TERM STRUCTURE VIEWS OF MONETARY POLICY

Sharon Kozicki and P.A. Tinsley*

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Abstract: Term structure models and many descriptions of the transmission of monetary policy rest on the empirical relevance of the expectations hypothesis. Small differences in the perceived policy reaction function in VAR models of agent expectations strongly influence the relevance in the transmission mechanism of the expected short rate component of bond yields. Mean-reverting or difference-stationary characterizations of interest rates require large and volatile term premiums to match the observable term structure. However, short rate descriptions that capture shifting perceptions of long-horizon inflation evident in survey data support a more substantial term structure role for short rate expectations.

Keywords: Expectations hypothesis, nonstationary inflation, shifting endpoint.

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*Authors' addresses are Federal Reserve Bank of Kansas City, 925 Grand Boulevard, Kansas City, MO, 64198 USA, skozicki@frbkc.org; and Faculty of Economics and Politics, University of Cambridge, Cambridge CB3 9DD, UK, ptinsley@econ.cam.ac.uk. The views expressed are those of the authors and do not necessarily represent those of the Federal Reserve Bank of Kansas City or the Federal Reserve Board.

1 Introduction

The term structure of interest rates is often characterized as a crucial transmission channel of monetary policy where accurate market perceptions of policy are required for effective policy execution. This description rests on three propositions: First, a short-term interest rate, such as the overnight federal funds rate, is an effective summary of monetary policy actions. Second, long-term bond yields are important determinants of the opportunity cost of investments. Third, under the expectations hypothesis, the anticipated path of the policy short-term rate is the main determinant of the term structure of bond rates. Although the empirical validity of each of these three propositions has been criticized, the accumulation of empirical evidence against the third proposition–the expectations hypothesis–is impressively large.[1] If variations in current bond rates are not well-connected to current and expected movements in the policy-controlled short-term rate, then the conventional description of monetary policy transmission is vacuous.

In no-arbitrage formulations of the term structure, variation in bond rates due to current and expected movements in short rates is determined by the description of short rate dynamics. Under the standard finance assumption that short rates are mean-reverting, the average of expected future short rates is considerably smoother than historical bond rates. Thus, the expectations hypothesis is empirically rejected by tests which assume constant term premiums, and postwar shifts in the term structure are often attributed to sizable movements in "liquidity" and "term" premiums. However, postwar data are consistent with descriptions of short rate movements other than mean reversion. This paper shows that small differences in the specification of the stochastic process for the short rate strongly influence the relative importance of short rate expectations and residual term premiums in bond rate movements.

As an alternative to conventional descriptions of short rate dynamics, a simple class of time-varying descriptions of short rate behavior is examined. Given well-documented shifts in postwar monetary policy, it seems highly probable that the short rate expectations of bond traders are heavily influenced by shifting perceptions of monetary policy. Short rate descriptions that

[1] For instance, Campbell and Shiller (1991) compare estimated "theoretical" spreads to actual spreads and conclude that the spread is too variable to accord with the expectations hypothesis. In addition, in regressions of long-rate changes on spreads, Shiller (1979), Shiller, Campbell, and Schoenholtz (1983), and Campbell and Shiller (1991) find that coefficient estimates on the spread tend to be significantly different than the hypothesized value of one, and typically are negative.

capture shifting perceptions of the long-run objective of monetary policy, formulated as a long-run inflation target, are supportive of a substantial term structure role for short rate expectations.[2]

In addition to rejecting the implication that high bond rates in the 1980s reflect large term premiums, the preferred description of short rate behavior also does not support interpretations that perceived inflation targets were rapidly reversed in the 1980s. More likely, the long-run inflation target perceived by the market behaved similarly to survey data on long-run expected inflation. Survey data suggest agents were cautious in adjusting their perceptions of long-run inflation.

This paper illustrates the term structure implications of alternative representations of monetary policy perceptions of agents. Section 2 develops a discrete-time, no-arbitrage model of the term structure where the stochastic discount factor is related to a vector of macroeconomic variables. Forecasts of this state vector are generated by a VAR with flexible specifications of long-run behavior. Section 3 discusses three VARs with different characterizations of agent perceptions of long-run behavior. Owing to the different characterizations of perceived long-run behavior, the VARs embed perceived policy reaction functions with different implied inflation targets. Section 4 indicates how estimates of expected short-rate components of bond yields and conventional "residual" estimates of term premiums depend critically on assumptions regarding the long-run behavior of policy targets in VAR proxies of agent expectations. Section 5 concludes.

2 A model of the term structure of interest rates

The term structure model described in this section is based on the affine specification developed in Campbell, Lo, and MacKinlay (1997). The derivation is in discrete time to facilitate discussion of the empirical time-series forecasting system that will be used to proxy for market expectations. The model links bond yields to expectations of monetary policy through a VAR proxy for expectations formation which contains an implicit policy reaction function. The implicit policy reaction function relates short term interest rates to deviations of economic variables from their long-run equilibrium values, including deviations of inflation from the long-run inflation goal of monetary policy. Thus, bond yields depend on monetary policy primarily through the influence of market perceptions of

[2]As developed later, shifting perceptions are represented in this paper as sequential learning, where agents test for changepoints in parameters of linear time series models. Other approaches to the apparent nonstationarity of interest rates include the fractional difference processes in Backus and Zin (1993), the multiple regimes models in Evans and Lewis (1995) and Bekaert, Hodrick, and Marshall (1997), and the "central tendency" factor of Balduzzi, Das, and Foresi (1997).

policy on short rate expectations.

The price of an n-period nominal bond, $P_{n,t}$, satisfies

$$P_{n,t} = E_t[P_{n-1,t+1}\ M_{t+1}], \tag{1}$$

where M_{t+1} is the nominal stochastic discount factor. Assuming M_{t+1} and the bond price are conditionally joint lognormally distributed, (2) can be represented as

$$p_{n,t} = E_t[m_{t+1} + p_{n-1,t+1}] + (1/2)Var_t[m_{t+1} + p_{n-1,t+1}], \tag{2}$$

with lower-case letters denoting the natural logarithms of the corresponding upper-case letters.

The yield-to-maturity on an n-period bond is equal to

$$R_{n,t} = -\frac{1}{n}p_{n,t}. \tag{3}$$

A recursive expression for yields can be obtained by substituting the yield-price relationship into (2):

$$R_{n,t} = \frac{1}{n}E_t[-m_{t+1} + (n-1)R_{n-1,t+1}] - \frac{1}{2n}Var_t(-m_{t+1} + (n-1)R_{n-1,t+1}). \tag{4}$$

Noting that for $n = 1$, $p_{n-1,t+1} = p_{0,t+1} = 0$, the yield on a one-period bond is $R_{1,t} = E_t(-m_{t+1}) - (1/2)Var_t(m_{t+1})$. Using this initial condition, (4), and mathematical induction, it is easy to show that n-period yields are related to one-period rates according to:

$$R_{n,t} = \frac{1}{n}E_t[\sum_{i=0}^{n-1} R_{t+i}] + \theta_{n,t} \tag{5}$$

where

$$\theta_{n,t} = -\frac{1}{2n}[E_t \sum_{i=1}^{n-1} Var_{t+i-1}((n-i)R_{n-i,t+i})] + \frac{1}{n}[\sum_{i=1}^{n-1} Cov_{t+i-1}(m_{t+i}, (n-i)R_{n-i,t+i})] \tag{6}$$

is the term premium, including Jensen's inequality terms.[3] This formulation explicitly identifies the roles of expected future short rates and term premium in longer maturity bond yields.

The model links bond yields to a vector of state variables commonly used in empirical macroeconomic by modelling short rate expectations using a VAR forecasting system. The VAR

[3] The first term in $\theta_{n,t}$ is a Jensen's inequality term while the second contains the more conventional liquidity, risk, or term premium. Generally, we will use the phrase "term premium" to refer to $\theta_{n,t}$.

contains short rates and and a collection of other state variables. The vector of state variables, x_t, is a non-explosive VAR process about the *endpoint* vector, $\mu_\infty^{(t-1)}$,

$$x_t = Hx_{t-1} + (I - H)\mu_\infty^{(t-1)} + u_t, \tag{7}$$

where the coefficient matrix, H, has all eigenvalues less than or equal to one in magnitude, and u_t contains serially uncorrelated innovations. Following Kozicki and Tinsley (1998), the endpoint, $\mu_\infty^{(I)}$, is the limiting conditional expectation of the vector x_t,

$$\mu_\infty^{(I)} \equiv \lim_{k\to\infty} E_I x_{t+k}, \tag{8}$$

with I indexing the time subscript of the information set on which expectations are conditioned.

The endpoint representation is sufficiently general to encompass more traditional VAR forecasting systems in which elements of x_{t+1} are classified as either I(0) or I(1). In particular, if an element of x_{t+1} is I(0), then the corresponding element of $\mu_\infty^{(t)}$ will be a constant; if an element of x_{t+1} is I(1), then the corresponding element of $\mu_\infty^{(t)}$ will be a linear combination of elements of x_t. The endpoint representation also encompasses cases in which elements of x_{t+1} may be subject to sporadic mean shifts with the corresponding elements of $\mu_\infty^{(t)}$ deterministic but subject to occasional shifts. Such specifications are convenient for explicitly accounting for changes in the perceived long-run inflation goals of monetary policy within a VAR framework. Three competing VAR specifications, differing primarily according to endpoint assumptions, are examined in detail in the next subsection.

Bond yields are related to state variables by substituting VAR forecasts of R_{t+i} for expectations of R_{t+i} in (5), and relating the stochastic discount factor, m_{t+1}, to the vector of state variables, x_{t+1}. Assume

$$-m_{t+1} = \phi' x_{t+1} + w_{t+1} \tag{9}$$

where w_{t+1} is a serially uncorrelated innovation. To account for correlation between w_{t+1} and the vector of VAR innovations u_{t+1} assume

$$w_{t+1} = \beta' u_{t+1} + v_{t+1} \tag{10}$$

where u_{t+1} and v_{t+1} are uncorrelated at all leads and lags. Let $\Sigma_{u,t+1} \equiv E_t(u_{t+1}u'_{t+1})$ represent the conditional covariance matrix of u_{t+1}. Assuming ι_r is a selector vector, with all entries zero except for a one identifying the position of R_t in the state vector x_t, it follows that $R_t = \iota_r' x_t$, and, forecasts of short rates can be constructed as:

$$E_t R_{t+i} = \iota_r'[H^i x_t + (I - H^i)\mu_\infty^{(t)}] \tag{11}$$

Furthermore, from (5) and (6), it follows that

$$R_{n-i,t+i} = E_{t+i-1}R_{n-i,t+i} + \frac{1}{n-i}\iota_r' \sum_{k=0}^{n-i-1}\sum_{j=0}^{n-i-1-k} H^j u_{t+i+k} + (E_{t+i} - E_{t+i-1})\theta_{n-i,t+i} \tag{12}$$

Using (9) - (12) in (5) and (6), the n-period yield can be rewritten in terms of the vector of state variables as

$$R_{n,t} = \frac{1}{n}\sum_{i=0}^{n-1} \iota_r'[H^i x_t + (I - H^i)\mu_\infty^{(t)}] + \theta_{n,t}. \tag{13}$$

Under additional assumptions relating $\Sigma_{u,t+1}$ to the vector of state variables, an explicit expression relating term premium to the state variables and uncertainty can be derived. In the absence of such assumptions, an expression for $\theta_{n,t}$ can still be derived for the case in which $E_{t+i}\Sigma_{u,t+i+j} = E_{t+i-1}\Sigma_{u,t+i+j}$ for $j = 1, 2, \ldots$:

$$\theta_{n,t} = \frac{-1}{2n}[\sum_{i=1}^{n-1}[\iota_r'(\sum_{j=0}^{n-i-1} H^j)E_t\Sigma_{u,t+i}(\sum_{j=0}^{n-i-1} H^j)'\iota_r] - \frac{1}{n}(\beta+\phi)'E_t\Sigma_{u,t+i}(\sum_{j=0}^{n-i-1} H^j)'\iota_r] \tag{14}$$

The expressions in (13) and (14) relate bond yields in t to contemporaneous observations on state variables, including the one-period rate in t. Predictions of yields, conditional on data through $t-1$ can be constructed as

$$E_{t-1}R_{n,t} = \frac{1}{n}\sum_{i=0}^{n-1} \iota_r'[H^{i+1} x_{t-1} + (I - H^{i+1})\mu_\infty^{(t-1)}] + E_{t-1}\theta_{n,t} \tag{15}$$

where

$$E_{t-1}\theta_{n,t} = \frac{-1}{2n}[\sum_{i=1}^{n-1}[\iota_r'(\sum_{j=0}^{n-i-1} H^j)E_{t-1}\Sigma_{u,t+i}(\sum_{j=0}^{n-i-1} H^j)'\iota_r] - \frac{1}{n}(\beta+\phi)'E_{t-1}\Sigma_{u,t+i}(\sum_{j=0}^{n-i-1} H^j)'\iota_r]. \tag{16}$$

Two features of the model are noteworthy. First, because the short rate equation in the VAR approximates agent perceptions of the monetary policy reaction function, monetary policy influences bond yields through a dependence of short rate expectations on perceptions of policy. Second, the explicit expression relating term premium to uncertainty and the parameters of the VAR used to proxy market expectations admits the potential for time-varying term premium.

3 VARs with fixed and time-varying policy goals

This section discusses the use of VARs to approximate agent expectations, especially longer-horizon expectations. Because expectations models of the term structure of interest rates embed long-horizon forecasts, the limiting conditional forecasts, or *endpoints*, of the VAR play a crucial role in term structure models. In particular, standard VAR specifications frequently used in empirical macroeconomic studies embed an assumption that the market believes the long-run policy goal for inflation has not and will not change over time.[4] This assumption is contradicted by survey data on long-horizon inflation expectations. This section shows how to generalize VAR specifications to permit expectations to be influenced by shifting perceptions of monetary policy goals. Operationally, such shifts are mapped into time-varying intercepts of the VAR equations.

Typically, forward-looking models, including those of the term structure of interest rates, contain implicit assumptions on long-horizon behavior. These long-run conditions are usually determined by the decision to include variables in level or differenced formats. This choice of dynamic formats has minimal impact on short-horizon VAR forecasts for variables that are highly persistent, such as interest rates or inflation. However, the dynamic format can have a large effect on long-horizon forecasts, as shown in Kozicki and Tinsley (1998) for univariate autoregressive models. Dynamic specifications are similarly important when VAR forecasts are used to proxy for long-horizon market expectations.

Kozicki and Tinsley (1998) indicate that a convenient way to examine long-run assumptions in a time series model is to identify the *endpoints* of the series being modeled. As introduced in the previous section, the endpoint of the vector of time series, x_t, is denoted $\mu_\infty^{(I)} \equiv \lim_{k\to\infty} E_I x_{t+k}$ where the expectation is conditioned on information set I.[5] If a series is mean-reverting or I(0), then the endpoint of the series will be a constant. This feature is just a restatement of the property that long-run forecasts of a mean-reverting series converge to a constant, which is equal to the

[4] In general, the standard approaches include variables such as interest rates and inflation in levels in VARs. When, as is usually the case, point estimates of the VAR coefficients are consistent with mean-reversion of VAR variables, the VARs implicitly embed an assumption that the VAR endpoints for interest rates and inflation are constant. Since the endpoint of the inflation process reasonably can be assumed to correspond to the long-run policy goal for inflation, these VARs implicitly assume that the long-run policy goal for inflation is a constant. Clarida, Gali, and Gertler (1997 and 1998) estimate policy rules assuming a constant inflation target since 1979.

[5] Strictly speaking, the infinite horizon subscript is applicable only for stochastic processes that do not contain unbounded deterministic trends.

mean of the series in large samples. By contrast, if a series is difference-stationary, I(1), then, in a univariate autoregressive model, the endpoint of the series will be a moving average of recent observations of the series. More generally, in a multivariate VAR, the endpoint of an I(1) series will be either a moving average of the series or a linear combination of moving averages of the series and other series with which it is cointegrated.

VARs can be readily rewritten to explicitly reveal dynamic adjustments of deviations from endpoints. An advantage of this reformulation is that alternative characterizations of long-run behavior can be easily implemented and interpreted. For example, the VARs considered in this section contain an implicit policy reaction function which relates deviations of the short rate from its endpoint to deviations of inflation and capacity utilization from their respective endpoints. The inflation endpoint thus plays the role of the perceived policy target for inflation. The implicit endpoint restrictions imposed by I(0) assumptions correspond to an assumption that the perceived policy target for inflation is fixed and equal to the sample mean of inflation. An alternative assumption that inflation is I(1) corresponds to a characterization that the perceived policy target for inflation is a moving average of inflation.[6] Relaxing the implicit endpoint restrictions imposed by I(0) or I(1) assumptions allows additional characterizations of time variation in the perceived policy goal for inflation.

The remainder of this section discusses three different VAR specifications to illustrate the long-horizon implications of alternative endpoint specifications. The VARs differ in their assumptions about long-run behavior. In particular, each incorporates a different characterization of the inflation endpoint, which represents the market perception of the long-run policy target for inflation. The VARs are similar in that each contains the same three variables: a one-month nominal interest rate, r, inflation, π, and the rate of capacity utilization, y. All interest rates referenced in this paper are end-of-month zero-coupon Treasury bond yields.[7] Monthly inflation is measured by the BEA chain-weighted deflator for personal consumption expenditures, and monthly capacity utilization by the FRB index for manufacturing.

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[6] This assumes no cointegration between capacity utilization, interest rates, and inflation. See the discussion on this point later in the section.

[7] Interest rates for 1960m1-1991m1 are from McCulloch and Kwon (1993). For comparability, these data were extended to 1997m9 by applying the cubic spline estimator described in McCulloch (1975) to end-of-month yields. Our thanks to Mark Fisher for his generous assistance.

3.1 *The fixed endpoints VAR*

The general structure of this VAR resembles the representative small-scale VARs used by macroeconomists such as Bernanke and Blinder (1992) and Fuhrer and Moore (1995) to represent the responses and effects of monetary policy. Such VAR specifications, with all variables included in levels, are typically fixed endpoint specifications as coefficient estimates are usually consistent with mean-reversion.

The top rows of Table 1 summarize estimates of univariate twelve-order autoregressions for the one-month bond rate, r, the inflation rate, π, and the manufacturing utilization rate, y. The point estimates of the coefficients of the lagged levels of each variable, b, are consistent with mean-reverting behavior. Under this specification, a long-horizon forecast will converge to the fixed endpoint, $-c/b$. For the sample spans underlying Table 1, the estimated endpoints are $r_\infty = 6.5$, $\pi_\infty = 4.1$, and $y_\infty = 82.8$.[8]

Selected coefficients of a fixed endpoints VAR for r, π, and y, using a common sample span of 1966m1-1997m9[9], are shown in the top panel of Table 2.[10] The short rate equation plays the role of a policy reaction function where a short-term interest rate, controlled by the policy authority, responds to deviations of inflation from a fixed long-run policy target for inflation and to deviations of output from trend.

In a mean-reverting VAR the implied policy target for inflation is equivalent to the fixed endpoint for inflation, assuming information on policy targets is symmetrically available to all public and private sector agents. As shown in the top panel of figure 1, the fixed endpoint for inflation over the 1966-1997 sample is estimated to be a bit less than 5% at an annual rate.[11] A

[8] In remaining empirical work, the mean of the utilization rate is removed, implying a fixed endpoint of zero.

[9] Models using a short-term interest rate to approximate the operating policy of the Federal Reserve often omit observations before 1966 due to changes in the behavior of the interbank market for overnight funds prior to the mid-1960s; see discussion of the relationship between the federal funds rate and the Federal Reserve discount rate in Tinsley et al. (1982). The VARs in Table 2 contains six lags of each variable. In the case of the fixed endpoints model, the p-values of likelihood ratios indicate that a three-lag specification is rejected in favor of six lags, but a six-lag specification is not rejected against the alternatives of 9 or 12 lags.

[10] Sims (1992) and Christiano, Eichenbaum, and Evans (1994) include commodity price indexes as an additional determinant of interest rate policy responses. Although we explored relative commodity price indexes in preliminary work, inclusion raised several specification issues, such as the well-known problem (Prebisch-Singer) of long-run negative trends in relative commodity prices, without contributing essential insights into the issue of time-varying endpoints.

[11] Using a similar calculation, Clarida, Gali, and Gertler (1998) estimated a constant inflation target slightly larger than 4% at an annual rate over 1979:10-1994:12.

feature of fixed endpoints is that forecasts formulated in any period of the sample will eventually converge to the same endpoint. This property is illustrated in the top panel of figure 2, where two multiperiod forecasts of monthly inflation rates are shown. The first forecast originates in 1972m1 and the second in 1979m10, when the dramatic change in the policy operating procedures of the Fed was announced by Paul Volcker. Despite the very different history of inflation preceding each forecast, the assumption of the fixed endpoints VAR is that the underlying policy target for inflation is believed to be constant.

3.2 *The moving average endpoints VAR*

The fundamental difference between the moving average endpoints VAR and the fixed endpoints VAR is that the former incorporates unit root restrictions on r and π. Returning to the top of Table 1, the format of the autoregressions in r, π, and y, is the same as that required for an ADF test of unit root behavior. Indeed, the t-ratios of the coefficients of the lagged dependent variable indicate that a unit root hypothesis cannot be rejected for both the short-term interest rate and inflation rate. The results of estimating the three-variable VAR under the condition that r and π are difference-stationary is summarized in the middle section of Table 2.[12]

In the present discussion, the interesting property of this specification is that the endpoints of r and π are now also $I(1)$. In each period, the conditional endpoint of a multiperiod inflation forecast is a moving average of inflation in the months just prior to the forecast period.[13] This moving average property is displayed in the middle panel of figure 1, where it is seen that the inflation endpoint—which functions as the market view of the long-run policy target— now moves very closely with recent inflation history. The two multiperiod forecasts of inflation generated by the moving endpoints VAR are presented in the middle panel of figure 2. Whereas the long-run inflation forecast in 1972m1 is now about 1% lower than the fixed endpoint in the top panel, the moving average endpoint for inflation forecasts originating in 1979m1 is an alarming 10%, owing to the large run-up in historical inflation in preceding months.

[12] Cointegration between r and π has not been imposed. A reasonable assumption might be that after-tax real rates are stationary. This would imply that r and π are cointegrated with a cointegrating vector that reflects tax rates. Since tax rates have changed over time, r and π would not be cointegrated with a constant cointegrating vector. And, time-varying cointegrating restrictions are beyond the scope of this paper.

[13] As shown in Kozicki and Tinsley (1996), the moving average endpoint is precisely the Beveridge-Nelson "permanent" component of unit-root stochastic processes. By construction, deviations from moving average endpoints of I(1) series are stationary.

3.3 *A shifting endpoints VAR*

The third VAR specification admits endpoints other than the fixed endpoints implied by the mean-reverting specification or the moving average endpoints provided by the difference-stationary specification. The format of an autoregression or VAR can be written to explicitly account for deviations from endpoints, according to

$$\Delta x_t = c + A(x_{t-1} - x_{\infty}^{(t-1)}) + A^*(L)\Delta x_{t-1} + a_t, \tag{17}$$

where $A^*(L)$ denotes a polynomial in the lag operator, $L^i x_t = x_{t-i}$. When expressed in this format, it is clear that endpoints need not be constrained to be fixed or moving averages.

In some instances, direct measurements of the endpoints of agent forecasts are available. For example, under the expectations hypothesis, bond rates contain ex ante long-horizon forecasts of short rates. Thus, as suggested in Kozicki and Tinsley (1998), one measure of the short-term interest rate endpoint is the average of expected short rates from $t+n$ to $t+n'$, for $n' > n$,

$$\hat{r}_{\infty}^{(t)} = \frac{n'(r_{n',t} - \theta_{n'}) - n(r_{n,t} - \theta_n)}{n' - n}, \tag{18}$$

where θ_n is an estimate of a constant term premium for an n-period bond. For the current study, estimates of the shifting endpoints of the short-term interest rate are based on the average of expected short rates between the 5-year and 10-year maturities. One check of the reasonableness of this interest rate endpoint is that deviations of the one-month bond rate from this endpoint should be stationary if agents' bond rate forecasts in a given period are internally consistent. The fourth equation listed in Table 1 indicates that the interest rate deviations from the constructed series of nominal rate endpoints reject the hypothesis of unit root behavior at a 99% significance level.

It is more difficult to obtain direct measurements of long-horizon endpoints for agents' forecasts of inflation. Although several surveys of expected 5-10 year inflation emerged in the 1980s, contiguous survey estimates of expected long-horizon inflation are not available for earlier decades. To generate backcasts of agent expectations of long-run inflation, bond traders are assumed to be "boundedly-rational" statistical agents, who sequentially test for intercept shifts in an autoregressive model of inflation.

A representative equation for inflation considered by these agents is

$$\Delta \pi_t = b_0 + \sum_k \delta(t - \tau_k)\Delta b_{0,\tau_k} + b_1 \pi_{t-1} + b(L)\Delta \pi_{t-1} + a_t. \tag{19}$$

To represent possible shifts in the intercept, the dummy variable notation, $\delta(\,.\,)$, denotes the Heaviside switching function where $\delta(t-\tau_k)=0$ if $t<\tau_k$. If a change in the intercept is detected for period τ_k, the function is switched "on" in all subsequent periods, $\delta(t-\tau_k)=1$ if $t\geq\tau_k$.

In the absence of intercept shifts, the long-run inflation rate defined by (19) is $\pi_\infty=-b_0/b_1$. However, if intercept shifts are sequentially detected, the evolution of expected long-run inflation is determined by the current estimate of the intercept, $\pi_\infty^{(t)}=-[b_0+\sum_{\tau_k<t}\Delta b_{0,\tau_k}]/b_1$.

In the learning simulations referenced in this paper, agents test for intercept shifts in a twelve-order autoregression in inflation using critical values extrapolated from Andrews (1993). Each simulated agent repeatedly tests as new observations are added in expanding monthly samples over the period 1954m1-1997m9. To account for heterogeneous expectations among bond traders, agents are divided into fifteen classes. Each class requires a different minimum number of monthly observations to accumulate before testing for a new changepoint, ranging from 12 to 96 months.

The method of aggregating over agent classes and additional details are discussed in Kozicki and Tinsley (1997).[14] However, for the current discussion, it is important to note that the aggregation procedure assumes that agent expectations of the endpoints of the nominal short rate, r_∞ and the inflation rate, π_∞, are linked by the following equation

$$(1-t_x)r_\infty \quad = \quad \rho_\infty+\pi_\infty, \tag{20}$$

where t_x is the tax rate on bond earnings and ρ_∞ is the long-horizon expectation of the after-tax real rate. Equation (20) has two relevant properties. First, unlike the traditional Fisher equation, nominal rates will move more than one-for-one with expected inflation under positive tax rates. Second, shifting agent perceptions of the long-run policy goal for inflation, as captured by π_∞, can be an important explanation of shifts in the perceived endpoint of the nominal rate, r_∞.

A useful by-product of this model of simulated learning agents is that it generates both the date of an estimated changepoint and the date of the subsequent recognition of that changepoint, when sufficient observations have been collected to satisfy the relevant critical value of the changepoint test. The concatenation of shifted endpoints in the estimated inflation model is termed the "calendar time" endpoint series, and the concatenation of estimated endpoints when perceived

[14] Briefly, a fixed allocation of agents to each class is estimated by relating movements in the after-tax endpoint of the nominal interest rate to the movements of the aggregated inflation endpoints, as perceived by agents in simulated (virtual) time. This aggregation procedure assumes aftertax real rates are stationary.

by the learning agents is termed the "virtual time" endpoint series. The latter lags the calendar time endpoint series by about 24 months, on average, over a 1966-97 sample. However, learning is nonlinear with time-varying learning lags. In the case of large estimated shifts in inflation, such as those in the late 1970s and early 1980s, all agents eventually detect these shifts and the average lag between an endpoint shift and perceptions of that shift can exceed 60 months. By contrast, estimated changes in the central tendency of inflation in the late 1980s and 1990s has been more modest. Consequently, not all simulated agents agree that permanent shifts have occurred.

The last two autoregressions shown in Table 1 provide evidence against the hypothesis that deviations of monthly inflation from either the calendar time endpoints series or the virtual time endpoints series are I(1).[15] Because the purpose of the VAR is to generate agent expectations that approximate information available to markets when the historical data are recorded, the assumption of symmetric access to policy target information implicit in the fixed and moving average endpoints models is dropped, and the virtual time inflation endpoint is selected as a more realistic estimate of historical market perceptions of the long-run policy target for inflation. This selection is supported in figure 3, which shows that the profile of the virtual time endpoint for inflation resembles two surveys of expected long-run inflation. The top panel shows the correspondence to the discontinued surveys conducted by Richard Hoey of expected inflation in the second five years of a forecast horizon, and the bottom panel compares the virtual time endpoint to the Michigan survey of expected 5-10 year inflation.

Representative multiperiod inflation forecasts of the shifting endpoints specification are shown in the bottom panel of figure 2. Although the inflation forecast in 1979m10 initially declines, somewhat like the beginning contour of the corresponding fixed endpoints forecast, the forecast eventually edges up to a higher endpoint, in this instance about 6%, as the contributions of the initial conditions of the forecast model diminish and the estimate of the inflation endpoint perceived in 1979m10 becomes more influential in distant periods of the forecast horizon.

[15] Although all simulated agents are long-run rational in the sense that any arbitrary fixed endpoint will be identified in large samples, there is no reason to expect deviations of historical inflation from the evolution of perceived inflation endpoints to appear stationary in a finite sample with shifting endpoints.

4 Term structure implications of VAR specification

This section explores the roles of expected short rates and term premium in longer maturity bond yields. In particular, the apparent term structure role for short rate expectations is shown to hinge on the VAR specification used to proxy agent expectations. Following the derivation in section 2, predictions of the expected short rate component can be constructed as

$$\frac{1}{n}\sum_{i=0}^{n-1} E_{t-1}R_{t+i} = (1/n)\sum_{i=0}^{n-1} \iota_r'[\hat{H}^{i+1}x_t + (I-\hat{H}^{i+1})\mu_\infty^{(t)}]. \tag{21}$$

where $\hat{H}$ is the companion form of an estimated VAR forecasting system. The first subsection examines the contribution of the expected short rate component to bond yields for each of the three VAR specifications introduced in section 3 Also analyzed are the implications of VAR specification for predictions of ex ante real rates, constructed according to

$$(1/n)\sum_{i=0}^{n-1}(\iota_r - \iota_\pi)'[\hat{H}^{i+1}x_t + (I-\hat{H}^{i+1})\mu_\infty^{(t)}]. \tag{22}$$

with ι_π a selector vector that identifies the position of inflation π_t in x_t.

The second subsection discusses the interpretation and properties of residual estimates of term premium. Residual estimates are constructed as the difference between observed bond yields and VAR-based constructions of expected future short rates:

$$\hat{\theta}_{n,t}^R = R_{n,t} - (1/n)\sum_{i=0}^{n-1}(\iota_r - \iota_\pi)'[\hat{H}^{i}x_t + (I-\hat{H}^{i})\mu_\infty^{(t)}]. \tag{23}$$

By construction, for VAR proxies of agent expectations that imply a relatively small term structure role for expected future short rates, movements of corresponding residual estimates of term premium are relatively large. An important empirical issue discussed in this section is the extent to which movements in residual estimates of term premium are driven by variation in actual term premium rather than by time variation in specification error.

4.1 *Predictions of the expected short rate component of yields*

The effects of alternative specifications of endpoints will often be negligible in short-horizon forecasts. This is demonstrated in figure 4, where the three panels display model predictions of expected short rate components of 3-month bond yields under each of the three VAR specifications. Predictions of expected short-rate components of bond yields are constructed as an average of expected future short rates over the maturity of the bond, approximated by forecasts from a VAR. As shown, the predictions under the alternative VAR specifications are visually indistinguishable.

The corresponding predictions of expected short-rate components of 10-year bond yields under the three VAR specifications are shown in figure 5. The influential roles of the alternative endpoint specifications are more apparent here than in the 3-month predictions examined above. In the top panel, the effect of the fixed endpoints for variables is that the forecast movements of the 10-year expected short rate component are excessively damped relative to historical movements in 10-year bond yields. Conversely, in the middle panel, the problem is reversed where the predicted short-rate component of the 10-year bond yield is more volatile than historical data on 10-year bond yields, because the endpoint of the short-term nominal rate is a weighted moving average of recent movements in the short rate. By contrast, the bottom panel of figure 5 indicates that movements of the 10-year expected short-rate component predicted by the shifting endpoints model most closely track the contours of the historical data on 10-year bond yields.

As noted in the introduction, an important role of expectations in many descriptions of the transmission of monetary policy is the market translation of current and anticipated policies into real rates on long-term assets, associated with market valuations of tangible wealth and the cost of borrowed funds for durable expenditures. Ex ante 10-year real rates predicted by the three VAR models are shown in figure 6. Here, tax rates on earnings from Treasuries are ignored and the predicted 10-year inflation rate is subtracted from the predicted 10-year average of expected short rates.[16]

"Stylized facts" based on the properties of fixed endpoint VARs are often encountered in discussions of monetary policy.[17] To illustrate the fragile nature of regularities based on mean-reverting VARs, scaled plots of the predicted 3-month bond rate are also included in the panels of figure 6. In an intriguing interpretation of the Bernanke and Blinder (1992) finding of strong effects of the short-term nominal interest rate on output, Fuhrer and Moore (1995) suggest that the short-term nominal rate is a close proxy for the long-term real rate. Indeed, this correspondence is reproduced based on the fixed endpoints VAR in the top panel of figure 6; the simple correlation between the predicted 10-year real rate and the predicted 3-month nominal rate

[16]This approach, also followed by Bernanke, Gertler, and Watson (1997), excludes term premium from ex ante real rate constructions.

[17]See for example Evans and Marshall (1997).

is .95. However, this close relationship is not maintained in the predicted real rates generated by the remaining VARs. The correlation of the 3-month rate with the real rate predicted by the moving endpoints specification falls to .42, and the correlation with the 10-year real rate predictions of the shifting endpoints specification is .43.

The movements of the ex ante 10-year real rates in the middle and lower panels of figure 6 are also much more volatile than those of the real rate predicted by the fixed endpoints specification. For example, the scale of the vertical axis for the real rate predicted by the moving average endpoints model in the middle panel is three times the scale of the real rate predicted by the fixed endpoints model in the top panel.

An important determinant of differences among the real rates predicted by the three VAR specifications is the implied responsiveness of the perceived inflation target, and thus expected long-run inflation to actual inflation. Of course, in the first panel, the perceived inflation target corresponds to the inflation endpoint which is constant regardless of the course of actual inflation. This implausible assumption is replaced in the middle panel by the moving average inflation endpoint. This inflation endpoint closely tracks actual inflation. Thus, the ex ante real rate is quite low in the high-inflation years of the 1970s and remains relatively high throughout much of the 1980s and 1990s as expected long-run inflation quickly falls in the early 1980s, tracking the relatively prompt reduction in historical inflation.[18] By contrast, expected long-run inflation in the shifting endpoints model remains elevated in the early 1980s, as supported by available survey evidence on long-run expectations. Consequently, the shifting endpoints model indicates several episodes of relatively low real rates in the 1980s when nominal bond rate predictions fell faster than the cautious downward revisions of long-run inflation expectations.

As shown earlier, the long-run forecasts of nominal interest rates and inflation rates based on a fixed endpoints VAR appear to have little correspondence with the historical movements of available measurements of agents' long-horizon forecasts, such as long-maturity bonds and surveys of long-horizon inflation and market expectations embedded in long-maturity bond yields. This is not to suggest that fixed endpoints VARs are not useful descriptors, especially as atheoretic summaries of short-term dynamic associations, but use of fixed endpoints models in long-horizon

[18]A rapid fall of expected inflation in the early 1980s also appears to be consistent with results in Fuhrer (1996) where agents infer the policy target for inflation without learning lags.

predictions of nonstationary behavior is likely to generate misleading regularities.

4.2 *Residual estimates of term premium*

The term premium component of bond yields, also known as the "liquidity" or "risk" premium, is the component of bond yields not accounted for by movements in expected short rates. In empirical studies employing the expectations hypothesis, such as Bernanke, Gertler, and Watson (1997), it is not uncommon to extract "residual" estimates of term premiums by the difference between observed bond yields and predictions of the expected short rate component of bond yields, where, as in section 4.1, the latter are formed as an average of expected future short rates approximated by forecasts from an empirical model of short rates. As illustrated in this section, these estimates are sensitive to the specification of the particular model used to generate short rate predictions.

If the model in question does not produce forecasts that match those of agents, then the "residual" term premiums also contain misspecification errors between the agent expectations and model-based proxies of the agent expectations. In other words, large movements in residual estimates of term premiums may not be indicative of variation in actual term premiums but misspecifications of the model used to describe agent forecasts of expected future short rates.

The residual estimate of the term premium is based on (5) but with market expectations of short rates replaced by forecasts of short rates from an estimated VAR describing dynamics of the vector of state variables. For notational convenience, let $\hat{R}_{t+i}$ represent the VAR-based conditional prediction of R_{t+i}. Let $\hat{\theta}^R_{n,t}$ denote the residual estimate of the term premium and $\theta^T_{n,t}$ denote the theory-based term premium as defined in equation (6).

$$\begin{aligned}\hat{\theta}^R_{n,t} &= R_{n,t} - (1/n)\sum_{i=0}^{n-1}\hat{R}_{t+i} \\ &= [(1/n)\sum_{i=0}^{n-1}E_tR_{t+i} - (1/n)\sum_{i=0}^{n-1}\hat{R}_{t+i}] + \theta^T_{n,t} \qquad (24)\end{aligned}$$

Thus, the residual estimate contains two components: one component is a specification error reflecting the gap between market expectations of future short rates and empirical predictions of the expected short-rate component of the bond yield and the second component is the theory-based term premium, $\theta^T_{n,t}$. As shown earlier, although near-term forecasts of short rates from a representative collection of empirical specifications may be similar, the same is not true for long-horizon forecasts. Thus, small variations in the specifications of forecast models can result in large differences in long-horizon forecasts. Furthermore, if empirical forecasts do not replicate market expectations, residual estimates of the term premium will contain a potentially large component of specification error in addition to the actual term premium.

Residual estimates of the term premium for 10-year bonds, as predicted by the three VAR specifications of the forecast model of agents, are shown in Figure 7. One important result is immediately obvious. Time variation in residual estimates of term premiums depends critically on the specification of the VAR used to proxy market expectations. The top panel of shows the residual estimate obtained when the VAR specification with fixed endpoints is used to approximate market expectations. For this specification, almost all of the variation in bond yields comes from temporal variation in the term premiums. This view of the term structure was taken by Campbell, Shiller, and Schoenholtz (1983) who concluded: "Variations in risk premiums are so large as to destroy any information in the term structure about future interest rates." Researchers that use fixed endpoints VARs to approximate market expectations are likely to conclude that the term structure of interest rates is not a reliable transmission channel of monetary policy. For policy transission to work through long rates, proponents of fixed endpoint VARs would have to believe that the transmission mechanism works indirectly, through the effects of short-rate expectations on term premiums.

The middle panel shows the residual estimate based on the VAR specification with moving average endpoints. Time variation in estimated term premiums are cyclical. However, this cyclicality merely reflects the cyclical spread between 10-year bond yields and short rates. Short rate predictions from the moving average VAR are very close to current short rates. Thus, the component of bond yields that is based on long averages of expected short rates will track movements in short rates quite closely. Researchers that use moving average endpoint VARs are likely to conclude that long-term interest rates are too smooth if they believe that term premiums should be constant. This view of the term structure was expressed by Campbell and Shiller (1991), who concluded that "long rates underreact to short-term interest rates." Alternatively, researchers that use moving average endpoint VARs may support arguments that term premiums vary considerably in a countercyclical fashion—in particular, that residual estimates of term premiums move with the long-short yield spread.

The bottom panel shows the residual estimate based on the VAR specification with shifting endpoints. Time-variation in term premiums is much smaller when the shifting endpoints VAR is used to approximate market expectations. Variation in bond yields largely reflects current and expected movements in short rates. With bond traders' expectations approximated by the shifting endpoints VAR, results support the hypothesis that the term structure of interest rates is an important transmission channel of monetary policy.

The shifting endpoints model suggests that the lion's share of historical movements in yields reflects changing market expectations for future short rates. Many previous studies which attributed substantial variation in bond yields to term premiums were based on VAR specifications with either fixed or moving average endpoints. Although these two VAR specifications have been used frequently in past empirical work, the shifting endpoints VAR comes closer to matching observable long-horizon market expectations. Thus, this VAR specification appears to be a preferred empirical proxy for market expectations.

5 Concluding remarks

In many macroeconomic models, an important transmission channel of monetary policy is variation in the value of wealth and the cost of borrowed funds due to policy-induced changes in long-term interest rates. Because most central banks directly control interest rates only in short-term banking markets, this implies that monetary policy is conducted more by auction market *perceptions* of current and anticipated policy actions than by recent activities of the central bank trading desk. Consequently, auction market prices are monitored by policy authorities and observers, not only because quotations are available on a more timely basis than other measurements of economic activity but also to discern market expectations.

As noted earlier, this stylized characterization of monetary policy transmission rests on a number of assumptions, of which the most beleaguered is the expectations hypothesis. Not only are various implications of the expectations hypothesis routinely rejected in postwar empirical literature but, as illustrated in this paper, multiperiod predictions of standard time series models of short-term interest rates provide relative poor tracking estimates of historical bond rates.

The difficulty, of course, is that researchers cannot reject the hypothesis that bond yields are nonstationary for samples that include the 1970s and 1980s. This is noteworthy because, by the Fisher equation, an important component of bond rates is expected inflation, and nonstationarity is not rejected also for postwar rates of inflation in consumer price indexes. Further, if the stochastic process of the short rate controlled by the policy authority is sufficient under the expectations hypothesis to explain much of the variation in bond yields, then the model of the short rate process needs to capture the response of the short policy rate to the behavior of inflation. The approach adopted in this paper is to represent bond trader expectations by small VARs that accommodate relationships among expectations of inflation and of interest rates.

A significant departure in this paper, however, is to represent market expectations by linear expansions around long-run expectations, termed "endpoints." These endpoints may be fixed, may shift, or may be nonstationary. All models in this class can be written as endpoint-reverting. An important empirical finding, shown in various ways in this paper, is that the estimated eigenvalues of endpoint-reverting VARs are relatively unimportant for long-horizon predictions, such as long-maturity bonds, because all endpoints, fixed, shifting, or nonstationary, are reached relatively early in the forecast horizon.

By contrast, the specification of long-horizon expectations is of pivotal importance. Standard VARs offer two options: that variables are mean-reverting or difference-stationary. The mean-reverting VAR is the workhorse of modern macroeconomic analysis, and many empirical features of this specification have become stylized facts in analyses of monetary policy. Unfortunately, in this specification the endpoints of VAR variables are fixed, with the unrealistic implication that market perceptions of the long-run inflation target of policy are independent of actual inflation. This "fixed" endpoints specification provides nearly constant predictions of long-horizon inflation and the expected short rate component of long bond yields. Consequently, the implied term premiums of bonds that are required to match historical bond rates swamp the forward short rate predictions of the mean-reverting VAR.[19] Thus, by default, under fixed endpoints the main channel for short rate expectations to influence bond yields is through time-varying term premiums. This channel, however, requires that the level of the short rate is a source of variation in term premiums—perhaps along the lines of the Cox-Ingersoll-Ross square-root specification of short rate volatility.

Turning to the other conventional specification, the endpoints of the difference-stationary VAR

[19] As noted by Kozicki and Tinsley (1997), including long-maturity rates into the state vector, such as proposed by many multi-factor term structure models, need not eliminate the problem of fixed endpoints in long-horizon forecasts because the long-horizon expectations of these variables also remain fixed.

are moving averages of difference-stationary states and, as a result, are also $I(1)$. As illustrated in earlier sections, these "moving average" endpoints move closely with realizations of state variables and provide poor predictions of long-horizon expectations and long-maturity yields under constant term premium assumptions.

Not all nonstationary variables are I(1), and the preferred specification in this paper is that endpoints of expectations shift if agents detect shifts in the long-run targets of monetary policy. By the Fisher equation, and assuming after-tax real rates are stationary, the tax-adjusted endpoint of nominal interest rates is linked to the long-run policy target for inflation. However, important results of this paper are that bond rates are driven by market *perceptions* of policy targets and there appear to be lengthy learning lags between actual shifts in indicators of policy targets, such as the expedient proxy of inflation changepoints used here, and shifts as estimated by markets.

Finally, the shifting endpoints VAR preferred in this paper is formulated in an open VAR format. That is, the historical evolution of the shifting inflation endpoint perceived by agents is measured but not modeled within the VAR proxy for market expectations. One start in the direction of an endogenous description of shifting market perceptions is the model of simulated learning agents who test for significant changes in long-run outcomes, outlined in section 3.

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Table 1: Autoregressions under alternative endpoint specifications[a]

$$\Delta x_t = c + bx_{t-1} + b^*(L)\Delta x_{t-1} + a_t.$$

x_t	c	b	$b^*(1)$	R^2	SEE
	fixed endpoints[b]				
r_t	.246	-.038	.065	.07	.684
	(2.4)	(-2.5)	(0.3)		
π_t	.310	-.076	-1.85	.29	1.64
	(2.2)	(-2.5)	(-4.1)		
y_t	2.65	-.032	.544	.18	.783
	(3.6)	(-3.6)***	(5.1)		
	shifting endpoints[b]				
$r_t - r_\infty^t$	-.019	-.087	.116	.09	.689
	(-0.5)	(-3.5)***	(0.4)		
$\pi_t - \pi_\infty^t$ [c]	-.002	-.228	-1.12	.32	1.60
	(-0.0)	(-4.2)***	(-2.1)		
$\pi_t - \pi_\infty^t$ [d]	.016	-.105	-1.40	.28	1.65
	(0.2)	(-3.0)**	(-3.1)		

[a]The one-month nominal bond rate is denoted by r, the PCE inflation rate by π, and the manufacturing capacity utilization rate by y. Monthly inflation and utilization rates are seasonally adjusted, and the sample spans are 1955m2-1997m9 for π and y, and 1966m1-1997m9 for r. Endpoint constructions are discussed in the text, where x_∞^t denotes the endpoint or long-horizon expectation of x as conditioned on information available in t.

[b]A unit root in endpoint deviations is rejected at 90% (*), 95% (**), or 99% (***) significance levels.

[c]Inflation endpoints (calendar time).

[d]Inflation endpoints when perceived (virtual time).

Table 2: VARs under alternative endpoint specifications[a]

$$\Delta x_t = c + A\tilde{x}_{t-1} + A^*(L)\Delta x_{t-1} + a_t. \quad \tilde{x}_t = x_t - x_\infty.$$

	regressor coefficients							
		r		π		y		
	c	A	$A^*(1)$	A	$A^*(1)$	A	$A^*(1)$	SEE
				fixed endpoints				
Δr	-.007	-.033	-.425	.050	-.305	.026	.285	.663
	(-0.1)	(-1.8)	(-2.7)	(2.7)	(-3.5)	(2.9)	(3.3)	
$\Delta\pi$	.313	.037	.202	-.114	-1.64	.043	.166	1.77
	(1.1)	(0.7)	(0.5)	(-2.3)	(-6.99)	(1.8)	(0.7)	
Δy	.379	-.056	.281	-.009	.084	-.039	.457	.626
	(3.73)	(-3.2)	(1.9)	(-0.5)	(1.0)	(-4.5)	(5.6)	
				moving average endpoints				
Δr	.018		-.462		-.176	.030	.254	.668
	(0.5)		(-3.3)		(-2.4)	(3.4)	(3.1)	
$\Delta\pi$	.013		.111		-1.94	.042	.298	1.78
	(0.1)		(0.3)		(-9.8)	(1.8)	(1.4)	
Δy	-.020		-.000		.059	-.028	.562	.639
	(-0.6)		(-0.0)		(0.8)	(-3.4)	(7.2)	
				shifting endpoints				
Δr	-.002	-.069	-.276	.029	-.261	.032	.196	.664
	(-0.7)	(-2.2)	(-1.6)	(1.7)	(3.0)	(3.3)	(2.0)	
$\Delta\pi$	.044	.023	.184	-.112	-1.64	.066	.098	1.77
	(0.5)	(0.3)	(0.4)	(-2.4)	(-7.1)	(2.5)	(0.4)	
Δy	-.036	-.091	.302	-.006	.064	-.014	.390	.631
	(-1.1)	(-3.1)	(1.9)	(-0.4)	(0.8)	(-1.5)	(4.2)	

[a]The 3×1 vector, x, contains the one-month nominal bond rate, r, the PCE inflation rate, π, and the manufacturing capacity utilization rate, y. Monthly inflation and utilization rates are seasonally adjusted, and the sample span is 1966m1-1997m9. Endpoint constructions are discussed in the text, where x_∞^t denotes the endpoint or long-horizon expectation of x as conditioned on information available in t.

figure 1: Alternative endpoints of inflation

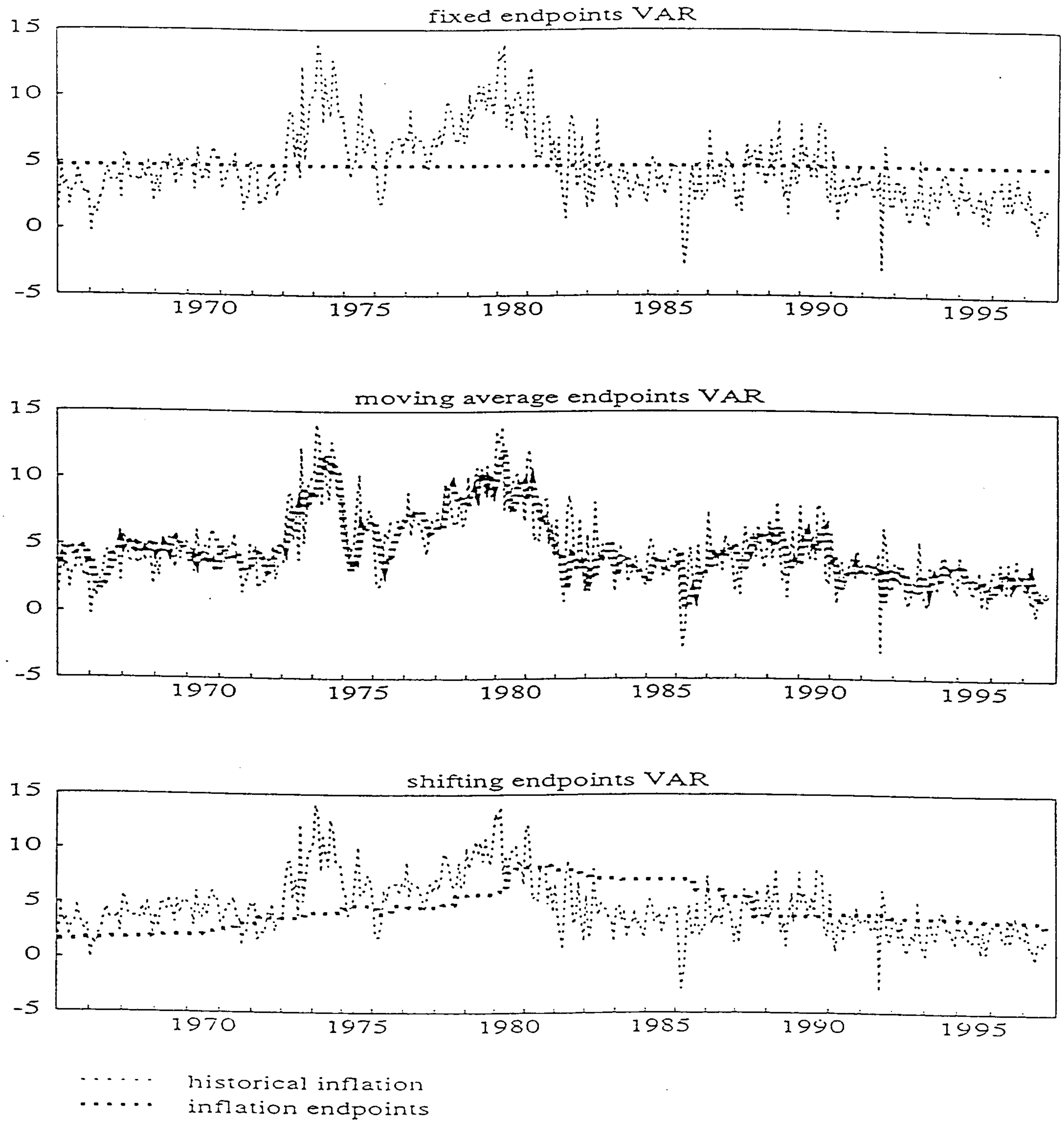


figure 2: VAR multiperiod predictions of 1-month inflation

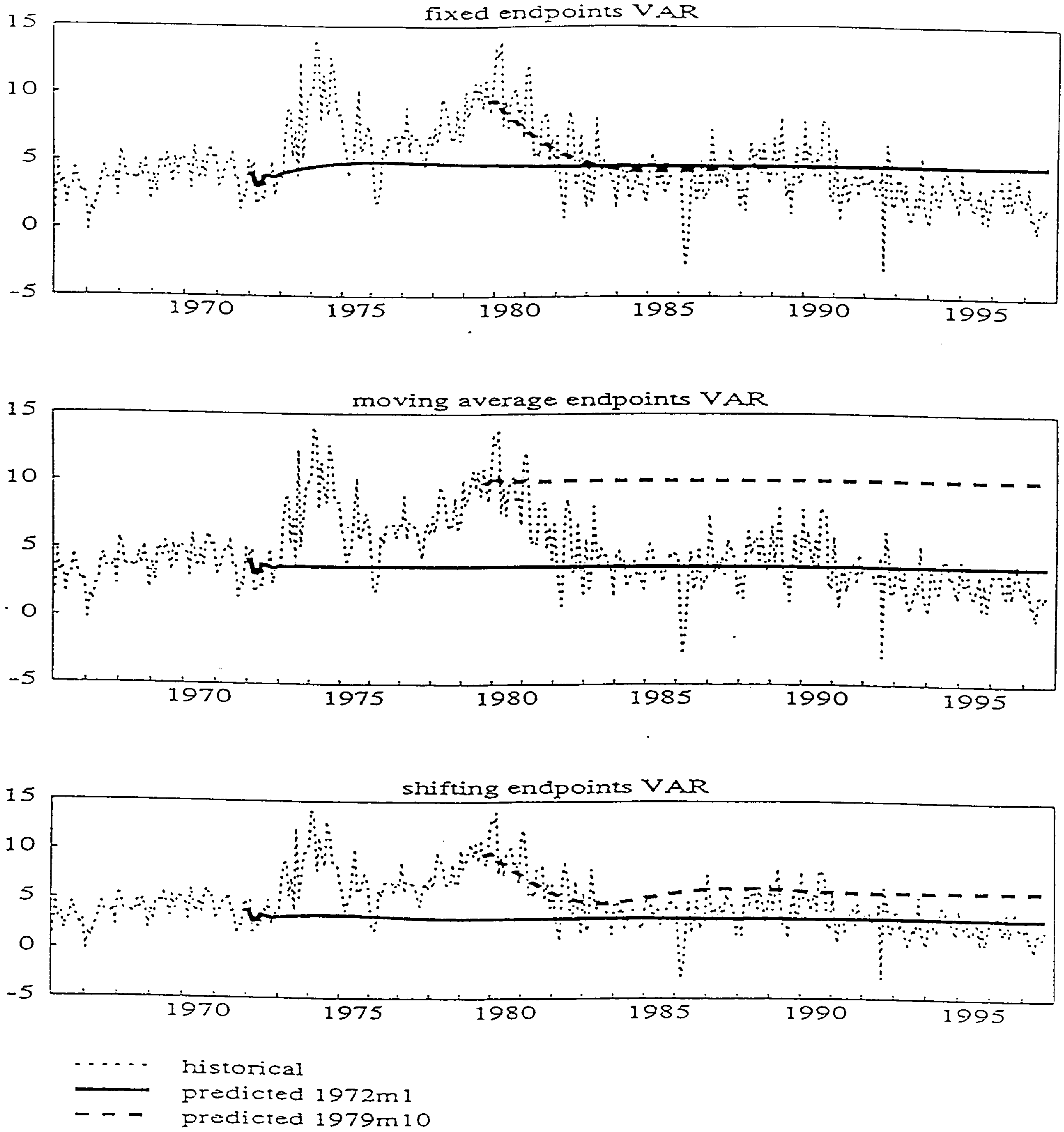
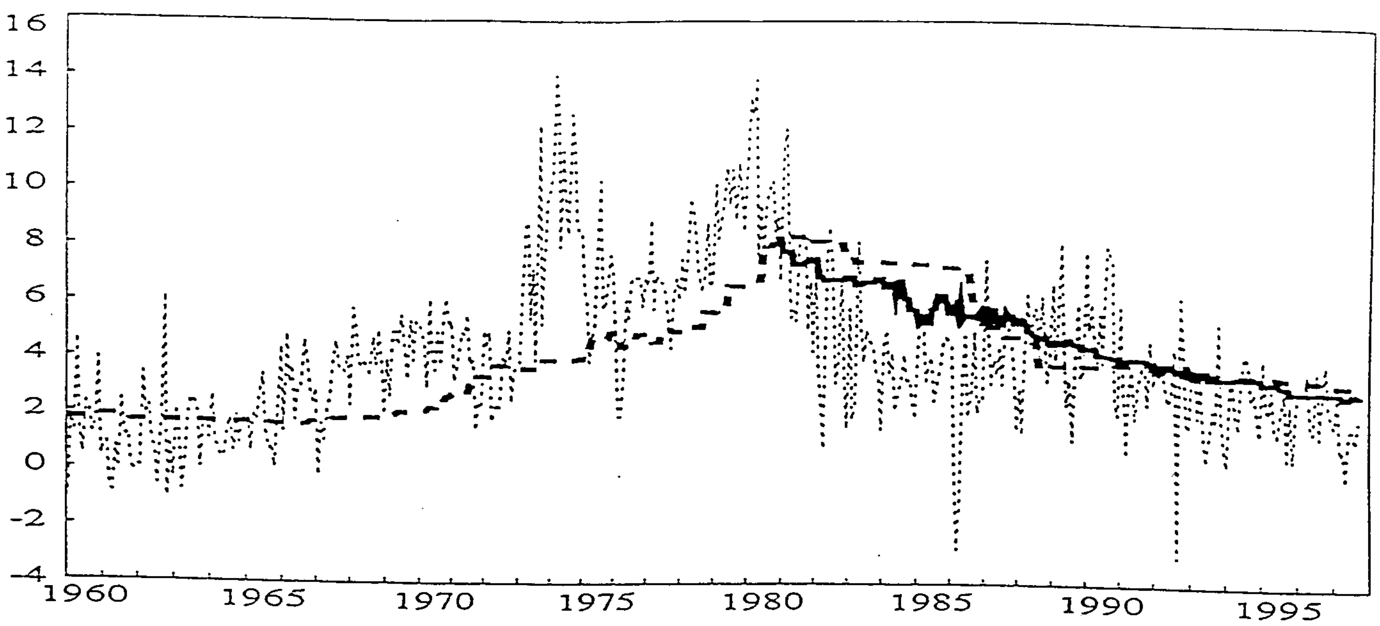
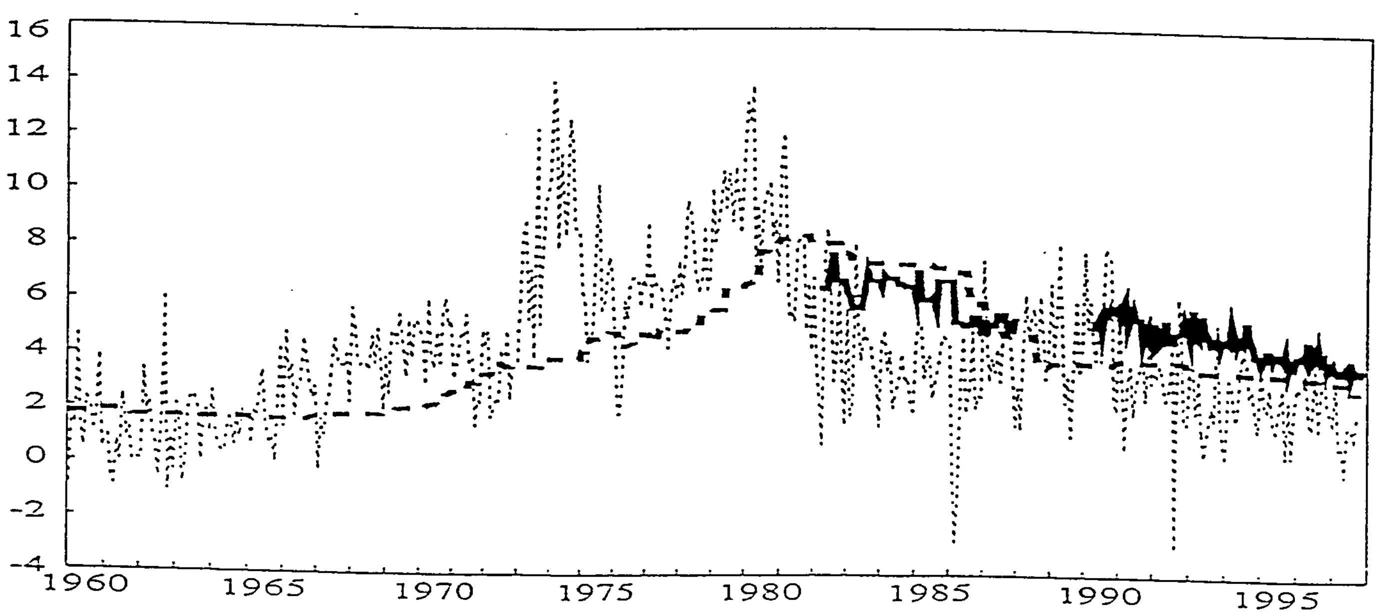


figure 3: Expected long-run inflation



expected inflation (virtual endpoint)
expected inflat'on, second five years (Hoey)/ next ten years (FRPhil 1990m7 on)
historical inflation



expected inflation (virtual endpoint)
expected inflation, next 5-10 years (Michigan)
historical inflation

figure 4: VAR predictions of 3-month bond rate

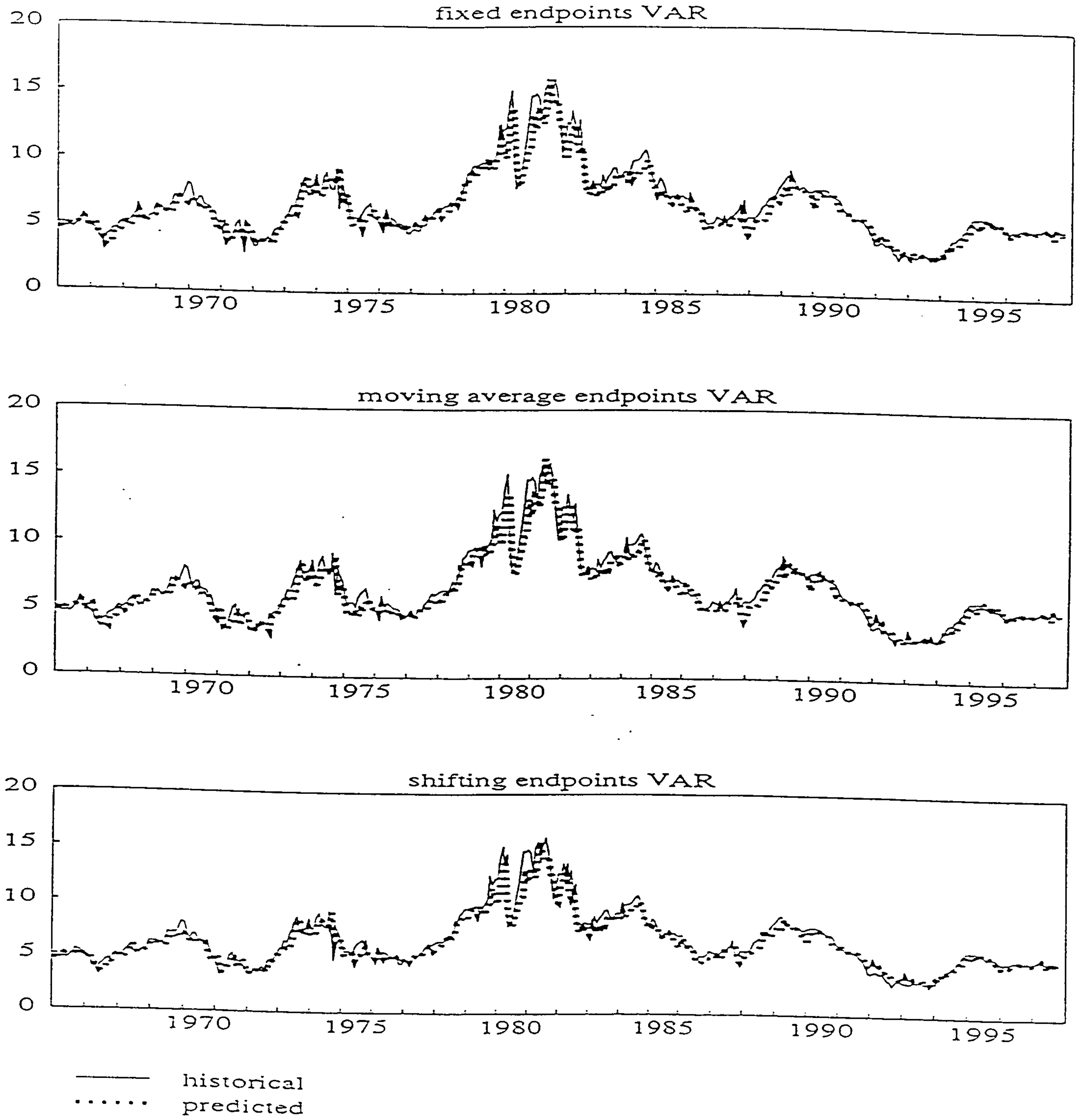


figure 5: VAR predictions of 10-year bond rate

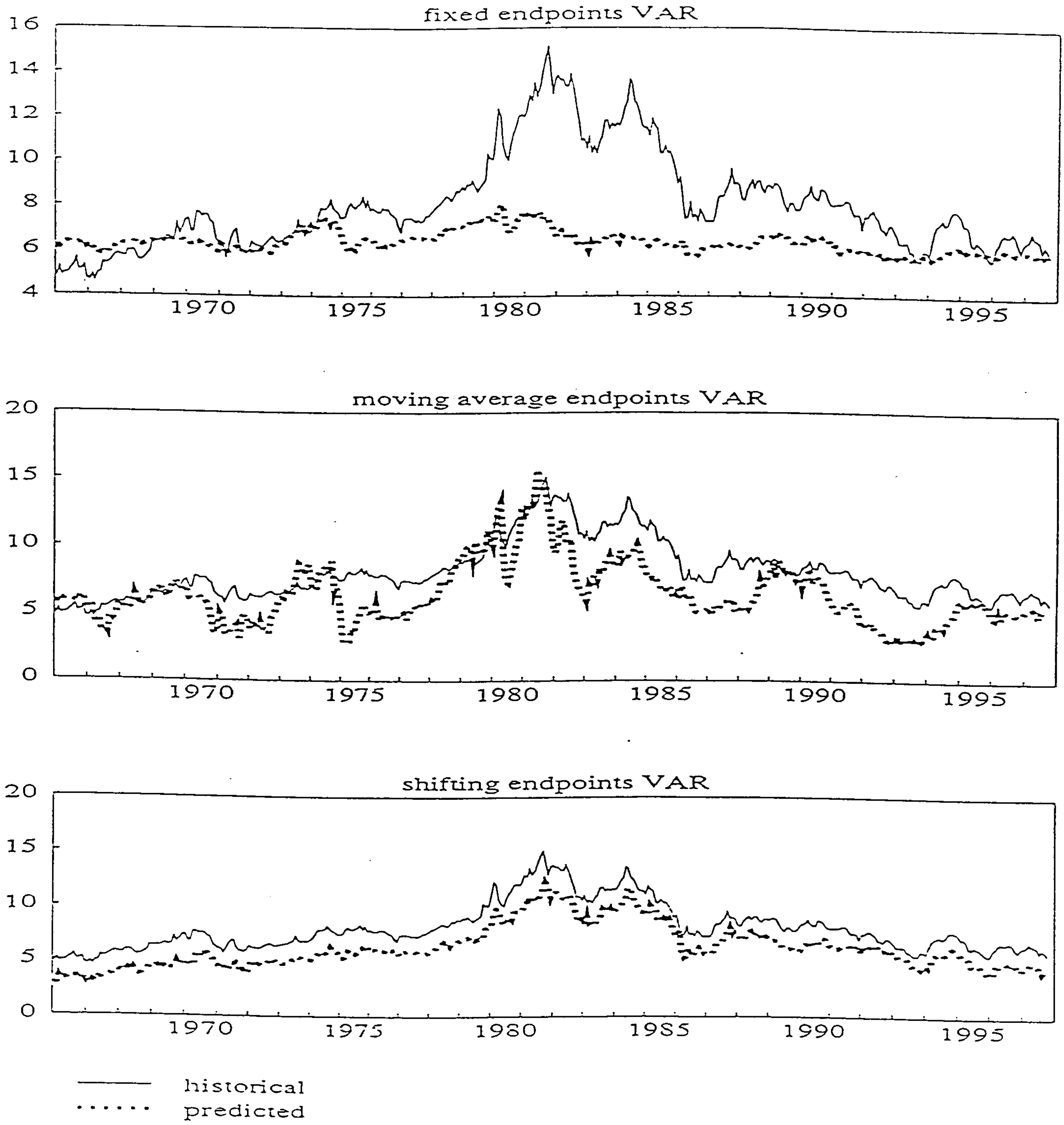


figure 6: VAR predictions of 10-year real rates

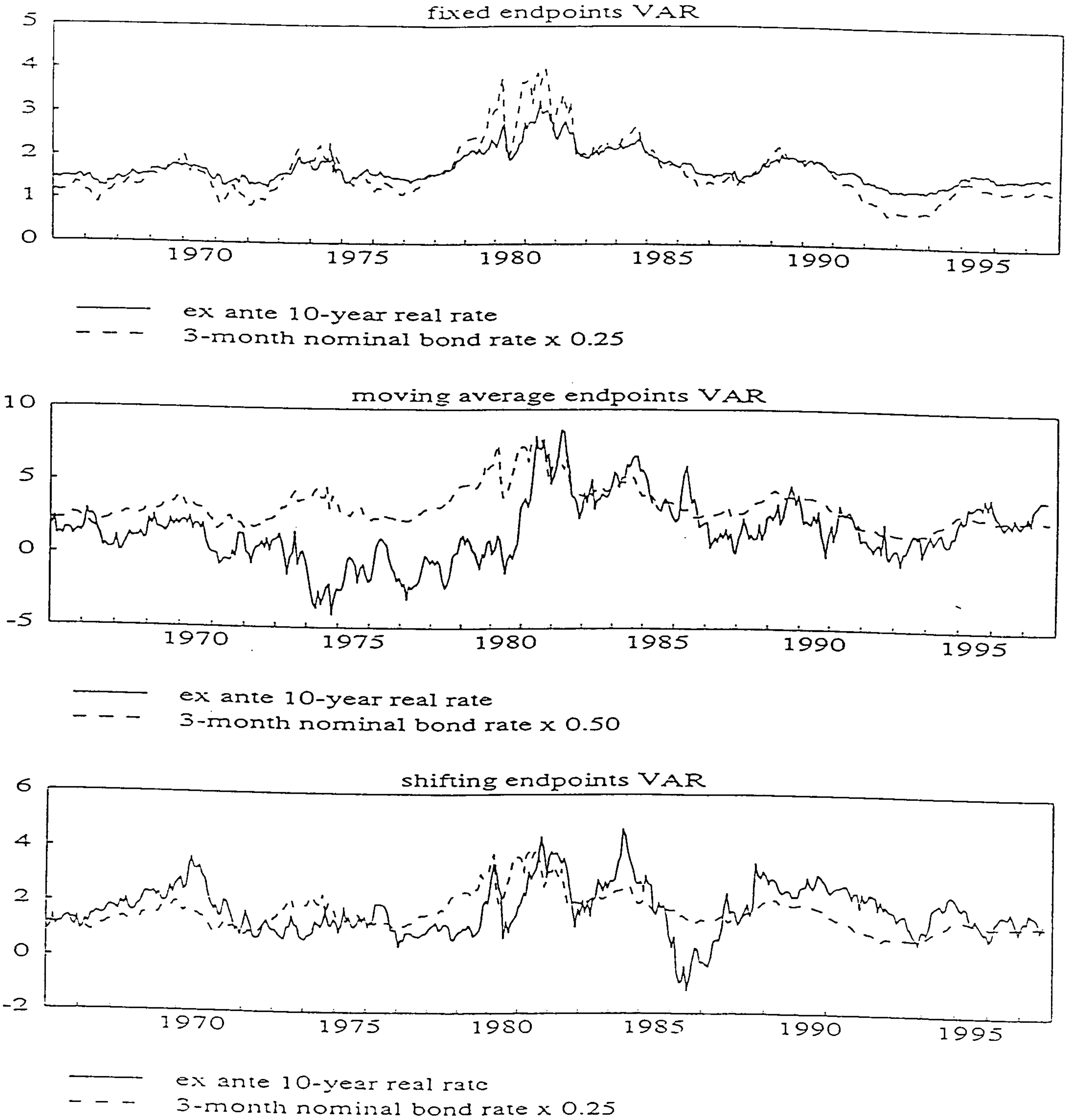


figure 7: Residual estimates of 10-year bond rate term premia