JOHN Y. CAMPBELL
Harvard University

ROBERT J. SHILLER
Yale University

LUIS M. VICEIRA
Harvard University

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 creates 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 and Mitsui (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 the 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

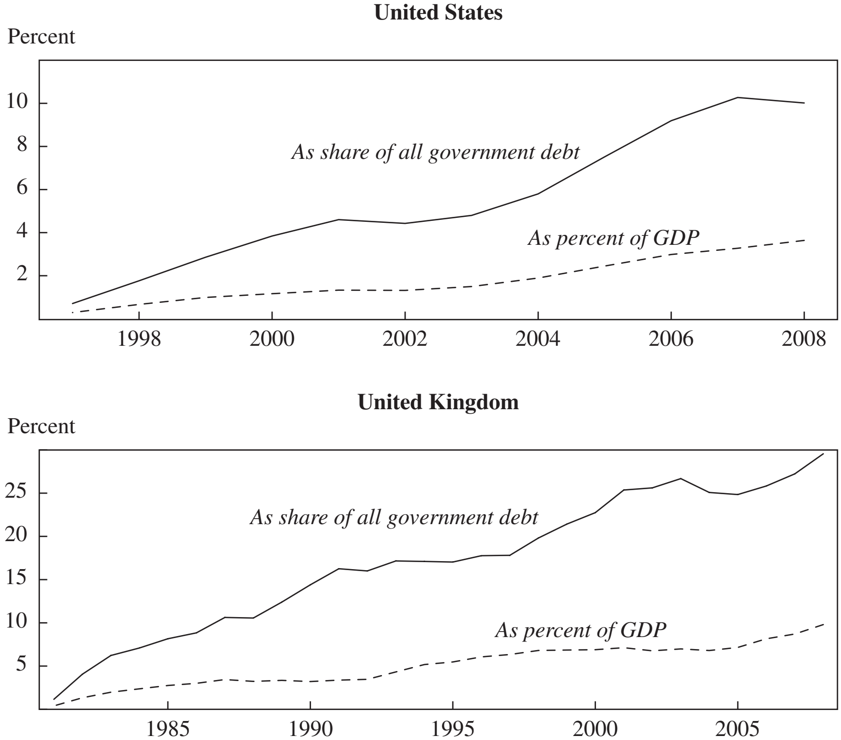
The top panel of figure 1 shows the growth of the outstanding supply of TIPS during the past 10 years. From modest beginnings in 1997, TIPS grew to around 10 percent of the marketable debt of the U.S. Treasury, and more than 3.5 percent of U.S. GDP, in 2008. This growth has been fairly smooth, with a 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

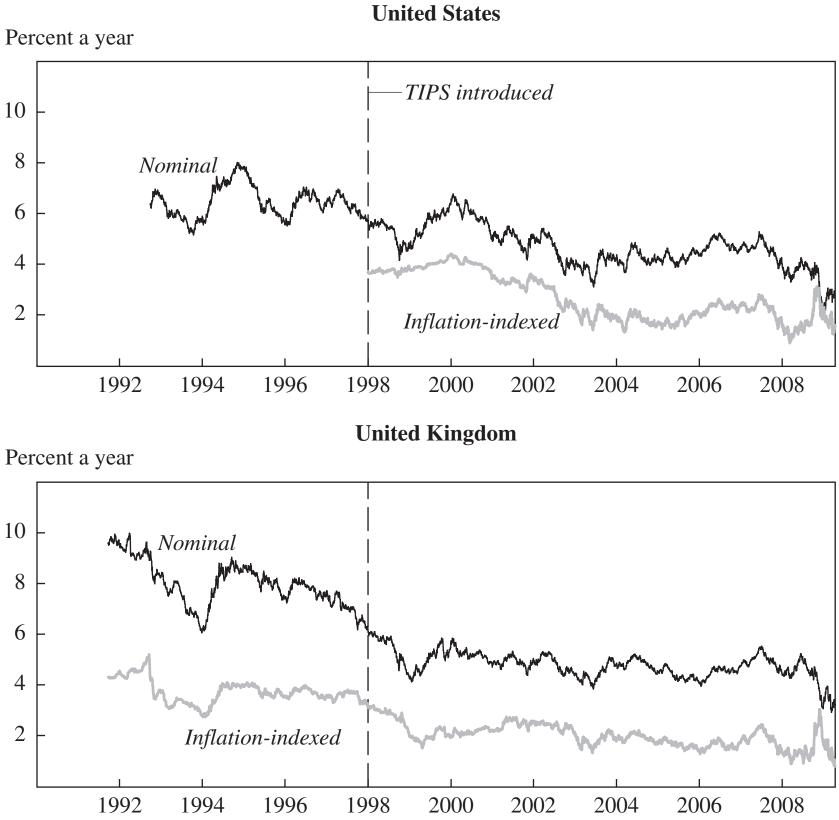


Sources: *Treasury Bulletin,* various issues, table FD-2; Heriot-Watt/Faculty and Institute of Actuaries Gilt Database (www.ma.hw.ac.uk/~andrewc/gilts/, file BGSAmounts.xls).

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

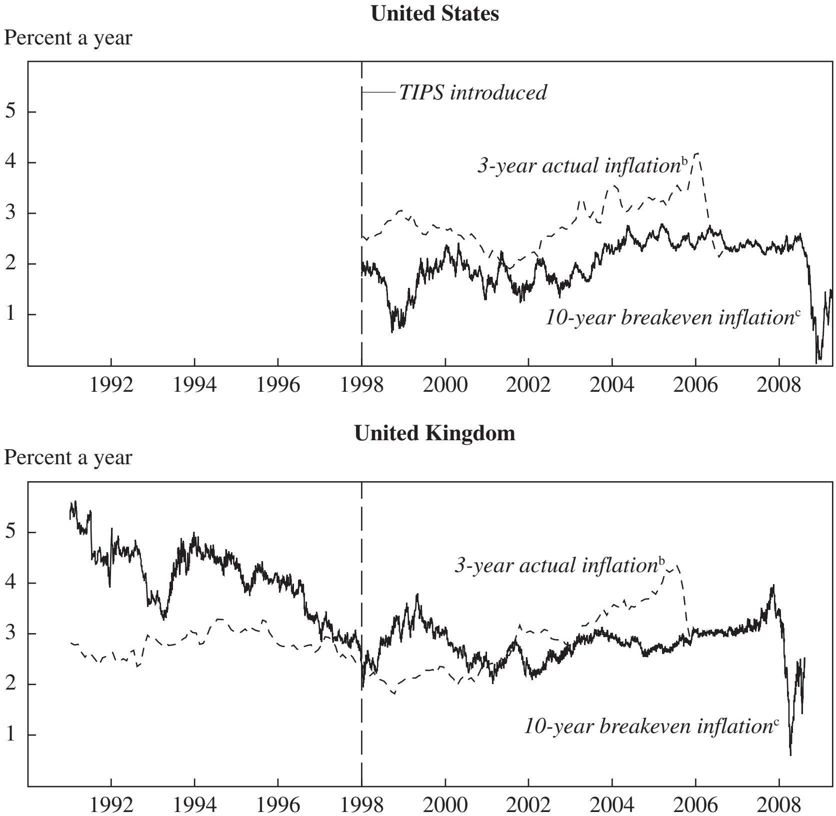


Source: Authors calc ulations using data from Bloomberg and Heriot-Watt/Faculty and Institute of Actuaries Gilt Database; see the online appendix (kuznets.fas.harvard.edu/~campbell/papers.html) for details.

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

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 3-year inflation rate. After the first

Figure 3. Breakeven Inflation Rates Implied by Ten-Year Nominal Inflation-Indexed Bond Yields, and Actual Three-Year 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 3 years.

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

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.

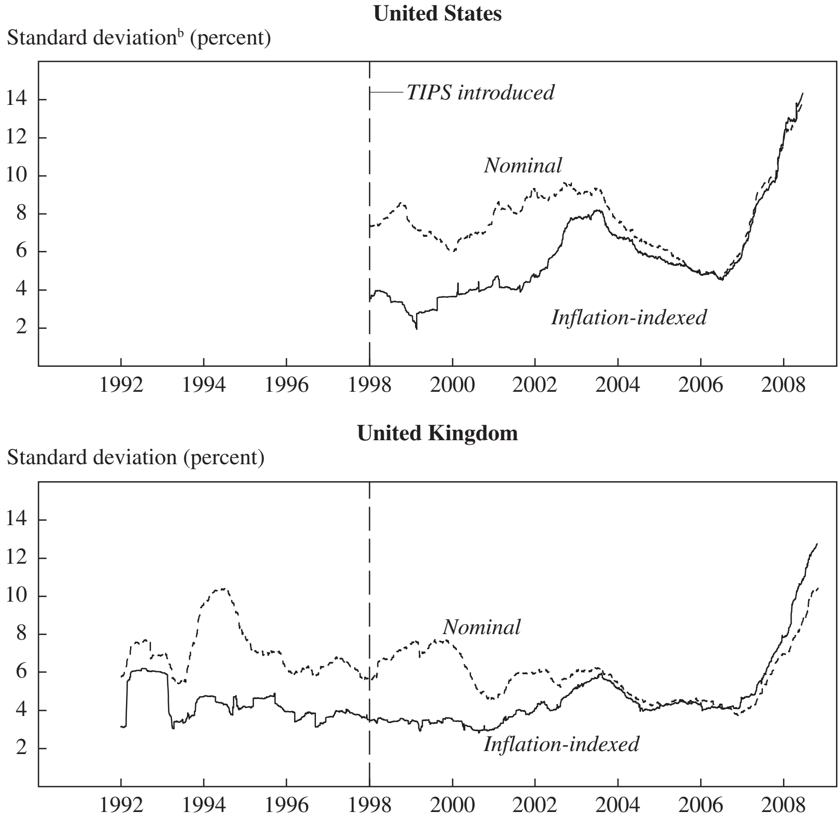
The bottom panel of figure 3 depicts the breakeven inflation history for the United Kingdom. It shows a strong decline in the late 1990s, probably associated with the granting of independence to the Bank of England by the newly elected Labour government in 1997, and a steady upward creep from 2003 to 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.

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 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 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 Ten-Year Nominal and Inflation-Indexed Government Bond Returns, 1992–2009[a]



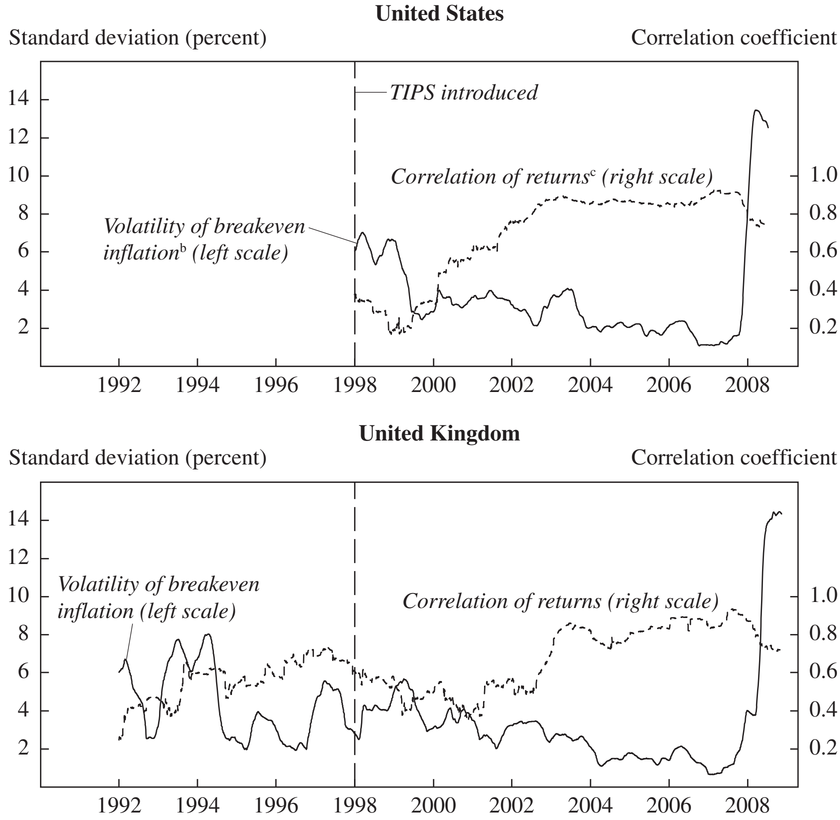
Source: Authors' calculations from Bloomberg data; see the online appendix for details.

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.

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 Ten-Year Breakeven Inflation and Correlation 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.

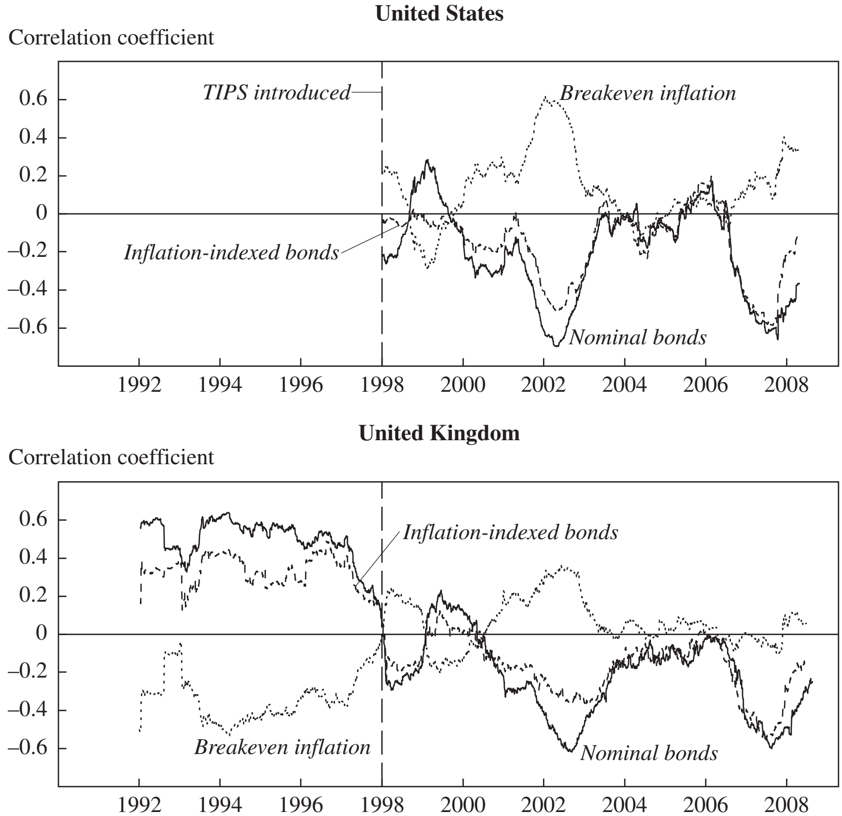
Although TIPS have been volatile assets, this does not necessarily imply that they should command large risk premiums. According to rational asset pricing theory, the risk premium on an asset should be driven by the covariance of its returns with the marginal utility of consumption rather than by the 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).

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 Ten-Year Government Bond Returns and Breakeven Inflation Rates with Equity Returns, 1992–2009[a]

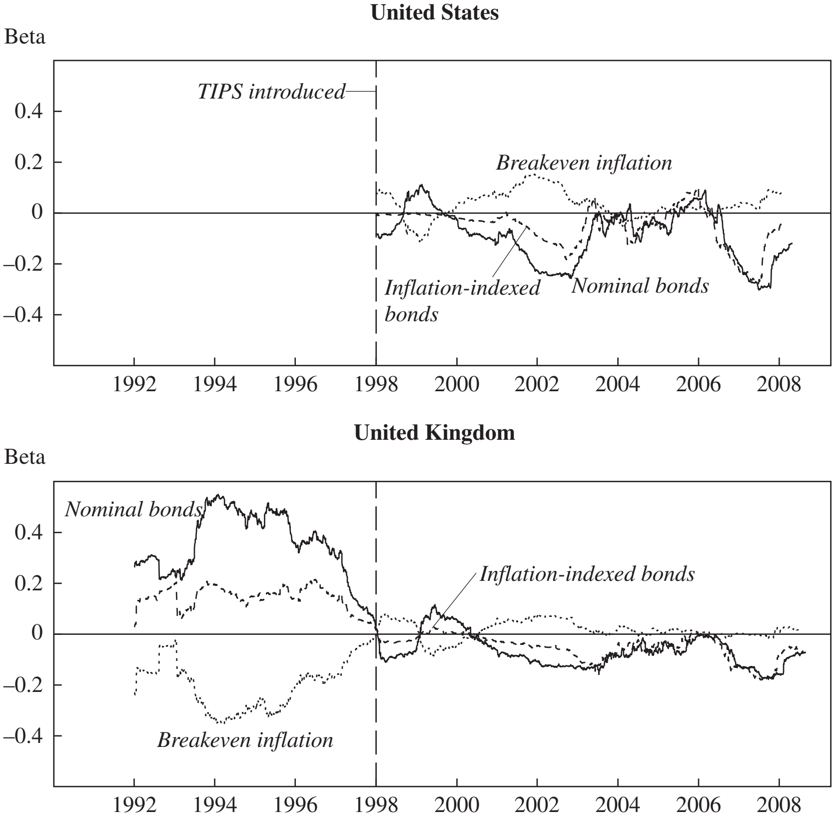


Source: Authors' calculations from Bloomberg and Center for Research in Security Prices data; see the online appendix for details.

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 Ten-Year Government Bond Returns and Breakeven Inflation Rates with Equity Returns, 1992–2009[a]



Source: Authors' calculations from Bloomberg and Center for Research in 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 3-month nominal Treasury bill, the nominal bill yield, and the once-

Table 1. Results of VAR Estimation and Observed and Hypothetical Moments of Ten-Year Inflation-Indexed Bond Yields, 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 bond yields	*Observed*		*Hypothetical*
Mean	2.66		1.04
Standard deviation	0.95		0.39
Correlation		0.71	

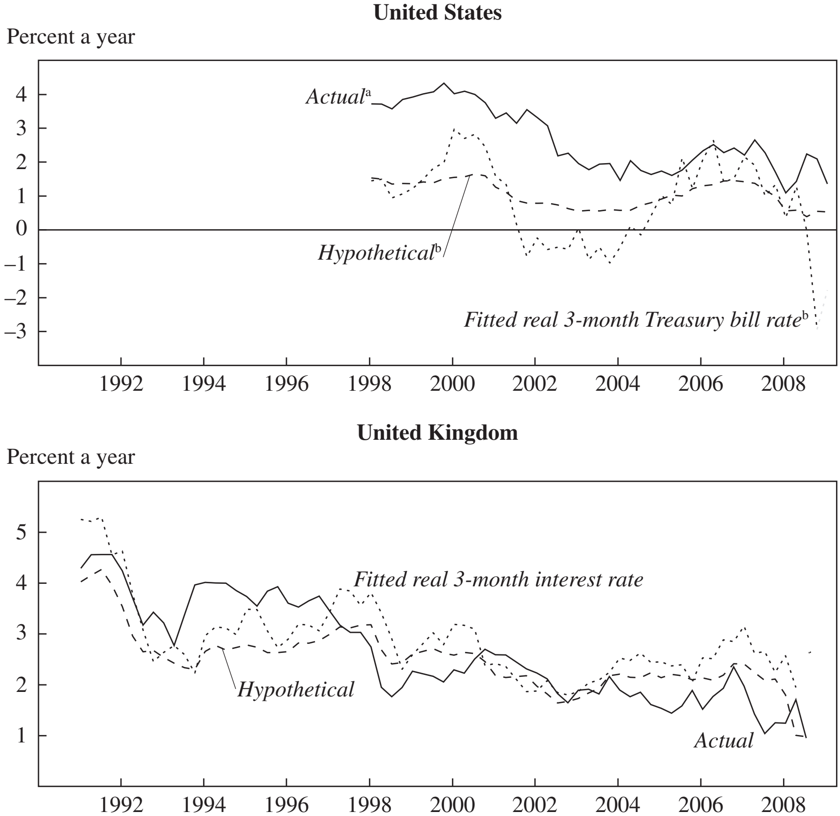
Source: Authors' regressions. Independent variables are lagged one period.
a. Numbers in parentheses are standard errors.
b. Non–seasonally adjusted all-urban-consumer price index (NSA CPI-U).

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.

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 Ten-Year Inflation-Indexed Bonds



Source: Authors' calculations from Bloomberg, Center for Research in 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

Table 2. Results of VAR Estimation and Observed and Hypothetical Moments of Ten-Year Inflation-Indexed Bond Yields, 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 bond yields	*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.

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 low average level of inflation-indexed gilt yields since 2005.

A new U.K. accounting standard introduced in 2000, FRS17, may account for this. As Viceira and Mitsui (2003) and Dimitri Vayanos and Jean-Luc Vila (2007) explain, FRS17 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

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

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

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

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

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

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]

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

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 41.

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; Kim and Nelson 1999; McConnell and Perez-Quiros 2000; 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

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

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

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

and v_t follows a standard AR(1) process,

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

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

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

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

$$(10) \qquad \text{cov}_t\left(r_{e,t+1}, r_{n,t+1}\right) = B_{x,n-1}\beta_{em}\sigma_{mx}v_t,$$

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

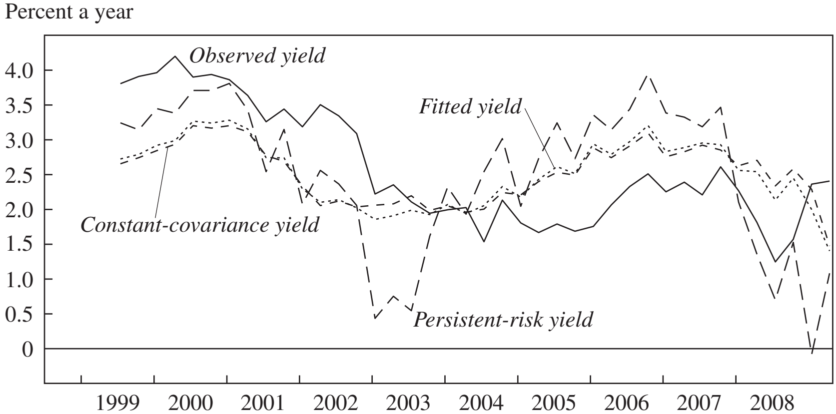
Source: Authors' calculations.
a. NA, not applicable. See the text for descriptions of the models.

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.

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.

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 Ten-Year Inflation-Indexed Bond Yields Implied by Alternative Risk Models, United States, 1998–2009[a]



Source: Authors' calculations based on data for yields from Gürkaynak, Sack, and Wright (2008) and for stock returns fom the Center for Research in 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.

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), "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.

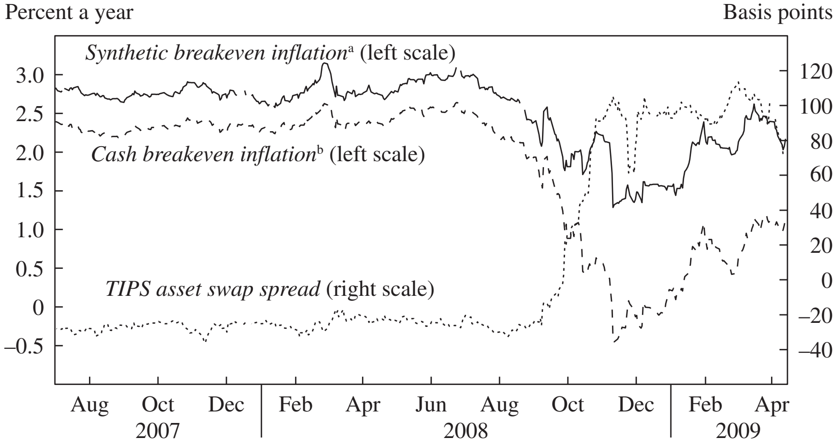
However, many observers doubt that the perceived macroeconomic impact of just this one bankruptcy could bring about such a radical change in expectations about real interest rates and inflation. At one point in 2008 the breakeven seven-year inflation rate reached −1.6 percent. According to Gang Hu and 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.

Figure 10 plots the cash breakeven inflation rate implied by off-the-run (as opposed to newly issued, or on-the-run) TIPS and nominal Treasury bonds maturing in July 2017, and the synthetic breakeven inflation 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 breakeven inflation 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, 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.

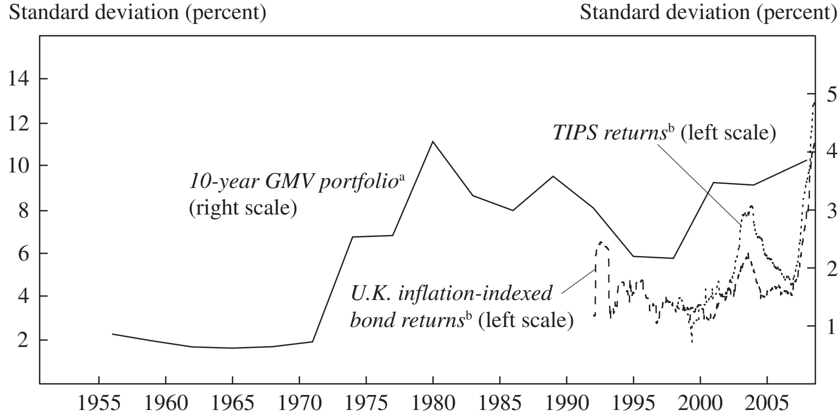
A simple quantitative measure of the usefulness of inflation-indexed bonds is the reduction in the long-run standard deviation of a portfolio that these bonds permit. One can estimate this reduction by calculating the long-run standard deviation of a portfolio of *other* assets chosen to minimize long-run 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]

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 can also hold an inflation-indexed perpetuity. We do not update this more complex calculation here.

Figure 11. Volatility of Returns on the Global Minimum Variance Portfolio and on Inflation-Indexed Government Bonds



Source: Authors' calculations from Bloomberg and Center for Research in 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.

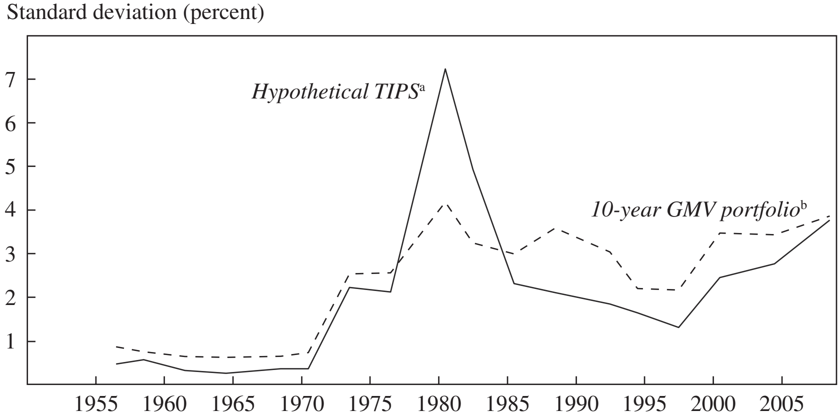
b. Annualized standard deviation of daily returns.

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 3-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.

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 Global Minimum Variance Portfolio and of Hypothetical Quarterly TIPS Returns



Source: Authors' calculations from Bloomberg and Center for Research in Security Prices data.
a. Annualized standard deviation of quarterly returns.
b. 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.

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.

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 and Mitsui 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 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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Comments and Discussion

COMMENT BY

FREDERIC S. MISHKIN This paper by John Campbell, Robert Shiller, and Luis Viceira is excellent. Indeed, I would have titled it, "Everything You Always Wanted to Know about Inflation-Indexed Bond Markets, But Were Afraid to Ask."[1] The paper documents many key facts and puzzles about this market, including the following:

—the decline in long-term real yields on inflation-indexed bonds from the 1990s;

—the instability of real yields and returns on these bonds during the recent financial crisis;

—the negative correlation of returns on these bonds with those on stock prices, indicating that these bonds can be used to hedge equity risk;

—the fact that real yields on these bonds differ in different countries;

—the fact that the expectations hypothesis view that long-term real yields are driven by expectations of short-term real interest rates is supported by the data;

—but also the fact that risk and liquidity premiums on these bonds are very important and are volatile, suggesting that institutional factors matter a lot to their yields;

—the fact that long-term inflation-indexed bonds have high short-term risk;

—but also the fact that this is fully consistent with their being good long-term risk reducers.

1. For readers too young to remember, this is a takeoff on the title of a popular book and a Woody Allen movie from the 1970s.

The paper focuses on inflation-indexed bonds from the perspective of the investor. Given my comparative advantage as a former governor of the Federal Reserve, I will instead provide a different perspective by discussing why their analysis is so important for policymakers.

One of the most important issues for monetary policymakers is whether they can keep long-run inflation expectations anchored. Such anchoring is key to successful monetary policy for several reasons, and this is one of the reasons that I and many other monetary economists have argued strongly for some form of inflation targeting. First, anchoring long-run inflation expectations leads to more stable inflation outcomes. As I discussed in Mishkin (2007), long-run expectations of inflation on the part of households and firms are a key factor in determining the actual behavior of inflation. If these expectations are unstable, so, too, will be inflation. Moreover, the commitment that inflation targeting provides can play an important role in minimizing the risk of what Marvin Goodfriend (1993) has called "inflation scares," that is, episodes in which longer-term inflation expectations jump sharply in response to specific macroeconomic developments or monetary policy actions.

Second, anchoring long-run inflation expectations can help stabilize output and employment. Specifically, to counter a contractionary demand shock, the monetary authorities need to reduce the short-run nominal interest rate; however, the effectiveness of such a policy action may be hindered if long-run inflation expectations are not firmly anchored. For example, if the private sector becomes less certain about the longer-run inflation outlook, the resulting increase in the inflation risk premium could boost longer-term interest rates by more than the increase in expected inflation. The higher premium would in turn place upward pressure on the real cost of long-term financing for households and businesses (whose debt contracts are almost always expressed in nominal terms) and hence might partly offset any direct monetary stimulus. Thus, firmly anchoring inflation expectations can make an important contribution to the effectiveness of the central bank's actions aimed at stabilizing economic activity in the face of adverse demand shocks.

Third, anchoring long-run inflation expectations provides the central bank with greater flexibility to respond decisively to adverse demand shocks. Well-anchored expectations help ensure that an aggressive policy easing is not misinterpreted as signaling a shift in the central bank's inflation objective; they thereby minimize the possibility that long-run inflation expectations could move upward in response to the easing and lead to a rise in actual inflation. Well-anchored expectations are especially valuable in periods of financial market stress; at such times, prompt and decisive policy action may be required to prevent a severe contraction in economic activity that could further exacerbate the uncertainty and the stress, leading to a further deterioration in macroeconomic activity, and so on. Thus, by providing the central bank with greater flexibility in mitigating the risk of such an adverse feedback loop, well-anchored long-run inflation expectations play an important role in promoting financial stability as well as the stability of economic activity and inflation.

Fourth, well-anchored long-run inflation expectations can help prevent deflation from setting in—a particularly relevant consideration today. Deflation can severely weaken economic activity by triggering debt-deflation of the type described by Irving Fisher (1933), in which the falling price level increases the real indebtedness of firms, undermining their balance sheets.

Fifth, well-anchored long-run inflation expectations can help minimize the effects of an adverse cost shock such as a persistent rise in the price of energy. Generally speaking, such shocks tend to result in weaker economic activity as well as higher inflation. However, when long-run inflation expectations are firmly anchored, these shocks are likely to have only transitory effects on actual inflation, thus obviating the need to raise interest rates aggressively to keep inflation from rising. Thus, well-anchored long-run inflation expectations can help reduce output and employment fluctuations that impose unnecessary hardship on workers and on the economy more broadly.

The bottom line is that anchoring long-run inflation expectations is so important to successful monetary policy that the monetary authorities need to know what is happening to these expectations at all times. Indeed, when I was on the Federal Reserve Board, we spent a lot of time and effort trying to assess where long-run inflation expectations were heading, and we looked at several measures of these expectations. Surveys of households, such as the University of Michigan Inflation Expectation Survey, are one important source of information, but they have an important drawback. Research in the field of behavioral economics suggests that biases due to framing are likely to make survey measures of long-run inflation expectations unreliable. The problem is that when survey measures of short-run inflation expectations change, survey measures of long-run inflation expectations are likely to move with them, even if long-run expectations have not changed. This might happen because questions about both are asked at the same time, and the answer to the first question influences ("frames") the response to the second, resulting in a spurious co-movement between the two. Indeed, this is exactly what has happened recently. When oil prices rose, driving up inflation in terms of the consumer price index (CPI), not only did one-year inflation expectations move up in the Michigan survey, which makes sense, but so did measures of 5-to-10-year inflation expectations. Then, when CPI inflation and one-year survey expectations came back down, so, too, did the 5-to-10-year survey expectations. These temporary fluctuations in the 5-to-10-year survey measure were almost surely illusory.

A second measure of long-run inflation expectations comes from the Survey of Professional Forecasters (SPF). In recent years this measure has been rock steady. Of course, this may indicate that inflation expectations are firmly anchored, but it may instead be that the measure is failing to capture long-run inflation expectations that are in fact moving around.

Skepticism about survey measures is one reason why many economists, including myself, are more willing to trust expectations measures that are derived from financial markets data. After all, people buying or selling securities are putting their money where their mouth is—they thus have a strong incentive to base their decisions on their true forecasts. Here the inflation-indexed bond market provides exactly the information desired. The difference between interest rates on nominal government bonds and those on inflation-indexed bonds, or what the paper calls "breakeven inflation" and the Federal Reserve Board calls "inflation compensation," serves as a measure of inflation expectations. Such measures can be used as the canary in the coal mine to let monetary policymakers know if inflation expectations are becoming unanchored. Indeed, when I was at Board meetings, I would always ask Jonathan Wright, the other discussant of this paper, what he thought long-run breakeven measures of inflation were telling us about long-run inflation expectations.

As the paper points out, however, there is one big problem with using breakeven inflation measures from inflation-indexed bonds to assess whether long-run inflation expectations are becoming unanchored, namely, the presence of risk and liquidity premiums. The paper demonstrates that these premiums are substantial and seem to vary a lot. Sorting out what drives these premiums is thus key to helping policymakers evaluate what is happening to inflation expectations, and the paper attempts to do that.

The results in the paper raise three issues, however. First, the standard risk premium theories do not seem to explain much of the actual movements in inflation-indexed bond yields. Second, these theories suggest that inflation-indexed bonds should be good hedges against both consumption risk and equity risk, in which case inflation-indexed bonds should have a negative risk premium. Yet, to the contrary, they seem to have a positive risk premium. Both of these findings suggest that the existing theories do not tell us much about why liquidity and risk premiums vary. Third, it appears that a lot of the fluctuation in real yields on inflation-indexed bonds is due to institutional factors. This became very apparent during the recent period of financial market stress, when there were huge swings in these yields. However, as the paper points out, how these institutional factors affect real yields on these bonds is not well understood.

The paper's bottom line is that financial economists do not yet understand what causes the risk and liquidity premiums on inflation-indexed bonds to move around. This means that extracting information from these bonds about expected inflation is not easy.

A striking example of this problem was occurring at the time of this conference. As the paper shows, long-run breakeven inflation as measured by the difference in bond yields declined precipitously as the economy went into a tailspin. Does this mean that long-run inflation expectations became unanchored in the downward direction? If so, the situation was dangerous indeed, because it meant that deflation was more likely to set in, and aggressive monetary policy to prevent this unanchoring of inflation expectations was called for. Yet because one could not be sure what was happening to the risk and liquidity premiums on inflation-indexed bonds, neither could one be sure that this decline in breakeven inflation really meant that long-run inflation expectations had fallen.

Even though there was still some uncertainty about what inflation-indexed bonds were saying about long-run inflation expectations, I do think the sharp fall in breakeven inflation was cause for worry—that the dangers of deflation were real. To me this suggests that it is even more imperative that the Federal Reserve take steps to anchor inflation expectations better. This is why I have argued, both when I was a governor of the Federal Reserve and afterward,[2] that if ever there was a time for the Federal Reserve to announce an explicit, numerical inflation objective, that time is now.

2. Mishkin (2008); Frederic S. Mishkin, "In Praise of an Explicit Number for Inflation," *Financial Times,* January 12, 2009, p. 7.

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COMMENT BY

JONATHAN H. WRIGHT It is now just over a decade since the United States began issuing inflation-linked Treasury bonds. This paper by John Campbell, Robert Shiller, and Luis Viceira is a timely and excellent analysis of what has been learned from the pricing of these new securities and their counterparts in other countries. TIPS yields have been more volatile than might have been anticipated. Campbell, Shiller, and Viceira discuss the reasons why this is so before turning to the most topical issue, namely, explaining the behavior of TIPS in the recent financial crisis.

ARE RISK PREMIUMS ON INFLATION-INDEXED BONDS POSITIVE OR NEGATIVE? Abstracting for the moment from issues of liquidity, the yield on an inflation-linked bond is the sum of the average expected real short-term interest rate over the life of the bond and a risk premium. Campbell, Shiller, and Viceira use both a consumption-based model of asset pricing and a capital asset pricing model to argue that the risk premium on TIPS ought to be low or even negative. That would make them an ideal instrument for a Treasury seeking to minimize expected debt-servicing costs.

Some simple pieces of empirical evidence can be brought to bear on the question of the typical sign of the risk premium on such bonds. The average 5-to-10-year-forward TIPS yield from January 2003 to August 2008 was 2½ percent. If the risk premium on TIPS is zero or negative, this means that the expectation of r^*, the equilibrium real short-term interest rate, must be at least 2½ percent (abstracting from any liquidity premium, but this was a time when TIPS liquidity was generally good). This seems a rather high number. Expectations of real short-term interest rates 5 to 10 years hence, computed from the twice-yearly Blue Chip survey of economic forecasters, are volatile but were around 2 percent over this period. This reasoning suggests that risk premiums on TIPS are positive.

Table 1. Average Slopes of Forward Yield Curves on Nominal and Inflation-Linked Government Bonds[a]
Basis points

Bond	*United Kingdom*	*United States*
Nominal	0.5	28.2
Inflation-linked	–6.5	13.7

Sources: Bank of England data; Federal Reserve research data (Gürkaynak, Sack, and Wright 2007, forthcoming).
a. Spread of six-year-ahead over five-year-ahead continuously compounded instantaneous forward rates for U.K. and U.S. yield curves; the spread is averaged over all days from the start of January 2003 to the end of August 2008.

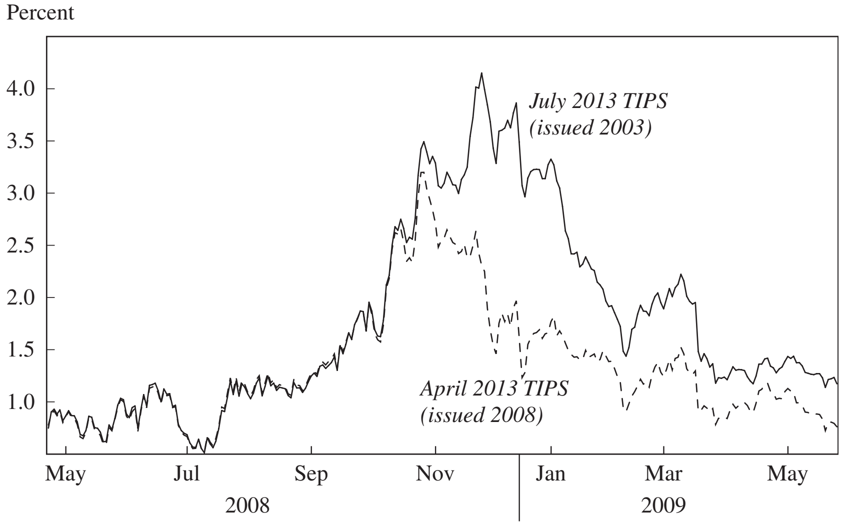
Another simple calculation uses the slope of the yield curve for inflation-linked bonds. In normal circumstances one might suppose that expectations of real short-term interest rates 5 to 10 years hence are fairly flat. If the forward TIPS yield curve at those horizons slopes up, that would suggest that term premiums are positive, and if the curve slopes down, it would suggest that they are negative. Table 1 shows the average slopes of the forward (five to six years out) yield curves on nominal and inflation-linked bonds in the United States and in the United Kingdom over the period from January 2003 to August 2008.[1] In the United Kingdom the yield curve for nominal bonds slopes up whereas the yield curve for inflation-linked gilts slopes down—evidence for the view expressed in the paper. In the United States the evidence is not so clear: the inflation-linked curve is flatter than the nominal one, but both slope up.

Taken together, this simple evidence does not seem to me to support the view that risk premiums on TIPS have typically been negative, although I agree that they are much lower than their nominal counterparts.

THE TIPS MARKET AND THE FINANCIAL CRISIS. Since the collapse of Lehman Brothers in September 2008, yields on inflation-linked and nominal bonds have decoupled and have been exceptionally volatile. The yields on some inflation-linked bonds rose above their nominal counterparts, making the breakeven inflation rate negative. This could represent either a fear of deflation or special demand for the comparative liquidity of nominal securities. Knowing which it is matters a lot. Indeed, it is surely the most important thing to understand from the TIPS market right now. It is a hard question to answer, but there are some clues.

1. Piazzesi and Schneider (2007) did a similar comparison for an earlier sample period.

Figure 1. Yields on Two TIPS of Comparable Maturity but Differing Issue Dates, 2008–09



Source: Bloomberg data.

TIPS bonds have the feature that the principal repayment cannot be less than the face value of the bond, even if the price level falls over the life of the bond. This gives TIPS an option-like feature in which the "strike price" is the reference CPI (that is, the price level at the time that the bond is issued). For a newly issued bond, any deflation will result in this option being in the money. For a bond issued, say, five years ago, however, deflation has to be very severe—enough to unwind all the cumulative inflation over the past five years—before this deflation option has any value.

This means that one can obtain information on the perceived probability of deflation by comparing the real yields on pairs of TIPS with comparable maturity dates but different reference CPIs. Figure 1 plots the real yields on the April 2013 and July 2013 TIPS. These were issued in 2008 and 2003, and the reference CPIs are 211.37 and 183.66, respectively. Before September 2008, the real yields on these two bonds were comparable, as the deflation option was perceived to be too far out of the money to matter. But subsequently the spread soared to 2 percentage points. The natural interpretation is that investors started to put substantial odds on deflation taking hold, increasing the relative attractiveness of the more recently issued TIPS.

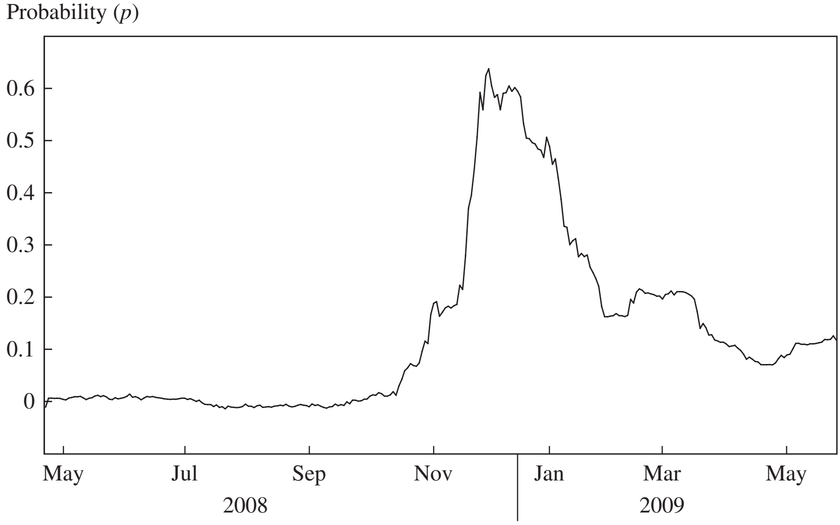
By comparing the yields on these two TIPS, one can calculate a lower bound on the implied probability of deflation over the period until 2013. This requires a number of strong assumptions, including risk neutrality.[2] But the calculation is based on comparing two TIPS yields, not a TIPS yield with a nominal yield, and so the technical factors that Campbell, Shiller, and Viceira cite as pushing down TIPS prices in the fall of 2008 should not distort this calculation, unless they affected one TIPS issue more than the other. Figure 2 shows how this implied probability of deflation evolved over time. From around zero before September 2008, it soared to over 60 percent before falling back to about 10 percent early in 2009. Again, the calculation embeds many strong assumptions, but it is only a lower bound, and so it seems reasonable to think that fear of deflation explains a significant part of the unusual behavior of TIPS last fall. That fear is now much reduced but has not entirely gone away.

Fear of deflation was surely not the only influence on inflation-linked bonds over this period; issues that come under the broad heading of liquidity were important, too. Campbell, Shiller, and Viceira make a compelling case that TIPS prices were depressed last fall as leveraged investors were

2. Here are the mechanics of the calculation. Pretend that the April 2013 and July 2013 TIPS are both zero-coupon bonds maturing June 1, 2013, and are identical apart from their reference CPIs. Let m denote the remaining time to maturity in years. Let x denote the CPI at the maturity date, and $f(x)$ and $F(x)$ the probability density and cumulative distribution functions of x, respectively. Assume that agents are risk-neutral. The reference CPIs are $x_u = 211.37$ and $x_l = 183.66$ for the April 2013 and the July 2013 bond, respectively, so that their principal repayments per dollar of face value are $\max(1, x/x_u)$ and $\max(1, x/x_l)$, respectively. Under these assumptions, the difference between the July 2013 and the April 2013 continuously compounded TIPS yields is $r = \frac{1}{m}\left\{\ln\frac{x_u}{x_l}F(x_l) + \int_{x_l}^{x_u}\ln\left(\frac{x_u}{x}\right)f(x)\,\mathrm{d}x\right\}$, which means that $r \leq \frac{1}{m}\left\{\ln\left(\frac{x_u}{x_l}\right)F(x_l) + \int_{x_l}^{x_u}\ln\left(\frac{x_u}{x_l}\right)f(x)\,\mathrm{d}x\right\} = \frac{1}{m}\ln\left(\frac{x_u}{x_l}\right)F(x_u)$. So the risk-neutral probability of deflation (that is, of the price index in 2013 being below $x_u = 211.37$, which is also approximately its current level) is bounded below as $F(x_u) \geq \frac{rm}{\ln(x_u/x_l)}$.

This is the probability shown in figure 2. The assumptions made are strong, and it is possible that part of the spread between the two TIPS represents instead a premium for the greater liquidity of the on-the-run issue, the April 2013 TIPS. However, there has never been much evidence of an on-the-run premium in the TIPS market, and qualitatively similar spreads between other pairs of TIPS issues with close maturity dates but different reference CPIs can also be observed since early fall 2008.

Figure 2. Probability of Deflation as Calculated from TIPS of Differing Issue Dates, 2008–09



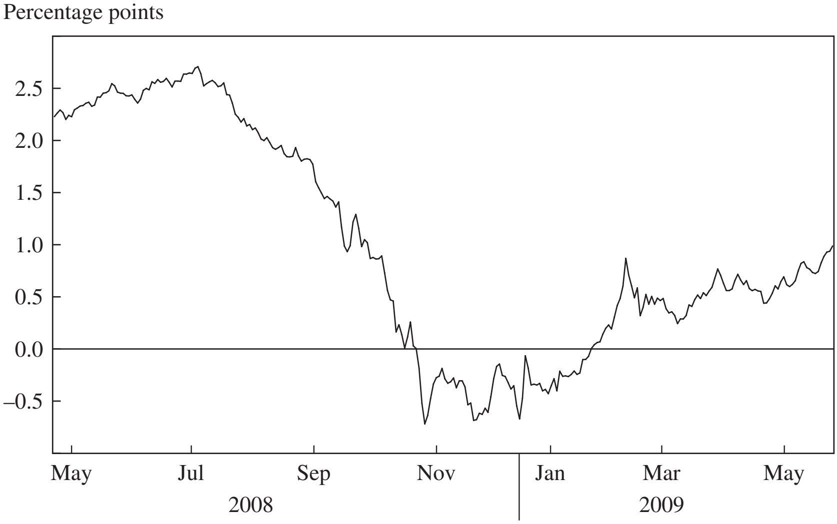
Source: Authors calc ulations.

forced to unwind large TIPS positions quickly.[3] Refet Gürkaynak, Brian Sack, and I (forthcoming) estimate that worsening liquidity pushed up five-year TIPS yields by more than a percentage point in the fall of 2008. The issue of liquidity can be seen starkly by comparing the yield on the April 2013 TIPS with the yield curve on nominal Treasury bonds. Because this TIPS was issued in 2008 (when the CPI was around its current level), and because the inflation adjustment to the TIPS principal cannot be negative, this particular TIPS effectively becomes a nominal security in the event of deflation,[4] while of course it pays off more than a nominal security in the event of inflation. Thus, the payoff on this security stochastically dominates the payoff on a nominal Treasury bond of corresponding

3. As Campbell, Shiller, and Viceira point out, the divergence between TIPS breakeven rates and rates quoted on inflation swaps is strongly suggestive of distressed TIPS sales. However, the inflation swaps market in the United States is tiny, with a trading volume roughly 1 percent of that in TIPS. One might be hesitant to read too much into prices from such a small and illiquid market.

4. This neglects the inflation adjustment to the coupon, which can be negative. The coupon rate on the April 2013 TIPS is tiny (five-eighths of a percentage point), and so even a sizable deflation should have only a small effect on the pricing of the security through coupon indexation.

Figure 3. Yield Spread between Nominal Treasury Bonds and the Most Recently Issued Five-Year TIPS[a]



Source: Bloomberg data and author's calculations using the Federal Reserve Board's smoothed yield curve.

a. Yield on nominal Treasury securities minus the yield on April 2013 TIPS (both securities of comparable maturity).

maturity. Figure 3 shows that the yield spread between the April 2013 TIPS and comparable-maturity nominal Treasury bonds went *negative* for an extended period in late 2008 and early 2009, and it was large and negative at times. This makes no sense from a standard asset pricing perspective, as it means that investors were leaving an arbitrage opportunity on the table. And even though the spread is now positive once again, it remains remarkably low given that there are surely sizable odds in favor of a pickup in inflation between now and 2013.

Lawrence Summers (1985) once quipped that financial economics entailed simply checking that two-quart bottles of ketchup sold for twice as much as one-quart bottles. Alas, it is not so any more—there have recently been many examples of investors seemingly leaving arbitrage opportunities unexploited. The comparison between the April 2013 TIPS yield and the nominal yield curve is one example. A second is the fact that the yield on old 30-year Treasury bonds is systematically higher than the yield on off-the-run 10-year notes of the same maturity. Another is that the yields on Resolution Funding Corporation (Refcorp) bonds, which are guaranteed by the Treasury,[5] are nonetheless substantially higher than yields on ordinary Treasury securities of comparable maturity.

All these Treasury market anomalies are conventionally treated as the effects of a "liquidity premium." For example, the cheapness of TIPS could be thought of as the compensation that investors demand for the poor liquidity of these instruments relative to nominal bonds. But TIPS are mainly bought by buy-and-hold investors, and bid-ask spreads on these securities are tiny. The cheapness of TIPS thus cannot really be rationalized as simply amortizing the transactions costs of a long-term investor. Moreover, as figure 4 shows, trading volume in TIPS (from the New York Federal Reserve Bank's survey of primary dealers) has declined but is still around its level in 2003. All this indicates to me that the TIPS liquidity premium has to have some explanation beyond just transactions costs. As Campbell, Shiller, and Viceira indicate, this explanation might be along the lines of a segmented market with arbitrageurs who rationally pass up hold-to-maturity arbitrage opportunities at times of market stress (Greenwood and Vayanos 2008; Shleifer and Vishny 1997).[6]

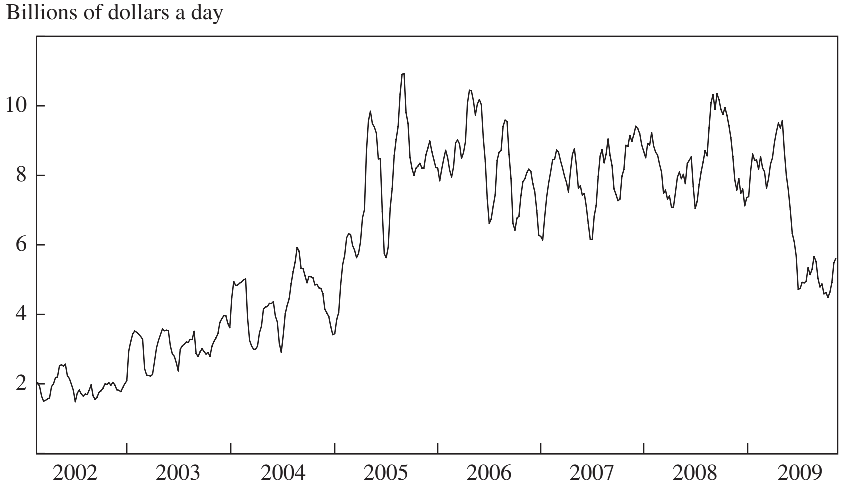
CENTRAL BANK PURCHASES OF TIPS. In standard equilibrium asset pricing models, a decision by the Federal Reserve to purchase bonds should do nothing to their price, unless expectations of future short-term interest rates are thereby affected (Eggertsson and Woodford 2003). Sufficiently large purchases would result in a corner solution in which the Federal Reserve owned all of the particular security being purchased, but the price would still be unaffected. However, if markets are segmented and highly illiquid, this story may break down.

The reaction to the announcement following the March 2009 Federal Open Market Committee (FOMC) meeting is a telling "event study" of the effects of central bank purchases. On that occasion the FOMC surprised market participants by announcing that the Federal Reserve would buy \$300 billion in Treasury securities. The yield curves for both nominal and inflation-linked securities right before and after this announcement are shown in figure 5. Both moved down sharply, but the TIPS yield curve moved even more, especially at shorter maturities. The magnitude of this

5. This is not just the implicit guarantee that could be thought to apply to agency securities in general. Rather, Refcorp bonds have principal payments that are fully collateralized by nonmarketable Treasury securities and coupon payments that are guaranteed by the Treasury under the Financial Institutions Reform, Recovery, and Enforcement Act.

6. One way to improve TIPS market functioning might be to encourage the formation of a TIPS futures market. Such a market would make hedging cheaper and easier while improving liquidity in the cash market as well.

Figure 4. Trading Volume in TIPS, 2002–09[a]

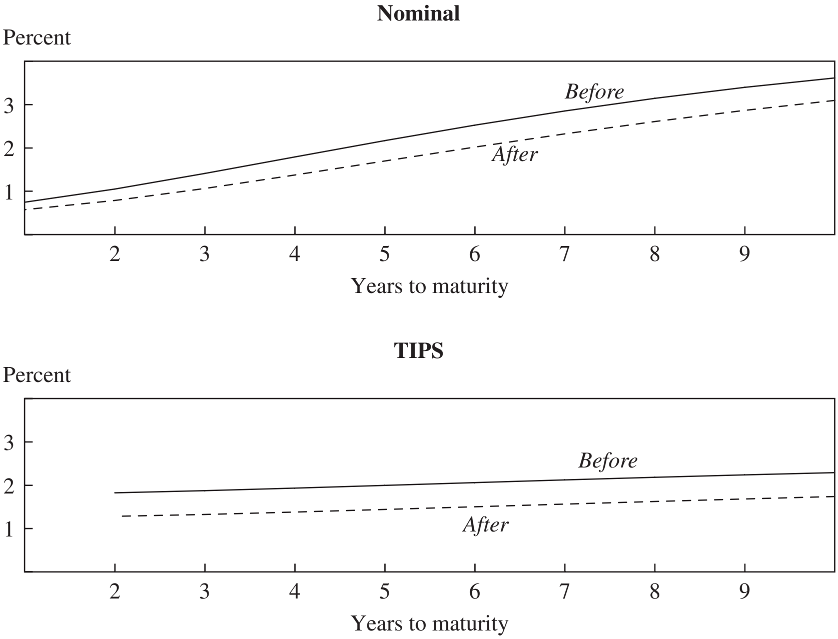


Source: Federal Reserve Bank of New York FR 2004 survey.
a. Eight-week moving average of interdealer volume in TIPS.

decline was far more than is consistent with what investors could have learned from the announcement about the expected path of future short-term interest rates. Other announcements of this sort by the Federal Reserve and by foreign central banks have had comparable effects. This indicates that central banks can indeed drive down longer-term interest rates by direct purchases of securities, at least at times of market stress. Of course, aggregate demand is more sensitive to the long-term interest rates paid by households and businesses than to Treasury yields. But lower Treasury rates could nonetheless spill over into private sector borrowing costs. More important, if changing asset supply affects prices in the Treasury market, then the same should be true in the markets for corporate bonds and mortgage-backed securities, meaning that the Federal Reserve could improve financial conditions by buying assets in these markets, too.

CONCLUSIONS. TIPS contain valuable information for economists and policymakers. In normal times they can be used to infer expectations of inflation and real short-term interest rates. They still can, but in the financial crisis that began last year, the most important information these securities provide is of how dysfunctional asset markets were and, to a large extent, still are. I emphasize two conclusions. First, in a financial crisis, markets are segmented and illiquid, and changes in effective asset supply brought about by Federal Reserve purchases can and evidently do have large effects on

Figure 5. Nominal and TIPS Yield Curves before and after the March 2009 FOMC Announcement[a]



Source: Federal Reserve Board estimates.
a. Data are as of the late afternoon of March 17 (before) and 18 (after).

prices. Second, policymakers and the press are often obsessed with finding the "market price" of extraordinarily opaque securities. TIPS are extremely simple securities. If, for whatever reason, the market cannot price TIPS coherently, then any faith in the ability of the market to come up with the textbook valuation of esoteric financial instruments seems quite misplaced.

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GENERAL DISCUSSION Matthew Shapiro agreed that market segmentation likely accounted for the spike in the TIPS yield in November. He suggested that hedge funds and other institutions were desperate for liquidity at that time. TIPS were among the few assets that were holding their value reasonably well, and so they were among the assets that got dumped on the market, thus revealing substantial segmentation between the market for indexed and that for nonindexed Treasury securities. Shapiro also suggested that with the breakdown of the barrier between fiscal and monetary policy observed in the response to the financial crisis, TIPS were an increasingly important tool for jointly disciplining fiscal and monetary policy. He speculated, however, that in the event of a hyperinflation, Congress might impose a windfall profits tax on the inflation indexation component of TIPS returns.

Ricardo Reis noticed that both expected inflation and the differential between TIPS and nominal bond yields had remained stable until around 2006, when the relationship started to break down. He compared this to the movement in oil prices shown in James Hamilton's paper in this volume. Oil prices went up and then came down by a lot, which, Reis felt, could have changed perceptions of what was happening to oil prices even at a 10-year horizon. He proposed that expectations of movements in the price of oil might account for part of the risk and liquidity premiums observed in TIPS prices, given that the Federal Reserve targets core inflation, which excludes oil, whereas TIPS are indexed to overall inflation. Reis also suggested that much of CPI inflation is actually relative price inflation, which would impact TIPS' hedging potential. His own research with Mark Watson found that 75 percent of annual variation, and 85 percent of quarterly variation, in the CPI is due to relative price changes. The results diminish over longer time horizons but are still in the range of 5 to 40 percent at a 10-year horizon. He suggested that relative price changes may also capture changes in the relative productivity of different sectors, providing a possible hedging opportunity in expected inflation based on relative productivity changes between sectors.

Alan Blinder observed that traditional monetary policy theory says that the central bank can manipulate nominal things but cannot manipulate real things, including real interest rates, and especially long-term real rates. He interpreted the evidence in the paper as showing that this theory is not just slightly wrong but very wrong. The paper's findings, in his view, are relevant to formulas such as the Taylor rule, where the real interest rate is usually assumed to be constant at 2 percent and it is the other factors that change. As a long-time advocate of inflation-linked bonds, Blinder had been excited when Campbell and Shiller's 1996 paper put an actual number on the likely interest rate savings to the Treasury. That paper, he recalled, said that TIPS should be cheaper for the Treasury because they were less risky to bondholders and would therefore pay a lower rate of return. In reality, they have not paid a lower rate, which, Blinder reasoned, was due to their lesser liquidity compared with nominal bonds. He wondered whether the main message of the paper was that economists have been focusing too much on risk and not enough on liquidity.

James Hamilton asked whether TIPS served equally well as nominal Treasuries as collateral for credit default swaps. John Campbell answered that he did not believe so but was unsure whether the difference was large and how much of the yield spread it would explain. He noted that there are other costs to using TIPS, such as larger "haircuts," which make their use as collateral less standard.

Benjamin Friedman expressed surprise that both the paper and the discussion thus far had proceeded entirely on a pre-tax basis. He suggested that differential taxation might impact TIPS' hedging properties, especially now that tax rates for individuals are lower on qualified dividends.

Michael Woodford commented on whether recent TIPS behavior indicated market segmentation. He felt this to be the most obvious explanation, but he disagreed with Jonathan Wright's hypothesis that market segmentation implies that Federal Reserve purchases of Treasury securities should be an effective way of stimulating aggregate demand. He instead proposed that as a result of market segmentation, a policy designed to lower TIPS yields (or other long-term Treasury yields) may change only the relationship of those yields to other real interest rates; the desired effect of such a policy, that of affecting the terms on which others can borrow, need not occur.

Justin Wolfers included himself among those economists who have always been hopeful that prices contain a lot of embedded information. Looking at the prices reported in the paper, however, he was glad that he was not a macrofinance economist looking for structural interpretations of price movements, because the conclusion he felt drawn to was that market prices are informative except when they are not. He recommended that the authors try to provide some guidance on determining under what circumstances TIPS prices will be uninformative.

Steven Davis was struck by the evidence for a market segmentation interpretation of TIPS behavior and said he would have liked to see a more thorough explanation of the extent, nature, and importance of that segmentation. He suggested that the authors conduct additional exercises that would help pinpoint where the segmentation occurs: is it between TIPS and nominal Treasuries, across different vintages and payoff horizons of TIPS themselves, or in markets that are thinly traded versus those that are not? Understanding this would be useful, he believed, in determining when drawing inferences from these securities about expectations and inflation might be more problematic. He also wanted to know whether the observed asset pricing anomalies occurred only in a very thinly traded, less important part of the market or were endemic to the system as a whole.

David Romer thought that segmentation was perhaps too easy an explanation and proposed instead that certain features of the market may dissuade people from arbitraging TIPS. It would be worth asking professional investors why TIPS do not provide a riskless opportunity or whether some sort of agency problem inhibits their purchase.

Gregory Mankiw addressed Alan Blinder's comment that a major argument for the creation of TIPS had been their lower cost of financing for the Treasury. He wondered whether that argument had been the primary one, and, if it had and now turned out to be wrong, whether Blinder felt that TIPS had been a mistake and should be phased out. Blinder responded that it had been the primary argument and that TIPS were a mistake from that perspective, but that TIPS should not therefore disappear, because they still provide a low-risk investment vehicle for investors, albeit at a cost to taxpayers.

Jonathan Wright addressed the question of whether purchases of large quantities of Treasuries would affect corporate borrowing and mortgage interest rates. The Federal Reserve's announcement of Treasury purchases had had some impact on these rates, but it was small. He suggested that the apparent market segmentation meant that the Federal Reserve could lower the interest rates paid by households and businesses more substantially, but only by buying assets that are riskier than Treasury securities, including securities with ratings below triple-A.

Janice Eberly remarked, in response to David Romer's comment, that a great deal of research is being conducted on markets for bonds similar to Treasuries that are trading at much higher premiums. For example, student loans, which are 97 percent guaranteed by the Treasury, trade at prices 200 basis points higher than Treasuries with the same maturity. The research she described is attempting to determine whether certain features of TIPS, like the deflation option, explain some of the difference, or whether characteristics of the other securities explain it, or whether market segmentation is the explanation.

Luigi Zingales further addressed David Romer's question by sharing answers given by a University of Chicago faculty member turned bond trader. The trader's explanation relied primarily on liquidity. After the Lehman Brothers collapse, the lenders who had to repossess the securities offered as collateral by Lehman discovered that they had to suffer losses when they liquidated a large amount of these relatively illiquid bonds. The differentiation in corporate bonds issued by the same entity makes the market for these securities segmented and thus less liquid. When many lenders dumped bonds on the market at the same time, they could not get full price because there were too few buyers. Without collateralized lending, it was more difficult to exploit arbitrage opportunities. As a result, many arbitrage opportunities became available. When many violations of arbitrage are occurring at the same time, Zingales thought it likely that traders with limited resources would focus on the low-hanging fruit, acting on the easiest and most profitable opportunities while ignoring others.