 9 that the inflation risk premium is negative in 2000-2003 and positive in 2004-2007. Overall negative inflation risk premium appears to be due to the negative numbers in the first half of the sample. It needs to be noted though, that the estimates of inflation risk premium in our sample are quite imprecise.

Evidence on both averages and volatilities of inflation risk premium over different horizons indicates that there is a significant shift in the behavior of inflation risk premium since the end of 2003. Whether it is a structural break, and therefore, a sample is split between two regimes remains an open question. Our ongoing research concerns the possibility that liquidity shifts in the TIPS market may explain this "structural break". As investors become more familiar with this new market, its liquidity seems to be gradually improving.[11] In the next section we present some preliminary estimates of the inflation risk premium controlling for liquidity effects.

C Estimating Liquidity Risk Premium

For the reasons outlined above, the estimates of inflation risk premium need to be "filtered" from liquidity component under the assumption that the determinants of inflation risk premium and liquidity risk premium are different. In general, we assume that the depth of the TIPS market is closely related to the liquidity risk premium in TIPS but unlikely to be related to the inflation risk premium. Therefore, we use bid-ask spreads of quoted TIPS prices and trading volume data to control for liquidity effects in the inflation risk premium. In particular, we consider the case of 10-year bonds because of the data issues with the

[9] We report IRP based on 1 year ahead GDP price deflator forecast, but do not focus on them because TIPS are linked to CPI index.

[10] See Figures 4, 5 and 6 in their paper.

[11] There are also tax considerations that might have affected the development of the TIPS market. See, for example, Hein and Mercer (2003) for a discussion.

bonds of different maturities.[12] Specifically, we assume the following statistical model

$$IRP_t(\tau) = \alpha_0 + \alpha_1 spread_t(\tau) + \alpha_2 volume_t(\tau) + u_t(\tau), \quad (20)$$

where $spread_t(\tau)$ is the average bid-ask spread of the outstanding 10-year TIPS issues, and $volume_t(\tau)$ is the log trading volume averaged across both on-the-run and off-the-run 10-year TIPS issues. $u_t(\tau)$ is the residual of the inflation risk premium not explained by liquidity variables. We run this regression for quarterly inflation risk premium which was estimated using expected inflation from the Survey of Professional Forecasters.[13] The corresponding IRP estimates are reported in Table 11. The reason we use quarterly estimates of inflation risk premium is that we view them as the most reliable since Ang, Bekaert, and Wei (2007a) show that surveys provide the best forecasts of inflation.

The regression (20) results are reported in Table 12. In the first row we present the estimates of Model I, where we restrict $\alpha_2 = 0$ and use only the average bid-ask spread as the explanatory variable for the magnitude of $IRP_t(\tau)$. We interpret the regression residual as part of the inflation risk premium not explained by TIPS liquidity issues. In the last two columns of the table we report the average residual for both the first and the second half of the sample. Recall from Table 3 that the first half of the sample period corresponds to the period of high real yields (10-year yields in 2000-2003 were on average 3.11%) and the second half of the sample corresponds to the period of much lower real yields(10-year yields in 2004-2006 were on average 1.98%). Given relatively flat curve of expected inflation during these periods (Table 1, Panel C), it follows that negative inflation risk premium[14] in the first half of the sample is due to high real yields that seem, in part due to the liquidity problems with TIPS market at that time. We observe lower real yields and positive inflation risk premium during 2004-2006.[15] Because the expected inflation was pretty flat during this time period, we conjecture that lower real yields are associated with lower liquidity risks on the TIPS market, albeit still present. This is the reason that we report the average residual for both subperiods that is "liquidity-free" estimate of inflation risk premium for each of the considered regression models that account for liquidity risk. In the case of Model I the

[12] We do not have a continuous time series for volume and bid-ask spreads for 5-year bonds because there were no outstanding 5-year TIPS between July 2002 and September 2004.

[13] We compute quarterly bid-ask spreads as average of weekly spreads within a particular quarter.

[14] Average 10-year inflation risk premium during 2000-2003 was on average minus 30 basis points, see Table 11.

[15] Average 10-year inflation risk premium in the second half of the sample was on average 24 basis points, see Table 11.

part of 10-year inflation risk premium, not explained by bid-ask spread is only 16.1, not 24 basis points, the inflation risk premium not adjusted for inflation. In the second row of the Table 12 we report the results of the regression model II where we use log trading volume in 10-year TIPS as a proxy for liquidity and restrict $\alpha_1 = 0$. In this case the adjusted inflation risk premium is 17.6 basis points. The $R^2 = .335$ in case of Model I and .283 in case of Model II. Both proxies are statistically significant. Next, we report the results of the regression Model III, where we include both the log trading volume and the average bid-ask spread as proxies for liquidity. In this case we observe that the estimates of 10-year inflation risk premium net of liquidity premium is 14.1 basis points. It is interesting that the average bid-ask spread drives away the log trading volume. The R^2 for this regression is .383. The average residual for all models is negative during the first half of the sample indicating severe liquidity issues on the TIPS market. This points out that some structural changes occurred in the TIPS market in the middle of 2003, the mid point of our sample. This result is consistent with Shen (2006) who also documents that the liquidity risk premium was significantly larger than the inflation risk premium.

4 Conclusion

In this paper we estimate the inflation risk premium directly using the prices of Treasury inflation-protected securities (TIPS). Using market data on prices of TIPS over the period 2000-2006, we find that the inflation risk premium is time varying. More specifically, it is negative in the first half of the sample but positive in the second half. We estimate that the mean inflation risk premium over the second half can be as low as two basis points and as high as 63 basis points depending on the inflation forecast measure and the maturity of the breakeven rate. The negative inflation risk premium during 2000-2003 appears to be due to liquidity problems in the TIPS market, since it seems to be driven by very high real rates at that time. We also find that inflation risk premium is considerably less volatile during 2004-2006, a finding consistent with the observations that inflation expectations became more stable during this period, investors became more familiar with TIPS market and the market liquidity has gradually improved. Once we adjust the inflation risk premium for liquidity in TIPS, we find that 10-year inflation risk premium is on average 14 basis points during the second half of our sample. These estimates are much lower than the ones from earlier studies.

Our empirical results on inflation risk premium estimated directly from TIPS should be valuable for practitioners, monetary authorities and policy makers alike because they help to assess the inflation expectations of bond market investors.

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Table 1: Summary Statistics of Zero-Coupon TIPS, Nominal Bonds and Inflation

The table reports sample statistics for zero-coupon yields on index-linked and nominal bonds with h months to maturity in Panels A and B respectively. $y^{TIPS}(h)$ is the yield on an h-month Treasury Protected Inflation Security (TIPS), $y(h)$ is the yield on an h-month nominal yield. Panel C reports breakeven inflation, the difference between nominal and TIPS yields. Panel D presents realized and expected inflation variables. Realized inflation variables are: CPI is seasonally unadjusted Consumer Price Index for All Urban Consumers, and seasonally adjusted Core CPI is Consumer Price Index Less Food and Energy. Expected inflation variables are: (1) 1-year ahead forecast from Michigan Consumer Survey, (2) 1-year ahead forecast based on GDP price deflator from the Survey of Professional Forecasters (SPF), (3) 1-year ahead forecast based on CPI price deflator from SPF, (4) 10-year ahead forecast based on CPI price deflator from SPF, and (5) 1-year ahead forecast from Blue Chip Economic Indicators. Data range for all variables is 2000:01-2007:12, monthly frequency, except SPF whose forecasts are quarterly. All numbers are in annual percentages. Source: Barclays Capital, Federal Reserve discount bonds data set, Federal Reserve Bank of St. Louis Economic Data Base, Federal Reserve Bank of Philadelphia and Aspen Publishers.

	Central Moments				Autocorrelations		
	Mean	Stdev	Skew	Kurt	Lag1	Lag2	Lag3
	Panel A: TIPS Yields						
$y^{TIPS}(60)$	2.2086	0.9527	0.5267	2.3081	0.9771	0.9540	0.9341
$y^{TIPS}(84)$	2.4028	0.8538	0.6334	2.2862	0.9800	0.9599	0.9423
$y^{TIPS}(120)$	2.5745	0.7717	0.6527	2.1644	0.9821	0.9645	0.9487
	Panel B: Nominal Bond Yields						
$y(60)$	4.2357	0.9651	0.4624	2.9804	0.9822	0.9647	0.9477
$y(84)$	4.5376	0.7916	0.6781	3.2276	0.9835	0.9675	0.9525
$y(120)$	4.8905	0.6382	0.7914	3.1276	0.9850	0.9707	0.9574
	Panel C: Breakeven Inflation						
$BEI(60)$	2.0271	0.4703	-0.5011	2.1996	0.9839	0.9670	0.9512
$BEI(84)$	2.1348	0.3816	-0.5073	2.1310	0.9849	0.9699	0.9564
$BEI(120)$	2.3160	0.3138	-0.3719	2.0856	0.9862	0.9734	0.9619
	Panel D: Inflation Variables						
CPI	2.7691	4.3112	-0.1789	3.0258	0.5538	0.1661	0.0848
Core CPI	2.2008	1.0133	-0.0405	2.6397	0.8099	0.8445	0.8093
Michigan 1yr forecast	2.8906	0.5468	-1.1144	8.6435	0.9786	0.9579	0.9441
SPF, GDP 1yr forecast	2.0535	0.2195	-0.3933	2.0437	0.9647	0.9257	0.8860
SPF, CPI 1yr forecast	2.3375	0.2378	-0.8740	4.0971	0.9625	0.9286	0.8902
SPF, CPI 10yr forecast	2.4844	0.0410	-1.8655	5.8855	0.9695	0.9391	0.9087
Blue Chips, CPI 1yr forecast	2.4475	0.3989	-0.3741	2.1034	0.9873	0.9731	0.9589

Table 2: VAR Risk Premia Estimates

The table reports estimates of $\gamma_t(\tau)$ computed as

$$\gamma_t(\tau) = i_1' \left[\sum_{i=1}^{\tau} A^{\tau-i} \left(\sum_{j=1}^{i} A^{i-j} V(e_{t+j}|z_t) A^{i-j'} \right) \right] i_2,$$

where i_1 is the selection vector such that $\Delta p_t = i_1' z_t$ and $q_t(l) = i_2' z_t$. This equation shows how the covariance between $\Delta^\tau p_{t+\tau}$ and $q_{t+\tau}(l)$ conditioned on z_t relates to the dynamics of VAR through the coefficient matrix A, and the innovation variances, $V(e_{t+j}|z_t)$. $\Delta^\tau p_{t+\tau}$ is the log change in the price level from time t to time $t+\tau$. $q_{t+\tau}(l)$ is the log of prices at time $t+\tau$ for a nominal bond maturing in l months.

Maturity τ	$\gamma(\tau)$	Impact on the real yields
12	-0.0001	0.0112
24	-0.0005	0.0274
36	-0.0014	0.0482
57	-0.0043	0.0897
60	-0.0048	0.0959
81	-0.0093	0.1379
84	-0.0101	0.1438
117	-0.0198	0.2026
120	-0.0207	0.2075

Table 3: TIPS and Real Yields Statistics

The table reports statistics for TIPS yields, $y_t^+(h)$, and implied real yields with h months to maturity. $y^{real}(h)$ is the real yield on an h-month zero-coupon bond, estimated using the following formula:

$$y^{real}(\tau) = \frac{h}{\tau} y_t^+(h) - \frac{l}{\tau} f_t(\tau, l) + \frac{1}{\tau}\gamma_t(\tau).$$

Data Range: 2000:01 to 2007:12, monthly frequency. Statistics is reported for various subsamples. The estimates are based on seasonally un-adjusted CPI, used to estimate index-linked premium reported in Table 2.

Year	Horizon,	TIPS Yields				Real Yields			
	τ months	Mean	Stdev	Skew	Kurt	Mean	Stdev	Skew	Kurt
2000-2007	57	2.209	0.953	0.527	2.308	1.970	0.976	0.507	2.305
	81	2.403	0.854	0.633	2.286	2.150	0.871	0.628	2.297
	117	2.575	0.772	0.653	2.164	2.286	0.783	0.660	2.184
2000-2003	57	2.685	1.036	-0.154	1.729	2.447	1.064	-0.144	1.720
	81	2.916	0.876	-0.190	1.755	2.663	0.901	-0.180	1.744
	117	3.107	0.728	-0.244	1.787	2.821	0.747	-0.233	1.775
2004-2007	57	1.732	0.545	-0.165	1.732	1.492	0.572	-0.185	1.733
	81	1.890	0.410	-0.067	1.715	1.636	0.426	-0.083	1.716
	117	2.042	0.307	-0.004	1.739	1.752	0.316	-0.008	1.738
2000	57	3.991	0.174	0.028	2.188	3.796	0.162	0.038	2.103
	81	4.001	0.176	0.109	2.299	3.784	0.171	0.097	2.262
	117	3.982	0.172	0.228	2.351	3.723	0.172	0.203	2.324
2001	57	3.059	0.189	-0.289	2.677	2.832	0.194	-0.227	2.489
	81	3.237	0.156	-0.420	3.019	2.994	0.158	-0.420	2.900
	117	3.388	0.136	-0.399	2.805	3.108	0.137	-0.412	2.762
2002	57	2.384	0.539	-0.105	1.750	2.131	0.534	-0.086	1.769
	81	2.679	0.482	-0.142	1.618	2.413	0.485	-0.129	1.616
	117	2.927	0.425	-0.163	1.539	2.630	0.432	-0.152	1.533
2003	57	1.309	0.227	0.495	2.012	1.031	0.222	0.530	2.021
	81	1.747	0.215	0.605	2.176	1.463	0.212	0.620	2.097
	117	2.133	0.206	0.586	2.223	1.823	0.205	0.586	2.134
2004	57	1.102	0.255	-0.527	2.404	0.814	0.256	-0.643	2.533
	81	1.496	0.237	-0.079	1.914	1.208	0.237	-0.147	1.991
	117	1.846	0.221	0.217	1.699	1.533	0.222	0.194	1.728
2005	57	1.513	0.316	0.699	2.073	1.280	0.331	0.677	2.072
	81	1.655	0.244	0.692	2.015	1.408	0.252	0.677	2.014
	117	1.798	0.185	0.631	1.930	1.512	0.189	0.624	1.914
2006	57	2.227	0.177	-0.903	2.769	2.010	0.181	-0.875	2.750
	81	2.256	0.169	-0.865	2.683	2.020	0.168	-0.879	2.722
	117	2.289	0.171	-0.657	2.348	2.011	0.169	-0.685	2.395
2007	57	2.085	0.427	-0.915	2.832	1.863	0.442	-0.937	2.848
	81	2.153	0.348	-0.876	2.873	1.908	0.362	-0.903	2.893
	117	2.234	0.276	-0.773	2.877	1.952	0.283	-0.794	2.887

Table 4: Expected Inflation

The table reports the estimates of the expected inflation. $E_t\pi_{t+\tau}(\tau)$ is the expected rate of inflation computed as $T-$year historical average of $\pi_{t+\tau}(\tau)$, $\tau-$period realized inflation. Panel A reports results using CPI, Consumer Price Index for All Urban Consumers, seasonally un-adjusted as a measure of realized inflation. Panel B reports expected inflation based on historical average of Core CPI, Consumer Price Index Less Food and Energy, seasonally adjusted.

Horizon, τ months	Estimation period, T years				
	1	3	5	7	10
	Panel A: Based on CPI				
57	2.470	2.436	2.454	2.526	2.743
	(0.132)	(0.069)	(0.068)	(0.146)	(0.289)
81	2.480	2.465	2.525	2.647	2.871
	(0.147)	(0.088)	(0.146)	(0.244)	(0.301)
117	2.539	2.617	2.738	2.868	3.067
	(0.132)	(0.216)	(0.288)	(0.301)	(0.282)
	Panel B: Based on Core CPI				
57	2.188	2.260	2.360	2.501	2.789
	(0.148)	(0.163)	(0.204)	(0.293)	(0.406)
81	2.282	2.363	2.500	2.675	2.969
	(0.164)	(0.210)	(0.291)	(0.371)	(0.417)
117	2.467	2.613	2.786	2.967	3.242
	(0.289)	(0.361)	(0.405)	(0.418)	(0.410)

Table 5: Inflation Risk Premium Regressions

The table reports the estimates of inflation risk premium regression:

$$IRP_t(\tau) = \alpha_0 + \alpha_1 \left[y_t(\tau) - y_t^{real}(\tau) \right] + u_{t+\tau},$$

where IRP is inflation risk premium computed using Consumer Price Index for All Urban Consumers, seasonally un-adjusted as a proxy for inflation. $y_t(\tau)$ is nominal τ-month yield, $y_t^{real}(\tau)$ is the estimate of the τ-month real yield computed from nominal and TIPS zero term structures. Newey-West corrected $t-$stats are given in parentheses below The lag used for Newey-West correction is 12.

Horizon, τ months	α_0	α_1	R^2
	$E_t\pi_{t+\tau}(\tau)$ is 1-year historical average		
57	-0.023	0.903	0.929
	(-26.272)	(21.035)	
81	-0.024	0.967	0.872
	(-12.162)	(10.176)	
117	-0.031	1.210	0.922
	(-15.073)	(17.120)	
	$E_t\pi_{t+\tau}(\tau)$ is 3-year historical average		
57	-0.023	0.941	0.982
	(-76.620)	(49.587)	
81	-0.026	1.064	0.961
	(-28.222)	(22.318)	
117	-0.037	1.408	0.875
	(-13.029)	(14.615)	
	$E_t\pi_{t+\tau}(\tau)$ is 5-year historical average		
57	-0.024	0.988	0.981
	(-33.377)	(32.311)	
81	-0.028	1.134	0.916
	(-16.939)	(17.421)	
117	-0.043	1.597	0.852
	(-12.906)	(13.565)	
	$E_t\pi_{t+\tau}(\tau)$ is 7-year historical average		
57	-0.027	1.083	0.936
	(-21.989)	(19.935)	
81	-0.034	1.328	0.866
	(-14.268)	(14.257)	
117	-0.045	1.636	0.850
	(-15.492)	(14.401)	
	$E_t\pi_{t+\tau}(\tau)$ is 10-year historical average		
57	-0.034	1.294	0.868
	(-17.165)	(15.078)	
81	-0.040	1.471	0.859
	(-18.715)	(16.181)	
117	-0.045	1.554	0.840
	(-15.611)	(13.635)	

Table 6: Inflation Risk Premium Regressions

Inflation proxy, $\pi_{t+\tau}(\tau)$, is measured using core inflation, Consumer Price Index Less Food and Energy, seasonally adjusted. Otherwise the table is identical to Table 5.

Horizon, τ months	α_0	α_1	R^2
	$E_t\pi_{t+\tau}(\tau)$ is 1-year historical average		
57	-0.026	1.201	0.967
	(-58.058)	(38.703)	
81	-0.030	1.287	0.949
	(-27.966)	(28.914)	
117	-0.040	1.583	0.843
	(-13.187)	(14.383)	
	$E_t\pi_{t+\tau}(\tau)$ is 3-year historical average		
57	-0.026	1.159	0.942
	(-33.644)	(26.440)	
81	-0.031	1.302	0.899
	(-20.424)	(19.570)	
117	-0.045	1.718	0.799
	(-11.086)	(11.474)	
	$E_t\pi_{t+\tau}(\tau)$ is 5-year historical average		
57	-0.028	1.182	0.910
	(-24.359)	(21.392)	
81	-0.034	1.381	0.828
	(-13.738)	(13.759)	
117	-0.049	1.828	0.788
	(-11.674)	(11.303)	
	$E_t\pi_{t+\tau}(\tau)$ is 7-year historical average		
57	-0.031	1.265	0.851
	(-17.086)	(15.119)	
81	-0.039	1.536	0.800
	(-13.326)	(12.681)	
117	-0.051	1.843	0.777
	(-12.140)	(10.893)	
	$E_t\pi_{t+\tau}(\tau)$ is 10-year historical average		
57	-0.038	1.436	0.811
	(-16.691)	(13.536)	
81	-0.044	1.626	0.786
	(-15.252)	(12.620)	
117	-0.053	1.805	0.770
	(-12.728)	(10.736)	

Table 7: Average Inflation Risk Premium based on CPI index

The table reports the mean estimates of the inflation risk premium (IRP), computed as $IRP = y_t(\tau) - y_t^{real}(\tau) - E_t\pi_{t+\tau}(\tau)$. $y_t(\tau)$ is nominal τ-month yield, $y_t^{real}(\tau)$ is the estimate of the τ-month real yield computed from nominal and TIPS zero term structures. $E_t\pi_{t+\tau}(\tau)$ is the expected rate of inflation computed as $T-$year historical average of $\pi_{t+\tau}(\tau)$, $\tau-$period realized inflation. CPI is seasonally un-adjusted Consumer Price Index for All Urban Consumers. Data Range: 2000:01 to 2006:12, monthly frequency. Statistics is reported for various subsamples.

Year	Horizon,	Estimation period, T years				
	τ months	1	3	5	7	10
2000-2007	57	-0.246	-0.212	-0.231	-0.302	-0.519
	81	-0.128	-0.114	-0.173	-0.296	-0.519
	117	0.039	-0.039	-0.160	-0.290	-0.489
2000-2003	57	-0.529	-0.539	-0.608	-0.765	-1.130
	81	-0.392	-0.440	-0.569	-0.792	-1.090
	117	-0.284	-0.448	-0.646	-0.803	-0.978
2004-2007	57	0.038	0.115	0.147	0.161	0.092
	81	0.136	0.212	0.223	0.201	0.051
	117	0.361	0.370	0.326	0.223	-0.001
2000	57	-0.106	-0.168	-0.327	-0.596	-1.017
	81	-0.183	-0.274	-0.571	-0.850	-1.081
	117	-0.451	-0.697	-0.894	-0.985	-1.161
2001	57	-0.764	-0.694	-0.802	-0.965	-1.392
	81	-0.642	-0.587	-0.752	-1.015	-1.306
	117	-0.472	-0.649	-0.891	-1.022	-1.179
2002	57	-0.712	-0.766	-0.793	-0.910	-1.270
	81	-0.524	-0.570	-0.614	-0.832	-1.166
	117	-0.241	-0.373	-0.577	-0.771	-0.940
2003	57	-0.536	-0.528	-0.511	-0.590	-0.841
	81	-0.218	-0.328	-0.341	-0.472	-0.806
	117	0.030	-0.072	-0.223	-0.435	-0.632
2004	57	0.107	0.175	0.172	0.159	-0.008
	81	0.424	0.350	0.286	0.234	-0.058
	117	0.544	0.485	0.376	0.202	-0.037
2005	57	0.269	0.285	0.306	0.325	0.229
	81	0.255	0.366	0.310	0.293	0.094
	117	0.397	0.400	0.331	0.208	-0.050
2006	57	0.103	0.164	0.215	0.225	0.188
	81	-0.020	0.205	0.245	0.227	0.133
	117	0.298	0.358	0.340	0.262	0.033
2007	57	-0.329	-0.165	-0.103	-0.065	-0.043
	81	-0.116	-0.071	0.053	0.050	0.033
	117	0.204	0.236	0.259	0.219	0.051

Table 8: Volatility of Inflation Risk Premium based on CPI index

The table reports the volatility estimates of the inflation risk premium (IRP), computed as $IRP = y_t(\tau) - y_t^{real}(\tau) - E_t\pi_{t+\tau}(\tau)$. $y_t(\tau)$ is nominal τ-month yield, $y_t^{real}(\tau)$ is the estimate of the τ-month real yield computed from nominal and TIPS zero term structures. $E_t\pi_{t+\tau}(\tau)$ is the expected rate of inflation computed as $T-$year historical average of $\pi_{t+\tau}(\tau)$, $\tau-$period realized inflation. CPI is seasonally un-adjusted Consumer Price Index for All Urban Consumers. Data Range: 2000:01 to 2006:12, monthly frequency. Statistics is reported for various subsamples.

Year	Horizon,	Estimation period, T years				
	τ months	1	3	5	7	10
2000-2007	57	0.464	0.470	0.494	0.554	0.687
	81	0.410	0.430	0.469	0.564	0.628
	117	0.406	0.485	0.557	0.571	0.546
2000-2003	57	0.419	0.399	0.373	0.351	0.377
	81	0.349	0.311	0.299	0.329	0.327
	117	0.297	0.330	0.356	0.326	0.314
2004-2007	57	0.309	0.263	0.249	0.243	0.225
	81	0.275	0.244	0.183	0.178	0.162
	117	0.180	0.156	0.129	0.122	0.124
2000	57	0.392	0.333	0.326	0.295	0.313
	81	0.326	0.271	0.242	0.242	0.264
	117	0.176	0.169	0.191	0.195	0.187
2001	57	0.373	0.381	0.364	0.350	0.342
	81	0.293	0.289	0.266	0.264	0.269
	117	0.220	0.207	0.204	0.208	0.209
2002	57	0.303	0.325	0.311	0.307	0.288
	81	0.237	0.265	0.251	0.236	0.241
	117	0.163	0.165	0.160	0.165	0.167
2003	57	0.269	0.294	0.292	0.305	0.327
	81	0.322	0.315	0.308	0.329	0.335
	117	0.302	0.310	0.324	0.330	0.319
2004	57	0.166	0.166	0.164	0.177	0.193
	81	0.125	0.144	0.135	0.146	0.160
	117	0.102	0.108	0.112	0.121	0.115
2005	57	0.210	0.222	0.215	0.215	0.207
	81	0.227	0.192	0.182	0.180	0.166
	117	0.174	0.164	0.156	0.148	0.148
2006	57	0.278	0.238	0.229	0.230	0.212
	81	0.211	0.219	0.185	0.187	0.161
	117	0.160	0.160	0.147	0.139	0.127
2007	57	0.209	0.195	0.193	0.182	0.173
	81	0.092	0.119	0.112	0.107	0.101
	117	0.060	0.066	0.067	0.070	0.081

Table 9: Average Inflation Risk Premium based on Core CPI Index

The table reports the mean estimates of the inflation risk premium (IRP), computed as $IRP = y_t(\tau) - y_t^{real}(\tau) - E_t\pi_{t+\tau}(\tau)$. $y_t(\tau)$ is nominal τ-month yield, $y_t^{real}(\tau)$ is the estimate of the τ-month real yield computed from nominal and TIPS zero term structures. $E_t\pi_{t+\tau}(\tau)$ is the expected rate of inflation computed as $T-$year historical average of $\pi_{t+\tau}(\tau)$, $\tau-$period realized inflation. Core CPI is the seasonally adjusted Core Consumer Price Index for All Urban Consumers. Data Range: 2000:01 to 2007:12, monthly frequency. Statistics is reported for various subsamples.

Year	Horizon,	Estimation period, T years				
	τ months	1	3	5	7	10
2000-2007	57	0.035	-0.036	-0.136	-0.277	-0.566
	81	0.070	-0.011	-0.149	-0.323	-0.617
	117	0.111	-0.035	-0.208	-0.389	-0.664
2000-2003	57	-0.473	-0.543	-0.674	-0.887	-1.287
	81	-0.383	-0.496	-0.691	-0.943	-1.285
	117	-0.380	-0.586	-0.805	-1.000	-1.264
2004-2007	57	0.543	0.470	0.401	0.333	0.156
	81	0.522	0.474	0.394	0.298	0.051
	117	0.602	0.515	0.389	0.222	-0.064
2000	57	-0.125	-0.280	-0.490	-0.803	-1.210
	81	-0.262	-0.464	-0.779	-1.055	-1.351
	117	-0.643	-0.891	-1.093	-1.258	-1.522
2001	57	-0.630	-0.714	-0.868	-1.113	-1.555
	81	-0.567	-0.662	-0.898	-1.180	-1.520
	117	-0.569	-0.821	-1.054	-1.238	-1.490
2002	57	-0.729	-0.734	-0.837	-1.009	-1.422
	81	-0.513	-0.568	-0.711	-0.968	-1.331
	117	-0.317	-0.494	-0.728	-0.937	-1.201
2003	57	-0.406	-0.445	-0.500	-0.622	-0.961
	81	-0.188	-0.290	-0.378	-0.571	-0.937
	117	0.006	-0.137	-0.346	-0.566	-0.842
2004	57	0.448	0.326	0.285	0.194	-0.067
	81	0.546	0.404	0.317	0.186	-0.157
	117	0.630	0.481	0.316	0.103	-0.190
2005	57	0.652	0.569	0.500	0.436	0.245
	81	0.606	0.533	0.428	0.334	0.049
	117	0.598	0.488	0.349	0.161	-0.140
2006	57	0.659	0.590	0.494	0.441	0.294
	81	0.560	0.556	0.463	0.382	0.170
	117	0.634	0.566	0.444	0.296	0.004
2007	57	0.414	0.396	0.327	0.260	0.151
	81	0.377	0.404	0.368	0.288	0.142
	117	0.544	0.528	0.447	0.329	0.070

Table 10: Volatility of Inflation Risk Premium based on Core CPI Index

The table reports the volatility estimates of the inflation risk premium (IRP), computed as $IRP = y_t(\tau) - y_t^{real}(\tau) - E_t\pi_{t+\tau}(\tau)$. $y_t(\tau)$ is nominal τ-month yield, $y_t^{real}(\tau)$ is the estimate of the τ-month real yield computed from nominal and TIPS zero term structures. $E_t\pi_{t+\tau}(\tau)$ is the expected rate of inflation computed as $T-$year historical average of $\pi_{t+\tau}(\tau)$, $\tau-$period realized inflation. Core CPI is the seasonally adjusted Core Consumer Price Index for All Urban Consumers. Data Range: 2000:01 to 2007:12, monthly frequency. Statistics is reported for various subsamples.

Year	Horizon,	Estimation period, T years				
	τ months	1	3	5	7	10
2000-2007	57	0.605	0.591	0.613	0.679	0.790
	81	0.523	0.543	0.601	0.680	0.726
	117	0.555	0.618	0.663	0.673	0.662
2000-2003	57	0.405	0.368	0.357	0.356	0.381
	81	0.321	0.298	0.322	0.348	0.342
	117	0.338	0.372	0.377	0.361	0.354
2004-2007	57	0.219	0.215	0.206	0.213	0.230
	81	0.178	0.164	0.153	0.162	0.191
	117	0.128	0.123	0.132	0.150	0.158
2000	57	0.321	0.311	0.295	0.282	0.298
	81	0.271	0.243	0.230	0.234	0.248
	117	0.160	0.169	0.179	0.182	0.176
2001	57	0.382	0.362	0.354	0.339	0.339
	81	0.284	0.272	0.259	0.258	0.262
	117	0.207	0.204	0.204	0.205	0.206
2002	57	0.325	0.317	0.306	0.295	0.285
	81	0.248	0.253	0.239	0.230	0.232
	117	0.168	0.160	0.158	0.159	0.161
2003	57	0.335	0.306	0.313	0.321	0.340
	81	0.333	0.317	0.322	0.339	0.341
	117	0.330	0.327	0.336	0.336	0.333
2004	57	0.185	0.187	0.186	0.192	0.211
	81	0.149	0.154	0.150	0.160	0.170
	117	0.114	0.118	0.126	0.129	0.126
2005	57	0.203	0.201	0.206	0.203	0.197
	81	0.176	0.167	0.169	0.166	0.159
	117	0.151	0.146	0.144	0.141	0.141
2006	57	0.211	0.201	0.197	0.198	0.189
	81	0.196	0.173	0.160	0.160	0.142
	117	0.152	0.137	0.130	0.122	0.118
2007	57	0.171	0.163	0.157	0.161	0.154
	81	0.101	0.104	0.099	0.099	0.095
	117	0.070	0.073	0.079	0.083	0.092

Table 11: Inflation Risk Premium based on the Surveys

The table reports the average estimates for inflation risk premium based on various forecasts of inflation produced by the Survey of Professional Forecasters (SPF) and Blue Chip Economic Indicators. The standard deviation of the estimates is given in the parenthesis below the estimates. Data Range: 2000:01 to 2007:12. We report quarterly estimates in the case of SPF and monthly estimates in the case of Blue Chips. Statistics is reported for various subsamples.

Sample	Horizon	Forecast Variable			
period	τ months	SPF			Blue Chips
		GDP, 1yr	CPI,1yr	CPI,10yr	CPI,1yr
2000-2007	57	0.142	-0.142	-0.289	-0.224
		(0.473)	(0.538)	(0.509)	(0.521)
	81	0.270	-0.014	-0.161	-0.096
		(0.409)	(0.476)	(0.418)	(0.490)
	117	0.503	0.219	0.072	0.131
		(0.381)	(0.448)	(0.343)	(0.497)
2000-2003	57	-0.158	-0.528	-0.691	-0.506
		(0.405)	(0.426)	(0.377)	(0.485)
	81	0.034	-0.336	-0.499	-0.312
		(0.370)	(0.396)	(0.298)	(0.490)
	117	0.329	-0.041	-0.204	-0.029
		(0.364)	(0.401)	(0.237)	(0.527)
2004-2007	57	0.442	0.245	0.113	0.058
		(0.327)	(0.314)	(0.221)	(0.388)
	81	0.505	0.307	0.176	0.121
		(0.301)	(0.299)	(0.168)	(0.386)
	117	0.677	0.480	0.349	0.290
		(0.320)	(0.329)	(0.157)	(0.413)

Table 12: Liquidity Risk Premium Regressions

The table reports the estimates of the following regression:

$$IRP_t(\tau) = \alpha_0 + \alpha_1 spread_t(\tau) + \alpha_2 volume_t(\tau) + u_t(\tau),$$

where $IRP_t(\tau)$ is the inflation risk premium computed using expected inflation from the Survey of Professional Forecasters and $\tau = 10$ years in this table. $spread_t(\tau)$ is the average bid-ask spread (in basis points) of the outstanding 10-year TIPS issues, and $volume_t(\tau)$ is the log trading volume averaged across both on-the-run and off-the-run 10-year TIPS. $u_t(\tau)$ is the residual of the inflation risk premium not explained by liquidity variables. Model I refers to the regression model where only the bid-ask spread is considered as the explanatory variable. Model II refers to the regression model where only the trading volume is considered as the explanatory variable. Model III refers to the regression model where both the bid-ask spread and the trading volume are considered as explanatory variables. The average residual is reported for both the first and the second half of the sample. Spreads data are obtained from Bloomberg and volume data are from Datastream. $t-$stats are given in parentheses below. Estimation period is 2000:Q1-2006:Q4, the data frequency is quarterly.

Regression	α_0	α_1	α_2	R^2	Average residual	
Models					First half	Second half
Model I	-1.653	29.160		0.335	-0.161	0.161
	(-3.747)	(3.621)				
Model II	0.195		0.244	0.283	-0.176	0.176
	(1.958)		(3.207)			
Model III	-1.036	20.350	0.128	0.383	-0.141	0.141
	(-1.668)	(2.004)	(1.385)			

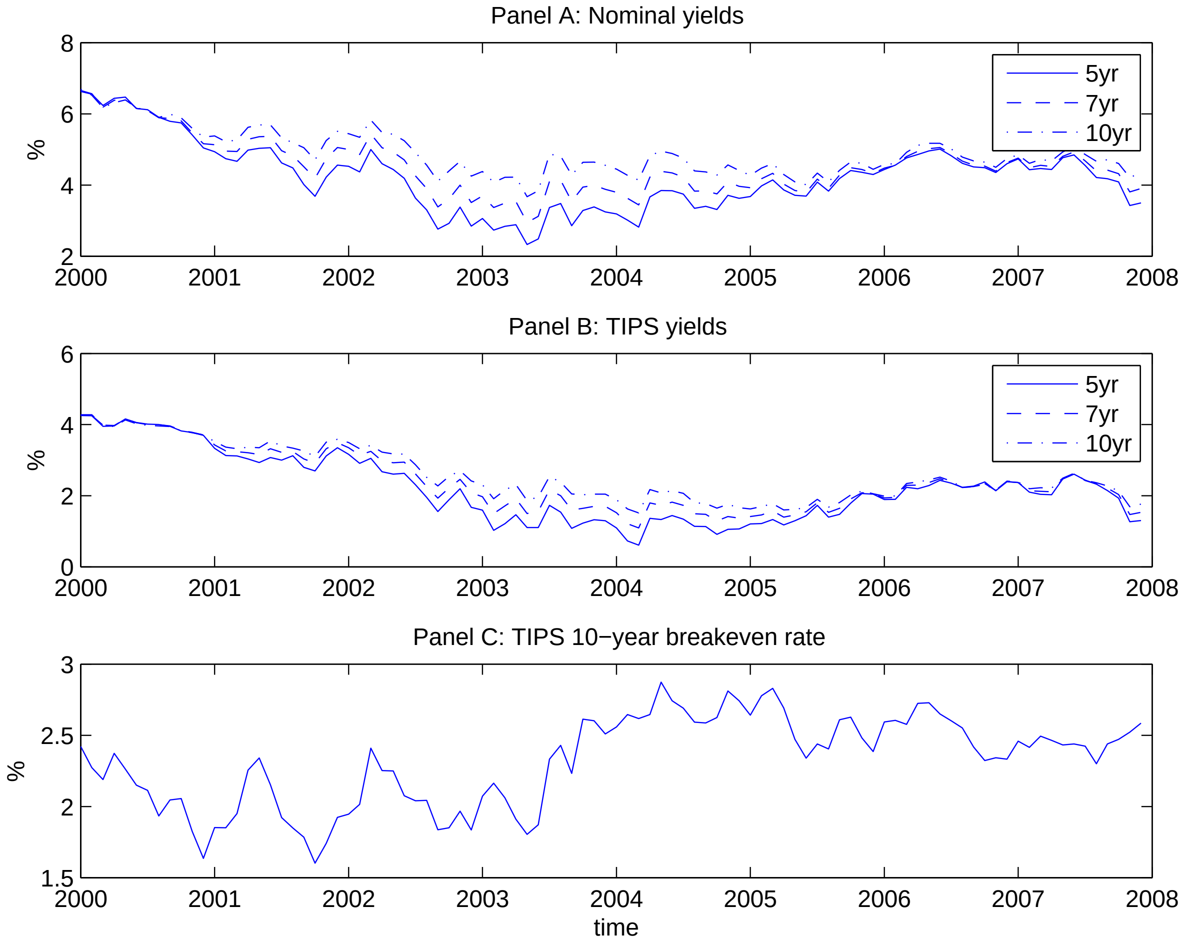

Figure 1: Zero-coupon Nominal and TIPS yields of 5, 7, and 10 year maturities from January 2000 to December 2007, and 10-year TIPS breakeven rate based on zero-coupon yield curves.

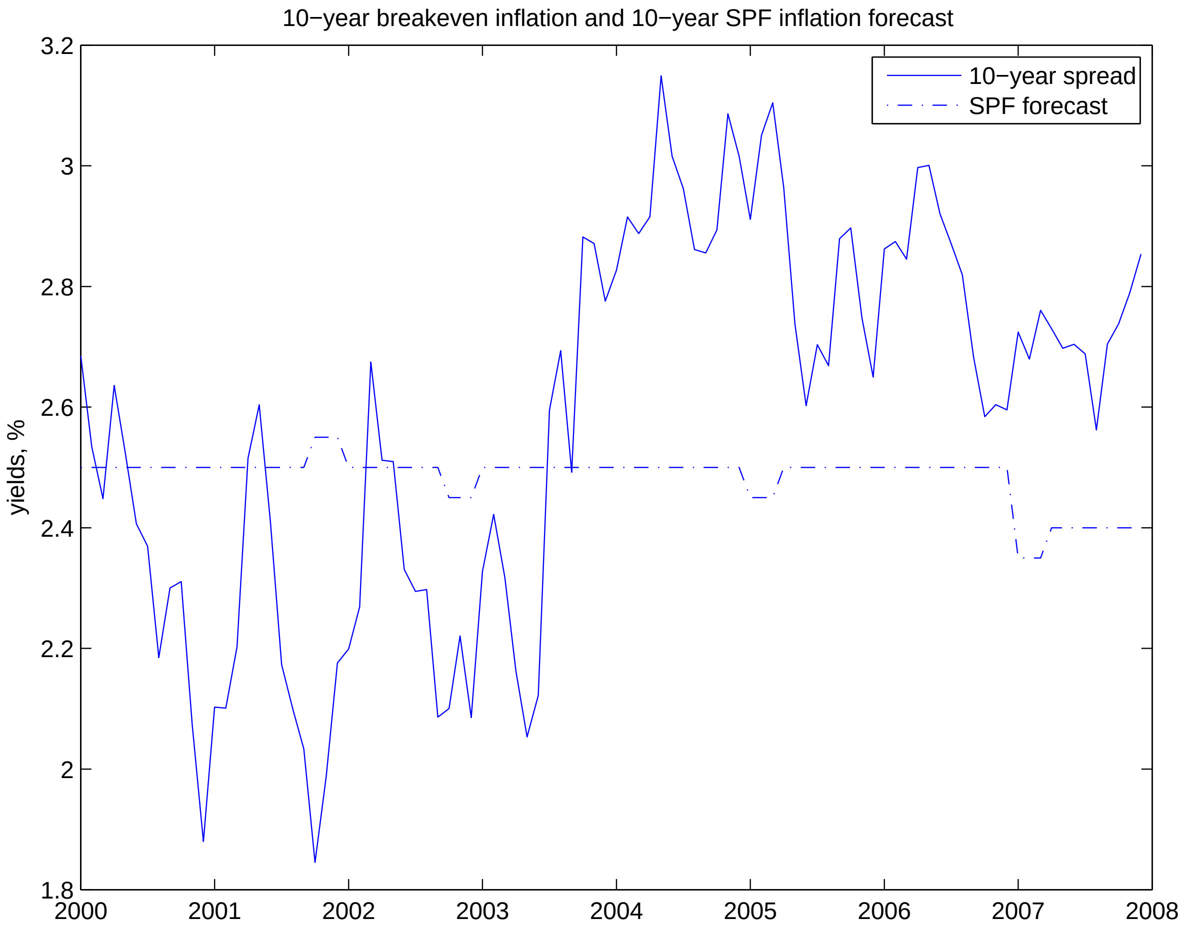

Figure 2: The 10-year breakeven inflation rate and the Survey of Professional Forecasters 10-year ahead inflation forecast.

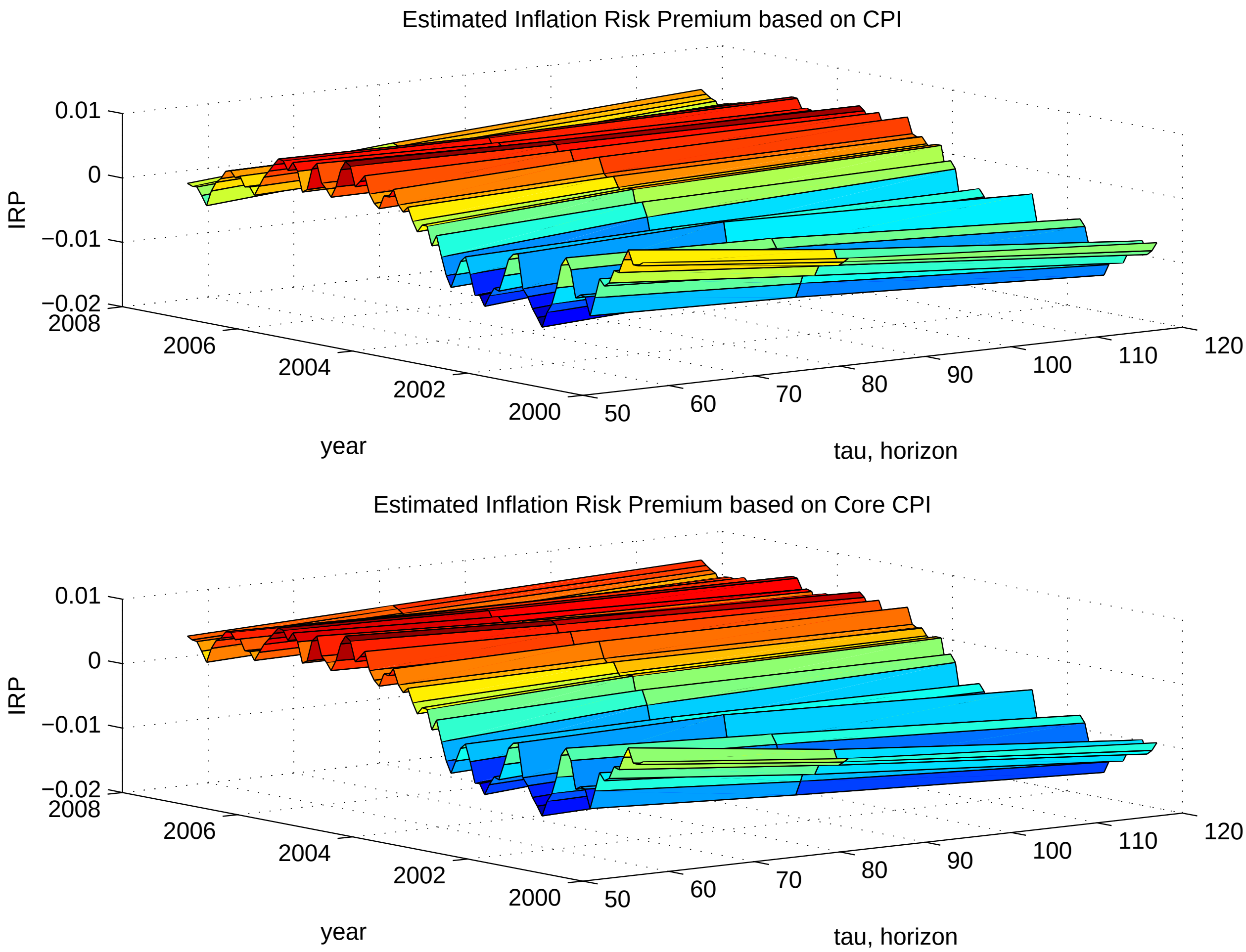

Figure 3: This figure presents inflation risk premium based on 5-year expected inflation reported in Table 4. Panel A shows inflation risk premium based on CPI, Consumer Price Index for All Urban Consumers, seasonally un-adjusted. Panel B presents inflation risk premium based on Core CPI, Consumer Price Index Less Food and Energy, seasonally adjusted. Data range is 2000:01 to 2007:12, monthly frequency.