

Working Paper 96-2 / Document de travail 96-2

**Decomposing U.S. Nominal Interest Rates into Expected  
Inflation and Ex Ante Real Interest Rates  
Using Structural VAR Methodology**

by  
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Bank of Canada



Banque du Canada



January 1996

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USING STRUCTURAL VAR METHODOLOGY**

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This paper is intended to make the results of Bank research available in preliminary form to other economists to encourage discussion and suggestions for revision. The views expressed are those of the author and do not necessarily represent the views of the Bank of Canada.

## **Acknowledgments**

I want to thank Alain Guay, Alain DeSerres, John Murray, Robert Lafrance, Simon van Norden, Dave Longworth, Agathe Côté, and Ron Lang for useful comments and discussions. Thanks are also due to Robert Vigfusson and Jim Day for their excellent research assistance. Of course, any errors are my own.

ISSN 1192-5434  
ISBN 0-662-24127-4

Printed in Canada on recycled paper

## **Abstract**

In this paper, the author uses structural vector autoregression methodology to decompose U.S. nominal interest rates into an expected inflation component and an ex ante real interest rate component. He identifies inflation expectations and ex ante real interest rate shocks by assuming that nominal interest rates and inflation expectations move one-for-one in the long-run – they are cointegrated (1,1) – and that the real interest rate is stationary. He finds that changes in inflation expectations and in the ex ante real interest rate are both important in explaining fluctuations in the U.S. 1-year and 10-year government bond rates. The author also finds that, while the increase in the 1-year and the 10-year bond rates in the 1970s and the early 1980s mainly reflects higher inflation expectations, changes in ex ante real interest rates appear to account for most of the fluctuations in these rates in 1994 and in the first half of 1995.

## **Résumé**

Dans cette étude, la méthode structurelle d'autorégression vectorielle est utilisée pour décomposer le taux d'intérêt nominal aux États-Unis en une composante d'inflation anticipée et en une composante de taux d'intérêt réel ex ante. Pour identifier les chocs d'inflation anticipée et de taux d'intérêt réel ex ante, l'auteur fait l'hypothèse que le taux d'intérêt nominal et le taux d'inflation anticipé sont cointégrés (1,1) et que le taux d'intérêt réel est stationnaire. L'auteur constate que tant les modifications des anticipations d'inflation que les variations du taux d'intérêt réel ex ante aident grandement à expliquer les fluctuations des taux des obligations à 1 an et à 10 ans du gouvernement des États-Unis. Il constate aussi que, si la hausse des taux des obligations à 1 an et à 10 ans observée au cours des années 70 et au début des années 80 tenait principalement à des anticipations inflationnistes plus fortes, l'essentiel des fluctuations de ces taux en 1994 et au cours du premier semestre de 1995 semble résulter des variations du taux d'intérêt réel ex ante.



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## 1 Introduction

In analysing fluctuations in long-term interest rates, economists often raise the question: Are the fluctuations caused by changes in inflation expectations or by changes in ex ante real interest rates? The answer has important implications for monetary policy. For example, an increase in long-term interest rates reflecting an increase in inflation expectations might be a signal for the monetary authority to tighten its policy. An increase in long-term interest rates reflecting higher ex ante real interest rates may have different implications.

In this paper, the structural vector autoregression (SVAR) methodology developed by Blanchard and Quah (1989) is used to decompose U.S. long-term interest rates into an expected inflation component and an ex ante real interest rate component.<sup>1</sup> This methodology involves estimating a vector autoregression (VAR) model and identifying different types of shocks on the basis of long-run assumptions about the structure of the economy.<sup>2</sup>

Structural shocks are identified via the long-run restriction that inflation expectation shocks have a permanent effect on interest rates, while ex ante real interest rates shocks have only a temporary effect. This is consistent with recent articles concluding that inflation expectations and nominal interest rates move one-for-one in the long run – they are cointegrated (1,1) – and that real interest rates are stationary.<sup>3</sup> Mishkin (1992) calls this a long-term Fisher effect, as opposed to a short-term Fisher effect, which is a stronger assumption in that it implies a constant real interest rate.

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1. See also Shapiro and Watson (1988), King, Plosser, Stock and Watson (1991), and Quah and Vahey (1995). See Blanchard and Watson (1986) or Sims (1986) for a similar approach using short-term instead of long-term identifying restrictions.
  2. This methodology was preferred to the Beveridge-Nelson approach (either univariate or multivariate) in part because that approach is more restrictive concerning the short-term dynamics of shocks. This is discussed further in Section 4 below.
  3. See Mishkin (1992), and Mishkin and Simon (1995). Engsted (1995) reports mixed results.

Once structural shocks have been identified, their dynamics and their relative importance are studied at different time horizons (using impulse responses and variance decompositions). The effect of these shocks is also cumulated to provide estimates of expected inflation and ex ante real interest rates. These series can then be used to analyse the historical behaviour of long-term interest rates.

One advantage of the approach used in this paper is that it does not require the often-used assumption that the ex ante real interest rate is constant.<sup>4</sup> This rate is only assumed to be stationary. Another advantage of the approach is that it is based on economic agents' behaviour reflected in market prices. In contrast, survey-based methods (e.g. the Livingston survey or the Michigan survey) are not necessarily consistent with the relevant prices and quantities observed in the marketplace.<sup>5</sup> Finally, the approach is simple and can provide timely estimates of inflation expectations (which is not necessarily the case with survey-based methods). It may be particularly useful in the case of countries that do not have markets for indexed bonds.<sup>6</sup>

The methodology in this paper is applied to the U.S. 1-year and 10-year government bond rates. These rates were chosen because relatively long time series are available, which is a desirable property when long-run restrictions are being used to identify structural shocks. Also, while many analysts and market participants focus on the 10-year bond rate, inflation expectations identified using the 1-year rate can be compared with the 1-year-ahead Michigan survey's expectations (this is done in Section 6 below).

This study finds that changes in inflation expectations and in the ex-ante real interest rate are both important in explaining fluctuations in the U.S.

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4. That assumption is used, among others, by Mishkin (1988).

5. This point is made by Ragan (1995).

6. Deacon and Derry (1994) derive inflation expectations by comparing rates on equal-maturity nominal and real (indexed) bonds.

1-year and 10-year government bond rates. Changes in the ex ante real interest rate appear particularly important at a short-term horizon, but their dynamic effects disappear relatively quickly. The paper also finds that while the increase in the 1-year and the 10-year bond rates in the 1970s and the early-1980s mainly reflected higher inflation expectations, changes in ex ante real interest rates appear to account for most of the fluctuations in these rates in 1994 and in the first half of 1995.

The rest of the paper is organized as follows. Section 2 discusses the underlying theoretical model. Section 3 describes and analyses the data. Section 4 presents and discusses the structural VAR. Section 5 reports the variance decomposition of the nominal long-term interest rate and the impulse responses to expected inflation and ex ante real interest rate shocks. Section 6 presents the estimated series of expected inflation and ex ante real interest rates and uses them to analyse some historical episodes. Finally, conclusions are presented in Section 7.

## 2 The theoretical model

The Fisher hypothesis states that nominal interest rates can be described as the sum of expected inflation and ex ante real interest rates:

$$i_{t,k} = rr_{t,k} + E(\pi)_{t,k} \quad (1)$$

In equation (1),  $i_{t,k}$  is the nominal interest rate at time  $t$  on a  $k$  period bond,  $rr_{t,k}$  is the ex ante real interest rate on the same bond and  $E(\pi)_{t,k}$  is the expected inflation rate at time  $t$  for the period  $t$  to  $t+k$ . In this paper I want to identify  $rr_{t,k}$  and  $E(\pi)_{t,k}$ .

Defining the inflation forecast error as

$$\varepsilon_{t,k} = \pi_{t,k} - E(\pi)_{t,k} \quad (2)$$

where  $\pi_{t,k}$  is realized inflation, gives the following:

$$i_{t,k} - \pi_{t,k} = rr_{t,k} - \varepsilon_{t,k} \quad (3)$$

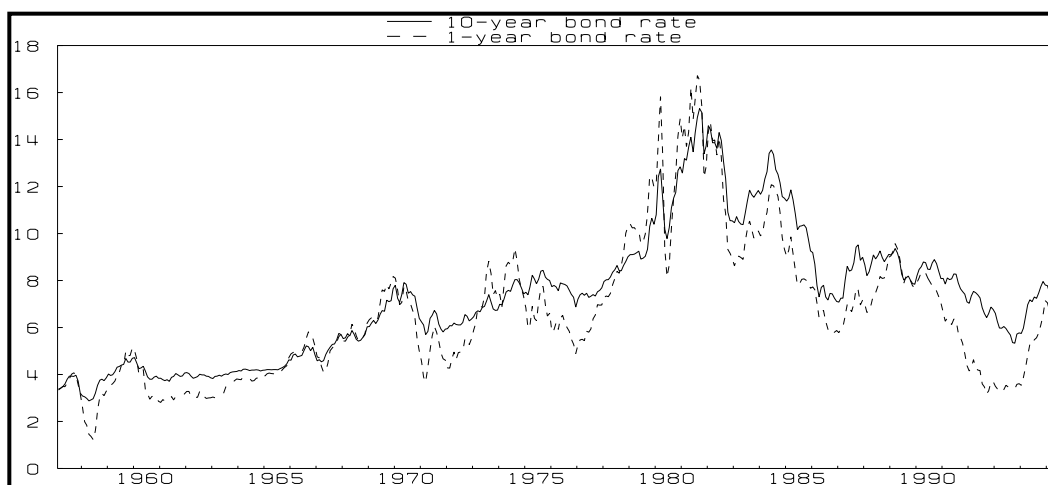
Assuming that  $\varepsilon_{t,k}$  is I(0), which is the case under rational expectations or under the less restrictive assumption that expected inflation and ex-post inflation are cointegrated of order 1, equation (3) implies that  $i_{t,k} - \pi_{t,k}$  can only be I(1) if  $rr_{t,k}$  is I(1). Similarly, testing for a unit root in  $i_{t,k} - \pi_{t,k}$  is the same as testing for a unit root in  $rr_{t,k}$ . This is done in the next section.

### 3 The data

The interest rates considered in this paper are the 1-year and 10-year U.S. government bond rates calculated by the Board of Governors of the Federal Reserve as the daily averages of yields on Treasury securities at constant maturity (see Chart 1). Inflation is measured as the (seasonally adjusted) annualized growth rate of the monthly U.S. consumer price index excluding food and energy.<sup>7</sup> The sample starts in February 1957 (the measure of inflation is not available before that date) and ends in June 1995.

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7. The use of total CPI would lead to similar results.

**CHART 1: 1-year and 10-year U.S. government bond rates**

It is assumed that there is a permanent component in the level of nominal long-term interest rates. Unit-root tests could not reject this assumption (see Appendix 1). The same tests were applied to the nominal interest rates minus the inflation rate ( $i_{t,k} - \pi_t$ ). The results suggest that this is stationary for the 10-year rate. Such a test is equivalent to testing the hypothesis that the nominal interest rate minus realized inflation ( $i_{t,k} - \pi_{t,k}$ ) is stationary, which implies that the ex ante real interest rate on the 10-year rate can be well approximated as a stationary process. Results for the 1-year rate minus inflation are mixed (the augmented Dickey-Fuller test does not reject the unit root). However, it is assumed that this is stationary.<sup>8</sup>

#### 4 The structural VAR

In order to distinguish between ex ante real interest rates and inflation expectations shocks, a variant of the structural VAR methodology is applied to an autoregressive system composed of two variables: the long-term

8. Mishkin (1992) concludes that real interest rates associated with the 1-month and 3-month rates are stationary, while Engsted (1995) reports mixed results for the real long-term rates of a group of countries.

nominal interest rate ( $i$ ) and this rate minus the rate of inflation ( $r$ ). It is assumed that nominal interest rate fluctuations are a function of two non-autocorrelated and orthogonal types of shocks: inflation expectation shocks ( $\varepsilon p$ ) and ex ante real interest rate shocks ( $\varepsilon r$ ). It is also assumed that inflation expectations are best characterized as a stochastic process corresponding to the permanent component of nominal interest rates, whereas ex ante real interest rate expectations correspond to the stationary component.

Note that the orthogonality assumption does not eliminate the possibility that real interest rates disturbances affect inflation expectations and vice versa. Its only implication is that these disturbances are not systematically correlated. The orthogonality assumption will be valid if disturbances have different sources in the economy. An example of a model compatible with this assumption is one in which inflation expectation shocks reflect perceived changes in the monetary policy regime that are not systematically correlated with factors affecting ex ante real interest rates, such as changes in the fiscal stance, political uncertainty or technological innovations. Note that the cumulative effect of the structural shocks can be correlated.

By the Wold decomposition theorem, the structural model can be given the following moving-average representation:

$$x_t = A_0 \varepsilon_t + A_1 \varepsilon_{t-1} + \dots = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} = A(L) \varepsilon_t \quad (4)$$

where

$$\varepsilon_t = \begin{bmatrix} \varepsilon p \\ \varepsilon r \end{bmatrix} \text{ and } x_t = \begin{bmatrix} \Delta i \\ r \end{bmatrix}$$

To simplify, the variance of the structural shocks is normalized so that  $E(\varepsilon_t \varepsilon_t') = I$  the identity matrix.

To identify the structural model, the following VAR is first estimated:

$$\Delta x_t = \Pi_1 \Delta x_{t-1} + \dots + \Pi_q \Delta x_{t-q} + e_t \quad (5)$$

where  $e_t$  is a vector of estimated residuals,  $q$  is the number of lags, and  $E(e_t e_t') = \Sigma$ .

The estimated VAR is then inverted to obtain the following moving-average representation:<sup>9</sup>

$$x_t = e_t + C_1 e_{t-1} + \dots = \sum_{i=0}^{\infty} C_i e_{t-i} = C(L) e_t \quad (6)$$

The residuals of the model's reduced form are related to the structural residuals in the following way:

$$e_t = A_0 \varepsilon_t \quad (7)$$

which implies that

$$E(e_t e_t') = A_0 E(\varepsilon_t \varepsilon_t') A_0' \quad (8)$$

and thus,

$$A_0 A_0' = \Sigma \quad (9)$$

In order to identify the structural shocks ( $\varepsilon$ ) from the information obtained by estimating the VAR (equation 2), that is, from the reduced-form

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9. We suppose that the determinantal polynomial  $|A(L)|$  has all its roots on or outside the unit circle. This condition rules out non-fundamental representations emphasized by Lippi and Reichlin (1993).

shocks ( $e$ ) and their variance ( $\Sigma$ ), one more identifying restriction is required. From (1), (4) and (6), it is clear that the matrix of long-run effects of the reduced-form shocks, that is  $C(1)$ , is related to the equivalent matrix of structural shocks, that is  $A(L)$ , through the following relation:

$$A(1) = C(1)A_0 \quad (10)$$

where the matrix  $C(1)$  is calculated from the estimated VAR. The restriction imposed, as stated above, is simply that ex ante real interest rate shocks do not affect the nominal long-term interest rate in the long run.

Therefore, the following structural decomposition is obtained:

$$\Delta i_t = A_\pi(1) \varepsilon_{\pi t} + A_\pi^*(L) \varepsilon_{\pi t} + A_{rr}^*(L) \varepsilon_{rrt} \quad (11)$$

The right-hand side of equation (11) is composed of the moving-average components of the different types of shocks to the nominal long-term interest rates. The  $A^*(L)$  represent the transitory components of the shocks (real interest rate shocks do not have a permanent component). The first two terms on the right-hand side of (11) represent the measure of inflation expectations, while the third term represents the measure of ex ante real interest rates.

It is interesting to compare the decomposition resulting from the methodology I use to that resulting from Beveridge-Nelson methodology. The Beveridge-Nelson methodology, either in its univariate or multivariate form (Evans and Reichlin, 1994) gives a decomposition that can be expressed in the following way:

$$\Delta y_t = C(1) \varepsilon_t + C^*(L) \varepsilon_t \quad (12)$$



with  $y_t$  being an arbitrary differenced-stationary time series. Equation (12) illustrates one important difference between the two approaches: the Beveridge-Nelson approach does not take into account the transitory component of the shocks that have a permanent impact, while the approach I use does.<sup>10</sup> I decided to use this less restrictive approach.

It is particularly important to include a sufficient number of lags in the VAR. Monte Carlo simulations carried on by DeSerres and Guay (1995) show that using a lag structure that is too parsimonious can significantly bias the estimation of the structural components. These authors also find that information-based criteria, such as the Akaike and Schwarz criteria, tend to select an insufficient number of lags, while Wald or likelihood-ratio (LR) tests, applied according to a general-to-specific strategy, perform much better. Accordingly, I selected the number of lags to be included in the VARs (17 in the case of the VAR of the 10-year interest rate and 19 in the case of the 1-year rate's VAR) on the basis of an LR test (using a 5 per cent critical value).

## **5 Variance decomposition and impulse responses**

In this section, I report the nominal long-term interest rates' decompositions of variance and the impulse responses of these rates to expected inflation and ex ante real interest rate shocks.

The decomposition of variance presented in Table 1 makes it possible to measure the relative importance of expected inflation and ex ante real interest rate shocks underlying nominal long-term interest rate fluctuations over different time horizons. Since I am imposing the restriction that ex ante real interest rate shocks have no permanent effect on the nominal interest rate, the proportion of

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10. This is discussed in more detail in DeSerres, Guay and St-Amant (1995). For a discussion of this type of issue in a univariate context see Watson (1986).

the variance of this series explained by these shocks gradually approaches zero per cent in the long run. Moreover, since these two types of shocks are uncorrelated by assumption, the proportion of the nominal interest rate variance caused by the sum of the two shocks is always equal to 100 per cent.

Table 1 suggests that both types of shocks have been important sources of nominal interest rate fluctuations. However, inflation expectation shocks appear to account for a larger share of the variance of the 1-year rate than of that of the 10-year rate at very short-term horizons.

A caveat to this analysis is that the 90 per cent confidence interval is very large.<sup>11</sup> This is not surprising, given the large number of lags included in the VARs and the fact that most econometric studies report large confidence intervals at conventional levels.

**TABLE 1: Variance decomposition of long-term interest rates**  
(relative contribution of the different types of shocks, in per cent)

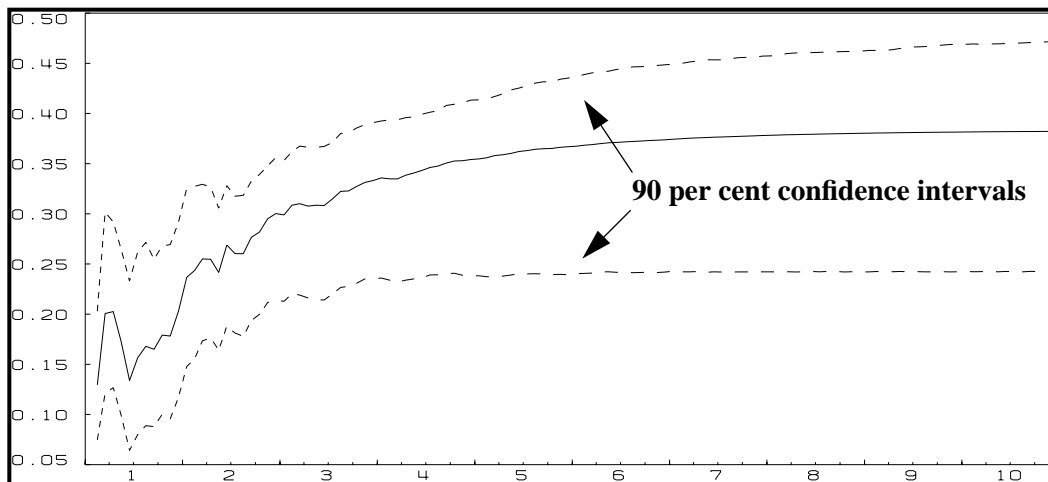
Horizon (months)	1-year government bond		10-year government bond	
	Expected inflation	Ex ante real interest rate	Expected inflation	Ex ante real interest rate
1	51 (25-93)	49 (7-75)	25 (9-68) <sup>a</sup>	75 (32-90)
6	49 (25-91)	51 (9-75)	28 (11-70)	72 (30-89)
12	51 (28-92)	49 (8-72)	33 (15-73)	67 (27-85)
24	64 (45-95)	36 (5-55)	56 (41-84)	44 (16-59)
48	81 (69-97)	19 (3-31)	79 (70-92)	21 (8-30)
long-term	100	0	100	0

a. 90 per cent confidence interval.

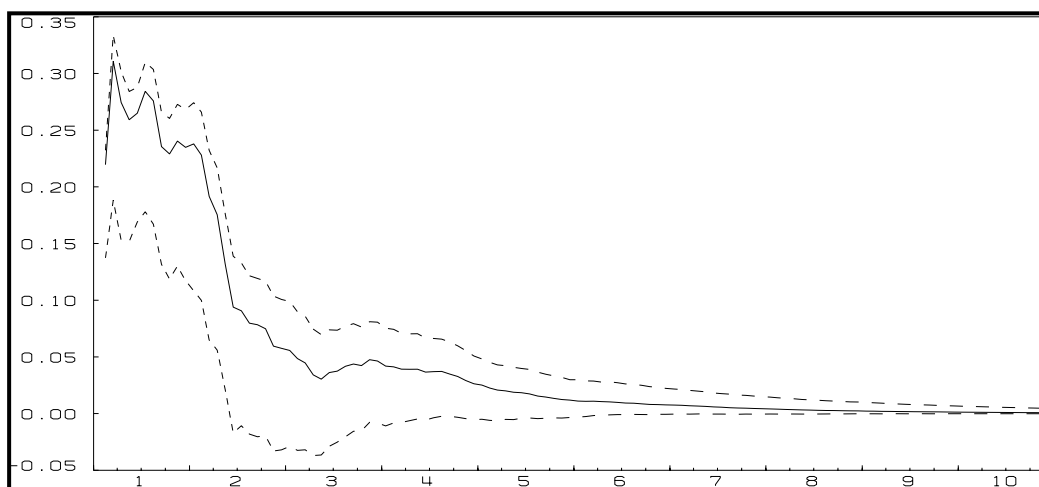
11. Confidence intervals were generated using Monte Carlo simulations in RATS with 1000 replications.

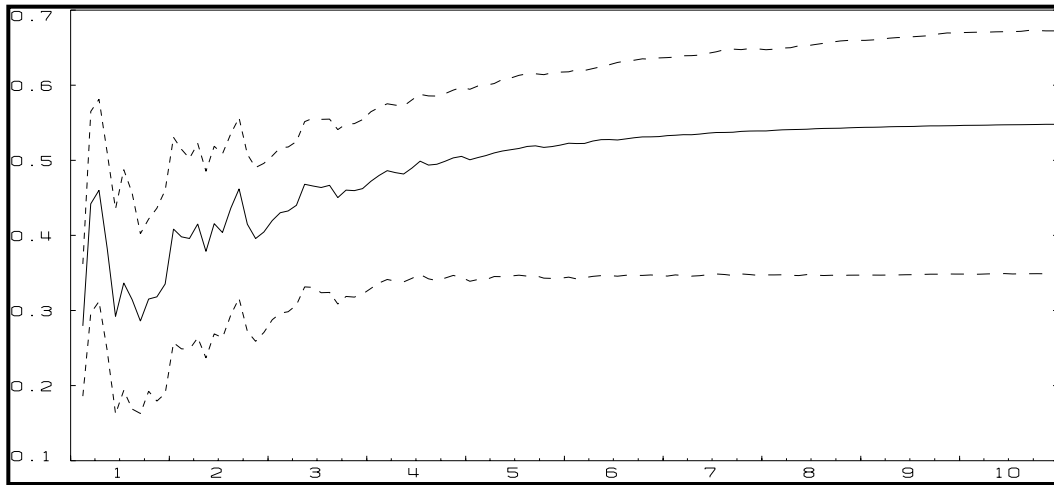
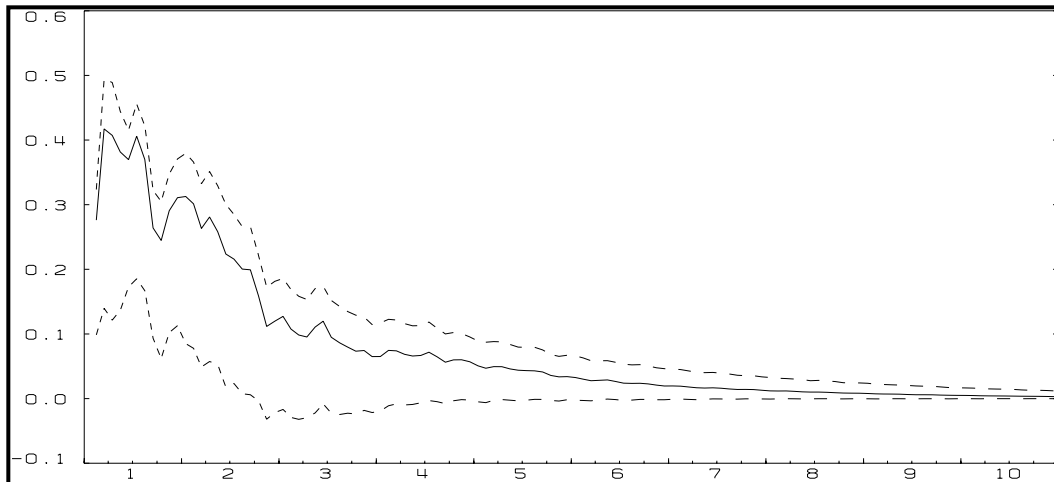
Charts 2 to 5 show the impulse responses of interest rates to the structural shocks. These shocks are one standard deviation in size. The horizontal axis represents the number of years.

**CHART 2: Response of the 10-year rate to an inflation expectation shock**



**CHART 3: Response of the 10-year rate to a real interest rate shock**



**CHART 4: Response of the 1-year rate to an inflation expectation shock****CHART 5: Response of the 1-year rate to a real interest rate shock**

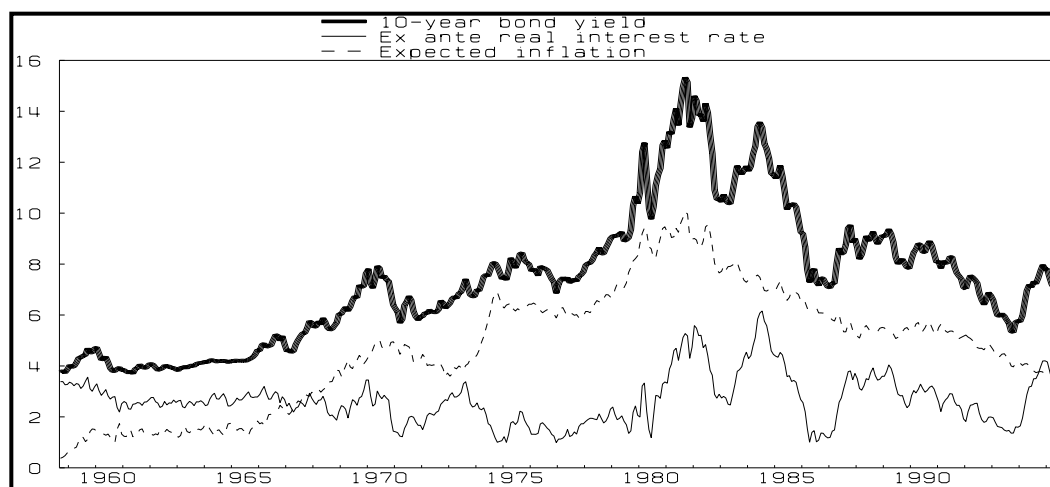
For both types of nominal interest rates, most of the effect of ex ante real interest rate shocks disappears in less than two years (remember that the short-term dynamics of the shocks is not constrained). The impact of the expected inflation shocks on the nominal interest rates is felt more gradually. This may reflect the dynamics of the adjustment of expectations to a change in the trend in inflation.

## 6 Ex ante real interest rates and expected inflation components

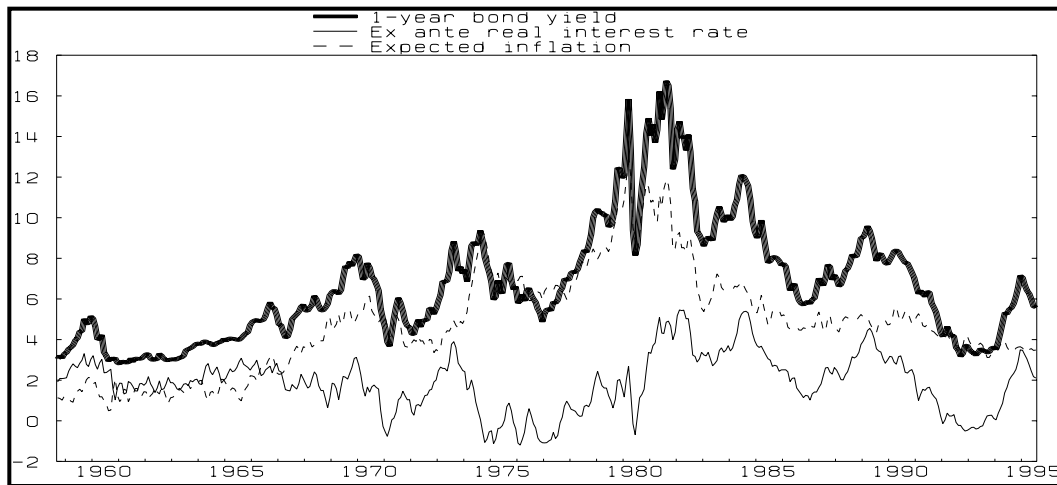
This section presents the estimated series of expected inflation and ex ante real interest rates and uses them to analyse some historical episodes.

The cumulation of the effect of the structural shocks gives the stationary and the permanent components of the nominal interest rates. An estimate of ex ante real interest rates can then be obtained by adding the stationary components to the mean of the difference between the observed nominal interest rates and the contemporaneous rate of inflation.<sup>12</sup> Subtracting this estimated ex ante real interest rate from the nominal interest rate then gives the estimated expected inflation series. The estimated ex ante real interest rate and the inflation expectation series associated with the 10-year rate are presented together with the 10-year rate in Chart 6. Chart 7 presents the same results for the 1-year interest rate.

**CHART 6: 10-year interest rate and its estimated components (in per cent)**

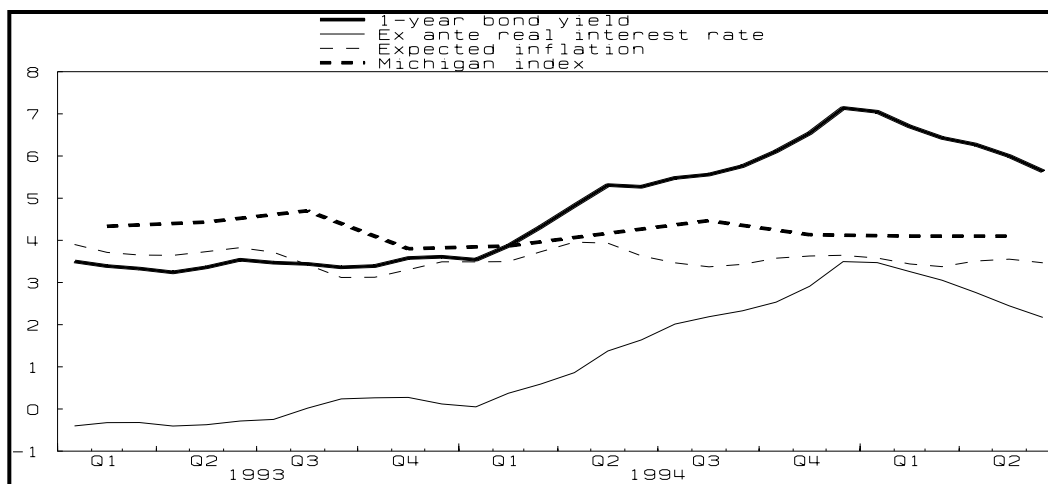


12. 2.65 per cent and 1.9 per cent, respectively, for the 10-year and the 1-year rates

**CHART 7: 1-year interest rate and its estimated components (in per cent)**

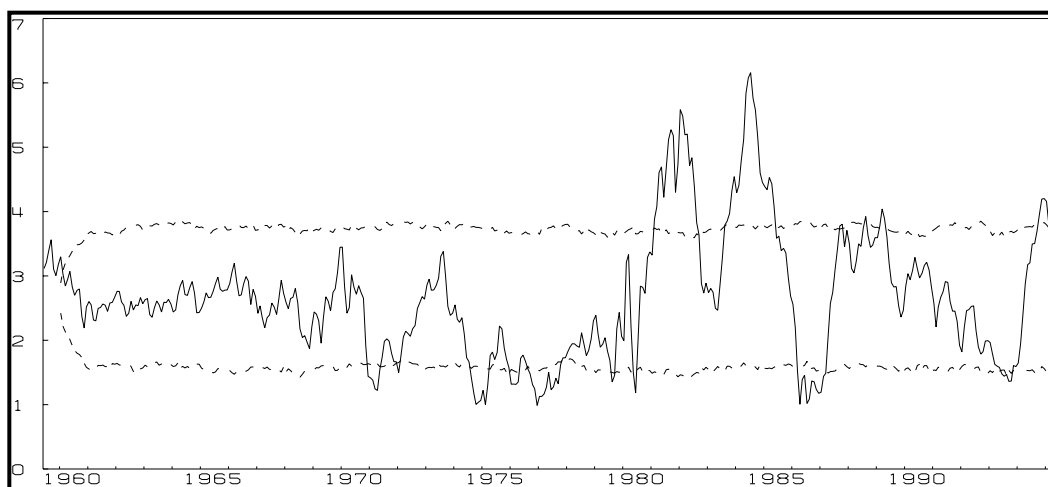
Charts 6 and 7 both suggest that higher inflation expectations accounted for most of the increase in the nominal interest rate in the 1970s and early 1980s (remember that the increase represents 1-year and 10-year-ahead expected inflation). The subsequent declining trends in these rates would be explained by a similar decline in inflation expectations. However, the volatility in the ex ante real interest rates seems to account for much of the volatility in both the 1-year and 10-year rates during the 1980s and the 1990s.

Chart 8 focusses on the 1993-95 period. It suggests that the large increase in the 1-year interest rate in 1994 and its subsequent decline in 1995 were mainly caused by parallel movements in the estimated ex ante real interest rate. A graph showing the 10-year rate and its components over this same period would tell a similar story. Chart 8 also shows one-year-ahead inflation expectations based on the University of Michigan survey over that period. Using that survey as a measure of inflation expectations would also lead to the conclusion that most of the volatility in the 1-year nominal rate in 1994-95 was caused by movements in the real interest rate.

**CHART 8: 1-year government bond rate and its components (93Q1 to 95Q2)<sup>a</sup>**

a. The Michigan survey series is quarterly, the other series are monthly.

A caveat to this analysis is, again, the uncertainty surrounding the estimations. This is illustrated by Chart 9, which shows the estimated ex ante real interest rate based on the 10-year rate together with 90 per cent confidence intervals. The mean of the observed series, consisting of the nominal interest rate minus contemporaneous inflation, 2.65 per cent, is added to that series. Confidence intervals are centred around that mean.

**CHART 9: Estimated ex ante real interest rate and confidence intervals**

## **7 Conclusions**

In this paper, the structural VAR methodology is used to decompose the U.S. 1-year and 10-year government bond rates into inflation expectations and ex ante real interest rates. My results suggest that the increase in those rates in the 1970s and early 1980s largely reflected higher inflation expectations, while the 1994-95 fluctuations mainly reflected changes in the ex ante real interest rate. However, there is a significant amount of uncertainty surrounding the estimates, as shown by the size of the estimated confidence intervals at conventional significance levels.

The approach considered in this paper can decompose nominal interest rates into their expected inflation and ex ante real interest rate components, but does not explain why these components behaved the way they did. To answer that question, a larger VAR could be estimated and more identification restrictions could be imposed. This is a possible avenue for future research.



## Appendix 1

### Unit-root tests

Table A-1 shows the results of the augmented Dickey-Fuller test (1979), Phillips-Perron (1988) and Phillips-Schmidt (1992) tests of the null hypothesis of non-stationarity of nominal interest rates and of these rates minus contemporaneous inflation. The results generally support the hypothesis that nominal interest rates are stationary in first difference, while the real interest rate is stationary in level. The only exception is the 1-year real interest rate, for which the evidence is mixed.

**Table A-1: Unit-root tests**  
(Sample: July 1959 – June 1995)

Series (in logarithms)	Test statistics <sup>a</sup>			
	ADF <sup>b</sup>	PP (l=5) <sup>c</sup>	PP (l=17)	PS <sup>b</sup>
10-year interest rate	1.72	5.05	5.50	3.24
10-year interest rate (first difference)	<b>5.40</b>	<b>242.40</b>	<b>237.98</b>	<b>409.77</b>
10-year interest rate minus inflation	<b>3.22</b>	<b>241.88</b>	<b>451.44</b>	<b>130.77</b>
1-year interest rate	2.18	9.57	8.86	4.93
1-year interest rate (first difference)	<b>5.17</b>	<b>250.56</b>	<b>211.16</b>	<b>434.74</b>
1-year interest rate minus inflation	2.46	<b>345.01</b>	<b>276.89</b>	<b>671.94</b>

- a. The ADF and PP tests assume that there is no linear trend in the series. Results are robust to this assumption. The critical limits at a 5 per cent significance level of the ADF and the PP tests are 2.89 and 13.7, respectively. The critical limit at a 5 per cent significance level of the PS test is 18.1. Bold figures indicate that the unit-root hypothesis is rejected.
- b. The number of lags for the ADF and PS tests was chosen using the recursive procedure suggested by Ng and Perron (1993).
- c. The choice of the lag lengths for the PP test is related to the size of the sample, according to formulas suggested by Schwert (1989).

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