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Understanding Inflation-Indexed Bond Markets

ABSTRACT This paper explores the history of inflation-indexed bond markets in the United States and the United Kingdom. It documents a massive decline in long-term real interest rates from the 1990s until 2008, followed by a sudden spike during the financial crisis of 2008. Breakeven inflation rates, calculated from inflation-indexed and nominal government bond yields, were stable from 2003 until the fall of 2008, when they showed dramatic declines. The paper asks to what extent short-term real interest rates, bond risks, and liquidity explain the trends before 2008 and the unusual developments that followed. Low yields and high short-term volatility of returns do not invalidate the basic case for inflation-indexed bonds, which is that they provide a safe asset for long-term investors. Governments should expect inflation-indexed bonds to be a relatively cheap form of debt financing in the future, even though they have offered high returns over the past decade.

In recent years government-issued inflation-indexed bonds have become available in a number of countries and have provided a fundamentally new instrument for use in retirement saving. Because expected inflation varies over time, conventional, nonindexed (nominal) Treasury bonds are not safe in real terms; and because short-term real interest rates vary over time, Treasury bills are not safe assets for long-term investors. Inflation-indexed bonds fill this gap by offering a truly riskless long-term investment (Campbell and Shiller 1997; Campbell and Viceira 2001, 2002; Brennan and Xia 2002; Campbell, Chan, and Viceira 2003; Wachter 2003).

The U.K. government first issued inflation-indexed bonds in the early 1980s, and the U.S. government followed suit by introducing Treasury inflation-protected securities (TIPS) in 1997. Inflation-indexed government bonds are also available in many other countries, including Canada, France, and Japan. These bonds are now widely accepted financial instruments. However, their history raises some new puzzles that deserve investigation.

First, given that the real interest rate is determined in the long run by the marginal product of capital, one might expect inflation-indexed bond yields to be extremely stable over time. But whereas 10-year annual yields on U.K. inflation-indexed bonds averaged about 3.5 percent during the 1990s (Barr and Campbell 1997), and those on U.S. TIPS exceeded 4 percent around the turn of the millennium, by the mid-2000s yields on both countries' bonds averaged below 2 percent, bottoming out at around 1 percent in early 2008 before spiking to near 3 percent in late 2008. The massive decline in long-term real interest rates from the 1990s to the 2000s is one puzzle, and the instability in 2008 is another.

Second, in recent years inflation-indexed bond prices have tended to move opposite to stock prices, so that these bonds have a negative "beta" with the stock market and can be used to hedge equity risk. This has been even more true of prices on nominal government bonds, although these bonds behaved very differently in the 1970s and 1980s (Campbell, Sunderam, and Viceira 2009). The reason for the negative beta on inflation-indexed bonds is not well understood.

Third, given integrated world capital markets, one might expect that inflation-indexed bond yields would be similar around the world. But this is not always the case. During the first half of 2000, the yield gap between U.S. and U.K. inflation-indexed bonds was over 2 percentage points, although yields have since converged. In January 2008, 10-year yields were similar in the United States and the United Kingdom, but elsewhere yields ranged from 1.1 percent in Japan to almost 2.0 percent in France (according to Bloomberg data). Yield differentials were even larger at long maturities, with U.K. yields well below 1 percent and French yields well above 2 percent.

To understand these phenomena, it is useful to distinguish three major influences on inflation-indexed bond yields: current and expected future short-term real interest rates; differences in expected returns on long-term and short-term inflation-indexed bonds caused by risk premiums (which can be negative if these bonds are valuable hedges); and differences in expected returns on long-term and short-term bonds caused by liquidity premiums or technical factors that segment the bond markets. The expectations hypothesis of the term structure, applied to real interest rates, states that only the first influence is time-varying whereas the other two are constant. However, there is considerable evidence against this hypothesis for nominal Treasury bonds, so it is important to allow for the possibility that risk and liquidity premiums are time-varying.

The path of real interest rates is undoubtedly a major influence on inflation-indexed bond yields. Indeed, before TIPS were issued, Campbell and Shiller (1997) argued that one could anticipate how their yields would behave by applying the expectations hypothesis of the term structure to real interest rates. A first goal of this paper is to compare the history of inflation-indexed bond yields with the implications of the expectations hypothesis, and to explain how shocks to short-term real interest rates are transmitted along the real yield curve.

Risk premiums on inflation-indexed bonds can be analyzed by applying theoretical models of risk and return. Two leading paradigms deliver useful insights. The consumption-based paradigm implies that risk premiums on inflation-indexed bonds over short-term debt are negative if returns on these bonds covary negatively with consumption, which will be the case if consumption growth rates are persistent (Backus and Zin 1994; Campbell 1986; Gollier 2007; Piazzesi and Schneider 2007; Wachter 2006). The capital asset pricing model (CAPM) implies that risk premiums on inflation-indexed bonds will be negative if their prices covary negatively with stock prices. The second paradigm has the advantage that it is easy to track the covariance of inflation-indexed bonds and stocks using high-frequency data on their prices, in the manner of Viceira (2007) and Campbell, Adi Sunderam, and Viceira (2009).

Finally, it is important to take seriously the effects of institutional factors on inflation-indexed bond yields. Plausibly, the high TIPS yields in the first few years after their introduction were due to slow development of TIPS mutual funds and other indirect investment vehicles. Currently, long-term inflation-indexed yields in the United Kingdom may be depressed by strong demand from U.K. pension funds. The volatility of TIPS yields in the fall of 2008 appears to have resulted in part from the unwinding of large institutional positions after the failure of the investment bank Lehman Brothers in September. These institutional influences on yields can alternatively be described as liquidity, market segmentation, or demand and supply effects (Greenwood and Vayanos 2008).

This paper is organized as follows. Section I presents a graphical history of the inflation-indexed bond markets in the United States and the United Kingdom, discussing bond supplies, the levels of yields, and the volatility and covariances with stocks of high-frequency movements in yields. Section II asks what portion of the TIPS yield history can be explained by movements in short-term real interest rates, together with the expectations hypothesis of the term structure. This section revisits the vector autoregression (VAR) analysis of Campbell and Shiller (1997). Section III discusses the risk characteristics of TIPS and estimates a model of TIPS pricing with time-varying systematic risk, a variant of the model in Campbell, Sunderam, and Viceira (2009), to see how much of the yield history can be explained by changes in risk. Section IV discusses the unusual market conditions that prevailed in the fall of 2008 and the channels through which they might have influenced inflation-indexed bond yields. Section V draws implications for investors and policymakers. An appendix available online presents technical details of our bond pricing model and of data construction.[1]

I. The History of Inflation-Indexed Bond Markets

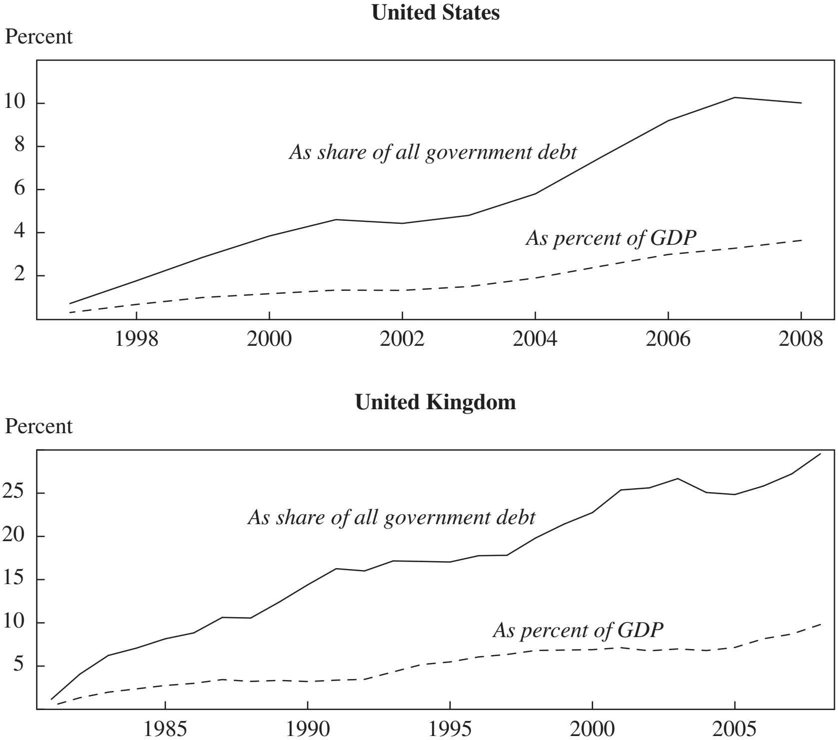
The top panel of figure 1 shows the growth of the outstanding supply of TIPS during the past 10 years. From modest beginnings in 1997, TIPS grew to around 10 percent of the marketable debt of the U.S. Treasury, and more than 3.5 percent of U.S. GDP, in 2008. This growth has been fairly smooth, with a minor slowdown in 2001–02. The bottom panel shows a comparable history for U.K. inflation-indexed gilts (government bonds). From equally modest beginnings in 1982, the stock of these bonds has grown rapidly and accounted for almost 30 percent of the British public debt in 2008, equivalent to about 10 percent of GDP. Growth in the inflation-indexed share of the public debt slowed in 1990–97 and reversed in 2004–05 but otherwise proceeded at a rapid rate.

The top panel of figure 2 plots yields on 10-year nominal and inflation-indexed U.S. Treasury bonds from January 1998, a year after their introduction, through March 2009.[2] The figure shows a considerable decline in both nominal and real long-term interest rates since TIPS yields peaked early in 2000. Through 2007 the decline was roughly parallel, as inflation-indexed bond yields fell from slightly over 4 percent to slightly over

1. The online appendix can be found at kuznets.fas.harvard.edu/~campbell/papers.html.

2. We calculate the yield for the longest-maturity inflation-indexed bond outstanding at each point in time whose original maturity at issue was 10 years. This is the on-the-run TIPS issue. We obtain constant-maturity 10-year yields for nominal Treasury bonds from the Center for Research in Security Prices (CRSP) database. Details of data construction are reported in the online appendix.

Figure 1. Stocks of Inflation-Indexed Government Bonds Outstanding

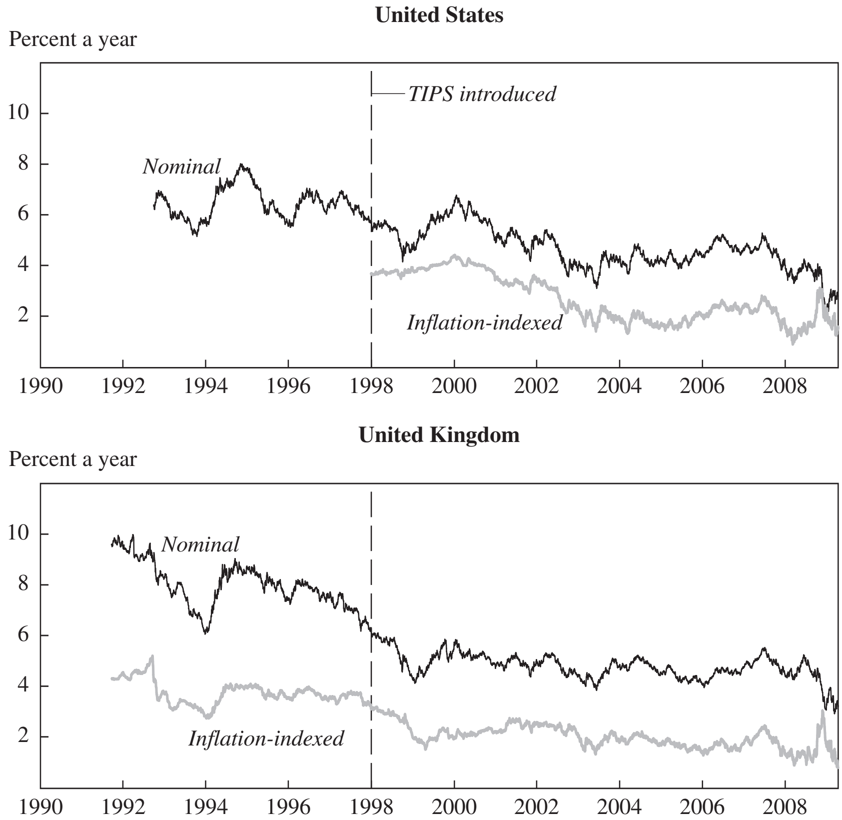


Source: Treasury Bulletin, various issues, table FD-2; Heriot-Watt/Faculty and Institute of Actuaries Gilt Database (www.ma.hw.ac.uk/~andrewc/gilts/, file BGSAmounts.xls).

1 percent, while yields on nominal government bonds fell from around 7 percent to 4 percent. Thus, this was a period in which both nominal and inflation-indexed Treasury bond yields were driven down by a large decline in long-term real interest rates. In 2008, in contrast, nominal Treasury yields continued to decline, while TIPS yields spiked above 3 percent toward the end of the year.

The bottom panel of figure 2 shows a comparable history for the United Kingdom since the early 1990s. To facilitate comparison of the two plots, the beginning of the U.S. sample period is marked with a vertical line. The downward trend in inflation-indexed yields is even more dramatic over this longer period. U.K. inflation-indexed gilts also experienced a dramatic yield spike in the fall of 2008.

Figure 2. Ten-Year Yields on Nominal and Inflation-Indexed Government Bonds, 1991–2009[a]

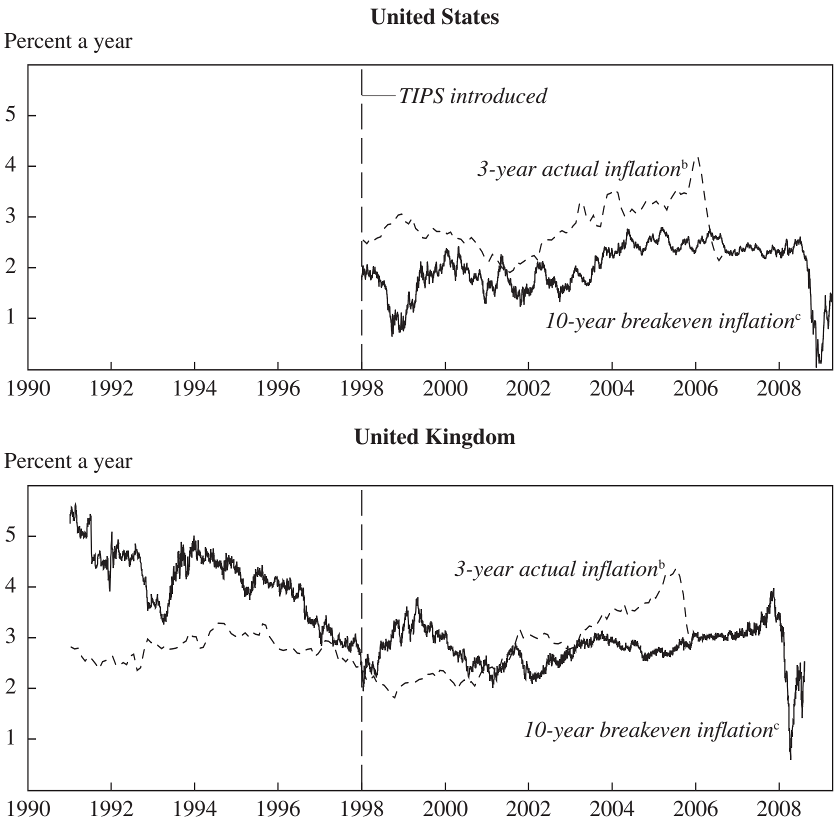


Source: Authors' calculations using data from Bloomberg and Heriot-Watt/Faculty and Institute of Actuaries Gilt Database; see the online appendix (kuznets.fas.harvard.edu/~campbell/papers.html) for details.

a. Yields are calculated from spliced yields and price data of individual issuances.

Fig. 3 The top panel of figure 3 plots the 10-year breakeven inflation rate, the difference between 10-year nominal and inflation-indexed Treasury bond yields. The breakeven inflation rate was fairly volatile in the first few years of the TIPS market; it then stabilized between 1.5 and 2.0 percent a year in the early years of this decade before creeping up to about 2.5 percent from 2004 through 2007. In 2008 the breakeven inflation rate collapsed, reaching almost zero at the end of the year. The figure also shows, for the early years of the sample, the subsequently realized three-year inflation rate. After the

Figure 3. Breakeven Inflation Rates Implied by Inflation-Indexed Bond Yields and Actual Inflation, 1991–2009[a]



Source: Authors' calculations from Bloomberg and Bureau of Labor Statistics data; see the online appendix for details.

a. Bond yields are computed from spliced yields and price data of individual issuances.

b. Annualized percent change in the consumer price index over the preceding three years.

c. Difference between 10-year yields of nominal and inflation-indexed bonds; monthly data.

first couple of years, in which there is little relationship between breakeven and subsequently realized inflation, a slight decrease in breakeven inflation between 2000 and 2002, followed by a slow increase from 2002 to 2006, is matched by similar gradual changes in realized inflation. Although this is not a rigorous test of the rationality of the TIPS market—apart from anything else, the bonds are forecasting inflation over 10 years, not 3 years—it does suggest that inflation forecasts influence the relative pricing of TIPS and nominal Treasury bonds. We explore this issue in greater detail in the next section.

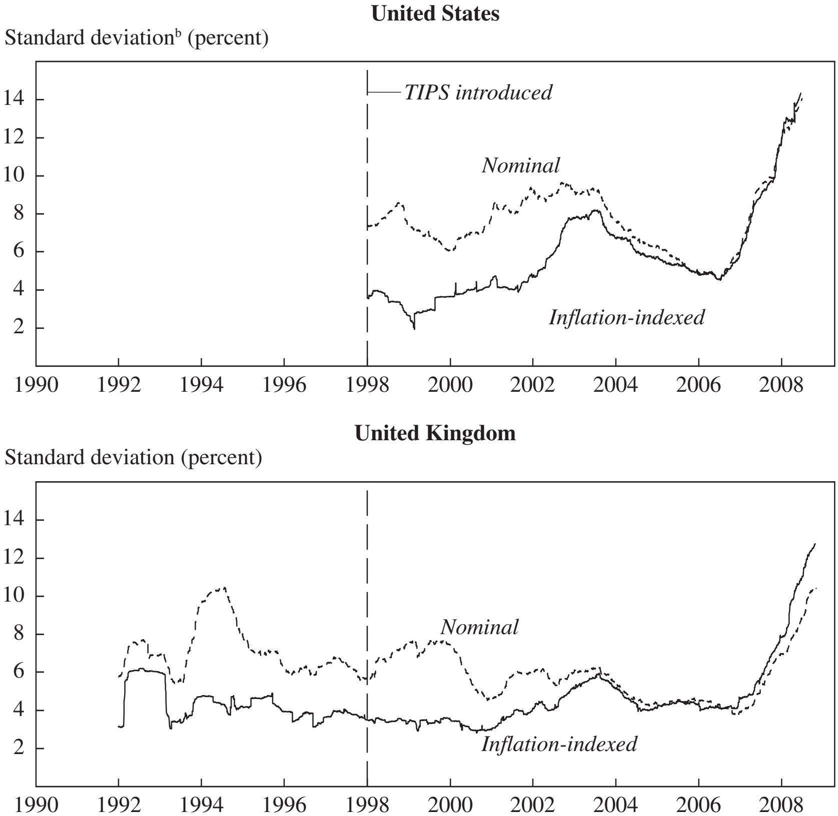
The bottom panel of figure 3 depicts the breakeven inflation history for the United Kingdom. It shows a strong decline in the late 1990s, probably associated with the granting of independence to the Bank of England by the newly elected Labour government in 1997, and a steady upward creep from 2003 to early 2008, followed by a collapse in 2008 comparable to that in the United States. Realized inflation in the United Kingdom also fell in the 1990s, albeit less dramatically than breakeven inflation, and rose in the mid-2000s.

Fig. 4 The top panel of figure 4 examines the short-run volatility of TIPS returns. Using daily government bond prices, with the appropriate correction for coupon payments, we calculate daily nominal return series for the on-the-run 10-year TIPS. This graph plots the annualized standard deviation of this series within a centered moving one-year window. For comparison, it also shows the corresponding annualized standard deviation for 10-year nominal Treasury bond returns, calculated from Bloomberg yield data on the assumption that the nominal bonds trade at par. The striking message of this graph is that TIPS returns have become far more volatile in recent years. In the early years, until 2002, the short-run volatility of 10-year TIPS was only about half that of 10-year nominal Treasury bonds, but the two standard deviations converged between 2002 and 2004 and have been extremely similar since then. The annualized standard deviations of both bonds ranged between 5 percent and 8 percent between 2004 and 2008 and then increased dramatically to almost 14 percent.

Mechanically, two variables drive the volatility of TIPS returns. The more important of these is the volatility of TIPS yields, which has increased over time; in recent years it has been very similar to the volatility of nominal Treasury bond yields as breakeven inflation has stabilized. A second, amplifying factor is the duration of TIPS, which has increased as TIPS yields
Ftn. 3 have declined.[3] The same two variables determine the very similar volatility patterns shown in the bottom panel of figure 4 for the United Kingdom.

3. The duration of a bond is the average time to payment of its cash flows, weighted by the present values of those cash flows. Duration also equals the elasticity of a bond's price with respect to its gross yield (one plus its yield in natural units). A coupon bond has duration less than its maturity, and its duration increases as its yield falls. Since TIPS yields are lower than nominal bond yields, TIPS have greater duration for the same maturity, and hence a greater volatility of returns for the same yield volatility, but the differences in volatility explained by duration are quite small.

Figure 4. Volatility of Nominal and Inflation-Indexed Government Bond Returns, 1992–2009[a]



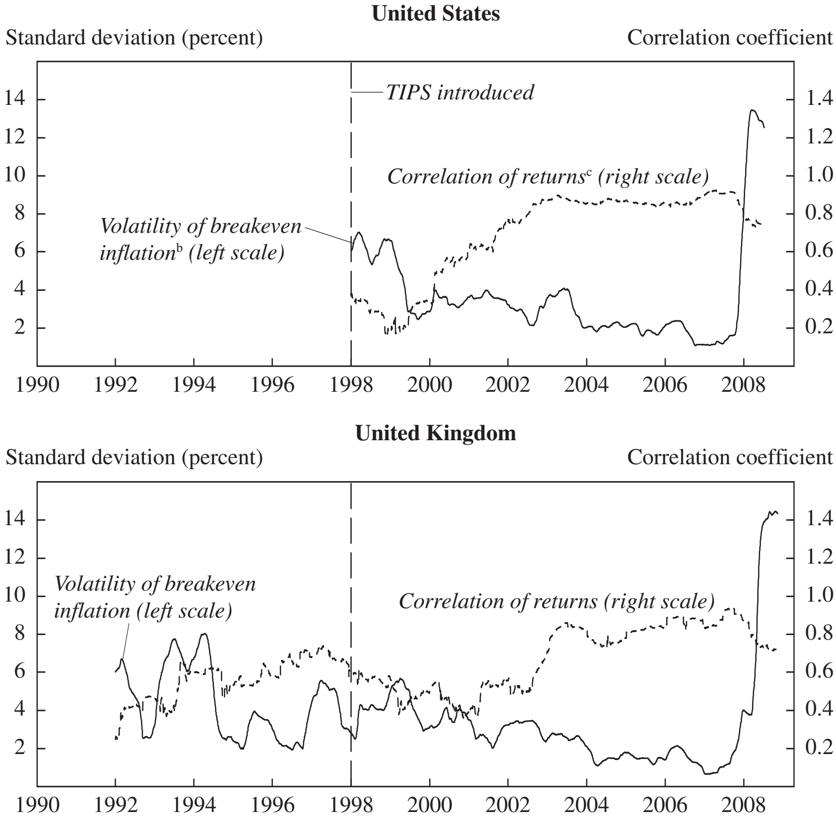
Source: Authors' calculations from Bloomberg data; see the online appendix for details.

a. Bond yields are computed from spliced yields and price data of individual issuances.

b. Standard deviation of daily returns on government bonds with 10 years to maturity, over a one-year centered moving window.

Fig. 5 The top panel of figure 5 plots the annualized standard deviation of 10-year breakeven inflation (measured in terms of the value of a bond position long a 10-year nominal Treasury bond and short a 10-year TIPS). This standard deviation trended downward from 7 percent in 1998 to about 1 percent in 2007 before spiking above 13 percent in 2008. To the extent that breakeven inflation represents the long-term inflation expectations of market participants, these expectations stabilized during most of the sample period but moved dramatically in 2008. Such a destabilization of

Figure 5. Volatility of Breakeven Inflation Rates and Correlations of Nominal and Inflation-Indexed Government Bond Returns, 1992–2009[a]



Source: Authors' calculations from Bloomberg data; see the online appendix for details.

a. Bond yields are computed from spliced yields and price data of individual issuances.

b. Standard deviation of the daily 10-year breakeven inflation rate, measured in terms of the value of a position long a 10-year nominal government bond and short a 10-year inflation-indexed bond, over a one-year moving window.

c. Correlation of daily inflation-indexed and nominal bond returns within a one-year moving window.

inflation expectations should be a matter of serious concern to the Federal Reserve, although, as we discuss in section IV, institutional factors may have contributed to the movements in breakeven inflation during the market disruption of late 2008. The bottom panel of figure 5 suggests that the Bank of England should be equally concerned by the recent destabilization of the yield spread between nominal and inflation-indexed gilts.

Figure 5 also plots the correlations of daily inflation-indexed and nominal government bond returns within a one-year moving window. Early in the period, the correlation for U.S. bonds was quite low at about 0.2, but it increased to almost 0.9 by the middle of 2003 and stayed there until 2008. In the mid-2000s TIPS behaved like nominal Treasuries and did not exhibit independent return variation. This coupling of TIPS and nominal Treasuries ended in 2008. The same patterns are visible in the U.K. data.

Although TIPS have been volatile assets, this does not necessarily imply that they should command large risk premiums. According to rational asset pricing theory, the risk premium on an asset should be driven by the covariance of its returns with the marginal utility of consumption rather than by the variance of returns. One common proxy for marginal utility, used in the CAPM, is the return on an aggregate equity index. Figure 6 plots the correlations of daily inflation-indexed bond returns, nominal government bond returns, and breakeven inflation returns with daily returns on aggregate U.S. and U.K. stock indexes, again within a centered moving one-year window. Figure 7 repeats this exercise for betas (regression coefficients of daily bond returns and breakeven inflation on the same stock indexes).

Fig. 6

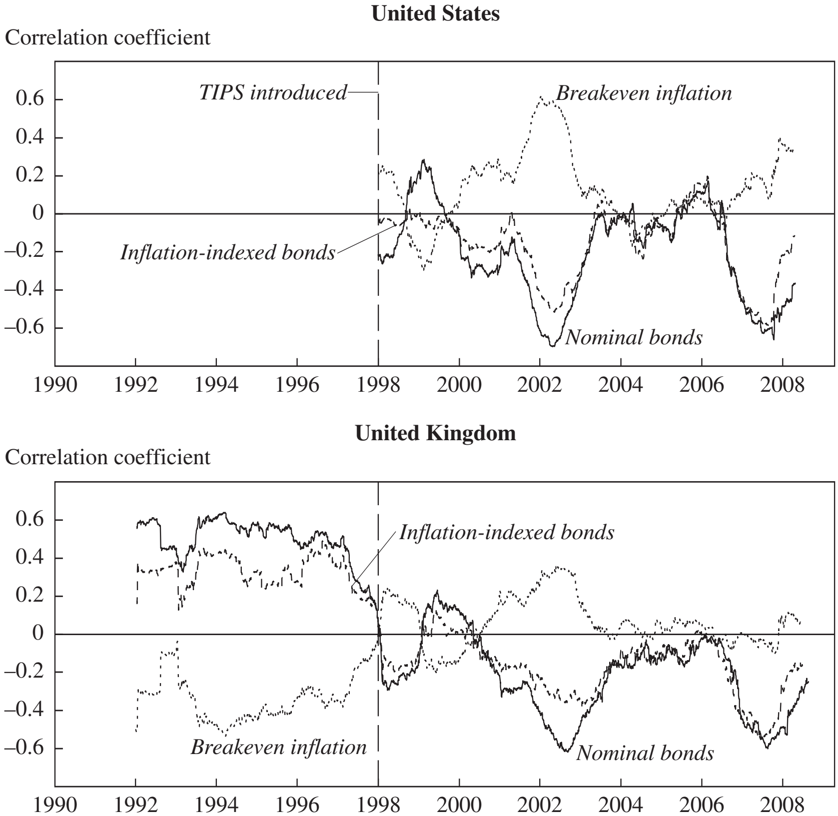
Fig. 7

All these figures tell a similar story. During the 2000s there has been considerable instability in both countries in the correlations between government bonds of both types and stock returns, but these correlations have been predominantly negative, implying that government bonds can be used to hedge equity risk. To the extent that the CAPM describes risk premiums across asset classes, government bonds should have predominantly negative rather than positive risk premiums. The negative correlation is particularly strong for nominal government bonds, because breakeven inflation has been positively correlated with stock returns, especially during 2002–03 and 2007–08. Campbell, Sunderam, and Viceira (2009) build a model in which a changing correlation between inflation and stock returns drives changes in the risk properties of nominal Treasury bonds. That model assumes a constant equity market correlation for TIPS and thus cannot explain the correlation movements shown for TIPS in figures 6 and 7. In section III we explore the determination of TIPS risk premiums in greater detail.

II. Inflation-Indexed Bond Yields and the Dynamics of Short-Term Real Interest Rates

To understand the movements of inflation-indexed bond yields, it is essential first to understand how changes in short-term real interest rates propagate along the real term structure. Declining yields for inflation-indexed bonds in the 2000s may not be particularly surprising given that short-term real interest rates have also been low in this decade.

Figure 6. Correlations of Government Bond Returns and Breakeven Inflation Rates with Equity Returns, 1992–2009[a]

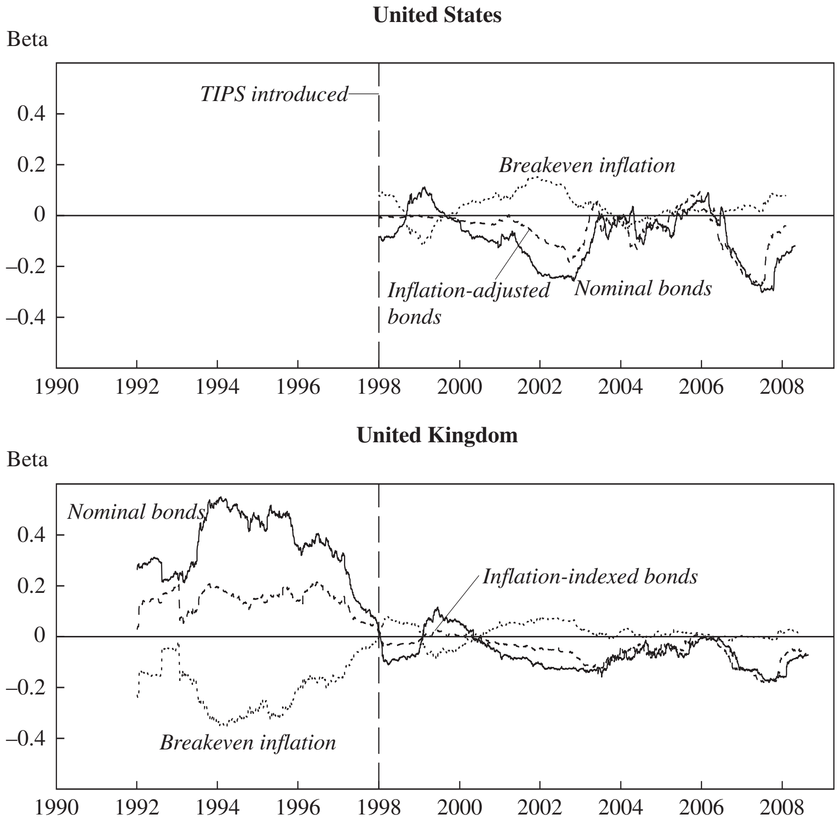


Source: Authors' calculations from Bloomberg and Center for Research on Security Prices data; see the online appendix for details.

a. Correlations between nominal returns on the stock index of the indicated country (CRSP Value-Weighted Index for the United States, FTSE-100 for the United Kingdom) and either nominal 10-year returns on the indicated bond type (computed from spliced yields and price data of individual issuances) or returns in the breakeven inflation rate (the difference between nominal bond returns and inflation-indexed bond returns).

Before TIPS were introduced in 1997, Campbell and Shiller (1997) used a time-series model for the short-term real interest rate to create a hypothetical TIPS yield series under the assumption that the expectations theory of the term structure in logarithmic form, with zero log risk premiums, describes inflation-indexed bond yields. (This does not require the assumption that the expectations theory describes nominal bond yields, a model that

Figure 7. Betas of Government Bond Returns and Breakeven Inflation Rates, 1992–2009[a]



Source: Authors' calculations from Bloomberg and Center for Research on Security Prices data; see the online appendix for details.

a. Coefficients from a regression of either nominal 10-year returns on the indicated bond type (computed from spliced yields and price data of individual issuances) or the breakeven inflation rate (the difference between nominal bond returns and inflation-indexed bond returns) on nominal returns on the stock index of the indicated country (CRSP Value-Weighted Index for the United States, FTSE-100 for the United Kingdom).

has often been rejected in U.S. data.) In this section we update Campbell and Shiller's analysis and ask how well the simple expectations theory describes the 12-year history of TIPS yields.

Campbell and Shiller (1997) estimated a VAR model on quarterly U.S. data over 1953–94. Their basic VAR included the ex post real return on a three-month nominal Treasury bill, the nominal bill yield, and the once-

Table 1. Results of VAR Estimation and Observed and Hypothetical Moments of 10-Year Inflation-Indexed Bonds, United States[a]

	Dependent variable		
Independent variable	*Inflation-indexed bill return*	*Nominal bill yield*	*Inflation*[b]
Inflation-indexed bill return	–0.06	0.01	–0.21
	(0.10)	(0.02)	(0.10)
Nominal bill yield	0.62	0.95	0.57
	(0.17)	(0.04)	(0.16)
Inflation	0.09	–0.04	0.58
	(0.08)	(0.02)	(0.08)
Constant	–0.005	0.001	0.007
	(0.002)	(0.0005)	(0.002)
R^2	0.26	0.91	0.63
Moments of 10-year inflation-indexed bonds	*Observed*		*Hypothetical*
Mean	2.66		1.04
Standard deviation	0.95		0.39
Correlation		0.71	

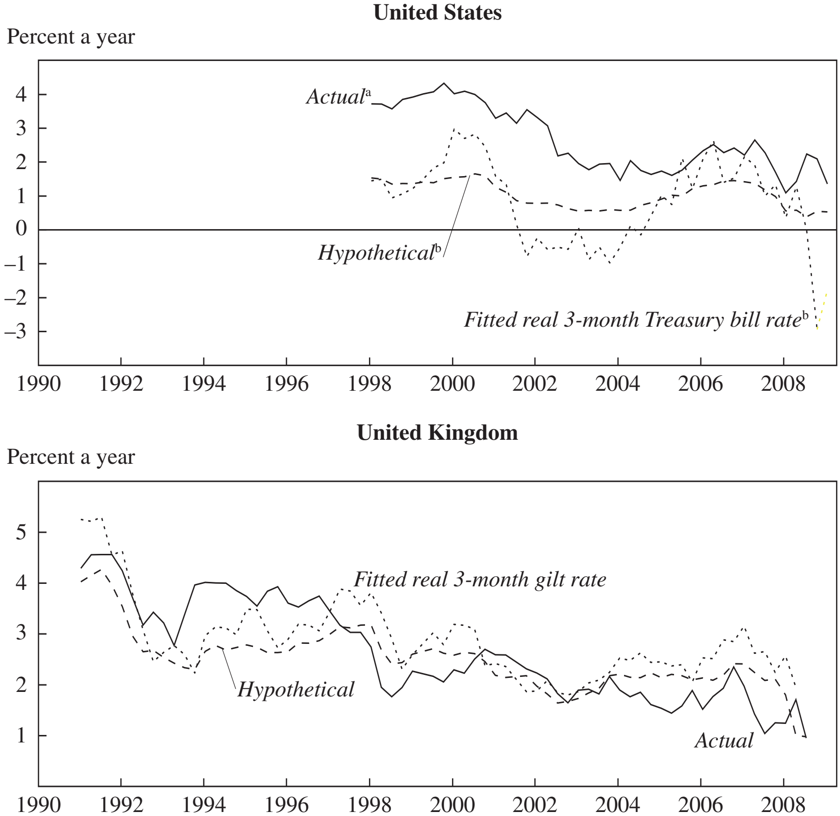
Source: Authors' regressions. Independent variables are lagged one period.
a. Numbers in parentheses are standard errors.
b. Non-seasonally adjusted all-urban consumer price index (NSA CPI-U).

lagged one-year inflation rate. They solved the VAR forward to create forecasts of future quarterly real interest rates at all horizons, and then aggregated the forecasts to generate the implied long-term inflation-indexed bond yield.

Tab. 1 Table 1 repeats this analysis for 1982–2008. The top panel reports the estimated VAR coefficients, and the bottom panel reports selected sample moments of the hypothetical VAR-implied 10-year TIPS yields, and for comparison the same moments of observed TIPS yields, over the period since TIPS were introduced. The table delivers several interesting results.

First, the hypothetical yields are considerably lower on average than the observed yields, with a mean of 1.04 percent compared with 2.66 percent. This implies that on average, investors demand a risk or liquidity premium for holding TIPS rather than nominal Treasuries. Second, hypothetical yields are more stable than observed yields, with a standard deviation of 0.39 percent as opposed to 0.95 percent. This reflects the fact that observed yields have declined more dramatically since 1997 than have hypothetical yields. Third, hypothetical and observed yields have a relatively high correlation of 0.71, even though no TIPS data were used to construct the hypothetical

Figure 8. Hypothetical and Actual Yields on Inflation-Indexed Bonds



Source: Authors' calculations from Bloomberg, Center for Research on Security Prices, and Bureau of Labor Statistics data; see the online appendix for details.

a. Quarterly averages of 10-year TIPS yields (from the top panel of figure 2).

b. Extracted from an estimated VAR(1) model in quarterly U.S. data over 1953-94 on the ex post real return on a 3-month nominal Treasury bill, the nominal bill yield, and the lagged one-year inflation rate.

yields. Real interest rate movements do have an important effect on the TIPS market, and the VAR system is able to capture much of this effect.

The top panel of figure 8 shows these results in graphical form, plotting the history of the observed TIPS yield, the hypothetical VAR-implied TIPS yield, and the VAR estimate of the ex ante short-term real interest rate. The sharp decline in the real interest rate in 2001 and 2002 drives down the hypothetical TIPS yield, but the observed TIPS yield is more volatile and declines more strongly. The gap between the observed TIPS yield and the Fig. 8

Table 2. Results of VAR Estimation and Observed and Hypothetical Moments of 10-Year Inflation-Indexed Bonds, United Kingdom[a]

	Dependent variable		
Independent variable	*Inflation-indexed bill return*	*Nominal bill yield*	*Inflation*[b]
Inflation-indexed bill return	0.09	−0.04	−0.39
	(0.09)	(0.03)	(0.09)
Nominal bill yield	0.42	1.07	0.82
	(0.19)	(0.05)	(0.18)
Inflation	0.02	−0.03	0.66
	(0.07)	(0.02)	(0.07)
Constant	0.0001	0.0002	0.0007
	(0.0019)	(0.0005)	(0.0018)
R^2	0.22	0.93	0.87
Moments of 10-year inflation-indexed bonds	*Observed*		*Hypothetical*
Mean	2.64		2.49
Standard deviation	1.00		0.61
Correlation		0.77	

Source: Authors' regressions. Independent variables are lagged one period.
a. Numbers in parentheses are standard errors.
b. Retail price index.

hypothetical yield shrinks fairly steadily over the sample period until the very end, when the 2008 spike in the observed yield widens the gap again. These results suggest that when they were first issued, TIPS commanded a high risk or liquidity premium, which then declined until 2008.

Tab. 2 Table 2 and the bottom panel of figure 8 repeat these exercises for the United Kingdom. Here the hypothetical and observed yields have similar means (2.64 and 2.49 percent, respectively), but again the standard deviation is lower for the hypothetical yield, at 0.61 percent, than for the observed yield, at 1.00 percent. The two yields have a high correlation of 0.77. The graph shows that the VAR model captures much of the decline in inflation-indexed gilt yields since the early 1990s. It is able to do this because the estimated process for the U.K. ex ante real interest rate is highly persistent, so that the decline in the real rate over the sample period translates almost one for one into a declining yield on long-term inflation-indexed gilts. However, for the same reason the model cannot account for variations in the spread between the short-term expected real interest rate and the long-term inflation-indexed gilt yield.

It is notable that the expectations hypothesis of the real term structure does not explain the decline in inflation-indexed gilt yields from 2005 through

2008. A new U.K. accounting standard introduced in 2000, FRS17, may account for this. As Viceira (2003) and Dimitri Vayanos and Jean-Luc Vila (2007) explain, FRS 17 requires U.K. pension funds to mark their liabilities to market, using discount rates derived from government bonds. The standard was implemented, after some delay, in 2005, and it greatly increased the demand for inflation-indexed gilts from pension funds seeking to hedge their inflation-indexed liabilities.

III. The Systematic Risks of Inflation-Indexed Bonds

The yield history and VAR analysis presented in the previous two sections suggest that U.S. and U.K. inflation-indexed bonds had low risk premiums in the mid-2000s, but the former, at least, had higher risk premiums when they were first issued. In this section we use asset pricing theory to ask what fundamental properties of the macroeconomy might lead to high or low risk premiums on inflation-indexed bonds. We first use the consumption-based asset pricing framework and then present a less structured empirical analysis that relates bond risk premiums to changing covariances of bonds with stocks.

III.A. Consumption-Based Pricing of Inflation-Indexed Bonds

A standard paradigm for consumption-based asset pricing assumes that a representative investor has Epstein-Zin (1989, 1991) preferences. This preference specification, a generalization of power utility, allows the coefficient of relative risk aversion γ and the elasticity of intertemporal substitution (EIS) ψ to be separate free parameters, whereas power utility restricts one to be the reciprocal of the other. Under the additional assumption that asset returns and consumption are jointly log normal and homoskedastic, the Epstein-Zin Euler equation implies that the risk premium RP on any asset i over the short-term safe asset is

$$RP_i \equiv E_t\left[r_{i,t+1}\right] - r_{f,t+1} + \frac{\sigma_i^2}{2} = \theta\frac{\sigma_{ic}}{\psi} + \left(1-\theta\right)\sigma_{iw}. \tag{1}$$

In words, the risk premium is defined to be the expected excess log return on the asset over the risk-free log return r_f, plus one-half its variance to convert from a geometric average to an arithmetic average, that is, to correct for Jensen's inequality. The preference parameter $\theta \equiv (1-\gamma)/[1-(1/\psi)]$; in the power utility case, $\gamma = 1/\psi$, so that $\theta = 1$. According to this formula, the risk premium on any asset is a weighted average of two conditional covariances, the consumption covariance σ_{ic} (scaled by the reciprocal of the EIS), which gets full weight in the power utility case, and the wealth covariance σ_{iw}. The risk premium is constant over time by the assumption of homoskedasticity.

It is tempting to treat the consumption covariance and the wealth covariance as two separate quantities, but this ignores the fact that consumption and wealth are linked by the intertemporal budget constraint and by a time-series Euler equation. By using these additional equations, one can substitute either consumption (Campbell 1993) or wealth (Restoy and Weil 1998) out of the formula for the risk premium.

The first approach explains the risk premium using covariances with the current market return and with news about future market returns; this might be called "CAPM+," as it generalizes the insight about risk that was first formalized in the CAPM. Campbell (1996) and Campbell and Tuomo Vuolteenaho (2004) pursue this approach, which can also be regarded as an empirical version of Robert Merton's (1973) intertemporal CAPM.

The second approach explains the risk premium using covariances with current consumption growth and with news about future consumption growth; this might be called "CCAPM+," as it generalizes the insight about risk that is embodied in the consumption-based CAPM with power utility. This approach has generated a large asset pricing literature in recent years (for example, Bansal and Yaron 2004; Bansal, Khatchatrian, and Yaron 2005; Piazzesi and Schneider 2007; Bansal, Kiku, and Yaron 2007; Bansal, Dittmar, and Kiku 2009; Hansen, Heaton, and Li 2008). Some of this recent work adds heteroskedasticity to the simple homoskedastic model discussed here.

The CAPM+ approach delivers an approximate formula for the risk premium on any asset as

$$RP_i = \gamma\sigma_{iw} - (\gamma - 1)\sigma_{i,TIPS},$$

where σ_{iw} is the covariance of the unexpected return on asset i with the return on the aggregate wealth portfolio, and $\sigma_{i,TIPS}$ is the covariance with the return on an inflation-indexed perpetuity.

The intuition, which dates back to Merton (1973), is that conservative long-term investors value assets that deliver high returns at times when investment opportunities are poor. Such assets hedge investors against variation in the sustainable income stream that is delivered by a given amount of wealth. In a homoskedastic model, risk premiums are constant, and the relevant measure of long-run investment opportunities is the yield on an inflation-indexed bond. Thus, the covariance with the return on an inflation-indexed perpetuity captures the intertemporal hedging properties of an asset. In equilibrium, an asset that covaries strongly with an inflation-indexed perpetuity will offer a low return as the price of the desirable insurance it offers.

Applying this formula to the inflation-indexed perpetuity itself, we find that

$$RP_{TIPS} = \gamma\sigma_{TIPS,w} - (\gamma - 1)\sigma^2_{TIPS}.$$

In words, the risk premium on a long-term inflation-indexed bond is increasing in its covariance with the wealth portfolio, as in the traditional CAPM, but decreasing in the variance of the bond return whenever the risk aversion of the representative agent is greater than 1. Paradoxically, the insurance value of inflation-indexed bonds is higher when these bonds have high short-term volatility, because in this case they hedge important variability in investment opportunities. In a traditional model with a constant real interest rate, inflation-indexed bonds have constant yields; but in this case there is no intertemporal hedging to be done, and the traditional CAPM can be used to price all assets, including inflation-indexed bonds.

The CCAPM+ approach can be written as

$$RP_i = \gamma\sigma_{ic} + \left(\gamma - \frac{1}{\psi}\right)\sigma_{ig}, \tag{2}$$

where σ_{ig} is the covariance of the unexpected return on asset i with revisions in expected future consumption growth $\tilde{g}_{t+1}$, defined by

$$\tilde{g}_{t+1} \equiv (E_{t+1} - E_t)\sum_{j=1}^{\infty} p^j \Delta c_{t+1+j}. \tag{3}$$

In equation 2 the risk premium on any asset is the coefficient of risk aversion γ times the covariance of that asset with consumption growth, plus $(\gamma - 1/\psi)$ times the covariance of the asset with revisions in expected future consumption growth, discounted at a constant rate ρ. The second term is zero if $\gamma = 1/\psi$, the power utility case, or if consumption growth is unpredictable so that there are no revisions in expected future consumption growth. Evidence on the equity premium and the time-series behavior of real interest rates suggests that $\gamma > 1/\psi$. This implies that controlling for assets' contemporaneous consumption covariance, investors require a risk premium to hold assets that pay off when expected future consumption growth increases. Ravi Bansal and Amir Yaron (2004) use the phrase "risks for the long run" to emphasize this property of the model.

What does this model imply about the pricing of an inflation-indexed perpetuity? When expected real consumption growth increases by 1 percentage point, the equilibrium real interest rate increases by $1/\psi$ percentage points, and thus the return on the inflation-indexed perpetuity is given by[4]

Ftn. 4

$$r_{TIPS,t+1} = -\frac{1}{\psi}\tilde{g}_{t+1}. \tag{4}$$

Combining equation 2 with equation 4, one can solve for the risk premium on the inflation-indexed perpetuity:

$$RP_{TIPS} = \gamma\left(-\frac{1}{\psi}\right)\sigma_{cg} + \left(\gamma - \frac{1}{\psi}\right)\left(-\frac{1}{\psi}\right)\sigma_g^2. \tag{5}$$

With power utility, only the first term in equation 5 is nonzero. This case is described by Campbell (1986). In a consumption-based asset pricing model with power utility, assets are risky if their returns covary positively with consumption growth. Since bond prices rise when interest rates fall, bonds are risky assets if interest rates fall in response to consumption growth. Because equilibrium real interest rates are positively related to expected future consumption growth, this is possible only if positive consumption shocks drive expected future consumption growth downward, that is, if consumption growth is negatively autocorrelated. In an economy with temporary downturns in consumption, equilibrium real interest rates rise and TIPS prices fall in recessions, and therefore investors require a risk premium to hold TIPS.

In the presence of persistent shocks to consumption growth, by contrast, consumption growth is positively autocorrelated. In this case recessions not only drive down current consumption but also lead to prolonged periods of slow growth, driving down real interest rates. In such an economy the prices of long-term inflation-indexed bonds rise in recessions, making them desirable hedging assets with negative risk premiums.

This paradigm suggests that the risk premium on TIPS will fall if investors become less concerned about temporary business-cycle shocks, and more concerned about shocks to the long-term consumption growth rate.

4. A more careful derivation of this expression can be found in Campbell (2003, p. 841), equation 34.

It is possible that such a shift in investor beliefs did take place during the late 1990s and 2000s, as the Great Moderation mitigated concerns about business-cycle risk (Bernanke 2004; Blanchard and Simon 2001; McConnell and Perez-Quiros 2000; Nelson and Kim 1999; Stock and Watson 2003) while long-term uncertainties about technological progress and climate change became more salient. Of course, the events of 2007–08 have brought business-cycle risk to the fore again. The movements of inflation-indexed bond yields have been broadly consistent with changing risk perceptions of this sort.

The second term in equation 5 is also negative under the plausible assumption that $\gamma > 1/\psi$, and its sign does not depend on the persistence of the consumption process. However, its magnitude does depend on the volatility of shocks to long-run expected consumption growth. Thus, increasing uncertainty about long-run growth drives down inflation-indexed bond premiums through this channel as well.

Overall, the Epstein-Zin paradigm suggests that inflation-indexed bonds should have low or even negative risk premiums relative to short-term safe assets, consistent with the intuition that these bonds are the safe asset for long-term investors.

III.B. Bond Risk Premiums and the Bond-Stock Covariance

The consumption-based analysis of the previous section delivers insights but also has weaknesses. The model assumes constant second moments and thus implies constant risk premiums; it cannot be used to track changing variances, covariances, or risk premiums in the inflation-indexed bond market. Although one could generalize the model to allow time-varying second moments, as in the long-run risks model of Bansal and Yaron (2004), the low frequency of consumption measurement makes it difficult to implement the model empirically. In this section we follow a different approach, writing down a model of the stochastic discount factor (SDF) that allows us to relate the risk premiums on inflation-indexed bonds to the covariance of these bonds with stock returns.

To capture the time-varying correlation of returns on inflation-indexed bonds with stock returns, we propose a highly stylized term structure model in which the real interest rate is subject to conditionally heteroskedastic shocks. Conditional heteroskedasticity is driven by a state variable that captures time variation in aggregate macroeconomic uncertainty. We build our model in the spirit of Campbell, Sunderam, and Viceira (2009), who emphasize the importance of changing macroeconomic conditions for an understanding of time variation in systematic risk and in the correlations of returns on fundamental asset classes. Our model modifies their quadratic term structure model to allow for heteroskedastic shocks to the real rate.

We assume that the log of the real SDF, $m_{t+1} = \log M_{t+1}$, can be described by

$$(6) \qquad -m_{t+1} = x_t + \frac{1}{2}\sigma_m^2 + \varepsilon_{m,t+1},$$

where x_t follows a conditionally heteroskedastic AR(1) process,

$$(7) \qquad x_{t+1} = \mu_x(1-\varphi_x) + \varphi_x x_t + v_t \varepsilon_{x,t+1} + \varepsilon'_{x,t+1},$$

and v_t follows a standard AR(1) process,

$$(8) \qquad v_{t+1} = \mu_v(1-\varphi_v) + \varphi_v v_t + \varepsilon_{v,t+1}.$$

The shocks $\varepsilon_{m,t+1}$, $\varepsilon_{x,t+1}$, $\varepsilon'_{x,t+1}$, and $\varepsilon_{v,t+1}$ have zero means and are jointly normally distributed with a constant variance-covariance matrix. We assume that $\varepsilon'_{x,t+1}$, and $\varepsilon_{v,t+1}$ are orthogonal to each other and to the other shocks in the model. We adopt the notation σ_i^2 to describe the variance of shock ε_i, and σ_{ij} to describe the covariance between shock ε_i and shock ε_j. The conditional volatility of the log SDF (σ_m) describes the price of aggregate market risk, or the maximum Sharpe ratio in the economy, which we assume to be constant.[5]

The online appendix to this paper (see footnote 1) shows how to solve this model for the real term structure of interest rates. The state variable x_t is equal to the log short-term real interest rate, which follows an AR(1) process whose conditional variance is driven by the state variable v_t.

In a standard consumption-based power utility model of the sort discussed in the previous subsection, v_t would capture time variation in the dynamics of consumption growth. When v_t is close to zero, shocks to the real interest rate are uncorrelated with the SDF; in a power utility model, this would imply that shocks to future consumption growth are uncorrelated with shocks to the current level of consumption. As v_t moves away from zero, the volatility of the real interest rate increases and its covariance with the SDF becomes more positive or more negative. In a power utility model,

5. Campbell, Sunderam, and Viceira (2009) consider a much richer term structure model in which σ_m^2 is time varying. They note that in that case the process for the log real SDF admits an interpretation as a reduced form of structural models such as those of Bekaert, Engstrom, and Grenadier (2006) and Campbell and Cochrane (1999) in which aggregate risk aversion is time varying. Campbell, Sunderam, and Viceira find that time-varying risk aversion plays only a limited role in explaining the observed variation in bond risk premiums. For simplicity, we set σ_m^2 constant.

this corresponds to a covariance between consumption shocks and future consumption growth that is either positive or negative, reflecting either momentum or mean reversion in consumption. Broadly speaking, one can interpret v_t as a measure of aggregate uncertainty about long-run growth in the economy. At times when that uncertainty increases, real interest rates become more volatile.

Solving the model for the real term structure of interest rates, we find that the log price of an n-period inflation-indexed bond is linear in the short-term real interest rate x_t, with coefficient $B_{x,n}$, and quadratic in aggregate economic uncertainty v_t, with linear coefficient $B_{v,n}$ and quadratic coefficient $C_{v,n}$. An important property of this model is that bond risk premiums are time varying. They are approximately linear in v_t, where the coefficient on v_t is proportional to σ_m^2.

A time-varying conditional covariance between the SDF and the real interest rate implies that the conditional covariance between inflation-indexed bonds and risky assets such as equities should also vary over time as a function of v_t. To see this, we now introduce equities into the model. To keep things simple, we assume that the unexpected log return on equities is given by

$$r_{e,t+1} - E_t r_{e,t+1} = \beta_{em} \varepsilon_{m,t+1}. \tag{9}$$

This implies that the equity premium equals $\beta_{em}\sigma_m^2$, the conditional standard deviation of stock returns is $\beta_{em}\sigma_m$, and the Sharpe ratio on equities is σ_m. Equities deliver the maximum Sharpe ratio because they are perfectly correlated with the SDF. Thus, we are imposing the restrictions of the traditional CAPM, ignoring the intertemporal hedging arguments stated in the previous subsection.

The covariance between stocks and inflation-indexed bonds is given by

$$Cov_t\left(r_{e,t+1}, r_{n,t+1}\right) = \beta_{x,n-1}\beta_{em}\sigma_{mx}v_t, \tag{10}$$

which is proportional to v_t. This proportionality is also a reason why we consider two independent shocks to x_t. In the absence of a homoskedastic shock $\varepsilon'_{x,t}$ to x_t, our model would imply that the conditional volatility of the short-term real interest rate would be proportional to the conditional covariance of stock returns with returns on inflation-indexed bonds. However, although the two conditional moments appear to be correlated in the data, they are not perfectly correlated, still less proportional to one another.

We estimate this term structure model by applying the nonlinear Kalman filter procedure described in Campbell, Sunderam, and Viceira (2009) to data on zero-coupon inflation-indexed bond yields, from Refet Gürkaynak, Brian Sack, and Jonathan Wright (2008) for the period 1999–2008, and total returns on the value-weighted U.S. stock market portfolio, from CRSP data.[6] Because the U.S. Treasury does not issue TIPS with short maturities, and there are no continuous observations of yields on near-to-maturity TIPS, this dataset does not include short-term zero-coupon TIPS yields. To approximate the short-term real interest rate, we use the ex ante short-term real interest rate implied by our VAR approach described in section II.

Our estimation makes several identifying and simplifying assumptions. First, we identify σ_m using the long-run average Sharpe ratio for U.S. equities, which we set to 0.23 on a quarterly basis (equivalent to 0.46 on an annual basis). Second, we identify β_{em} as the sample standard deviation of equity returns in our sample period (0.094 per quarter, or 18.9 percent per year) divided by σ_m, for a value of 0.41. Third, we exactly identify x_t with the ex ante short-term real interest rate estimated from the VAR model of the previous section, which we treat as observed, adjusted by a constant. That is, we give the Kalman filter a measurement equation that equates the VAR-estimated short-term real interest rate to x_t with a free constant term but no measurement error. The inclusion of the constant term is intended to capture liquidity effects that lower the yields on Treasury bills relative to the longer-term real yield curve.

Fourth, because the shock $\varepsilon_{x,t+1}$ is always premultiplied by v_t, we normalize σ_x to 1. Fifth, we assume that there is perfect correlation between the shock $\varepsilon_{x,t+1}$ and the shock $\varepsilon_{m,t+1}$ to the SDF; equivalently, we set σ_{mx} equal to 0.23. This delivers the largest possible time variation in inflation-indexed bond risk premiums and thus maximizes the effect of changing risk on the TIPS yield curve. Sixth, we treat equation 10 as a measurement equation with no measurement error, where we replace the covariance on the left-hand side of the equation with the realized monthly covariance of returns on 10-year zero-coupon TIPS with returns on stocks. We estimate the monthly realized covariance using daily observations on stock returns and on TIPS returns from the Gürkaynak-Sack-Wright dataset. Since β_{em} and σ_{mx} have been already exactly identified, this is equivalent to identifying the process v_t with a scaled version of the covariance of returns on TIPS and stocks.

6. The CRSP (Center for Research in Security Prices) data cover all three major U.S. stock exchanges. Gürkaynak, Sack, and Wright estimate zero-coupon TIPS yields by fitting a flexible functional form, a generalization of Nelson and Siegel (1987) suggested by Svensson (1994), to the instantaneous forward rates implied by off-the-run TIPS yields. From fitted forward rates it is straightforward to obtain zero-coupon yields.

Table 3. Parameter Estimates for Alternative Risk Models

		Restricted models	
Parameter	*Full model*	*Constant-covariance model*	*Persistent-risk model*
φ_x	0.94	0.93	0.95
μ_x	0.0028	0.0104	0.0034
φ_v	0.77	NA[a]	Set to 1
μ_v	-2.01×10^{-5}	NA	0.0010
σ_m	Set to 0.23	Set to 0.23	Set to 0.23
σ_x	Set to 1	0.0031	Set to 1
σ_{mx}	0.23	7.23×10^{-4}	0.23
σ'_x	0.0048	NA	0.0031
σ_v	0.0003	NA	0.0004
β_{em}	Set to 0.41	NA	Set to 0.41
σ_{yield}	1.16×10^{-6}	1.12×10^{-4}	9.14×10^{-6}
σ_{cov}	4.74×10^{-4}	NA	5×10^{-4}
Premium	0.0157	0.0016	0.00160

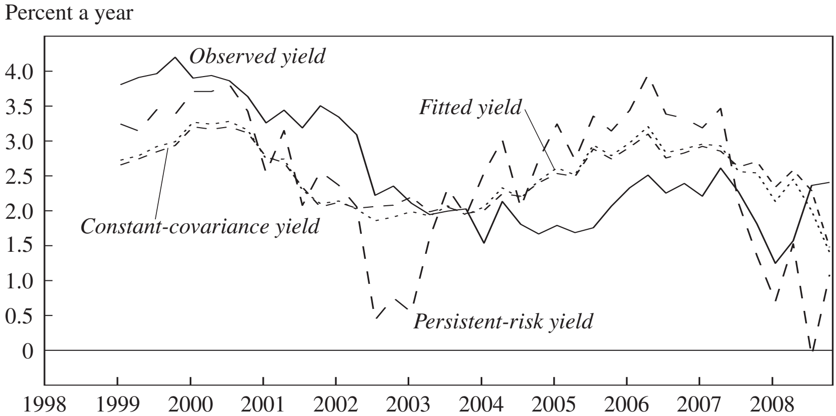
Source: Authors' calculations.
a. NA, not applicable. See the text for descriptions of the models.

We include one final measurement equation for the 10-year zero-coupon TIPS yield using the model's solution for this yield and allowing for measurement error. The identifying assumptions we have made imply that we are exactly identifying x_t with the ex ante short-term real interest rate, v_t with the realized covariance of returns on TIPS and stocks, and the log SDF with stock returns. Thus, our estimation procedure in effect generates hypothetical TIPS yields from these processes and compares them with observed TIPS yields.

Tab. 3 Table 3 reports the parameter estimates from our full model and two restricted models. The first of these two models, reported in the second column, drops the measurement equation for the realized stock-bond covariance and assumes that the stock-bond covariance is constant, and hence that TIPS have a constant risk premium, as in the VAR model of section II. The second restricted model, reported in the last column, generates the largest possible effects of time-varying risk premiums on TIPS yields by increasing the persistence of the covariance state variable v_t from the freely estimated value of 0.77, which implies an eight-month half-life for covariance movements, to the largest permissible value of 1.

Fig. 9 Figure 9 shows how these three variants of our basic model fit the history of the 10-year TIPS yield. The yields predicted by the freely estimated model of changing risk and by the restricted model with a constant bond-stock covariance are almost on top of one another, diverging only slightly

Figure 9. Real TIPS Yields Implied by Alternative Risk Models, 1998–2009[a]



Source: Authors' calculations based on data for yields from Gürkaynak, Sack, and Wright (2005) and for stock returns fom the Center for Research on Security Prices.
a. See the text for descriptions of the models.

in periods such as 2003 and 2008 when the realized bond-stock covariance was unusually negative. This indicates that changing TIPS risk is not persistent enough to have a large effect on TIPS yields. Only when we impose a unit root on the process for the bond-stock covariance do we obtain large effects of changing risk. This model implies that TIPS yields should have fallen more dramatically than they did in 2002–03, and again in 2007, when the covariance of TIPS with stocks turned negative. The persistent-risk model does capture observed TIPS movements in the first half of 2008, but it dramatically fails to capture the spike in TIPS yields in the second half of 2008.

Over all, this exploration of changing risk, as captured by the changing realized covariance of TIPS returns and aggregate stock returns, suggests that variations in risk play only a supporting role in the determination of TIPS yields. The major problem with a risk-based explanation for movements in the inflation-indexed yield curve is that the covariance of TIPS and stocks has moved in a transitory fashion, and thus should not have had a large effect on TIPS yields unless investors were expecting more persistent variation and were surprised by an unusual sequence of temporary changes in risk.

These results contrast with those reported by Campbell, Sunderam, and Viceira (2009), who find that persistent movements in the covariance between inflation and stock returns have had a powerful influence on the nominal U.S. Treasury yield curve. They find that U.S. inflation was negatively correlated with stock returns in the late 1970s and early 1980s, when the major downside risk for investors was stagflation; it has been positively correlated with stock returns in the 2000s, when investors have been more concerned about deflation.[7] As a result, Campbell, Sunderam, and Viceira argue that the inflation risk premium was positive in the 1970s and 1980s but has been negative in the 2000s, implying even lower expected returns on nominal Treasury bonds than on TIPS. The movements in inflation risk identified by Campbell, Sunderam, and Viceira are persistent enough to have important effects on the shape of the nominal U.S. Treasury yield curve, reducing its slope and concavity relative to what was typical in the 1970s and 1980s. Ftn. 7

IV. The Crisis of 2008 and Institutional Influences on TIPS Yields

In 2008, as the subprime crisis intensified, the TIPS yield became highly volatile and appeared to become suddenly disconnected from the yield on nominal Treasuries. At the beginning of 2008, the 30-year TIPS yield as reported by the Federal Reserve Bank of St. Louis fell to extremely low levels, as low as 1.66 percent on January 23, 2008. Shorter-maturity TIPS showed even lower yields, and in the spring and again in the summer of 2008 some of these yields became negative, falling below –0.5 percent, reminding market participants that zero is not the lower bound for inflation-indexed bond yields. The fall of 2008 then witnessed an unprecedented and short-lived spike in TIPS yields, peaking at the end of October 2008 when the 30-year TIPS yield reached 3.44 percent.

These extraordinary short-run movements in TIPS yields are mirrored in the 10-year TIPS yield shown in figure 2. The extremely low TIPS yield in early 2008 was given a convenient explanation by some market observers, namely, that investors were panicked by the apparently heightened risks in financial markets due to the subprime crisis and sought safety at just about any price. But if this is the correct explanation, the massive surge in the TIPS yield later in that year remains a mystery. This leap upward was puzzling, since it was not observed in nominal bond yields and so marked a massive drop in the breakeven inflation rate, as seen in figure 3. The U.K. market behaved in similar fashion.

7. The top panel of figure 6 illustrates the positive correlation of U.S. inflation and stock returns during the 2000s, and the bottom panel shows that this correlation has changed sign in the United Kingdom since the early 1990s.

The anomalous sudden jump in inflation-indexed bond yields came as a total surprise to market participants. Indeed, just as the jump was occurring in October 2008, some observers were saying that because inflation expectations had become extremely stable, TIPS and nominal Treasury bonds were virtually interchangeable. For example, Marie Brière and Ombretta Signori concluded, in a paper published in March 2009 (p. 279), that, "Although diversification was a valuable reason for introducing IL [inflation-linked] bonds in a global portfolio before 2003, this is no longer the case." The extent of this surprise suggests that the rise in the TIPS yield, and its decoupling from nominal Treasury yields, had something to do with the systemic nature of the crisis that beset U.S. financial institutions in 2008.

Indeed, the sharp peak in the TIPS yield and the accompanying steep drop in the breakeven inflation rate occurred shortly after an event that some observers blame for the anomalous behavior of TIPS yields. This was the bankruptcy of the investment bank Lehman Brothers, announced on September 15, 2008. The unfolding of the Lehman bankruptcy proceedings also took place over the same interval of time during which the inflation-indexed bond yield made its spectacular leap upward.

Lehman's bankruptcy was an important event, the first bankruptcy of a major investment bank since that of Drexel Burnham Lambert in 1990. That is not to say that other investment banks did not also get into trouble in the meantime, especially during the subprime crisis. But the federal government had always stepped in to allay fears. Bear Stearns was sold to the commercial bank J.P. Morgan in March 2008 in a deal arranged and financed by the government. Bank of America announced its purchase of Merrill Lynch on September 14, 2008, again with government financial support. Yet the government decided to let Lehman fail, and investors may have interpreted this event as indicative of future government policy that might spell major changes in the economy.

One conceivable interpretation of the events that followed the Lehman bankruptcy announcement is that the market viewed the bankruptcy as a macroeconomic indicator, a sign that the economy would be suddenly weaker. This could have implied a deterioration in the government's fiscal position, justifying an increase in expected future real interest rates and therefore in the long-term real yield on Treasury debt, as well as a decline in inflation expectations, thus explaining the drop in breakeven inflation.

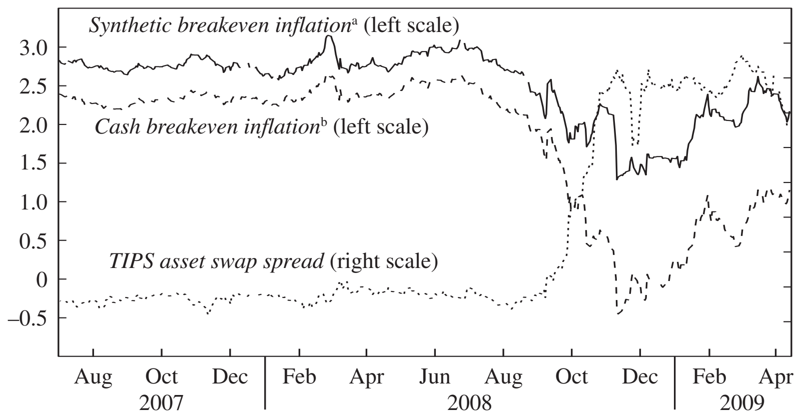
However, many observers doubt that the perceived macroeconomic impact of just this one bankruptcy could bring about such a radical change in expectations about real interest rates and inflation. At one point in 2008 the breakeven seven-year inflation rate reached −1.6 percent. According to Gang Hu and Mihir Worah (2009, p. 1), bond traders at PIMCO, "The market did not believe that it was possible to realize that kind of real rate or sustained deflation."

Another interpretation is that there was a shift in the risk premium for inflation-indexed bonds. In terms of our analysis above, this could be a change in the covariance of TIPS returns with consumption or wealth. But such a view sounds even less plausible than the view that the Lehman effect worked through inflation expectations. We have shown that the observed fluctuations in the covariances of TIPS returns with other variables are hard to rationalize even after the fact, and so it is hard to see why the market would have made a major adjustment in this covariance.

Hu and Worah (2009, pp. 1, 3) conclude instead that, "the extremes in valuation were due to a potent combination of technical factors. . . . Lehman owned Tips as part of repo trades or posted Tips as counterparty collateral. Once Lehman declared bankruptcy, both the court and its counterparty needed to sell these Tips for cash." The traders at PIMCO saw then a flood of TIPS on the market, for which there appeared to be few buyers. Distressed market makers were not willing to risk taking positions in these TIPS; their distress was marked by a crisis-induced sudden and catastrophic widening, by October 2008, in TIPS bid-asked spreads. Making the situation worse was the fact that some institutional investors in TIPS had adopted commodity overlay strategies that forced them to sell TIPS because of the fall at that time in commodity prices. Moreover, institutional money managers had to confront a sudden loss of client interest in relative value trades. Such trades, which take advantage of unusual price differences between securities with related fundamentals, might otherwise have exploited the abnormally low breakeven inflation.

An important clue about the events of fall 2008 is provided by the diverging behavior of breakeven inflation rates in the TIPS cash market and breakeven inflation rates implied by zero-coupon inflation swaps during the months following the Lehman bankruptcy. Zero-coupon inflation swaps are derivatives contracts in which one party pays the other cumulative CPI (consumer price index) inflation over the term of the contract at maturity, in exchange for a predetermined fixed rate. This rate is known as the "synthetic" breakeven inflation rate, because if inflation grew at this fixed rate over the life of the contract, the net payment on the contract at maturity would be zero. As with the "cash" breakeven inflation rate implied by TIPS and nominal Treasury bonds, this rate reflects both expected inflation over the relevant period and an inflation risk premium.

Figure 10. Breakeven Inflation Rates and Asset Swap Spreads on TIPS, July 2007–April 2009



Source: Authors' calculations based on data from Barclays Capital.

a. Synthetic breakeven inflation rate derived from interest rates on zero-coupon inflation swaps.

b. Breakeven inflation rate derived from differences in yields on nominal government bonds and TIPS.

Fig. 10 Figure 10 plots the cash inflation breakeven rate implied by off-the-run (as opposed to newly issued, or on-the-run) TIPS and nominal Treasury bonds maturing on July 2017, and the synthetic inflation breakeven rate for the 10-year zero-coupon inflation swap, from July 2007 through April 2009. The figure also plots the TIPS asset swap spread, explained below. The two breakeven rates track each other very closely until mid-September 2008, with the synthetic inflation breakeven rate about 35 to 40 basis points above the cash breakeven inflation rate on average.

This difference in breakeven rates is typical under normal market conditions. According to analysts, it reflects among other things the cost of manufacturing pure inflation protection in the United States. Most market participants supplying inflation protection in the U.S. inflation swap market are leveraged investors such as hedge funds and banks' proprietary trading desks. These investors typically hedge their inflation swap positions by simultaneously taking long positions in TIPS and short positions in nominal Treasuries in the asset swap market. A buying position in an asset swap is functionally similar to a leveraged position in a bond. In an asset swap, one party pays the cash flows on a specific bond and receives in exchange interest at the London interbank offer rate (LIBOR) plus a spread known as the asset swap spread. Typically this spread is negative and larger in absolute magnitude for nominal Treasuries than for TIPS. Thus, leveraged investors selling inflation protection in an inflation swap face a positive financing cost derived from their long-TIPS, short-nominal Treasuries position.

Figure 10 shows that starting in mid-September 2008, cash breakeven inflation rates fell dramatically while synthetic rates did not fall nearly as much; at the same time TIPS asset swap spreads increased from their normal level of about −35 basis points to about +100 basis points. Although not shown in the figure, nominal Treasury asset swap spreads remained at their usual levels. That is, financing long positions in TIPS became extremely expensive relative to historical levels just as their cash price fell abruptly.

There is no reason why declining inflation expectations should directly affect the cost of financing long positions in TIPS relative to nominal Treasuries. The scenario that these two simultaneous changes suggest instead is one of intense selling in the cash market and insufficient demand to absorb those sales—as described by Hu and Worah—and simultaneously another shortage of capital to finance leveraged positions in markets other than that for nominal Treasuries; that is, the bond market events of the fall of 2008 may have been a "liquidity" episode.

Under this interpretation, the synthetic breakeven inflation rate was at the time a better proxy for inflation expectations in the marketplace than the cash breakeven inflation rate, despite the fact that in normal times the inflation swap market is considerably less liquid than the cash TIPS market. The synthetic breakeven inflation rate declined from about 3 percent a year to about 1.5 percent at the trough. This long-run inflation expectation is perhaps more plausible than the 10-year expectation of zero inflation reflected in the cash market for off-the-run bonds maturing in 2017.

Interestingly, cash breakeven inflation rates also diverged between on-the-run and off-the-run TIPS with similar maturities during this period. The online appendix shows that breakeven rates based on on-the-run TIPS were lower than those based on off-the-run TIPS. This divergence reflected another feature of TIPS that causes cash breakeven inflation rates calculated from on-the-run TIPS to be poor proxies for inflation expectations in the face of deflation risk. Contractually, TIPS holders have the right to redeem their bonds at maturity for the greater of either par value at issuance or that value plus accrued inflation during the life of the bond. Thus, when there is a risk of deflation after a period of inflation, new TIPS issues offer better deflation protection than older ones. Accordingly, on-the-run TIPS should be more expensive than off-the-run TIPS, and thus their real yields should be lower. Breakeven inflation rates derived from on-the-run TIPS must be adjusted upward for this deflation protection premium to arrive at a measure of inflation expectations.

We view the experience with TIPS yields after the Lehman bankruptcy as reflecting a highly abnormal market situation, where liquidity problems suddenly created severe financial anomalies. This may seem to imply that one can regard the recent episode as unrepresentative and ignore the observations from these dates. However, investors in TIPS who would like to regard them as the safest long-term investment must consider the extraordinary short-term volatility that such events have given their yields.

V. The Uses of Inflation-Indexed Bonds

We conclude by drawing out some implications of the recent experience with inflation-indexed bonds for both investors and policymakers.

V.A. Implications for Investors

The basic case for investing in inflation-indexed bonds, stated by Campbell and Shiller (1997) and further developed by Michael Brennan and Yihong Xia (2002), Campbell and Viceira (2001, 2002), Campbell, Yeung Lewis Chan, and Viceira (2003), and Jessica Wachter (2003), is that these bonds are the safe asset for long-term investors. An inflation-indexed perpetuity delivers a known stream of real spending power to an infinite-lived investor, and a zero-coupon inflation-indexed bond delivers a known real payment in the distant future to an investor who values wealth at that single horizon. This argument makes no assumption about the time-series variation in yields, and so it is not invalidated by the gradual long-term decline in inflation-indexed bond yields since the 1990s, the mysterious medium-run variations in TIPS yields relative to short-term real interest rates, the spike in yields in the fall of 2008, or the high daily volatility of TIPS returns.

There are, however, two circumstances in which other assets can substitute for inflation-indexed bonds to provide long-term safe returns. First, if the breakeven inflation rate is constant, as will be the case when the central bank achieves perfect anti-inflationary credibility, then nominal bonds are perfect substitutes for inflation-indexed bonds, and conventional government bonds will suit the preferences of conservative long-term investors. For a time in the mid-2000s, it looked as if this nirvana of central bankers was imminent, but the events of 2008 dramatically destabilized inflation expectations and reaffirmed the distinction between inflation-indexed and nominal bonds.

Second, if the ex ante real interest rate is constant, as Eugene Fama (1975) famously asserted, then long-term investors can roll over short-term

Treasury bills to achieve almost perfectly certain long-term real returns. Because inflation uncertainty is minimal over a month or a quarter, Treasury bills expose investors to minimal inflation risk. In general, they do expose investors to the risk of persistent variation in the real interest rate, but this risk is absent if the real interest rate is constant over time.

Investors can tell whether this happy circumstance prevails by forecasting realized real returns on Treasury bills and measuring the movements of their forecasts, as we did in figure 8, or more simply by measuring the volatility of inflation-indexed bond returns. If inflation-indexed bonds have yields that are almost constant and returns with almost no volatility, then Treasury bills are likely to be good substitutes.[8] Seen from this point of view, Ftn. 8
the high daily volatility of inflation-indexed bond returns illustrated in figure 4, far from being a drawback, demonstrates the value of inflation-indexed bonds for conservative long-term investors.

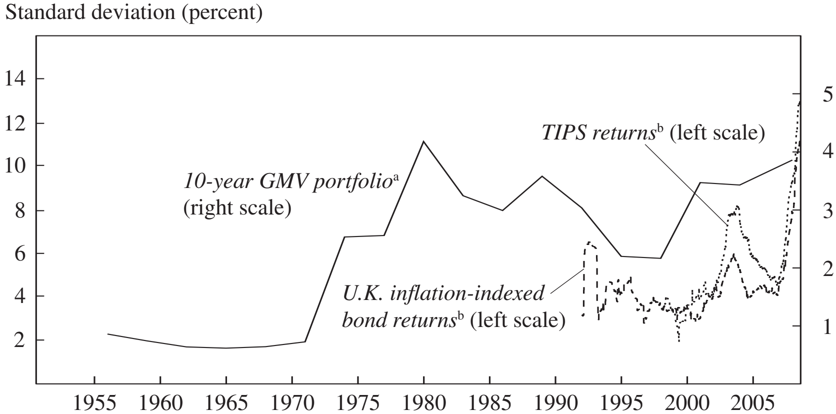
A simple quantitative measure of the usefulness of inflation-indexed bonds is the reduction in the long-run standard deviation of a portfolio that these bonds permit. One can estimate this reduction by calculating the long-run standard deviation of a portfolio of *other* assets chosen to minimize long-run risk (what we call the global minimum variance, or GMV, portfolio). This is the smallest risk that long-run investors can achieve if inflation-indexed bonds are unavailable. Once inflation-indexed bonds become available, the minimum long-run risk portfolio consists entirely of these bonds and has zero long-run risk. Thus, the difference between the minimized long-run standard deviation of the GMV portfolio and zero measures the risk reduction that inflation-indexed bonds make possible.[9] Ftn. 9

We constructed a 10-year GMV portfolio consisting of U.S. stocks, nominal 5-year Treasury bonds, and 3-month Treasury bills. To derive the composition of this portfolio and its volatility at each horizon, we used the long-horizon mean-variance approach described in Campbell and Viceira (2005) and its companion technical guide (Campbell and Viceira 2004). We estimated a VAR(1) system for the ex post real return on Treasury bills

8. Strictly speaking, this argument assumes that real yields are described by the expectations hypothesis of the term structure, so that constant short-term real interest rates imply constant long-term real yields. Volatile risk or liquidity premiums on inflation-indexed bonds could make their yields volatile even if short-term real interest rates are constant. However, it is quite unlikely that time variation in risk or liquidity premiums would stabilize the yields on inflation-indexed bonds in an environment of time-varying real interest rates.

9. As an alternative approach, Campbell, Chan, and Viceira (2003) calculate the utility of an infinite-lived investor who has access to stocks, nominal bonds, and bills, and the utility gain when this investor also can hold an inflation-indexed perpetuity. We do not update this more complex calculation here.

Figure 11. Volatility of Returns on the GMV Portfolio and on Inflation-Indexed Government Bonds



Source: Authors' calculations from Bloomberg and Center for Research on Security Prices data.

a. Annualized 10-year standard deviation of the 10-year global minimum variance portfolio of U.S. stocks, nominal 5-year Treasury bonds, and 3-month Treasury bills, computed from a VAR model as described in the text.

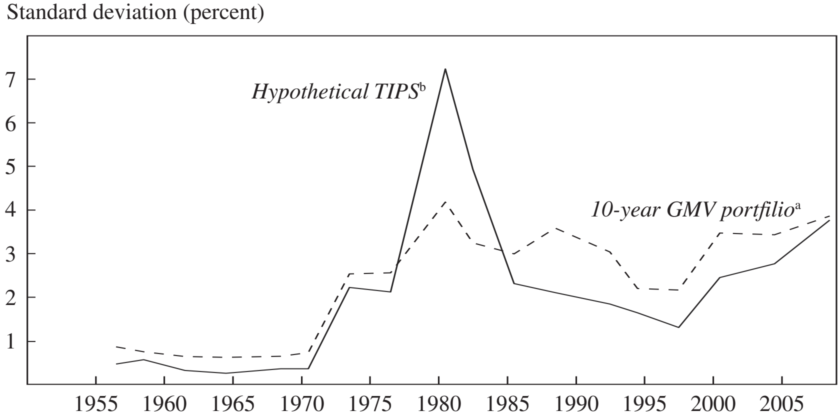
b. Annualized standard deviation of daily returns.

and the excess log return on stocks and nominal bonds. The system also includes variables known to forecast bond and equity risk premiums: the log dividend-price ratio, the yield on Treasury bills, and the spread between that yield and the 5-year Treasury bond yield. From this system we extracted the conditional variance-covariance of 10-year returns using the formulas in Campbell and Viceira (2004) and found the portfolio that minimizes this variance.

Instead of estimating a single VAR system for our entire quarterly sample, 1953Q1–2008Q4, we estimated two VAR systems, one for 1953Q1–1972Q4 and another for 1973Q1–2008Q4. We split the sample this way because we are concerned that the process for inflation and the real interest rate might have changed during the period as a whole. The conditional long-horizon moments of returns also depend on the quarterly variance-covariance matrix of innovations, which we estimated using three-year windows of quarterly data. Within each window and VAR sample period, we combined the variance-covariance matrix with the full-sample estimate of the slope coefficients to compute the 10-year GMV portfolio and its annualized volatility.

Fig. 11 Figure 11 compares the estimated standard deviation of the GMV portfolio with the annualized daily standard deviations of TIPS and inflation-

Figure 12. Volatility of Returns on the GMV Portfolio and of Hypothetical Quarterly TIPS Returns



Source: Authors' calculations from Bloomberg and Center for Research on Security Prices data.

a. Annualized 10-year standard deviation of the 10-year global minimum variance portfolio of U.S. stocks, nominal 5-year Treasury bonds, and 3-month Treasury bills, computed from a VAR model as described in the text.

b. Annualized standard deviation of quarterly returns.

indexed gilts over the period where these bonds exist. Figure 12 compares the same GMV standard deviation with the estimated standard deviation of hypothetical TIPS returns, constructed from the VAR system using the method of Campbell and Shiller (1997) and section II of this paper, which assumes the log expectations hypothesis for inflation-indexed bonds. The annualized 10-year standard deviation of the 10-year GMV portfolio is fairly low in the 1960s, at around 1 percent a year. This is the period that led Fama (1975) to assert that the ex ante real interest rate is constant over time. Starting in the 1970s, however, persistent movements in the real interest rate cause the standard deviation to rise rapidly to about 4 percent a year. The standard deviation drops back to about 2 percent in the mid-1990s, but by 2008 it is once again at a historical high of 4 percent. These numbers imply that inflation-indexed bonds substantially reduce risk for long-term investors. Fig. 12

Both comparisons show that, historically, the minimum long-run risk that can be achieved using other assets has been high when short-term TIPS returns have been volatile. In other words, inflation-indexed bonds are particularly good at reducing long-run risk whenever their short-run risk is high. Such a result may seem paradoxical, but it follows directly from the fact that the need for inflation-indexed bonds for long-term safety is greater when real interest rates vary persistently over time.[10]

Inflation-indexed bonds also play an important role for institutional investors who need to hedge long-term real liabilities. Pension funds and insurance companies with multiyear commitments should use inflation-indexed bonds to neutralize the swings in the present value of their long-dated liabilities due to changes in long-term real interest rates. Of course, these swings become apparent to institutional investors only when they discount real liabilities using market real interest rates, as the United Kingdom has required in recent years. The resulting institutional demand for inflation-indexed gilts seems to have been an important factor driving down their yields (Viceira 2003; Vayanos and Vila 2007).

The total demand of long-term investors for inflation-indexed bonds will depend not only on their risk properties, but also on their expected returns relative to other available investments and on the risk tolerance of the investors. An aggressive long-term investor might wish to short inflation-indexed bonds and invest the proceeds in equities, since stocks have only very rarely underperformed bonds over three or more decades in U.S. and U.K. data. In 2008 it was reported that Clare College, University of Cambridge, was planning to undertake such a strategy.[11] However, Campbell, Chan, and Viceira (2003) estimated positive long-term demand for inflation-indexed bonds by long-term investors who also have the ability to borrow short term or to issue long-term nominal bonds.

Long-term inflation-indexed bonds may be of interest to some short-term investors. Given their high short-run volatility, however, short-term investors will wish to hold these bonds only if they expect to receive high excess returns over Treasury bills (as might reasonably have been the case in 1999–2000 or during the yield spike of the fall of 2008), or if they hold other assets, such as stocks, whose returns can be hedged by an inflation-indexed bond position. We have shown evidence that TIPS and inflation-indexed gilts did hedge stock returns during the downturns of the early 2000s and the late 2000s, and this should make them attractive to short-term equity investors.

10. This point is related to the asset pricing result discussed in section III.A, namely, that when one controls for the stock market covariance of inflation-indexed bonds, the equilibrium risk premium on these bonds for a conservative, infinite-lived, representative investor is declining in their variance.

11. David Turner, "College to Invest 15m Loan in Shares," *Financial Times,* October 27, 2008.

The illiquidity of inflation-indexed bonds is often mentioned as a disadvantage. But in developed countries these bonds are illiquid only relative to the same countries' nominal government bonds, which, along with foreign exchange, are the most liquid financial assets. Compared with almost any other long-term investment vehicle, inflation-indexed government bonds are extremely cheap to trade. In addition, long-term buy-and-hold investors should care very little about transactions costs since they will rarely need to turn over their bond positions.

V.B. Implications for Policymakers

In managing the public debt, the Treasury seeks to minimize the average cost of debt issuance while paying due regard to risk, including refinancing risk. It is commonly thought that short-term Treasury bills are less expensive than long-term debt but that exclusive reliance on bills would impose an unacceptable refinancing risk, as bills must frequently be rolled over.

In the period since TIPS were introduced in 1997, they have proved to be an expensive form of debt ex post, because of the unexpected decline in real interest rates from the 1990s through early 2008. However, our analysis implies that the cost of TIPS should be lower than that of Treasury bills ex ante, because TIPS offer investors desirable insurance against future variation in real interest rates. This is the relevant consideration going forward, as Jennifer Roush, William Dudley, and Michelle Steinberg Ezer (2008) emphasize, and therefore governments should not be deterred from issuing inflation-indexed bonds by the high realized returns on their past issues.

In the current environment, with inflation positively correlated with stock prices, the inflation risk premium in nominal Treasury bonds is likely negative. This implies that long-term nominal debt should be even cheaper for the Treasury than TIPS. However, the correlation between inflation and stock prices has changed sign in the past (Campbell, Sunderam, and Viceira 2009), and it may easily do so again in the future.

Several other considerations also suggest that inflation-indexed bonds are a valuable form of public debt. First, to the extent that particular forms of debt have different investment clienteles, all with downward-sloping demand curves for bonds, it is desirable to diversify across different forms so as to tap the largest possible market for government debt (Greenwood and Vayanos 2008; Vayanos and Vila 2007).

Second, inflation-indexed bonds can be used to draw inferences about bond investors' inflation expectations, and such information is extremely

Ftn. 12 valuable for monetary policymakers.[12] It is true that market disruptions, such as those that occurred in the fall of 2008, complicate the measurement of inflation expectations, but our analysis shows that it is possible to derive meaningful information even in these extreme conditions.

Finally, inflation-indexed bonds provide a safe real asset for long-term investors and promote public understanding of inflation. Fiscal authorities should take these public benefits into account as part of their broader mission to improve the functioning of their economies.

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12. Recent papers extracting information from the inflation-indexed yield curve include Beechey and Wright (2008), Christensen, Lopez, and Rudebusch (2009), D'Amico, Kim, and Wei (2008), Grishchenko and Huang (2008), and Haubrich, Pennacchi, and Ritchken (2008).

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