Information Content of Inflation-Indexed Bond Prices: Evaluation of U.S. Treasury Inflation-Protection Securities

Yukinobu Kitamura

In January 1997, the U.S. Treasury started issuing Treasury Inflation-Protection Securities (TIPS; hereafter TIPS and indexed bonds interchangeably) and, as of September 2002, a total of 10 issues were being traded on the market, while one issue had already matured. The purpose of this paper is to attempt an evaluation of indexed bonds based on the record of five and a half years of market trading in TIPS, and to present the results as a reference for the issue of similar securities by the Japanese government in the future. The results of this paper are as follows. (1) Real interest rates are relatively stable and remain near the 4 percent mark. The 30-year bond is even more stable. (2) The expected inflation rate is more closely linked to the realized consumer price index (CPI) than to the real yield. However, the expected inflation rate is far more stable and its fluctuations smaller. In particular, the 30-year bond is steady, near the 2 percent mark. (3) While the economic information derived from the 10-year bond is strongly influenced by short-term economic fluctuations, the economic information derived from the 30-year bond is generally unresponsive to short-term economic fluctuations. (4) Examination of the derived information using econometric methods indicates that useful economic information was obtained from the following indexed bonds in the secondary markets: Series Three and Four 10-year bonds. Hence, while a total of 11 indexed bonds have been issued, very few of them have proven to be truly useful. These useful bonds turn out to have fair initial conditions, are continuously arbitraged with the nominal bonds, and trade actively in the secondary markets.

Keywords: Inflation-indexed bond; Expected inflation rate; Real yield
JEL Classification: E31, E44, G14

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I. Introduction

In January 1997, the U.S. Treasury started issuing Treasury Inflation-Protection Securities (TIPS; hereafter TIPS and indexed bonds interchangeably) and, as of September 2002, a total of 10 issues were being traded on the market, while one issue had already matured. The purpose of this paper is to attempt an evaluation of indexed bonds based on the record of five and a half years of market trading in TIPS, and to present the results as reference for the issue of similar securities by the Japanese government in the future.

Table 1 provides the simplest form of comparison for the five-year indexed bond that matured in July 2002 by pairing it with the nominal bond with the closest issue (maturity) date. The indexed bond paid back a total of US$131.5344, while the paired nominal bond paid US$130, indicating that the government did not recoup the cost of the finances involved. On the other hand, investors did not substantially benefit during this period from the opportunity of being able to avoid inflationary risks by holding the indexed bond. Hence, the yield was not particularly high. An objective assessment of the figures indicates that the market mechanism had worked toward achievement of *ex post* arbitrage. A more detailed review of the cash flow of the indexed bond shows that interest payments amounted to US$19.2681, while the inflation-adjusted principal amounted to US$112.2664. As the nominal bond generated US$30 in interest payments, the nominal bond outperformed the indexed bond in the area of interest cash flow. However, the redeemed principal of the indexed bond was substantially larger, as the principal was indexed.[1]

Indexed bonds have been issued by a total of 30 countries. Major examples of such issues are outlined in Table 2, which shows that in most instances the issuance of indexed bonds began after the start of the 1990s. While this in part reflects the

Table 1 Cash Flow of Nominal Bond Paired with Series One Five-Year Indexed Bond

Indexed bond		Nominal bond	
Payment date	Yield	Payment date	Yield
Jan. 15, 1998	1.8283	Jan. 31, 1998	3.0000
July 15, 1998	1.8406	July 31, 1998	3.0000
Jan. 15, 1999	1.8560	Jan. 31, 1999	3.0000
July 15, 1999	1.8809	July 31, 1999	3.0000
Jan. 15, 2000	1.9041	Jan. 31, 2000	3.0000
July 15, 2000	1.9380	July 31, 2000	3.0000
Jan. 15, 2001	1.9697	Jan. 31, 2001	3.0000
July 15, 2001	2.0061	July 31, 2001	3.0000
Jan. 15, 2002	2.0095	Jan. 31, 2002	3.0000
July 15, 2002	2.0348	July 31, 2002	3.0000
Subtotal	19.2681	Subtotal	30.0000
Principal payment	112.2664	Principal payment	100.0000
Total receipt	131.5344	Total receipt	130.0000

1. In the United Kingdom, the coupons are stripped and traded separately. Indexed bonds are back-loaded in the sense that cash flow increases in the second half as maturity nears because of the inflation adjustment effect.

Table 2 Countries Issuing Indexed Bonds

Country	Issue date	Index used
Argentina	1972–89	Non-agricultural wholesale price
Australia	1983–	Consumer prices
	1991	Average weekly earnings
Austria	1953	Electricity prices
Brazil	1964–90	Wholesale prices
	1991–	General prices
Canada	1991–	Consumer prices
Chile	1966–	Consumer prices
Colombia	1967	Wholesale prices
	1995–	Consumer prices
Czech Republic	1997–	Consumer prices
Denmark	1982–	Consumer prices
Finland	1945–67	Wholesale prices
France	1952, 1973	Gold price
	1956	Level of industrial production
	1956	Average value of French securities
	1957	Price of equities
Greece	1997–	Consumer prices
Hungary	1995–	Consumer prices
Iceland	1955–	Consumer prices
	1964–80	Cost of building index
	1980–94	Credit Terms Index
	1995–	Consumer prices
Ireland	1983–	Consumer prices
Israel	1955–	Consumer prices
Italy	1983	Deflator of GDP at factor cost
Mexico	1989–	Consumer prices
New Zealand	1977–84	Consumer prices
	1995–	Consumer prices
Norway	1982	Consumer prices
Poland	1992–	Consumer prices
Sweden	1952	Consumer prices
	1994–	Consumer prices
Turkey	1994–97	Wholesale prices
	1997–	Consumer prices
United Kingdom	1975–	Consumer prices
	1981–	Consumer prices
United States	1742, 1780	Commodity prices
	1997–	Consumer prices

Note: In addition to government bonds, this table includes issues by public corporations, semi-governmental authorities, and those that carry a government guarantee.

Source: Deacon and Derry (1998, table 1.1).

actions taken by such high-inflation countries as Brazil, Turkey, and Mexico, several factors have contributed to growing demand for long-term financial products with built-in inflation hedges. Since their introduction in the United Kingdom in 1981, pension funds, life insurance companies, and other institutional investors have been increasingly drawn to indexed bonds, in light of the aging of society. Indexed bonds also provide various advantages to issuers and have come to be recognized as a standard financial asset issued by governments. For instance, they have been used as a means of inflation control and fiscal discipline to bolster market confidence. Furthermore, the expected inflation rate can be unambiguously derived from market prices. With the adoption of inflation targeting by a growing number of countries during the 1990s, most of them issue indexed bonds to serve as a source of market information on inflation.[2]

This paper is organized as follows. Section II describes how U.S. TIPS are traded. Section III compares the indexed bonds with the nominal bonds in terms of coupon rates and market prices, and examines the statistical properties of the real yields and expected inflation rates. In Section IV, the purpose is not to define a specific price model for indexed bonds, but rather to identify the features of price formation. Specifically, we verify the efficiency of the bond market by testing for the random-walk hypothesis and examine whether bond prices are being affected by other market information. As such, we are interested in determining whether fluctuations in trading prices are being significantly affected by factors other than changes in the expected rate of inflation, such as the prices of other financial products, equities, foreign exchange rates, the federal funds (FF) rate and bid-ask spreads. In Section V, expected inflation rates derived jointly from the indexed and nominal bonds are examined econometrically. The information content of expected inflation rates is evaluated by the inflation forecasting model and the FF rate forecasting model. Section VI provides a summary in the form of an evaluation of the U.S. TIPS for the first five and a half years.

II. Structure of U.S. TIPS

As of June 2001, the outstanding balance of U.S. TIPS amounted to US$129.3 billion, equivalent to 2.3 percent of the total outstanding U.S. government bonds. Compared to the United Kingdom, where indexed bonds held a 24.0 percent share as of September 2001, the U.S. figures indicate that the market scale remains small.

The structure of TIPS can be summarized as follows.

First, ensuring the real value of interest and principal requires indexation. The Treasury Department does this by multiplying the principal by the ratio between the Consumer Price Index for All Urban Consumers (CPI-U) as measured three months prior

2. Countries appearing in Table 2 that have adopted inflation targeting are Australia, Brazil, Canada, Chile, the Czech Republic, Israel, New Zealand, Poland, Sweden, and the United Kingdom. To control inflation via day-to-day monetary operations, the central banks need daily information about the expected inflation rates, rather than one-month lagged CPI monthly data. For this, it is desirable to obtain daily expected inflation rates by issuing inflation-indexed bonds. Note, however, that many countries which have issued indexed bonds have not adopted inflation targeting and that information from indexed bonds can be useful for other monetary policy objectives.

to settlement date and the CPI-U for the first issue date. Specifically, the following formula is used.

$$IR_{SD} = \frac{RefCPI_{SD}}{RefCPI_{FID}}. \tag{1}$$

Daily CPI values are linearly interpolated using the CPI for the first of the month and the first of the following month.

$$RefCPI_{SD} = \frac{RefCPI_{M+(t-1)}}{D\,(RefCPI_{M+1} - RefCPI_{M})}, \tag{2}$$

where D = number of days in the month, t = settlement date, $RefCPI_M = CPI$ for the first day of the month M, and $RefCPI_{M+1} = CPI$ for the first day of the M+1 month.

Inflation compensation (IC) is defined as the difference between the indexed and nominal principals.

$$IC_{SD} = (Prin\ IR_{SD}) - Prin. \tag{3}$$

Twice-a-year interest payments are computed as follows.

$$IP_{DD} = \frac{c}{2}(Prin + IC_{DD}), \tag{4}$$

where c = annual coupon rate, and PD = interest payment date.

Given this definition, the relation between the price and interest payments of TIPS in the secondary markets can be expressed as follows.[3]

(Nominal) price per US$100 face value
= inflation-adjusted price + inflation-adjusted accrued interest. (5)

This relation can be specified as follows.

$$P_{ib} = \frac{RefCPI_{setdate}}{RefCPI_{first}}\left[\left(\frac{1}{1+\frac{f}{d}\frac{r}{2}}\right)\left\{\frac{C_{ib}}{2} + \frac{C_{ib}}{2}\sum_{h=1}^{n}\left(\frac{1}{1+\frac{r}{2}}\right)^{h} + 100\left(\frac{1}{1+\frac{r}{2}}\right)^{n}\right\} - \frac{C_{ib}}{2}\left(\frac{d-f}{d}\right)\right], \tag{6}$$

3. The U.S. Treasury Department guarantees that principal at redemption will not fall below the nominal value, 100, even under deflation. This points to an asymmetry in indexation in the sense that U.S. TIPS are adjusted to guarantee real values under inflation, while nominal values are guaranteed under deflation. As opposed to this, U.K. indexed bonds are also adjusted under deflation to guarantee real amounts. The fact that U.S. indexed bonds guarantee the nominal value of the principal implies that a call option comes into play under deflation. Strictly speaking, the price of this option should also be calculated. This paper does not consider taxes, either.

where P_{ib} = the market price of the indexed bond, d = the number of days between interest payment dates, f = the number of days between the settlement date and the next interest payment date, n = the number of interest payments between the next interest payment date and maturity, C_{ib} = the real coupon rate of TIPS, and r = the real yield.

During the last six months to maturity, cash flow is discounted based on simple interest instead of compound interest.

Similarly, the price of nominal bonds can be expressed as follows.

$$P_{nb}=\left(\frac{1}{1+\frac{g}{e}\frac{R}{2}}\right)\left[\frac{C_{nb}}{2}+\frac{C_{nb}}{2}\sum_{j=1}^{m}\left(\frac{1}{1+\frac{R}{2}}\right)^{j}+100\left(\frac{1}{1+\frac{R}{2}}\right)^{m}\right]-\frac{C_{nb}}{2}\left(\frac{e-g}{e}\right), \tag{7}$$

where P_{nb} = the market price of the nominal bond, e = the number of days between interest payment dates, g = the number of days between the settlement date and the next interest payment date, m = the number of interest payments between the next interest payment date and maturity, C_{nb} = the nominal coupon rate, and R = the nominal yield.

The following relation holds when arbitrage takes place between the nominal bond and TIPS interest rates.

Because $(1+r)(1+p)=(1+R)$,

$$r=\frac{1+R}{1+\pi}-1=\frac{R-\pi}{1+\pi}\quad\text{or}\quad\pi=\frac{R-r}{1+r}. \tag{8}$$

In other words, if the yield of the nominal bond (R) and the yield of TIPS (r) are known, it is possible to compute the expected inflation rate (p).

III. Overview of TIPS

A. Conditions at Issuance and Price Spreads

Let us review the data used in this paper. Table 3 provides a summary of conditions at issuance and market price spreads between the indexed and nominal bonds.

The prices of nominal bonds are constantly higher for the Series One 10-year and Series Three 30-year bonds and the standard deviations of prices are higher accordingly. Those for the Series One and Two 30-year bonds are continually higher for the indexed bonds. The price spreads for the 30-year bonds may exist due to the inflation risk premium for the long-term securities, given that the coupon rate spreads are, more or less, the same as for the 10-year bonds.

The price spreads for the Series One five-year and the Series Two to Seven 10-year bonds are not so large; the time series of market prices reveal equilibrium between the indexed and nominal bonds.

Table 3 Indexed Bond and Nominal Bond Pair

Indexed bond				Nominal bond				Price spread		
	Issue date	Issue amount	Interest rate (percent)		Issue date	Issue amount	Interest rate (percent)	Number of observations	Mean	Std. div.
Series One 10-year	Jan. 15, 1997	171	3.375	TB1	Feb. 15, 1997	131	6.250	1,521	–5.56	3.20
Series One five-year	July 15, 1997	181	3.625	TB2	July 31, 1997	122	6.000	1,205	–1.32	1.58
Series Two 10-year	Jan. 15, 1998	180	3.625	TB3	Feb. 15, 1998	136	5.500	1,266	–1.18	2.53
Series One 30-year	Apr. 15, 1998	179	3.625	TB4	Aug. 15, 1998	118	5.500	1,132	3.16	4.29
Series Three 10-year	Jan. 15, 1999	167	3.625	TB5	May 15, 1999	148	5.500	942	1.23	1.96
Series Two 30-year	Apr. 15, 1999	207	3.875	TB6	Feb. 15, 1999	114	5.250	960	11.92	3.32
Series Four 10-year	Jan. 15, 2000	116	4.250	TB7	Aug. 15, 1999	274	6.000	767	0.67	1.99
Series Five 10-year	Jan. 15, 2001	110	3.500	TB8	Feb. 15, 2001	234	5.000	487	1.44	1.80
Series Three 30-year	Oct. 15, 2001	50	3.375	TB9	Nov. 15, 1999	170	6.250	313	–6.89	3.35
Series Six 10-year	Jan. 15, 2002	60	3.375	TB10	Feb. 15, 2002	248	4.875	229	2.19	1.37
Series Seven 10-year	July 15, 2002	90	3.000	TB11	Aug. 15, 2002	18	4.375	99	2.23	0.77

Note: Unit of issue amount is billion U.S. dollars.

Among these indexed bonds, the Series One five-year bond has already reached its maturity and been redeemed. This bond is ignored below. The Series Seven 10-year bond has been issued only recently and therefore sufficient information is not available at present, so it is omitted from this paper.

B. Real Yields

Let us review the characteristics of real yields obtained from equation (6) (see Figure 1). Real yields continued to climb between February 1997 and February 2002, and thereafter declined. However, the real yield of almost all indexed bonds remains in the 3 percent range. In this context, real yields are higher for bonds with earlier issue dates and lower for more recent issues. For instance, there is a differential of roughly 2 percentage points between the Series One 10-year issue of February 6, 1997 and the Series Six 10-year issue of January 15, 2002.

A careful examination of Table 4 and Figure 1 shows that real yield computed using our method traces a clean term structure. However, indexed bonds only have a history of five and a half years, while most issues have maturities of 10 or 30 years. Hence, the market is divided into two segments: bonds with five to 10 years remaining to maturity, and bonds with 26 to 30 years remaining. The intermediate period of 10 to 25 years is currently empty. Assuming that the U.S. Treasury Department continues to issue indexed bonds every year, it will still take 15 years to achieve a

Figure 1 Real Yield

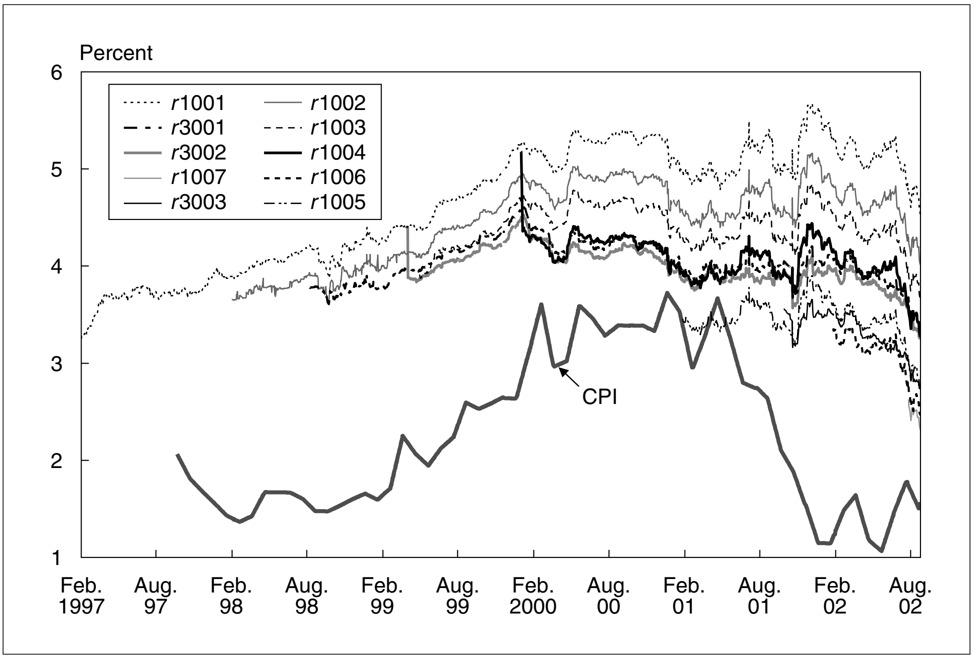


Table 4 Basic Statistics on Real Interest Rates

	Number of observations	Mean	Std. dev.	Min.	Max.
Series One 10-year	1,444	4.634	0.6133	3.2601	5.6737
Series Two 10-year	1,189	4.462	0.4104	3.6206	5.1607
Series Three 10-year	865	4.411	0.2208	3.6574	4.8540
Series Four 10-year	690	4.080	0.2173	3.2791	5.1787
Series Five 10-year	410	3.454	0.2019	2.7346	3.9003
Series Six 10-year	152	3.094	0.2333	2.4711	3.3791
Series One 30-year	1,055	4.039	0.2199	3.3569	4.6288
Series Two 30-year	883	3.990	0.2093	3.2575	4.5296
Series Three 30-year	236	3.311	0.2176	2.7400	3.6573

remaining-period structure with no gaps between zero and 30 years. Figure 2 provides a conceptual diagram of the real interest term-structure based on yields computed at the present time.

Table 5 shows correlations for the real yield that we have calculated. Correlations are high among 10-year bonds and among 30-year bonds, while the correlation between 10-year and 30-year bonds is quite low. The levels of Figure 1 and Table 4 also confirm that our computed real yield has remained steady at high levels in recent years. Sack and Elsasser (2004) have stated that, given the real yield that they have computed, the recent growth in demand for indexed bonds is puzzling.[4] However, based on our data, there is no puzzle here.

4. Judging from Sack and Elsasser (2004, pp. 48–50), their estimations of real yield and the expected inflation rate appear to differ from ours. The methodological differences between their estimations and ours are not clear.

Figure 2 Conceptual Diagram of Term Structure of Real Interest Rate (1997–2002 Average)

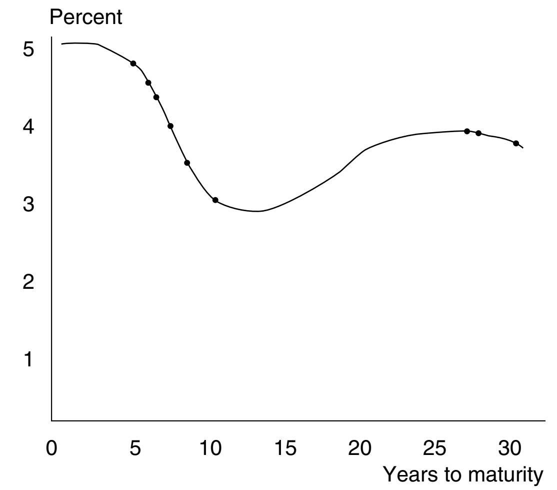


Table 5 Correlation Matrix of Real Yields

	Derived real interest rate									CPI
	Series One 10-year	Series Two 10-year	Series Three 10-year	Series Four 10-year	Series Five 10-year	Series Six 10-year	Series Two 30-year	Series Three 30-year	Series Four 30-year	
Series One 10-year	1.000									
Series Two 10-year	0.992	1.000								
Series Three 10-year	0.971	0.992	1.000							
Series Four 10-year	0.974	0.991	0.998	1.000						
Series Five 10-year	0.969	0.988	0.997	0.999	1.000					
Series Six 10-year	0.960	0.982	0.992	0.994	0.996	1.000				
Series One 30-year	0.834	0.886	0.928	0.928	0.933	0.935	1.000			
Series Two 30-year	0.833	0.886	0.929	0.927	0.933	0.935	1.000	1.000		
Series Three 30-year	0.803	0.859	0.908	0.901	0.903	0.903	0.983	0.984	1.000	
CPI	–0.374	–0.396	–0.404	–0.412	–0.436	–0.443	–0.354	–0.353	–0.256	1.000

Kitamura (1997) computed the real yields for inflation-indexed U.K. government bonds and also found extremely stable trends.[5] This may be explained as follows. If we assume that real yields to a certain degree reflect productivity in the real economy, there is no reason to expect sharp fluctuations.[6] It can be inferred that U.S. real

5. The U.K. inflation-indexed bonds were issued 16 years earlier than the U.S. ones. Their structure was much more complicated. See Kitamura (1997) for the formal structure of the U.K. indexed bonds and derivations of real yields and expected inflation rates. Kitamura (1997) obtained the real yields and expected inflation rates by using monthly data (the end of the month data) and combining different series of bonds.
6. The real yields from the indexed bonds are determined in the financial market, given the expected inflation rates of the investors. Their movements differ substantially from those of the *ex post* real yields obtained from the nominal yields minus the realized historical inflation rate. In general, the expected inflation rate is more stable than the realized historical inflation rate.

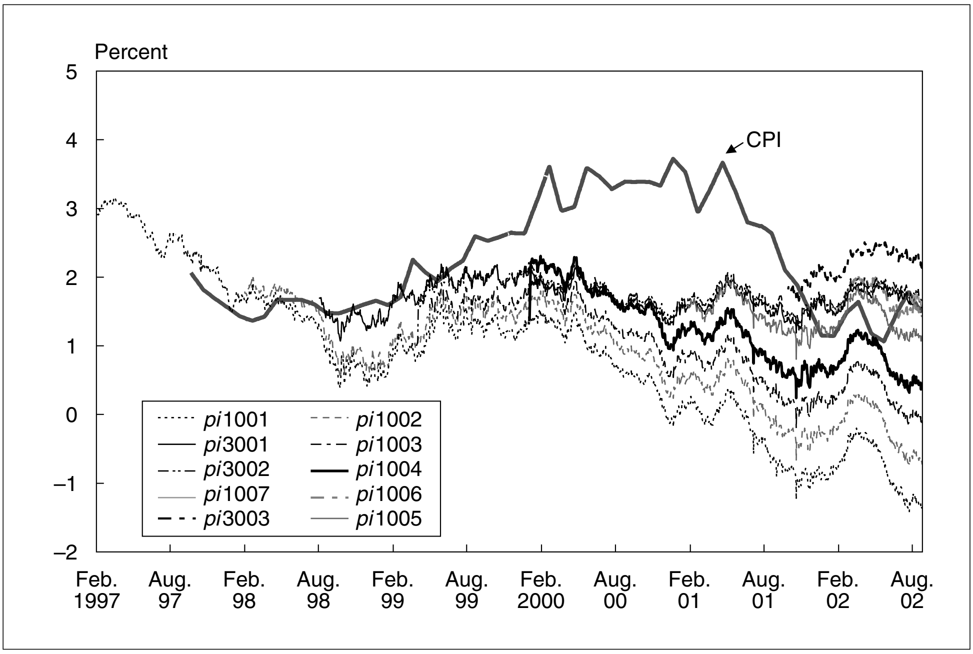
yields, which have been generally stable in the 4 percent range, reflect the trend in real productivity of the U.S. economy. While real yields may fluctuate in response to economic conditions, the level of fluctuation is far smaller than that of the nominal yields observed in the financial markets.

C. Expected Inflation Rates

Assume that pairs of nominal and indexed bonds continue to satisfy arbitrage conditions. Using the procedures outlined in Section II to obtain the nominal yield of nominal bonds and the real yield of indexed bonds, the expected inflation rate can then be defined as the differential between the two yields.[7] The information produced using this method forms the basis of this paper. In a stricter sense, to say that arbitrage is being conducted between nominal and indexed bonds implies that market prices are in equilibrium. Expected inflation rates can be used only in the cases when the pairs are genuinely in equilibrium. This is a subset of all information derived above, and the data become discontinuous. We were able to utilize all of the paired information by relaxing arbitrage conditions.

Figure 3 and Tables 6–7 depict our computer projections for rates of inflation and realized CPI. Regarding the expected inflation rate, unlike the real yields cited above, the computed expected inflation rate fluctuates more widely, and is highly correlated

Figure 3 Expected Rate of Inflation



7. This formula includes the risk premium and liquidity premium that are the subjective variables over time. It is important to identify empirically these premiums from expected inflation rates. In fact, from our experience, we can consider both risk and liquidity premiums to have been negligible or near constant if not negligible, at least for the 10-year bonds over the sample period.

Table 6 Basic Statistics on Expected Rate of Inflation

	Number of observations	Mean	Std. dev.	Min.	Max.
Series One 10-year	1,444	0.847	1.1086	–1.4211	3.1636
Series Two 10-year	1,189	0.840	0.7273	–0.7296	1.9940
Series Three 10-year	865	0.986	0.6106	–0.2055	1.9954
Series Four 10-year	690	1.216	0.5254	0.2396	2.3062
Series Five 10-year	410	1.428	0.2463	0.8065	2.0293
Series Six 10-year	152	1.710	0.2006	1.4068	2.0522
Series One 30-year	1,055	1.697	0.2238	1.0701	2.1880
Series Two 30-year	883	1.790	0.1917	1.0075	2.2088
Series Three 30-year	236	2.179	0.2218	1.6548	2.5116

Table 7 Correlation Matrix of Expected Inflation

	Expected inflation									CPI
	Series One 10-year	Series Two 10-year	Series Three 10-year	Series Four 10-year	Series Five 10-year	Series Six 10-year	Series Two 30-year	Series Three 30-year	Series Four 30-year	
Series One 10-year	1.000									
Series Two 10-year	0.999	1.000								
Series Three 10-year	0.992	0.995	1.000							
Series Four 10-year	0.991	0.994	0.998	1.000						
Series Five 10-year	0.977	0.982	0.993	0.996	1.000					
Series Six 10-year	0.926	0.937	0.961	0.966	0.981	1.000				
Series One 30-year	0.502	0.529	0.590	0.584	0.624	0.696	1.000			
Series Two 30-year	0.510	0.536	0.596	0.589	0.628	0.697	0.998	1.000		
Series Three 30-year	0.258	0.288	0.361	0.350	0.400	0.506	0.929	0.930	1.000	
CPI	–0.396	–0.400	–0.395	–0.372	–0.350	–0.341	–0.274	–0.281	–0.318	1.000

to the CPI. Particularly after the start of 2001, the expected inflation rate derived from 10-year bonds has traced a downward trend closely paralleling that of the CPI. In the case of 30-year bonds, no short-term correlation with CPI trends is formed.

IV. Econometric Analysis of the Market Price of Indexed Bonds

A. Unit Root Test

First, to identify the statistical properties of the market price of indexed bonds, we use the Dickey-Fuller test and the Phillips-Perron test[8] to test whether individual indexed bond prices follow a random walk.

The results are summarized in Table 8. In all cases, the null hypothesis that a unit root exists cannot be rejected at the 1 percent significance level. That is, based on the data used, the hypothesis that indexed bond prices follow a random walk cannot be rejected.

8. For detail in diagnostic tests, see Hamilton (1994, p. 514). Campbell, Lo, and MacKinlay (1997, chapter 2) suggest various tests for autocorrelations and variance ratios, in addition to the unit root test for random walk in financial statistical data.

Table 8 Unit Root Test (Indexed Bond)

[1] Dickey-Fuller Test

	Number of observations	Test statistics $Z(t)$	MacKinnon approximate p-value for $Z(t)$
Series One 10-year	1,159	1.607	0.9949
Series Two 10-year	970	0.591	0.9857
Series One 30-year	912	0.943	0.9915
Series Three 10-year	763	1.078	0.9927
Series Two 30-year	704	1.012	0.9921
Series Four 10-year	551	0.117	0.9667
Series Five 10-year	344	0.557	0.9848
Series Six 10-year	137	0.739	0.9886
Series Three 30-year	188	0.246	0.9738

Note: Significance level: $Z(t)$: 1 percent –3.430, 5 percent –2.860, 10 percent –2.570.

[2] Phillips-Perron Test

	Number of observations	Test statistics $Z(\rho)$	Test statistics $Z(t)$	MacKinnon approximate p-value for $Z(t)$
Series One 10-year	1,159	2.206	1.021	0.9922
Series Two 10-year	970	1.167	0.539	0.9844
Series One 30-year	912	1.756	0.752	0.9889
Series Three 10-year	763	1.296	0.691	0.9878
Series Two 30-year	704	1.469	0.760	0.9890
Series Four 10-year	551	–0.428	–0.220	0.9368
Series Five 10-year	344	–0.045	–0.017	0.9571
Series Six 10-year	137	1.135	0.961	0.9916
Series Three 30-year	188	0.099	0.046	0.9619

Note: Significance level: $Z(\rho)$: 1 percent –20.700, 5 percent –14.10, 10 percent –11.300.
$Z(t)$: 1 percent –3.430, 5 percent –2.860, 10 percent –2.570.

B. Estimating the Price of Indexed Bonds Using Additional Financial Market Information

While the unit root test showed that the proposition that indexed bond prices follow a random walk cannot be rejected, this does not imply that other economic information has no impact on prices. To examine this possibility, we undertook a regression analysis of indexed bond prices and the (indexed) prices of other financial assets, interest rates, foreign exchange rates, and bond prices themselves against lags of one, seven, 15, and 30 days. The results are summarized in Table 9.

The results indicate an excellent fit when the entire series of estimation equations is evaluated based on the values of adjusted R-squares. However, diagnostic tests show that the specification of several models generates problems in the light of other statistical properties. For instance, the RESET test indicates that there were no problems in specifying the models for the Series Four 10-year, Series Two 30-year, Series Five 10-year, and Series Six 10-year bonds and that, in all other instances,

Table 9 Regression Analysis of Indexed Bond

Dependent variable: market price of indexed bond	Series One 10-year		Series Two 10-year		Series One 30-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
Market price of paired nominal bond	0.0172	7.38	0.0300	6.94	0.0419	7.36
FF rate	0.0223	1.65	0.0212	1.07	0.0653	1.64
Yield on three-month T-bill	−0.0059	−0.35	0.0122	0.49	−0.0795	−1.58
Dow Jones Industrial index	0.0001	5.12	0.0001	5.16	0.0003	5.41
S&P 500 index	−0.0012	−6.62	−0.0016	−6.15	−0.0027	−5.86
NASDAQ index	0.0001	5.42	0.0001	4.87	0.0002	4.30
Yen-U.S. dollar rate	−0.0007	−1.18	0.0010	1.02	−0.0054	−2.35
Mark-U.S. dollar rate	0.1498	3.58	0.1718	3.19	0.1865	1.69
Indexed bond price, one day prior	0.9930	101.30	0.9496	71.97	0.9716	75.88
Indexed bond price, seven days prior	−0.0226	−1.89	0.0051	0.32	−0.0238	−1.56
Indexed bond price, 15 days prior	0.0012	0.12	0.0072	0.57	0.0030	0.26
Indexed bond price, 30 days prior	−0.0016	−0.26	−0.0089	−1.07	0.0062	0.82
Bid-ask spread	−0.2854	−0.47	−0.0947	−0.30	−0.3689	−0.72
Constant	1.1845	2.68	1.3025	1.96	0.5172	0.65
Diagnostic test						
Number of observations	1,412		1,206		1,070	
F	$F(13, 1{,}398) = 59{,}196.59$		$F(13, 1{,}192) = 28{,}944.61$		$F(13, 1{,}056) = 22{,}279.68$	
Adj R^2	0.9982		0.9968		0.9963	
Reset *F* test	3.94***		10.11***		4.19***	
Heteroskedasticity χ^2 test	169.11***		80.42***		253.95***	
Durbin's h-test	54.301***		1.721		19.135***	

Dependent variable: market price of indexed bond	Series Three 10-year		Series Two 30-year		Series Four 10-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
Market price of paired nominal bond	0.0432	7.52	0.0600	7.72	0.0542	7.58
FF rate	0.0335	1.35	0.0998	1.91	0.0707	2.10
Yield on three-month T-bill	0.0038	0.12	−0.1157	−1.81	−0.0331	−0.79
Dow Jones Industrial index	0.0001	4.24	0.0003	4.39	0.0003	5.71
S&P 500 index	−0.0016	−5.40	−0.0032	−5.33	−0.0025	−5.80
NASDAQ index	0.0001	4.34	0.0002	4.18	0.0001	3.26
Yen-U.S. dollar rate	0.0012	0.65	−0.0073	−1.91	−0.0036	−1.24
Mark-U.S. dollar rate	0.1298	2.11	0.2918	2.19	0.0998	0.69
Indexed bond price, one day prior	0.9756	71.06	0.9730	69.65	0.9494	61.89
Indexed bond price, seven days prior	−0.0430	−2.74	−0.0347	−2.13	−0.0347	−2.10
Indexed bond price, 15 days prior	0.0170	1.39	0.0000	0.00	0.0127	0.99
Indexed bond price, 30 days prior	−0.0155	−1.94	0.0043	0.55	−0.0133	−1.60
Bid-ask spread	0.8892	2.00	0.3019	0.74	5.2437	2.36
Constant	2.0649	2.98	1.0670	1.20	3.2319	2.91
Diagnostic test						
Number of observations	900		872		705	
F	$F(13, 886) = 29{,}104.19$		$F(13, 858) = 21{,}682.11$		$F(13, 691) = 15{,}942.99$	
Adj R^2	0.9976		0.9969		0.9966	
Reset *F* test	2.23***		1.63		1.33	
Heteroskedasticity χ^2 test	217.21***		179.71***		101.35***	
Durbin's h-test	15.164***		30.293***		37.806***	

Note: *** denotes a 1 percent level of significance, ** a 5 percent level of significance, and * a 10 percent level of significance.

(Continued on next page)

Table 9 (continued)

Dependent variable: market price of indexed bond	Series Five 10-year		Series Six 10-year		Series Three 30-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
Market price of paired nominal bond	0.0453	4.54	0.1249	4.06	0.2460	9.35
FF rate	0.0608	1.14	0.0756	0.32	0.1058	0.37
Yield on three-month T-bill	−0.0064	−0.09	−0.8760	−1.87	0.4567	0.89
Dow Jones Industrial index	0.0003	4.22	0.0000	−0.10	0.0017	4.23
S&P 500 index	−0.0036	−3.16	0.0015	0.38	−0.0096	−2.05
NASDAQ index	0.0001	0.25	−0.0012	−1.36	−0.0017	−1.61
Yen-U.S. dollar rate	−0.0042	−0.85	−0.0388	−1.94	0.0128	0.77
Mark-U.S. dollar rate	0.7009	1.97	2.8739	1.84	−3.7939	−2.58
Indexed bond price, one day prior	0.9734	52.15	0.8569	23.62	0.7809	26.53
Indexed bond price, seven days prior	−0.0517	−2.49	−0.0654	−2.09	0.0026	0.10
Indexed bond price, 15 days prior	0.0123	0.73	0.0450	1.75	−0.0561	−3.09
Indexed bond price, 30 days prior	−0.0075	−0.63	−0.0310	−1.47	−0.0127	−1.01
Bid-ask spread	−0.7529	−0.16	0.3951	0.09	(dropped)	
Constant	2.3187	1.31	8.4952	2.47	4.9147	1.50
Diagnostic test						
Number of observations	443		211		266	
F	$F(13, 429) = 4{,}392.75$		$F(13, 197) = 1{,}889.87$		$F(12, 253) = 3{,}443.04$	
Adj R^2	0.9923		0.9915		0.9936	
Reset *F* test	0.91		0.72		5.58***	
Heteroskedasticity χ^2 test	33.33***		6.51**		2.93*	
Durbin's h-test	9.317***		1.797		21.992***	

Note: *** denotes a 1 percent level of significance, ** a 5 percent level of significance, and * a 10 percent level of significance.

the models seem to be incorrectly specified.[9] The heteroskedasticity test is designed to verify whether the distribution of the error terms of additional independent variables is subject to variance.[10] This test revealed that heteroskedasticity problems existed for all indexed bonds. This points to the possibility that prices fluctuated due to certain shocks or new information during the estimation period that could not be controlled by the independent variables. Regarding autocorrelation, the standard Durbin-Watson statistic cannot be used, because lag terms of the dependent variable are included in the independent variables. Instead, Durbin's alternative statistic was used. The results showed autocorrelation in all estimations with the exception of the Series Two 10-year and Series Six 10-year bonds. This suggests two possibilities: the inclusion of endogenously determined independent variables, or incorrect specification of the model.

An examination of the estimation equation itself indicates that prices of all nominal bonds paired with the indexed bonds have a significantly positive effect.

9. Proposed by Ramsey (1969) and generally known as the RESET test. The RESET test examines whether some independent variables have been omitted in the specification of the model. This is done by adding the second, third, and fourth terms of the dependent variable to the independent variables and verifying the significance of their coefficients.
10. See Cook and Weisberg (1983).

The coefficient of the FF rate is always positive, but not significant. The Dow-Jones Industrial index has a significant positive effect in all cases other than the Series Six 10-year issue. On the other hand, the S&P 500 index has a significant negative effect.[11] This may simply mean that we must make a choice between the better of the two stock indices. During the first half of the sample period, the New York Stock Exchange was very active, and the NASDAQ price index also had a significantly positive effect. However, during the second half, with the exception of the Series Five 10-year issue, the level of significance of the coefficients declined, or their signs changed to negative.

The yen-U.S. dollar rate and the mark-U.S. dollar rate were not very significant and their coefficients underwent sign changes. Among AR(1), AR(7), and AR(30) of the indexed bond price, only AR(1) was significant. Although the coefficient was not one, it was fairly close to one. While this is related to the unit root test summarized in Table 8, the finding implies that autocorrelation is the main factor affecting fluctuations in price. A more detailed look reveals that this tendency was particularly strong in the cases of the Series One 10-year, Series Three 10-year, Series Five 10-year, Series One 30-year, and the Series Two 30-year issues. How should this be interpreted?

Why would price differentials persist between indexed bonds and nominal bonds issued and maturing at essentially the same time? The following general reasons can be posited. (1) Preference for one type of bond during the auction process creates price distortions that persist in the secondary markets. (2) Professional bond dealers are very active participants in the secondary markets for nominal bonds, which is used for various hedging purposes. On the other hand, participants in the secondary markets for indexed bonds are limited, and the markets are not widely used for hedging purposes. This situation could change if the private sector started issuing inflation-indexed corporate bonds and if inflation indexing were built into economic contracts. While this would certainly spur demand, the secondary markets as they stand now do not have adequate depth.

Thus, the pairing information leads us to make the following inference. In the case of indexed bonds for which lagged variables have high explanatory power, transaction volumes may be low because arbitrage does not occur in the secondary markets. As this can be checked using the bid-ask spread for indexed bonds in the secondary markets, the bid-ask spread has been included in the independent variables.[12] The coefficient is significant for the Series Three 10-year and Series Four 10-year bonds. For these issues, it is shown that a widening in the bid-ask spread is associated with a rise in the price of the indexed bond (positive coefficient). This can be explained as follows. A widening in the bid-ask spread implies reduced liquidity, which in turn raises the liquidity risk premium and results in a higher price for the bond. If we assume that the bid-ask spread exerts almost no impact on the bond price when trading demand is weak because the secondary markets are extremely quiet, we are led to conclude that the secondary markets are functioning to some degree in the case of the above-mentioned Series Three 10-year and Series Four 10-year bonds.

11. The coefficient for Series Six 10-year bonds is positive but not statistically significant.
12. Fleming (2003) argues that the bid-ask spread is a useful indicator of market liquidity of the U.S. Treasury securities.

V. Econometric Analysis of Expected Inflation Rates

In this section, we examine, by means of econometric techniques, whether the real yields and expected inflation rates derived from the market prices can provide useful information for monetary policy. In particular, we compare nine series of expected inflation rates, identify the best information, and supply reasons therefore. This has certain ramifications for policymaking.

There are at least three empirical models concerning expected inflation rates. First is the inflation forecasting model in which the officially announced CPI is explained by its own lags and expected inflation rates from the indexed bonds. Second is the inflation expectation formation model in which the expected inflation rate is explained by its own lags and other relevant variables. Third is the FF rate forecasting model that is explained by the lagged expected inflation rates. This model actually evaluates whether the expected inflation rates can provide useful information for monetary policy, i.e., the FF rate formation.

As the officially announced CPI is monthly data, the daily CPI inflation rates are calculated by a year-on-year change from the linear extrapolation of the monthly CPI. According to Figure 3, the daily changes of extrapolated CPI are very little, if any, compared with the expected inflation rates from the indexed bonds. It may thus not be appropriate to build the official CPI inflation forecasting model based on the expected inflation rate.[13] We will focus on the other two models below.

A. Unit Root Test

Table 10 reports the results of the unit root test of expected inflation rates. Except for Series One and Two 30-year indexed bonds, the existence of unit roots cannot be rejected. This implies that the expected inflation rate one day prior explains almost all variations of the day and that the time series of expected inflation rates is nonstationary, in a statistical sense.

B. Inflation Expectation Formation

The purpose of the CPI forecasting model is to examine how accurately the official CPI can be traced, not to identify how inflation expectations are formulated. This section is concerned with the mechanism of inflation expectation, utilizing the expected inflation rate obtained from the indexed bonds.

Table 10 displays the results of the unit root test for expected rates of inflation derived from the Series Three 10-year bond and the Series Four 10-year bond. The null hypothesis of the existence of the unit root cannot be rejected at the 1 percent significance level. This means that the link between the previous day's expected inflation rate and today's expected inflation rate is quite strong.

13. In fact, we estimated the CPI inflation forecasting model that is explained by its own lags, expected inflation rates, and other relevant variables. Apart from the significance of the first lag of CPI inflation, explanatory powers of other variables, particularly the expected inflation rate, vary among different series of indexed bonds. Overall explanatory power of the expected inflation rates seems very limited.

Table 10 Unit Root Test (Expected Rate of Inflation)

[1] Dickey-Fuller Test

	Number of observations	Test statistics $Z(t)$	MacKinnon approximate p-value for $Z(t)$
Series One 10-year	1,148	–1.374	0.5933
Series Two 10-year	948	–1.232	0.6592
Series One 30-year	839	–2.978	0.0370
Series Three 10-year	689	–1.184	0.6804
Series Two 30-year	701	–4.769	0.0001
Series Four 10-year	549	–1.909	0.3280
Series Five 10-year	326	–2.076	0.2544
Series Six 10-year	121	–1.097	0.7165
Series Three 30-year	188	–2.516	0.1117

Note: Significance level: $Z(t)$: 1 percent –3.430, 5 percent –2.860, 10 percent –2.570.

[2] Phillips-Perron Test

	Number of observations	Test statistics $Z(\rho)$	Test statistics $Z(t)$	MacKinnon approximate p-value for $Z(t)$
Series One 10-year	1,148	–1.953	–1.340	0.6096
Series Two 10-year	948	–2.259	–1.113	0.7102
Series One 30-year	839	–15.655	–2.888	0.0467
Series Three 10-year	689	–1.976	–1.022	0.7457
Series Two 30-year	701	–32.113	–4.835	0.0000
Series Four 10-year	549	–3.614	–1.879	0.3420
Series Five 10-year	326	–6.075	–1.796	0.3826
Series Six 10-year	121	–2.483	–1.023	0.7454
Series Three 30-year	188	–5.591	–2.538	0.1065

Note: Significance level: $Z(\rho)$: 1 percent –20.700, 5 percent –14.10, 10 percent –11.300.
$Z(t)$: 1 percent –3.430, 5 percent –2.860, 10 percent –2.570.

Table 11 further examines whether the inflation expectation formation model can be improved through the addition of financial market variables. The model is based largely on the previous day's expected rate, but is also influenced by other financial variables and expected rates that existed two or more days prior thereto.

Although the coefficient of the determinant (R-square) is significantly high at 0.99, and diagnostic statistics indicate signs of serial correlation and heteroskedasticity, the model may omit some variables or/and may be misspecified.

The public announcement of the CPI usually takes place in the middle of the month,[14] which provides information up to the end of the last month (an approximate 15-day lag). This information lag increases gradually thereafter and reaches a 45-day lag at maximum. That is to say, since the information lag varies from 15 days to 45 days, the CPI announcement amounts to information equivalent to about 30 days.

14. Although the date of public announcement of the CPI varies from month to month, it is usually between the 15th and 20th of the month. The announcement time is 8:30 a.m. Eastern Daylight Time, that is, before the financial markets open. This information is reflected in the announcement day's trading.

Table 11 Expectation Formation Model of Inflation

Dependent variable: expected rate of inflation	Series One 10-year		Series Two 10-year		Series One 30-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
CPI announcement date dummy	0.0050	−0.69	0.0024	0.33	0.0012	0.18
FF rate	−0.0038	−0.70	0.0010	0.17	0.0062	1.25
Three-month bond yield	0.0032	0.47	0.0006	0.09	−0.0115	−1.85
Dow Jones Industrial index	0.0000	0.76	0.0000	1.82	0.0000	2.59
S&P 500 index	0.0000	−0.04	0.0000	0.24	0.0000	−0.63
NASDAQ index	0.0000	−0.29	0.0000	0.66	0.0000	0.76
Yen-U.S. dollar rate	−0.0002	−0.75	0.0005	1.55	−0.0005	−1.67
Mark-U.S. dollar rate	−0.0313	−2.10	−0.0662	−3.95	−0.0359	−3.22
Expected inflation, one day prior	0.8903	31.13	0.8681	27.99	0.9167	27.17
Expected inflation, two days prior	0.0794	2.09	0.0927	2.28	0.0105	0.23
Expected inflation, three days prior	−0.0530	−1.39	−0.0430	−1.04	0.0021	0.05
Expected inflation, four days prior	0.0265	0.70	0.0084	0.20	0.0203	0.45
Expected inflation, five days prior	0.0078	0.21	0.0109	0.27	−0.0068	−0.15
Expected inflation, six days prior	0.0377	1.00	0.0653	1.60	−0.0419	−0.93
Expected inflation, seven days prior	0.0301	0.79	0.0219	0.53	0.0945	2.09
Expected inflation, eight days prior	0.0010	0.03	−0.0167	−0.40	−0.0284	−0.62
Expected inflation, nine days prior	0.0308	0.81	−0.0016	−0.04	0.0182	0.40
Expected inflation, 10 days prior	−0.0215	−0.57	0.0192	0.46	0.0137	0.30
Expected inflation, 11 days prior	−0.0361	−0.95	−0.0573	−1.39	−0.0520	−1.14
Expected inflation, 12 days prior	0.0095	0.25	0.0238	0.57	0.0030	0.07
Expected inflation, 13 days prior	−0.0379	−1.01	−0.0044	−0.11	−0.0254	−0.57
Expected inflation, 14 days prior	0.0157	0.42	−0.0394	−0.96	0.0211	0.47
Expected inflation, 15 days prior	0.0174	0.62	0.0328	1.06	0.0077	0.24
Constant	0.0447	1.17	−0.0549	−1.17	0.1002	2.27
Diagnostic test[1]						
Number of observations	1,295		1,096		937	
R^2	0.9975		0.9948		0.9633	
Durbin's χ^2 test	0.014		0.612		9.904***	
LM test for autocorrelation	1.015		0.626		10.066***	
Heteroskedasticity χ^2 test	18.92***		9.84***		0.51	
ARCH (1, 1) test	94.337***		61.499***		8.308***	
F-test for parameter restrictions on expected inflation[2]	$F(14, 1{,}271) = 2.32$*** Prob > $F = 0.0037$		$F(14, 1{,}072) = 1.93$** Prob > $F = 0.020$		$F(14, 913) = 0.77$ Prob > $F = 0.7070$	

Notes: 1. *** denotes a 1 percent level of significance, ** a 5 percent level of significance, and * a 10 percent level of significance.
2. Null hypothesis of zero coefficient on expected inflation, two days prior or before.

Table 11 (continued)

Dependent variable: expected rate of inflation	Series Three 10-year		Series Two 30-year		Series Four 10-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
CPI announcement date dummy	−0.0113	−1.34	0.0027	0.37	−0.0091	−0.98
FF rate	−0.0003	−0.05	0.0078	1.20	0.0010	0.10
Three-month bond yield	0.0014	0.16	−0.0111	−1.47	−0.0015	−0.14
Dow Jones Industrial index	0.0000	1.52	0.0000	1.67	0.0000	1.03
S&P 500 index	0.0000	0.03	0.0000	−0.68	0.0000	0.13
NASDAQ index	0.0000	1.45	0.0000	1.22	0.0000	1.27
Yen-U.S. dollar rate	0.0006	1.12	0.0001	0.15	0.0006	0.94
Mark-U.S. dollar rate	−0.0637	−3.12	−0.0411	−3.01	−0.0367	−1.13
Expected inflation, one day prior	0.8567	23.66	0.8831	23.39	0.8315	20.31
Expected inflation, two days prior	0.0504	1.06	0.0352	0.70	0.0351	0.66
Expected inflation, three days prior	0.0198	0.41	0.0140	0.28	0.0822	1.52
Expected inflation, four days prior	0.0151	0.32	0.0361	0.72	0.0426	0.80
Expected inflation, five days prior	0.0236	0.50	−0.0384	−0.76	−0.0260	−0.49
Expected inflation, six days prior	0.0225	0.47	−0.0151	−0.30	0.0000	0.00
Expected inflation, seven days prior	0.0515	1.08	0.0626	1.25	0.0620	1.16
Expected inflation, eight days prior	−0.0562	−1.14	0.0156	0.31	−0.0757	−1.37
Expected inflation, nine days prior	0.0277	0.57	−0.0558	−1.10	0.0442	0.82
Expected inflation, 10 days prior	−0.0469	−0.99	0.0432	0.87	−0.0520	−0.98
Expected inflation, 11 days prior	−0.0333	−0.70	−0.0286	−0.59	−0.0354	−0.66
Expected inflation, 12 days prior	0.0484	1.02	−0.0097	−0.21	0.0823	1.53
Expected inflation, 13 days prior	−0.0080	−0.17	−0.0081	−0.18	−0.0519	−1.03
Expected inflation, 14 days prior	0.0082	0.17	0.0319	0.70	0.0453	0.98
Expected inflation, 15 days prior	−0.0100	−0.28	−0.0184	−0.55	−0.0205	−0.60
Constant	−0.0709	−1.25	0.0835	1.50	−0.1215	−1.71
Diagnostic test[1]						
Number of observations	800		747		633	
R^2	0.9933		0.9495		0.9911	
Durbin's χ^2 test	2.514		5.119**		3.756*	
LM test for autocorrelation	2.586		5.259**		3.886**	
Heteroskedasticity χ^2 test	7.27***		2.06		15.78***	
ARCH (1, 1) test	37.433***		3.968**		31.431***	
F-test for parameter restrictions on expected inflation[2]	$F(14, 776) = 1.39$ Prob > F = 0.1525		$F(14, 723) = 0.62$ Prob > F = 0.8490		$F(14, 609) = 1.61$* Prob > F = 0.0713	

(Continued on next page)

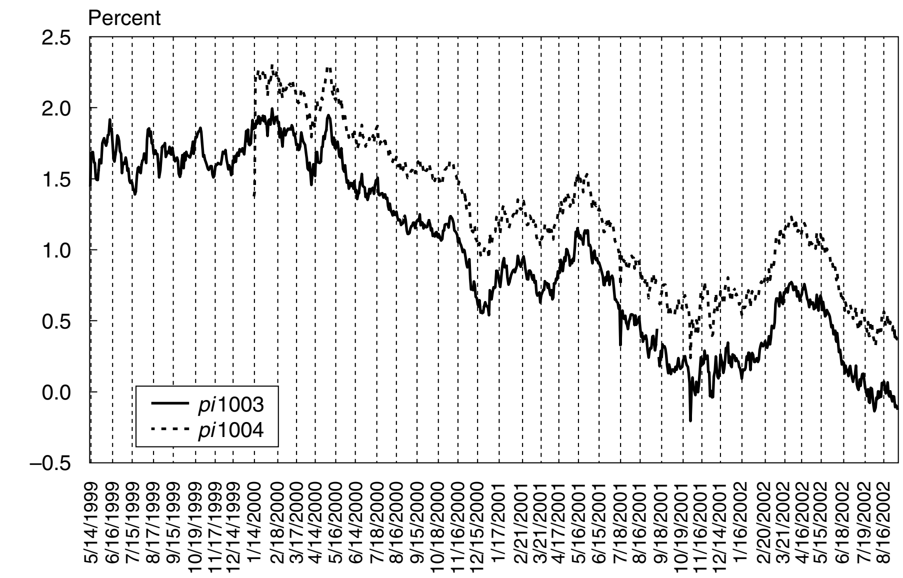
Table 11 (continued)

Dependent variable: expected rate of inflation	Series Five 10-year		Series Six 10-year		Series Three 30-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
CPI announcement date dummy	−0.0047	−0.33	0.0133	0.69	0.0082	0.59
FF rate	0.0163	0.88	0.0294	0.58	0.0072	0.28
Three-month bond yield	−0.0143	−0.64	−0.1545	−1.19	0.0767	1.34
Dow Jones Industrial index	0.0001	2.37	0.0001	1.47	0.0002	4.64
S&P 500 index	−0.0003	−1.22	−0.0014	−2.18	−0.0016	−4.07
NASDAQ index	0.0000	0.18	0.0006	3.37	0.0003	3.01
Yen-U.S. dollar rate	0.0002	0.20	−0.0039	−0.88	−0.0024	−1.28
Mark-U.S. dollar rate	0.0458	0.52	0.1896	0.62	−0.0398	−0.29
Expected inflation, one day prior	0.7750	13.43	0.5713	6.02	0.7244	9.52
Expected inflation, two days prior	0.0588	0.81	0.0299	0.28	−0.0132	−0.14
Expected inflation, three days prior	0.0090	0.12	0.0324	0.30	−0.0068	−0.07
Expected inflation, four days prior	0.0852	1.17	0.1810	1.62	0.1143	1.23
Expected inflation, five days prior	0.0025	0.03	−0.2321	−2.02	−0.0591	−0.64
Expected inflation, six days prior	−0.0361	−0.49	0.1622	1.47	−0.1158	−1.24
Expected inflation, seven days prior	0.0812	1.09	0.0422	0.37	0.2077	2.19
Expected inflation, eight days prior	−0.0997	−1.27	0.0120	0.10	−0.1349	−1.45
Expected inflation, nine days prior	0.0504	0.68	0.1154	1.02	0.0201	0.22
Expected inflation, 10 days prior	−0.0385	−0.53	−0.1881	−1.58	0.0064	0.07
Expected inflation, 11 days prior	−0.0457	−0.62	0.0409	0.34	−0.0262	−0.27
Expected inflation, 12 days prior	0.1007	1.36	0.0169	0.15	−0.0404	−0.42
Expected inflation, 13 days prior	0.0354	0.48	0.0553	0.48	0.2147	2.25
Expected inflation, 14 days prior	−0.0745	−1.00	0.0386	0.33	−0.1316	−1.33
Expected inflation, 15 days prior	0.0106	0.18	−0.0599	−0.66	0.1164	1.60
Constant	−0.2769	−2.06	0.2790	0.88	0.0550	0.39
Diagnostic test[1]						
Number of observations	336		133		197	
R^2	0.9535		0.9637		0.9692	
Durbin's χ^2 test	3.418*		5.345**		7.91***	
LM test for autocorrelation	3.563*		6.282**		8.661***	
Heteroskedasticity χ^2 test	11.08***		0.61		2.32	
ARCH (1, 1) test	12.16***		0.000		0.104	
F-test for parameter restrictions on expected inflation[2]	$F(14, 312) = 1.00$ Prob > $F = 0.4493$		$F(14, 109) = 1.57$* Prob > $F = 0.0978$		$F(14, 173) = 1.83$** Prob > $F = 0.0381$	

Notes: 1. *** denotes a 1 percent level of significance, ** a 5 percent level of significance, and * a 10 percent level of significance.
2. Null hypothesis of zero coefficient on expected inflation, two days prior or before.

Table 11 examines the effect of the announcement day (using a dummy variable for announcement date = 1, otherwise = 0) on the expectation formation (see Figure 4). During the sample period, the announcement of the CPI reduces the expected inflation rate by 0.01 percent. This effect is not statistically significant, and other market information released between the CPI announcement dates has a greater bearing on the regularity of inflation expectation formation.

Figure 4 Expected Rate of Inflation and CPI Announcement Date



C. FF Rate Forecasting Model

The forecasting model of the FF rate, the main policy instrument of the U.S. Federal Reserve Board, is reported in Table 12. The model contains 15 lagged FF rates, the lagged expected inflation rates, and the dummy variable for the CPI announcement date. In this way, the same FF rate can be explained by different expected inflation rates from different series of indexed bonds, and thus its information content can be compared over different indexed bonds. Note, however, that we cannot compare the forecasting performance for exactly the same duration because of different issue dates and maturities.

Judging from the goodness of fit, i.e., coefficient of determination (R-square), Series Three, Four, and Five 10-year and Series Two 30-year bonds exceed 0.99. The significance test for coefficients of the expected inflation rates implies whether the expected inflation rates have a significant influence on the FF rates.[15] Series Two, Three, and Four 10-year bonds were significant.

Combining the statistical results, information content of Series Three and Four 10-year bonds seems to surpass that from other bonds. Based on this assumption, the attractive bond prices shown in Tables 3 and 9 appear to have triggered active secondary market trading.

15. This is basically equivalent to the Granger causality test.

Table 12 FF Rate Forecasting Model

Dependent variable: FF rate	Series One 10-year		Series Two 10-year		Series One 30-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
CPI announcement date dummy	−0.0920	−2.35	−0.0748	−1.85	−0.0727	−1.74
FF rate, one day prior	0.4005	10.43	0.3964	9.54	0.4022	8.59
FF rate, two days prior	0.0605	1.41	0.1342	2.91	0.1826	3.51
FF rate, three days prior	0.1121	2.54	0.0586	1.20	0.1170	2.19
FF rate, four days prior	−0.0265	−0.61	−0.0446	−0.93	−0.1224	−2.31
FF rate, five days prior	0.1625	3.77	0.1837	3.84	0.2161	4.15
FF rate, six days prior	−0.0789	−1.87	−0.1157	−2.47	−0.0713	−1.40
FF rate, seven days prior	0.0004	0.01	0.0368	0.76	0.0202	0.38
FF rate, eight days prior	0.0440	1.01	0.0481	0.99	0.0373	0.70
FF rate, nine days prior	−0.0050	−0.12	−0.0057	−0.12	−0.0021	−0.04
FF rate, 10 days prior	0.2433	5.50	0.2305	4.75	0.2137	3.97
FF rate, 11 days prior	0.0813	1.83	0.0266	0.55	0.0199	0.37
FF rate, 12 days prior	−0.0033	−0.08	0.0151	0.33	−0.0244	−0.50
FF rate, 13 days prior	0.0602	1.41	0.0558	1.21	0.0720	1.49
FF rate, 14 days prior	−0.0732	−1.72	−0.0449	−0.99	−0.0654	−1.37
FF rate, 15 days prior	0.0113	0.30	0.0045	0.11	0.0046	0.11
Expected inflation, same day	0.0834	0.55	0.1349	0.84	0.2812	1.45
Expected inflation, one day prior	−0.4613	−2.24	−0.4998	−2.32	−0.4963	−1.86
Expected inflation, two days prior	0.2518	1.21	0.2229	1.03	0.0895	0.34
Expected inflation, three days prior	0.2477	1.20	−0.0019	−0.01	0.1431	0.55
Expected inflation, four days prior	−0.1059	−0.51	0.2241	1.03	0.0464	0.18
Expected inflation, five days prior	−0.0906	−0.45	−0.0545	−0.25	−0.1203	−0.46
Expected inflation, six days prior	0.0265	0.14	−0.1274	−0.62	−0.0063	−0.02
Expected inflation, seven days prior	0.0703	0.37	0.2049	1.00	0.1345	0.51
Expected inflation, eight days prior	−0.1211	−0.62	−0.2944	−1.37	−0.2572	−0.97
Expected inflation, nine days prior	0.1818	0.93	0.2649	1.22	0.3094	1.16
Expected inflation, 10 days prior	−0.1252	−0.64	0.0162	0.07	−0.0248	−0.09
Expected inflation, 11 days prior	0.0013	0.01	−0.0212	−0.10	−0.0173	−0.06
Expected inflation, 12 days prior	−0.0872	−0.43	−0.1286	−0.59	0.0463	0.17
Expected inflation, 13 days prior	0.1993	0.99	−0.0848	−0.39	−0.1576	−0.57
Expected inflation, 14 days prior	0.1761	0.88	0.3547	1.64	0.4953	1.78
Expected inflation, 15 days prior	−0.2185	−1.45	−0.1434	−0.86	−0.2986	−1.43
Constant	0.0121	0.37	0.0162	0.55	−0.3084	−3.54
Diagnostic test[1]						
Number of observations	706		611		493	
R^2	0.9795		0.9847		0.9887	
Durbin's χ^2 test	2.614		2.277		2.338	
LM test for autocorrelation	2.736*		2.402		2.499	
Heteroskedasticity χ^2 test	23.02***		21.5***		17.85***	
ARCH (1, 1) test	39.794***		39.159***		22.706***	
F-test for parameter restrictions on expected inflation[2]	$F(16, 673) = 1.37$ Prob > $F = 0.1499$		$F(16, 578) = 1.58$* Prob > $F = 0.0682$		$F(16, 460) = 1.47$ Prob > $F = 0.1044$	

Notes: 1. *** denotes a 1 percent level of significance, ** a 5 percent level of significance, and * a 10 percent level of significance.
2. Null hypothesis of zero coefficient on expected inflation, two days prior or before.

Table 12 (continued)

Dependent variable: FF rate	Series Three 10-year		Series Two 30-year		Series Four 10-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
CPI announcement date dummy	−0.0860	−1.95	−0.0856	−2.02	−0.0827	−2.27
FF rate, one day prior	0.3526	6.88	0.3712	7.15	0.4976	8.94
FF rate, two days prior	0.2746	4.68	0.1550	2.57	0.1409	2.23
FF rate, three days prior	0.0490	0.75	0.1815	2.91	0.1016	1.63
FF rate, four days prior	−0.0961	−1.49	−0.0539	−0.87	0.0105	0.17
FF rate, five days prior	0.2052	3.02	0.1863	2.94	0.0744	1.15
FF rate, six days prior	−0.0975	−1.41	−0.0873	−1.37	−0.0768	−1.20
FF rate, seven days prior	0.0020	0.03	−0.0025	−0.04	0.0130	0.20
FF rate, eight days prior	0.0983	1.41	0.0600	0.93	0.1024	1.60
FF rate, nine days prior	0.0113	0.17	−0.0128	−0.20	−0.0384	−0.61
FF rate, 10 days prior	0.1522	2.23	0.1906	2.94	0.1688	2.63
FF rate, 11 days prior	0.0277	0.42	0.0218	0.35	−0.0446	−0.72
FF rate, 12 days prior	−0.0242	−0.38	−0.0267	−0.43	0.0670	1.10
FF rate, 13 days prior	0.0452	0.67	0.0891	1.37	−0.0349	−0.54
FF rate, 14 days prior	−0.0289	−0.44	−0.0511	−0.81	−0.0103	−0.16
FF rate, 15 days prior	0.0104	0.18	−0.0189	−0.36	0.0106	0.20
Expected inflation, same day	0.0314	0.17	0.3767	1.84	−0.1044	−0.64
Expected inflation, one day prior	−0.3807	−1.58	−0.6156	−2.23	−0.0494	−0.23
Expected inflation, two days prior	0.3031	1.27	0.1967	0.71	−0.0370	−0.18
Expected inflation, three days prior	−0.1763	−0.73	−0.1130	−0.41	0.0341	0.16
Expected inflation, four days prior	−0.0576	−0.24	0.0655	0.24	−0.0699	−0.32
Expected inflation, five days prior	0.1634	0.69	−0.0240	−0.09	0.3453	1.65
Expected inflation, six days prior	0.0741	0.33	0.0901	0.33	−0.2372	−1.18
Expected inflation, seven days prior	0.1188	0.53	0.2196	0.81	0.2530	1.25
Expected inflation, eight days prior	−0.3116	−1.31	−0.4143	−1.49	−0.2682	−1.26
Expected inflation, nine days prior	0.2904	1.21	0.2529	0.91	0.1825	0.86
Expected inflation, 10 days prior	−0.0588	−0.25	0.1872	0.68	0.1497	0.71
Expected inflation, 11 days prior	0.0489	0.21	0.0231	0.09	−0.3155	−1.50
Expected inflation, 12 days prior	0.0825	0.35	0.1325	0.53	0.0742	0.35
Expected inflation, 13 days prior	−0.2418	−1.01	−0.4654	−1.86	0.0494	0.23
Expected inflation, 14 days prior	0.4973	2.09	0.4259	1.69	0.2783	1.29
Expected inflation, 15 days prior	−0.2985	−1.61	−0.1862	−1.02	−0.1879	−1.12
Constant	−0.0232	−0.97	−0.2977	−2.67	−0.0640	−2.80
Diagnostic test[1]						
Number of observations	415		414		351	
R^2	0.9910		0.9918		0.9951	
Durbin's χ^2 test	6.11**		6.413**		1.609	
LM test for autocorrelation	6.55**		6.871***		1.772	
Heteroskedasticity χ^2 test	13.38***		14.06***		13.07***	
ARCH (1, 1) test	38.77***		16.616***		4.052**	
F-test for parameter restrictions on expected inflation[2]	$F(16, 382) = 1.55$* Prob > F = 0.0786		$F(16, 381) = 1.42$ Prob > F = 0.1268		$F(16, 318) = 1.53$* Prob > F = 0.0872	

(Continued on next page)

Table 12 (continued)

Dependent variable: FF rate	Series Five 10-year		Series Six 10-year		Series Three 30-year	
	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics	Estimated coefficient	Robust *t*-statistics
CPI announcement date dummy	−0.1403	−3.07	−0.0303	−0.59	−0.0146	−0.25
FF rate, one day prior	0.4462	5.77	0.1176	0.91	0.4034	3.50
FF rate, two days prior	0.1202	1.36	−0.0737	−0.55	0.2007	1.64
FF rate, three days prior	0.1077	1.23	−0.0494	−0.38	0.0152	0.12
FF rate, four days prior	0.0646	0.76	−0.0607	−0.44	0.0319	0.22
FF rate, five days prior	0.0333	0.37	−0.0830	−0.58	0.0717	0.49
FF rate, six days prior	−0.1846	−2.06	−0.2374	−1.64	−0.1812	−1.23
FF rate, seven days prior	−0.0021	−0.02	−0.2219	−1.50	0.0354	0.23
FF rate, eight days prior	0.1164	1.28	0.0275	0.18	0.1572	0.89
FF rate, nine days prior	−0.0021	−0.02	−0.0950	−0.63	−0.0365	−0.21
FF rate, 10 days prior	0.1705	1.91	0.1570	1.07	0.3619	2.21
FF rate, 11 days prior	−0.0184	−0.23	0.0541	0.34	−0.0429	−0.24
FF rate, 12 days prior	0.1444	1.73	−0.1142	−0.75	−0.0393	−0.23
FF rate, 13 days prior	−0.0730	−0.82	−0.1347	−0.92	−0.0425	−0.26
FF rate, 14 days prior	−0.1422	−1.54	−0.1754	−1.17	−0.1965	−1.17
FF rate, 15 days prior	0.1907	2.48	−0.1046	−0.69	0.0504	0.33
Expected inflation, same day	−0.0575	−0.30	0.0166	0.07	−0.0145	−0.04
Expected inflation, one day prior	0.0271	0.11	−0.4267	−1.37	−0.1247	−0.31
Expected inflation, two days prior	0.0188	0.08	0.5653	1.80	0.0587	0.15
Expected inflation, three days prior	−0.2196	−0.92	−0.3683	−1.09	−0.1508	−0.37
Expected inflation, four days prior	0.1195	0.50	−0.2651	−0.77	0.0298	0.07
Expected inflation, five days prior	0.4704	1.99	0.8904	2.48	0.5739	1.42
Expected inflation, six days prior	−0.3180	−1.39	−0.6868	−1.86	−0.2651	−0.60
Expected inflation, seven days prior	0.3703	1.61	0.4166	1.17	0.1595	0.36
Expected inflation, eight days prior	−0.5756	−2.25	−0.1929	−0.56	−0.4721	−1.08
Expected inflation, nine days prior	0.1858	0.70	−0.1188	−0.34	0.5257	1.25
Expected inflation, 10 days prior	0.1932	0.76	0.8080	2.40	0.2920	0.72
Expected inflation, 11 days prior	−0.2765	−1.08	−0.9169	−2.60	−0.7101	−1.71
Expected inflation, 12 days prior	−0.0647	−0.25	0.8870	2.46	0.4599	1.09
Expected inflation, 13 days prior	−0.0670	−0.26	−0.3952	−1.07	−0.3468	−0.83
Expected inflation, 14 days prior	0.2029	0.78	−0.2312	−0.64	0.1988	0.46
Expected inflation, 15 days prior	0.0305	0.15	0.1057	0.41	−0.1742	−0.56
Constant	−0.0122	−0.20	3.3232	2.73	0.2720	0.50
Diagnostic test[1]						
Number of observations	190		92		106	
R^2	0.9915		0.3968		0.7311	
Durbin's χ^2 test	0.520		0.771		1.12	
LM test for autocorrelation	0.632		1.207		1.623	
Heteroskedasticity χ^2 test	9.17***		3.56*		18.1***	
ARCH (1, 1) test	0.752		0.826		0.201	
F-test for parameter restrictions on expected inflation[2]	$F(16, 157) = 1.00$ Prob > $F = 0.4610$		$F(16, 59) = 1.33$ Prob > $F = 0.2109$		$F(16, 73) = 0.72$ Prob > $F = 0.7620$	

Notes: 1. *** denotes a 1 percent level of significance, ** a 5 percent level of significance, and * a 10 percent level of significance.
2. Null hypothesis of zero coefficient on expected inflation, two days prior or before.

VI. Evaluation of Indexed Bonds

The preceding analysis indicates that our derived real interest rates and expected rates of inflation have the following characteristics.

(1) Real interest rates are relatively stable and remain near the 4 percent mark. The 30-year bond is even more stable.

(2) The expected inflation rate is more closely linked to the realized CPI than to the real yield. However, the expected inflation rate is far more stable and its fluctuations smaller. In particular, the 30-year bond is steady, near the 2 percent mark.

(3) While the economic information derived from the 10-year bond is strongly influenced by short-term economic fluctuations, the economic information derived from the 30-year bond is generally unresponsive to short-term economic fluctuations.

(4) Examination of the derived information using econometric methods indicates that useful economic information was obtained from the following indexed bonds in the secondary markets: Series Three and Four 10-year bonds. Information included in the expected inflation rate was useful in the cases of the Series Three and Four 10-year bonds. Hence, while a total of 11 indexed bonds have been issued, very few of them have proven to be truly useful. The conclusion of this paper is that the Series Three and Four 10-year bonds are the only ones that can really be used. These bonds turn out to have fair initial conditions, are continuously arbitraged with the nominal bonds, and trade actively in the secondary markets.

(5) On the other hand, the information content of the expected inflation rates from the indexed bonds is limited, provided that the issue conditions are not fair, that a wide gap in issuing dates between the paired index and nominal bonds exists, that issue conditions for the nominal bonds are not inadequate, and that trading in the secondary markets is absent. Series One[16] and Five[17] 10-year bonds and Series Three[18] 30-year bonds are cases in point.

Some issues and problems remaining for future discussion can be summarized as follows.

(1) In the spring of 2002, the U.S. Treasury Department announced it would continue to actively and regularly issue the indexed bonds (TIPS). A longer time is needed to accumulate sufficient information to construct the complete term structure of the indexed bonds. Comparisons of the term structure of interest rates between the nominal and indexed bonds and constructions of the term structure of the expected inflation rates remain as topics to be researched in the future.

16. The market demand for the first indexed bond overwhelms its supply so that the price is too high (i.e., the coupon rate is too low), thus arbitrage between TIPS and the nominal bond scarcely takes place.

17. In this case, the problem does not lie in its pricing but in its issue amount differences, i.e., the amount of the nominal bonds is more than twice that of the indexed bonds.

18. In this case, there are substantial differences in coupon rates and issue amounts between the indexed and nominal bonds, although it may be too early to conclude anything definitive.

(2) Limited information on trading volumes has thus far prevented the determination of a benchmark. Based on the results of our econometric analysis, we believe that the Series Three or Four 10-year bonds are strong candidates as a benchmark.
(3) Cost of issuance and performance evaluation have not been adequately discussed. Evaluation is certainly difficult, given the limited number of indexed bonds that have matured to date. Nevertheless, evaluation of financial performance to date can be attempted using the realized CPI.
(4) It is known that indexed bonds carry a risk premium or a liquidity premium in comparison to nominal bonds, and these premiums can be specified using calculations. While it is unlikely that these calculations will affect the general direction of the findings of this paper, it is nevertheless worthwhile to perform them.

APPENDIX: BLOOMBERG METHOD FOR DERIVING REAL YIELD

Market price and yield data for U.S. inflation-indexed bonds are made widely available by Bloomberg. In this paper, we have basically relied on Bloomberg for data concerning prices and yields for both the indexed bonds and the nominal bonds. The same information appears daily in the *Wall Street Journal*. Similarly, price and yield data for U.K. government indexed bonds are published in the *Financial Times* and are widely used by financial market participants. That is, market participants use these data in making day-to-day investment decisions and advising their customers. For instance, under "Real Interest Rates and Expected Inflation Rate as Indicated by 10-Year Indexed Government Bonds" (figure 17) in "Current Investment Strategies" (September 6, 2002, Issue No. 250) of Deutsche Securities (Deutsche Bank Group), Bloomberg data are used to derive the yield differential between normal government bonds and indexed bonds, which is defined as the expected inflation rate.

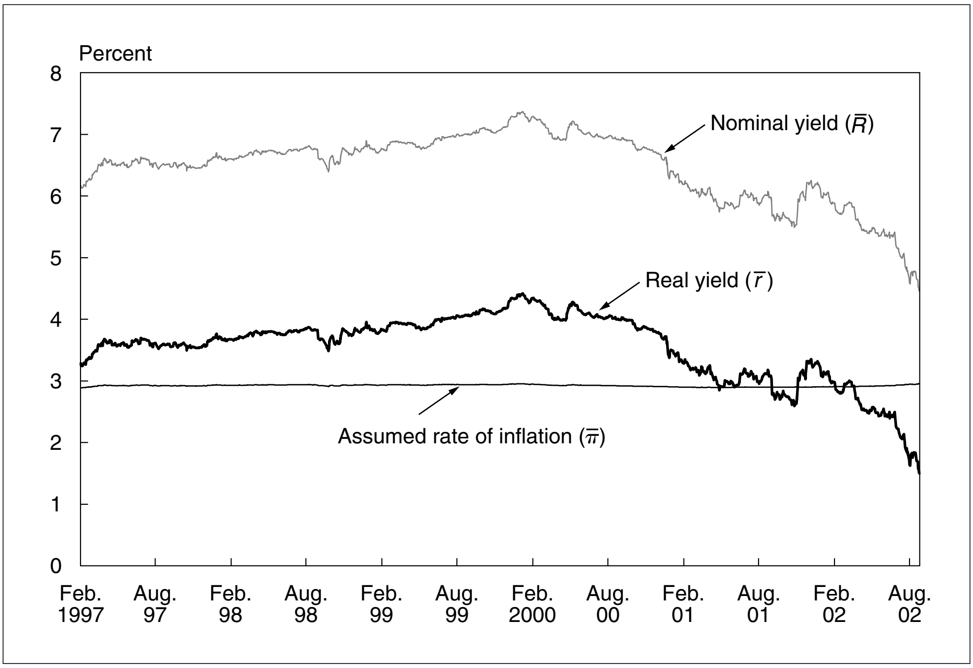
It appears that the real yield of indexed bonds as made available on Bloomberg monitors is calculated as follows.

(1) The average CPI inflation rate for the year immediately preceding the issuance of the indexed bond is obtained and used as the indexed bond's assumed inflation rate ($\bar{\pi}$).
(2) The assumed nominal coupon (interest) rate ($\bar{C}$) is obtained by adding the indexed bond's contracted real interest rate (r) to the assumed inflation rate ($\bar{\pi}$).
(3) The value of coupon $\bar{C}$ is inserted into "coupon rate C_{nb}" in equation (7) above to obtain nominal yield $\bar{R}$.
(4) Assumed inflation rate $\bar{\pi}$ is subtracted from $\bar{R}$ to arrive at real yield. Real yield $\bar{r} = \bar{R} - \bar{\pi}$.

Bloomberg's assumed real yield ($\bar{r}$) differs widely from our real yield (r) derived using equation (6). (See Appendix Figure 1 for calculation of real yield of the Series One 10-year bond.) The variance arises because the Bloomberg equation differs from equation (6) used by the U.S. Treasury. Specifically, price fluctuations, albeit with a three-month lag, are continuously fed into the Treasury Department's equation (6) for valuing indexed bonds. In Bloomberg's simplified method, the inflation rate prevailing before issuance is used throughout without modification. For instance, the assumed inflation rate for the Series One 10-year bond is 2.903 percent (1.4515 percent for half-year), and this figure is used without modification until the bond matures 10 years later. While the gap between the assumed and realized rates of inflation is small immediately after issuance, it increases progressively with the passage of time.

The unwitting use of biased data by capital market participants leads to various problems. Discussions of the level and direction of the expected inflation rate without regard to this bias not only generates errors in the investment strategies of market participants but also poses a problem in monetary policy formation. Unfortunately, this problem is not unique to the Bloomberg data. Exactly the same problem exists for real yields on U.K. government-indexed bonds published in the *Financial Times.*

Appendix Figure 1 Real Yield by the Bloomberg Method



In the case of the Japanese government indexed bonds, it would be highly desirable for market data providers and business newspapers to derive and publish real yields using the same method employed by the Ministry of Finance in its formal announcements.

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