DANMARKS NATIONALBANK WORKING PAPERS 2003 • 11

Anders Møller Christensen

Danmarks Nationalbank

Heino Bohn Nielsen

University of Copenhagen

Has US Monetary Policy Followed the Taylor Rule? A Cointegration Analysis 1988-2002

September 2003

The Working Papers of Danmarks Nationalbank describe research and development, often still ongoing, as a contribution to the professional debate.

The viewpoints and conclusions stated are the responsibility of the individual contributors, and do not necessarily reflect the views of Danmarks Nationalbank.

As a general rule, Working Papers are not translated, but are available in the original language used by the contributor.

Danmarks Nationalbank's Working Papers are published in PDF format at www.nationalbanken.dk. A free electronic subscription is also available at this Web site.

The subscriber receives an e-mail notification whenever a new Working Paper is published.

Please direct any enquiries to
Danmarks Nationalbank, Information Desk, Havnegade 5, DK-1093 Copenhagen K Denmark
Tel: +45 33 63 70 00 (direct) or +45 33 63 63 63
Fax: +45 33 63 71 03
E-mail: info@nationalbanken.dk

Nationalbankens Working Papers beskriver forsknings- og udviklingsarbejde, ofte af foreløbig karakter, med henblik på at bidrage til en faglig debat.

Synspunkter og konklusioner står for forfatternes regning og er derfor ikke nødvendigvis udtryk for Nationalbankens holdninger.

Working Papers vil som regel ikke blive oversat, men vil kun foreligge på det sprog, forfatterne har brugt.

Danmarks Nationalbanks Working Papers er tilgængelige på Internettet www.nationalbanken.dk i pdf-format. På webstedet er det muligt at oprette et gratis elektronisk abonnement, der leverer en e-mail notifikation ved enhver udgivelse af et Working Paper.

Henvendelser kan rettes til:
Danmarks Nationalbank, Informationssektionen, Havnegade 5, 1093 København K.
Telefon: 33 63 70 00 (direkte) eller 33 63 63 63
Fax: 33 63 71 03
E-mail: info@nationalbanken.dk

ISSN (trykt/print) 1602-1185

ISSN (online) 1602-1193

Has US Monetary Policy Followed the Taylor Rule? A Cointegration Analysis 1988–2002*

Anders Møller Christensen
Economics Department
Danmarks Nationalbank
amc@nationalbanken.dk

Heino Bohn Nielsen
Institute of Economics
University of Copenhagen
heino.bohn.nielsen@econ.ku.dk

September 9, 2003

Abstract

Based on the equilibrium correction structure of a cointegrated vector autoregression it is rejected that US monetary policy 1988-2002 can be described by a traditional Taylor (1993) rule. Instead we find a stable long-term relationship between the Federal funds rate, the unemployment rate, and the long-term interest rate, with deviations from the long-term relation being corrected primarily via changes in Federal funds rate. This is taken as an indication that the FOMC sets interest rates with a view to activity and to expected inflation and other conditions available in financial markets.

Keywords: Taylor rule; Bond rate; Cointegration; Equilibrium Correction.
JEL Classification: C32; E52.

Resume

På baggrund af tilpasningen til ligevægt i et kointegreret vektorautoregressivt system kan det forkastes, at pengepolitikken i USA i perioden 1988-2002 kan beskrives ved en traditionel Taylorregel (John B. Taylor, "Discretion versus policy rules in practice", Carnegie-Rochester Conference Series on Public Policy, 1993). Vi finder i stedet en stabil langsigtssammenhæng mellem den toneangivende pengepolitiske rente, Federal funds rate, arbejdsløshedsprocenten og den lange rente, hvor afvigelser fra langsigtssammenhængen primært korrigeres via ændringer i Federal funds rate. Det tages som tegn på, at renten fastlægges under hensyntagen til såvel aktiviteten som den forventede inflation og andre forhold, som kan udledes af de finansielle markeder.

*The authors would like to thank colleagues from our institutions for comments. Remaining errors and shortcomings are the sole responsibilities of the authors.

1 Introduction

In an influential article Taylor (1993) suggests that US monetary policy 1987 – 1992 can be summarized by a simple policy rule, in which the Federal funds rate reflects deviations of inflation and activity from their policy targets. That initiated two large strands of literature. One line of research deals with the representation of actual central bank behavior, and tries to elaborate on the so-called Taylor rule, see *inter alia* Evans (1998), Judd and Rudebusch (1998), Orphanides (2001), and Ball and Tchaidze (2002). Another line of research deals with issues regarding the optimal monetary policy given the central banks objectives and tries to encompass the Taylor rule in a framework of optimizing agents.

The present paper is of the empirical kind and considers the monetary policy in the United States since 1988. The approach taken in this paper differs from most other research on Taylor rules in at least two respects.

First, the econometric technique of multivariate cointegration analysis is applied, allowing for a simultaneous investigation of long-term relationships and the short-term dynamics. We argue that a long-term relationship involving what is considered a monetary policy rate can only be interpreted as a monetary policy rule if deviations from the equilibrium rate is corrected via changes in the policy instrument. This is a testable hypothesis on the equilibrium correction structure of the multivariate dynamic model.

The second difference concerns the choice of variables entering the analysis. Inspired by the role of the yield-curve in recent monetary analysis and in the literature on leading indicators, the long-term bond rate is included in the analysis in parallel with the inflation rate and the unemployment rate. The extended information set makes it possible to analyze the role of financial market information in monetary policy.

The results clearly suggest that the Federal funds rate does not equilibrium correct to a traditional Taylor (1993) rule, which we therefore reject as a representation of the behavior of the monetary policy managed by the Federal Open Market Committee (FOMC). Instead, it seems like the short-term rate is set as if the information on the economy available in the capital market, here represented by the bond rate, has played an important role in addition to developments in unemployment. We do not consider this a real-time policy rule but it is a better representation than the Taylor rule of the kind of factors that have entered the decision making process.

The rest of the paper is organized as follows. Sections 2 and 3 briefly discuss the basic concepts regarding Taylor rules and measurement. Section 4 presents the econometric tools involved in cointegration analysis and some important testable hypotheses implied by the Taylor rule. Section 5 presents the empirical evidence on simple monetary policy rules for the US since 1988, while Section 6 concludes.

2 Taylor Rules

Taylor (1993) suggests that the FOMC has managed the Federal funds rate according to the simple linear formula

$$f_t = \pi_t + \lambda_1 \cdot \widetilde{u}_t + \lambda_2 \cdot \widetilde{\pi}_t + \kappa_0,$$

where f_t denotes the Federal funds rate, π_t and $\widetilde{\pi}_t$ denote the inflation and the deviation of inflation from a specified target respectively, $\widetilde{u}_t$ denotes deviation of economic activity from a natural level, and the constant κ_0 is interpretable as the target real interest rate in equilibrium. If the inflation gap is measured as the deviation from a constant target, $\widetilde{\pi}_t = \pi_t - \pi^*$, as it is usually the case, π^* is not empirically identifiable and the relation collapses to

$$f_t = \lambda_1 \cdot \widetilde{u}_t + (1 + \lambda_2) \cdot \pi_t + \kappa_1, \tag{1}$$

where $\kappa_1 = \kappa_0 - \lambda_2 \pi^*$. The original rule in Taylor (1993) was based on the current-quarter output gap and the change in the GDP deflator, and the conjectural coefficients $\lambda_1 = \lambda_2 = 0.5$ and $\kappa_1 = 1$ was used to interpret US monetary policy $1987 - 1992$.

Inter alia Orphanides (2001) emphasizes the importance of using real-time and not final, revised data, and Evans (1998) and Ball and Tchaidze (2002) consider policy rules based on the deviation of unemployment from an estimated natural rate and consumer price inflation, possibly after excluding some volatile components. That allows for an analysis based on monthly rather than quarterly data, and is also the approach taken in this paper.

In the basic formulation, the relation (1) is contemporaneous and the Federal funds rate could at any time be approximated by the right hand side. Some empirical applications, therefore, use (1) directly as a regression equation, see e.g. Evans (1998) and Ball and Tchaidze (2002). Alternatively the right hand side of (1) can be considered a notional target, f_t^*, and a model for partial adjustment of f_t to f_t^* can be considered, e.g.

$$f_t = \rho \cdot f_{t-1} + (1 - \rho) \cdot (\lambda_1 \cdot \widetilde{u}_t + (1 + \lambda_2) \cdot \pi_t + \kappa_1), \tag{2}$$

see Judd and Rudebusch (1998) and Orphanides (2001) for examples and English, Nelson, and Sack (2003) for a discussion. For $\rho = 0$ (2) collapses to the usual Taylor rule while some degree of interest rate smoothing prevails if $\rho > 0$.

In empirical analyses, inflation is often found to be best approximated by a unit root process. In that case, simple inference on the parameters in (1) and (2) is only valid if the variables cointegrate, a hypothesis which is rarely tested in this literature. In the present paper we take a different route and consider the relation (1) as a candidate for an equilibrium relation and estimate the parameters within a multivariate dynamic framework. This approach has several advantages. First, it is possible to test if the Federal fund rate is related to the explanatory variables in a relation like (1) such that the deviations, $f_t - f_t^*$, are stationary. Second, the multivariate approach allows us to test for the endogeneity of the included variables with respect to the parameters in (1). For the relation to be interpreted as a policy rule, deviations $f_t - f_t^*$ should be corrected by f_t – with the interpretation that the FOMC seeks to eliminate misalignment from the target rate. If there are no dynamic forces in the model making f_t correct to f_t^*, then there is no natural interpretation of f_t^* as a target value for f_t. Furthermore, we can test if the variables of interest, unemployment and inflation, react to the stance of monetary policy and test if the variables are actually controllable by the monetary policy instrument as defined in Johansen and Juselius (2001), see further in Section 4.

Bernanke and Blinder (1992) suggest to use the spread between the Federal fund rate, f_t, and a long term bond rate, b_t, as an indicator of the stance of monetary policy. The bond rate naturally incorporates information on inflation expectations, and at the same time it is insensitive to short-run variations in monetary conditions. The bond rate could also contain other relevant information. A sudden increase in the bond rate could reflect a declining credibility of monetary policy and the FOMC could react by a preemptive increase in the Federal funds rate, see also Carey (2001). Mehra (2001) and Carey (2001) include the bond rate as an additional variable in a Taylor rule like (1). Since b_t will react with a one-to-one impact from inflation expectations, and inflation is already present, we insert in (1) only the 'new' information as measured by the real bond rate, $b_t - \pi_t$, and correct for the average 'tilt' of the yield curve, τ, to obtain

$$f_t = \lambda_1 \cdot \widetilde{u}_t + (1 + \lambda_2 - \lambda_3) \cdot \pi_t + \lambda_3 \cdot b_t + \kappa_2,$$

where $\kappa_2 = \kappa_0 - \lambda_2 \pi^* - \lambda_3 \tau$. If there is a one-to-one impact from the bond rate to the Federal funds rate, $\lambda_3 = 1$, we obtain a simple Taylor-type rule for the interest rate spread:

$$f_t = b_t + \lambda_1 \cdot \widetilde{u}_t + \lambda_2 \cdot \pi_t + \kappa_2. \tag{3}$$

The interest rate spread is often considered to be a predictor of future inflation or activity, cf. Mishkin (1990), Estrella and Hardouvelis (1991), and the survey by Estrella and Mishkin (1996). Taking the information on expectations of future activity and inflation in the long-term rates into consideration when setting short-term rates is therefore straightforward in a certain sense. However, in theory the relationship is normally turned the other way round, making long-term rates a function of expected future short-term rates as in the expectation theory of the term structure, even if Schiller (1990) acknowledges that a lot of evidence speaks against the empirical validity of the theory. Christensen (2002) suggests that a normalized interest rate spread is a straightforward method to reveal real-time information on the real interest rate gap of recent monetary theory, cf. Woodford (2002) and Svensson (2003).

Several applications have emphasized the forward looking nature of monetary policy, see Clarida, Galí, and Gertler (1998), Clarida, Galí, and Gertler (2000), Orphanides (2001), and Svensson (2003). In the present study this feature is mainly implicit, in the sense that the applied vector autoregression is consistent with the concept of forward looking expectations using data based projection functions. However, when data on long-term interest rates are included in the data set, information on expected future inflation and expected alternative real yields are included more directly without restrictions on the way expectations are formed.

3 Data Measurements

To analyze monetary policy reaction functions like (1) and (3) we consider a monthly data set, $Y_t = (f_t : b_t : u_t : \pi_t)'$, comprising the effective Federal funds rate, f_t, a constant maturity 10 year Treasury bill rate, b_t, the unemployment rate corrected for a linear trend, u_t, and core inflation measured as 100 times the year-on-year change in the log transformed consumer price index excluding food and energy, π_t.[1] The considered sample covers the period since Alan Greenspan began as the chairman of the Federal Reserve Board. The effective sample is $1988:1-2002:12$, and we condition the analysis on the last months of 1987.

Graph (A) in Figure 1 depicts the Federal funds rate and the Treasury bill rate and graph (B) depicts the spread, $f_t - b_t$. The interest rates have some similarities, but have been far from parallel. On average f_t has been lower than b_t, but on three occasions the Federal funds rate has exceeded the bond yield.

Graph (C) depicts the unemployment rate. Several authors have suggested a fall in the natural rate of unemployment in the period under consideration, see *inter alia* Ball and Tchaidze (2002). To allow for a decline in the natural rate in a transparent way and to avoid a deterministic trend in the empirical analysis of the monetary policy rules we take a very simple approach and correct *a priori* for a linear trend in unemployment using least squares. We make no assumptions on the level of the natural rate and include in the empirical analysis the variable

$$u_t = u_t^* - 0.00996 \cdot \left(t - \bar{t}\right),$$

where u_t^* is the observed unemployment rate and $\left(t - \bar{t}\right)$ is the demeaned linear trend such that u_t and u_t^* have same means over the period. The estimated linear trend is also depicted in graph (C) and assumes that the natural rate has fallen approximately 2% in the sample period. We are of course aware that the linear correction creates problems if extrapolations are made. However, in this way we avoid making more subjective manipulations of data. We are confident that this specific choice is not material for the results reported below. The sample period covers a slack in the early 1990s and a subsequent long upturn ending sharply in 2000. A comparison of (C) and (A) indicates a negative correlation between u_t and f_t, and there is also a clear correlation between u_t and the interest rate spread, $f_t - b_t$, in (B).

[1] All data series are taken from the EcoWin data base. The unemployment rate is calculated from the total number of unemployed and the total civilian labor force, both seasonally adjusted.

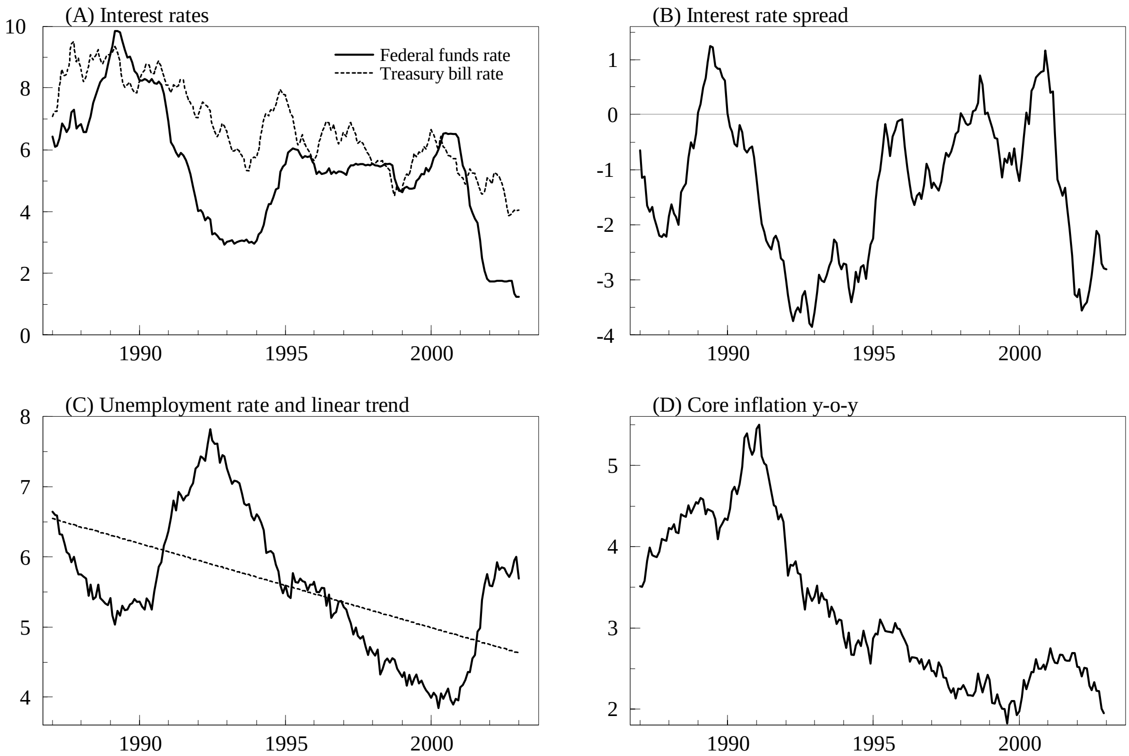

Figure 1: The data 1987-2002.

Finally graph (D) depicts core inflation. Inflation has been steadily decreasing over the period with bouts of rising inflation. One in early 1990s and one in early 2000s. Comparing developments in core inflation with the Federal funds rate and the interest rate spread indicates a weaker correlation.

4 Econometric Tools

To analyze the interaction between the interest rates, unemployment, and inflation, we assume that the variables are integrated of at most first order, and use a $p-$dimensional vector autoregression (VAR):

$$H(r): \Delta Y_t = \alpha\left(\beta' Y_{t-1} + \mu'\right) + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_{t-i} + \epsilon_t, \quad t = 1, 2, ..., T. \tag{4}$$

The innovations ϵ_t are assumed to be independently and identically Gaussian distributed, $N(0, \Omega)$, and the initial values, $Y_{-k+1}, ..., Y_0$, are considered fixed. If the levels Y_t are cointegrated with r long-run relations then α and β are of dimension $p \times r$ such that the rank of $\Pi = \alpha\beta'$ is $r \leq p$, see Johansen (1996). Based on theoretical considerations we do not allow for deterministic linear trends in the variables and include only a constant restricted to the cointegrating relations.

Maximum Likelihood (ML) estimation of $H(r)$ is given by reduced rank regression, which reduces to solving a certain eigenvalue problem, see Johansen (1996, chapter 6). To determine the number of long-run relations, r, the nested models, $H(0) \subset ... \subset H(r) \subset ... \subset H(p)$, can be compared using likelihood ratio (LR) tests, the so-called *trace tests*, which have non-standard asymptotic distributions due to the unit roots in the processes under the null. Conditional on r, it is possible to test restrictions on the long-run coefficients, $\beta^* = \left(\beta' : \mu'\right)'$, and on the short-run adjustment coefficients, α. In this paper we consider hypotheses involving linear restrictions on the columns in α and β^*, i.e.

$$\mathcal{H} : \alpha = (A_1\phi_1 : ... : A_r\phi_r) \quad \text{and} \quad \beta^* = (H_1\varphi_1 : ... : H_r\varphi_r),$$

where ϕ_i and φ_i contain the free parameters in column i of α and β^* respectively. Under $\mathcal{H}$ the model can be estimated using e.g. the switching algorithm of Boswijk (1995); and the LR test statistic for $\mathcal{H}$ is asymptotically distributed as a χ^2 under the null.

The solution of (4) for the levels, Y_t, in terms of the innovations and initial values is given by the so-called Granger representation

$$Y_t = C\sum_{i=1}^{t} \epsilon_i + C(L)\,\epsilon_t + \tau_0, \tag{5}$$

where $C = \beta_\perp \left(\alpha'_\perp \left(I - \Gamma_1 - ... - \Gamma_{k-1}\right)\beta_\perp\right)^{-1}\alpha'_\perp$ is the $p \times p$ dimensional long-run impact matrix of rank $p - r$, $C(L)$ is a convergent polynomial in the lag operator L, and τ_0 are coefficients depending on μ and the initial values, see Johansen (1996, Theorem 4.2). The interpretation of a coefficient C_{ij} in C is the long-run effect on variable i from an innovation to ϵ_j.

Johansen and Juselius (2001) analyze how to implement monetary policy control rules in a cointegrated vector autoregression. They consider a target variable $d'Y_t$ and a given instrument $a'Y_t$, where a and d are $p-$dimensional vectors (often unit vectors). The definition of *controllability* of $d'Y_t$ with $a'Y_t$ in this context is that $d'Y_t$ can be made stationary around a target value d^* by intervening in $a'Y_t$ at all points in time. The necessary control rule and the properties of the controlled process are derived in Johansen and Juselius (2001, Theorem 7). To analyze if such a control rule has been in action, a necessary condition is that $d'Y_t$ is stationary. The condition for controllability is that $d'Ca \neq 0$, such that interventions to the instruments give a non-zero long-run impact on the target.

Implied Hypotheses for Monetary Policy Rules. For the present data, Y_t, and for $r = 1$, which is the main case considered in the empirical analysis, the first part of (4) can be written as

$$\begin{pmatrix} \Delta f_t \\ \Delta b_t \\ \Delta u_t \\ \Delta \pi_t \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{pmatrix} (f_{t-1} + \beta_2 b_{t-1} + \beta_3 u_{t-1} + \beta_4 \pi_{t-1} + \mu) + ...$$

where the long-run relation is normalized on the Federal funds rate, f_{t-1}. For the empirical model to be interpretable as a characterization of monetary policy we propose two requirements:

1. That the coefficients $(1 : \beta_2 : \beta_3 : \beta_4 : \mu)'$ are interpretable as a policy rule. From theory we expect $\beta_2 \leq 0$, $\beta_3 \geq 0$, and $\beta_4 \leq 0$. If $\beta_2 = 0$ the relation collapses to the conventional Taylor rule (1). If $\beta_2 = -1$ the relation is a simple rule for the interest rate spread (3).

2. That $\alpha_1 < 0$ such that deviations of the Federal funds rate from the equilibrium value is corrected by monetary policy actions.

Besides tests of these requirements, it is also possible to test the effect of misalignments of the policy rate from the equilibrium rate on unemployment and inflation. This corresponds to inference on α_3 and α_4 respectively. In particular, we expect high interest rates to put downward pressure on inflation, $\alpha_4 \leq 0$, and upward pressure on unemployment, $\alpha_3 \geq 0$. This involves a Phillips-curve trade-off between the two goals in the optimal policy setting.

Controllability of the inflation rate, π_t, with the Federal funds rate, f_t, can be tested as the hypothesis that $C_{41} \neq 0$. *A priori* we expect $C_{41} < 0$.

5 Empirical Analysis of US Monetary Policy

In this section we look at the empirical evidence on monetary policy in the US based on the monthly data set, $Y_t = (f_t : b_t : u_t : \pi_t)'$, for the effective sample $t = 1988:1, ..., 2000:12$.[2]

First step in the analysis is to determine the lag length k of the VAR. Information criteria and successive testing for removal of lags point towards $k = 3$ or $k = 4$. Since there are some residual autocorrelation in the model with three lags, we base the analysis of the long-run structure on a VAR with $k = 4$ lags. By and large similar results as the ones presented below are obtained for $k = 3$.

Table 1 reports a battery of misspecification tests. The only deviation from the different nulls of a well specified model is a marginal autoregressive conditional heteroscedasticity (ARCH) in the equation for core inflation. This is not unusual for monthly data and is not easily remedied within the VAR framework. Work of Rahbek, Hansen, and Dennis (2002) indicates that moderate ARCH effects do not disturb the analysis of the cointegrated VAR, and we choose to ignore this potential problem in the following. It is interesting to note that there are no extreme outliers in the data and the null of normality of the residuals is accepted. This is also the case for the Federal funds rate which is managed by the FOMC.

Long-Run Structure. Next we want to determine the cointegration rank. It is known from simulation studies that it is no easy task to select the cointegration rank in empirical applications, and the finite sample distribution of the trace test for a cointegration rank of $Rank\,(\Pi) \leq r$ against the unrestricted alternative, $H\,(p)$, is typically displaced to the right relative to the asymptotic distribution. To take account of the resulting size distortion, Johansen (2002) proposes a Bartlett correction for the trace test. This is applied to the current data in Table 2. The model $H(0)$ with no cointegration is rejected, with a $p-$value based on the Bartlett corrected test of 2%. The test for model $H(1)$ with $r = 1$ long-run relation is a borderline case, with a $p-$value of 8% according to the Bartlett corrected test. However, as this model is in line with the theoretical setup we choose this for the main analysis.

Based on the model with $r = 1$ we want to analyze the information in the data of the structure of the long-run relation. The unrestricted estimates of α and β^* are reported in Table 3 under $\mathcal{H}_0$, with $t-$values based on the asymptotic standard deviations in parentheses. The relation is normalized on the Federal funds rate and the $t-$values indicate a significant coefficient to the Treasury bill rate. A magnitude in the proximity of one is also found in Mehra (2001) for a longer sample period. The coefficient to unemployment is 1.7, indicating that a high unemployment is associated with a low Federal funds rate. The coefficient is clearly significant, with a $t-$value of 9.6. The coefficient for core inflation is also positive, which is the opposite of the expected for a monetary policy rule, but it is not

[2]The empirical analysis was carried out using a set of procedures programmed in Ox 3.0, see Doornik (2001), and PcGive, see Doornik and Hendry (1997).

Table 1: Tests for misspecification of the unrestricted VAR(4)

	AR(1)	AR(1-7)	ARCH(7)	Normality
Δf_t	.63 [.43]	1.04 [.41]	1.96 [.06]	4.39 [.11]
Δb_t	.91 [.34]	1.27 [.27]	.78 [.60]	4.31 [.12]
Δu_t	.05 [.82]	1.05 [.40]	.51 [.82]	.91 [.64]
$\Delta \pi_t$	.02 [.88]	1.75 [.10]	2.43 [.02]	.45 [.80]
Multivariate tests:	.82 [.66]	1.09 [.26]	...	9.96 [.27]

Note: Figures in square brackets are $p-$values. AR(1) are the $F-$tests for first order autocorrelation and are distributed as F(1,162) and F(16,477) for the single equation and vector tests respectively. AR(1-7) are tests for up to seventh order autocorrelation and are distributed as F(7,156) and F(112,526) respectively. ARCH (7) tests for ARCH effects up to the seventh order and is distributed as F(7,149). The last column reports results of the Doornik and Hansen (1994) test for normality, distributed as $\chi^2(2)$ and $\chi^2(8)$ respectively.

Table 2: Trace tests for the cointegration rank

$H(r)$	$r = 0$	$r \leq 1$	$r \leq 2$	$r \leq 3$
Eigenvalues	.144	.109	.069	.017
LR statistic	64.59	36.62	15.89	3.01
Asymptotic $p-$value	[.00]	[.03]	[.18]	[.59]
Bartlett factor	1.11	1.11	1.69	1.35
Corrected $p-$value	[.02]	[.08]	[.70]	[.73]

Note: Likelihood Ratio tests for $H(r)$ against $H(p)$. Case with a restricted constant. Figures in square brackets are asymptotic $p-$values based on the approximate critical values derived from $\Gamma-$distributions by Doornik (1998).

Table 3: Identification of the long-run structure

	$\mathcal{H}_0$		$\mathcal{H}_1$		$\mathcal{H}_2$		$\mathcal{H}_3$		$\mathcal{H}_4$	
	α	β^*	α	β^*	α	β^*	α	β^*	α	β^*
f_t	-0.062 (-3.88)	1 (...)	-0.000 (-0.01)	1 (...)	-0.063 (-3.56)	1 (...)	-0.063 (-3.56)	1 (...)	-0.080 (-4.46)	1 (...)
b_t	0.004 (0.15)	-1.284 (-5.26)	-0.027 (-1.95)	0 (...)	-0.011 (-0.39)	-1 (...)	-0.012 (-0.45)	-1 (...)	0 (...)	-1 (...)
u_t	-0.015 (-1.04)	1.657 (9.63)	-0.019 (-2.38)	3.062 (9.85)	-0.025 (-1.60)	1.783 (12.48)	-0.022 (-1.42)	1.782 (12.51)	0 (...)	1.637 (11.74)
π_t	-0.042 (-2.94)	0.290 (0.87)	-0.029 (-3.62)	-1.418 (-5.66)	-0.047 (-3.04)	-0.077 (-0.67)	-0.049 (-3.10)	0 (...)	-0.040 (-2.37)	0 (...)
1	...	-6.914 (-4.82)	...	-17.677 (-9.43)	...	-8.349 (-9.70)	...	-8.584 (-10.78)	...	-7.797 (-10.01)
LR statistic	...		5.796		0.489		0.896		2.862	
$p-$value	...		0.016		0.484		0.639		0.581	
Distribution	...		$\chi^2(1)$		$\chi^2(1)$		$\chi^2(2)$		$\chi^2(4)$	

Note: $t-$values based on asymptotic standard errors in parentheses.

significantly different from zero. The adjustment coefficients in α clearly suggest an interpretation of the relation as a monetary reaction function. In particular, the adjustment coefficient in the Federal funds equation is negative and clearly significant with a $t-$value of -3.9. There is also a significantly negative impact in the inflation equation, indicating that a high interest rate relative to the target lowers inflation. The adjustment in the equation for Treasury bill rate is close to zero and the adjustment in the unemployment relation is negative but not significantly different from zero.

Based on the unrestricted coefficients, the long-run relation thus looks like a monetary policy rule. A conventional Taylor rule would imply a zero coefficient for the Treasury bill rate, $\beta_2 = 0$. Imposing this restriction gives the results reported under $\mathcal{H}_1$. First it could be noted that the restriction is formally rejected at a 5% level, indicating that the simple Taylor rule does not seem to be an adequate description of the present sample. In the restricted relation, both the coefficient to u_t and π_t are significant with the expected signs and the magnitude of the coefficient to inflation is close to the 1.5 suggested by the original Taylor rule. A static least squares regression of f_t on u_t, π_t and a constant term, often seen in the empirical literature on Taylor rules, yields

$$f_t = \underset{(-32.56)}{-1.773} \cdot u_t + \underset{(25.10)}{1.206} \cdot \pi_t + \underset{(33.78)}{11.500}, \tag{6}$$

where $t-$values are in parentheses and R^2 is 0.90. The estimated equation (6) is close to the quarterly results in Ball and Tchaidze (2002) and is not too far from the long-run relation in $\mathcal{H}_1$, although the coefficient to unemployment is somewhat smaller. At a first glance the results look like a monetary policy reaction function, but the adjustment coefficients to the long-run relation in $\mathcal{H}_1$ do not give much support for this interpretation, since there is no feedback to the Federal funds rate. Deviations from the relation are corrected by u_t and π_t but not by the Federal funds rate, f_t. This highlights the dangers of estimating structural Taylor rules from static regressions. Firstly, with likely unit roots in the variables inference on (4) is difficult, and secondly the dynamic adjustment to a possible equilibrium is not modelled, making the interpretation of the nature of the relation hazardous.[3]

The above results suggest an important role for the bond rate. The theoretical relation (3) gives a simple interpretation as a Taylor-type rule for the interest rate spread if the coefficient to b_t is restricted to minus one. Under $\mathcal{H}_2$ we have reported the results after imposing $\beta_2 = -1$. The restriction produces a LR test statistic of 0.49 corresponding to a $p-$value of 0.48 in a $\chi^2(1)$ distribution. In this relation the coefficient to inflation has the expected sign, but it is clearly insignificant with a $t-$value of 0.67. Imposing the additional restriction, $\beta_4 = 0$, does only marginally change the likelihood and produces the results reported under $\mathcal{H}_3$.

The coefficients under $\mathcal{H}_3$ still suggest that the feedbacks to b_t and u_t are very weak, and imposing the two additional restrictions that b_t and u_t are weakly exogenous for the long-run coefficients, $\alpha_2 = \alpha_3 = 0$, produces the preferred results reported under $\mathcal{H}_4$.

[3] We can add, that weak exogeneity of the Federal funds rate is not a result of including the bond rate in the model. The same result appears in an analysis of $(f_t : u_t : \pi_t)'$.

A Characterization of US Monetary Policy 1988-2002. In the preferred model, the long-run relation can be written as

$$f_t - b_t = -1.637 \cdot u_t + 7.797, \tag{7}$$

which is a Taylor-type rule for the interest rate spread with a significant impact from unemployment and a zero impact from inflation beyond that contained in the expected inflation via b_t. The constant contains the average value of unemployment and the average shape of the yield curve. Deviations from this relation is corrected primarily by the Federal funds rate, eliminating 8% of a misalignment each month. There is also a negative coefficient in the equation for $\Delta\pi_t$, indicating that a high funds rate suppress inflation. The effect is not terribly strong, with a $t-$value of -2.4. The preferred structure is accepted as a reduction of the unrestricted specification with a LR statistic of 2.86 corresponding to a $p-$value of 0.58 in a $\chi^2(4)$.

The result that actual inflation is not directly present in the empirical rule could reflect that the period under consideration has been characterized by little inflationary pressure and therefore limited information on the impact of actual inflation in the policy rule. As mentioned before, expected inflation is present with a coefficient of 1 via the long-term interest rate.

For the Federal funds rate to be a valid instrument for controlling inflation, it is required that $\widehat{C}_{41}$ is significantly negative, where $\widehat{C}$ is the estimated counterpart to C. The estimated long-run impact matrix is given by

$$\widehat{C} = \begin{pmatrix} \underset{(0.19)}{0.167} & \underset{(3.70)}{1.820} & \underset{(-3.05)}{-2.748} & \underset{(-0.67)}{-0.336} \\ \underset{(-0.06)}{-0.025} & \underset{(5.10)}{1.143} & \underset{(-0.34)}{-0.141} & \underset{(0.22)}{0.051} \\ \underset{(-0.32)}{-0.118} & \underset{(-2.00)}{-0.414} & \underset{(4.20)}{1.593} & \underset{(1.13)}{0.236} \\ \underset{(-1.86)}{-0.376} & \underset{(2.63)}{0.299} & \underset{(-1.90)}{-0.397} & \underset{(6.54)}{0.755} \end{pmatrix},$$

with standard normal distributed asymptotic $t-$values in parentheses. The relevant coefficient is -0.376, indicating that a one percentage point innovation to the Federal funds rate lowers the long-run core inflation rate with slightly less than 0.4 percentage points on average. The parameter is not particularly well-determined, however, with a $t-$value of -1.86. Again this could reflect that the variation in inflation in the sample period, and the amount of information on the monetary transmission channel, is limited. For a longer sample, $1985:8-1999:2$, and a data set comprising real money, (interpolated) real GDP, monthly inflation as well as 5 interest rates, Johansen and Juselius (2001) find less support for the controllability of inflation with the Federal funds rate; in their analysis $\widehat{C}_{41}$ is actually positive.

Graph (A) in Figure 2 depicts the Federal funds rate and the long-run target, while graph (B) depicts deviations of the Federal funds rate from the target together with the deterministic component comprising the effects of the initial values $1987:9-1987:12$.

Graph (A) clearly demonstrates that the long-run relation in general has been leading the Federal funds rate when major changes in the latter has occurred corresponding to visual evidence of the endogeneity of the federal funds rate in the system. The deviations show that interest rates in the initial period and during 1988 was lower than suggested by the relationship. A common interpretation relates this to concern for the financial stability after the crash in the stock market in late 1987.[4] The same type of concern might explain the relatively low interest rates in 1999 after the financial crisis in Russia and the problems related to LTCM. Such effects are clearly outside the information set of the current simple model. In 1995/1996 rates were higher than suggested by (7). A likely interpretation is that this was due to a real-time belief that the natural rate of unemployment had not fallen significantly from the level of the early 1990's as documented by e.g. Orphanides and Williams (2002). They report that the real time assessment of the natural rate of unempolyment in 1995 was 6.0% while the most recent estimate from CBO in 2002 was 5.3%. It is interesting to note that by the end of the sample, 2002 : 12, where the Federal funds rate is at a historic low, the policy rate is still above its equilibrium value according to our estimates.

An important issue for the interpretation of the results in terms of a policy reaction function is the structural stability of the estimates. According to the Lucas-critique view on empirical analyses, only *deep parameters*, such as characterizations of preferences and technical relationships, can be expected to be stable, whereas reaction functions and reduced forms are prone to instabilities following shocks to the system. Reversing this line of argument, stable coefficient estimates can be taken as indicative evidence against the Lucas critique for the present sample. To evaluate the stability of the relation we depict in graph (C) the recursively estimated parameters to unemployment in the long-run relation, see Hansen and Johansen (1999). The estimates look remarkably stable, and the narrowing of the 95% confidence bands indicate an increasing information on the parameters. Finally graph (D) depicts the recursively calculated test statistic for the over-identifying restrictions. The identifying structure is clearly acceptable in all sub-samples.

Short-Run Structure. The VAR used to characterize the long-run properties is heavily over-parametrized, with many insignificant parameters. To illustrate the short-run adjustment we use a general-to-specific modelling strategy, see Hendry and Mizon (1993), to find a more parsimonious representation. Using a conventional 5% critical level and

[4]We have tried to recalculate the analysis starting the effective sample in 1989 : 1 to remove the effects of the initial misalignment, but the estimation results are only marginally affected.

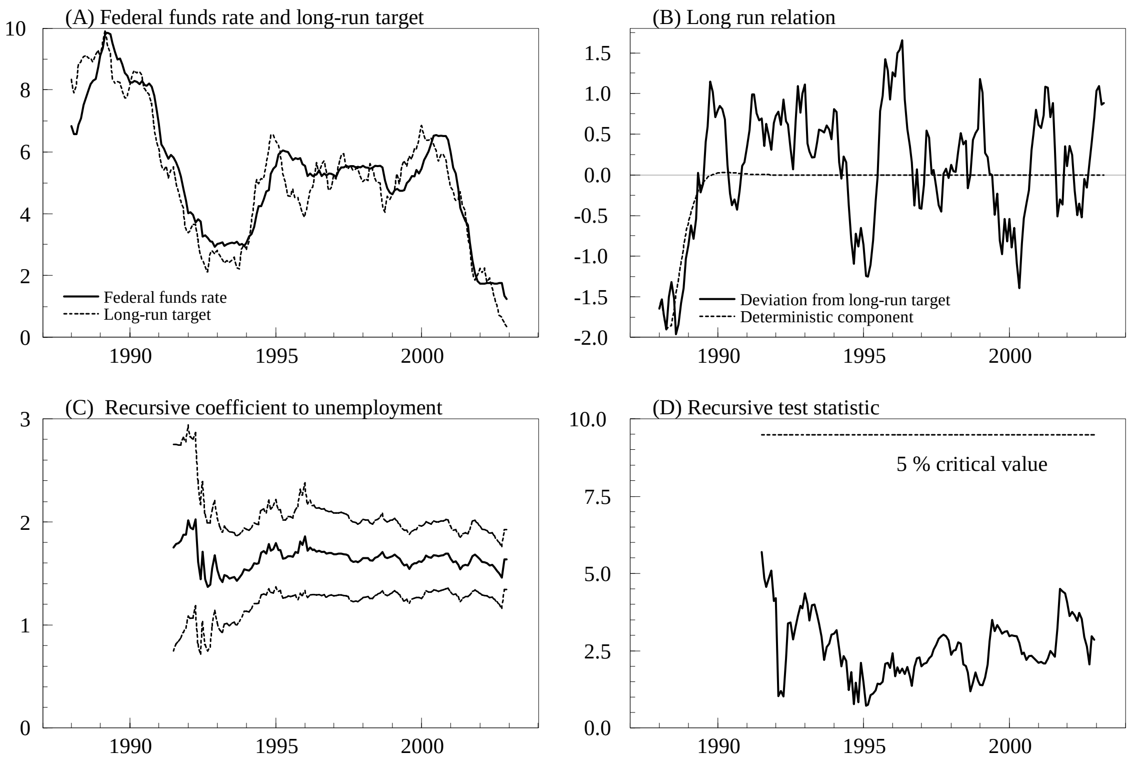

Figure 2: Deviations from the cointegrating relation and recursive results. The recursive estimation is done for sub-samples $t = 1988 : 1, ..., T_0$*, where the endpoints take the values* $T_0 = 1991 : 7, ..., 2002 : 12$*. In each sub-sample the short-run parameters are fixed at their full-sample estimates, see Hansen and Johansen (1999). By and large similar results are obtained if the short-run parameters are reestimated in each sub-sample, although a larger initial sample is necessary. (D) depicts the test statistics for the 4 over-identifying restrictions in* $\mathcal{H}_4$ *and the* 5% *critical value for individual tests, see Kongsted (1998).*

retaining the adjustment coefficient α_4 to inflation yield the following representation

$$\begin{pmatrix} \Delta f_t \\ \Delta b_t \\ \Delta u_t \\ \Delta \pi_t \end{pmatrix} = \begin{pmatrix} \underset{(-5.15)}{-0.085} \\ \underset{(...)}{0} \\ \underset{(...)}{0} \\ \underset{(-1.86)}{-0.024} \end{pmatrix} \left(f_{t-1} - f^*_{t-1}\right) + \begin{pmatrix} \underset{(2.88)}{0.188} & \underset{(3.47)}{0.167} & \underset{(-3.21)}{-0.257} \\ \underset{(...)}{0} & \underset{(4.57)}{0.322} & \underset{(...)}{0} \\ \underset{(-3.48)}{-0.159} & \underset{(...)}{0} & \underset{(...)}{0} \\ \underset{(...)}{0} & \underset{(...)}{0} & \underset{(...)}{0} \end{pmatrix} \begin{pmatrix} \Delta f_{t-1} \\ \Delta b_{t-1} \\ \Delta u_{t-1} \end{pmatrix}$$
$$+ \begin{pmatrix} \underset{(2.40)}{0.149} & \underset{(...)}{0} \\ \underset{(...)}{0} & \underset{(...)}{0} \\ \underset{(...)}{0} & \underset{(...)}{0} \\ \underset{(2.17)}{0.100} & \underset{(-2.19)}{-0.158} \end{pmatrix} \begin{pmatrix} \Delta f_{t-2} \\ \Delta \pi_{t-2} \end{pmatrix} + \begin{pmatrix} \underset{(3.08)}{0.177} & \underset{(...)}{0} \\ \underset{(...)}{0} & \underset{(...)}{0} \\ \underset{(...)}{0} & \underset{(2.02)}{0.145} \\ \underset{(...)}{0} & \underset{(...)}{0} \end{pmatrix} \begin{pmatrix} \Delta f_{t-3} \\ \Delta u_{t-3} \end{pmatrix},$$

which produces a LR test statistic of 39.89 compared to the unrestricted vector equilibrium correction model, corresponding to $p-$value of 0.48 in a $\chi^2(40)$.

Considering the equation for the Federal funds rate, which is the main focus here, indicates a simple behavior. Besides the autoregressive terms in Δf_{t-1}, Δf_{t-2}, and Δf_{t-3}, which describe the interest rate smoothing, there are additional short-run terms only for one period lagged bond rate and unemployment. The coefficient to Δb_{t-1} is 0.17, well below the long-run impact of one. The coefficients to the lagged change in the unemployment rate, Δu_{t-1}, is -0.26. In the parsimonious system the adjustment coefficient α_4 in the inflation equation is smaller and less significant than in the unrestricted model, giving less support for the short-run controllability of inflation.

Interpretation of a Second Long-Run Relation. In the rank determination in Table 2, a second long-run relation was borderline significant. To illustrate that the main conclusions are robust to the choice of cointegration rank, r, we briefly discuss the possible interpretation of a second long-run relation.

Allowing for a second long-run relation and imposing restrictions on α and β^* yields the structure

$$\begin{pmatrix} \Delta f_t \\ \Delta b_t \\ \Delta u_t \\ \Delta \pi_t \end{pmatrix} = \begin{pmatrix} \underset{(-4.81)}{-0.086} & \underset{(-3.88)}{-0.115} \\ \underset{(...)}{0} & \underset{(...)}{0} \\ \underset{(...)}{0} & \underset{(...)}{0} \\ \underset{(-1.74)}{-0.029} & \underset{(-3.28)}{-0.089} \end{pmatrix} \begin{pmatrix} f_{t-1} - b_{t-1} + \underset{(2.67)}{0.839} \\ u_{t-1} - \underset{(-27.67)}{5.276} \end{pmatrix} + ...,$$

which is accepted with a test statistic of 6.79, corresponding to a $p-$value of 0.56 in a $\chi^2\,(8)$ distribution. Note that for $r = 2$, the cointegration space separates into a stationary interest rate spread, $f_t - b_t$, and a stationary unemployment rate, u_t, while the inflation rate can still be excluded from the long-run relationships. The policy rule is therefore no longer explicitly in the system, but the main conclusions from the analysis of $r = 1$ are preserved:

The Federal funds rate, f_t, significantly equilibrium corrects to both long-run relations, and based on the weights of the two relations in the dynamic equation for Δf_t, the implicit policy rule is still of the form (7) although with a slightly smaller coefficient of numerically $0.086/0.115 = 1.34$ to unemployment. The bond rate, b_t, and unemployment, u_t, are still weakly exogenous for the long-run parameters, while inflation, π_t, equilibrium corrects to both relations, although the interest rate spread is marginally insignificant, indicating the somewhat weak link from the Federal funds rate to inflation.

6 Concluding Remarks

We have found that the interest-rate setting of the FOMC in the period 1988-2002 has been somewhat different to that implied by other research. We can reject that monetary policy has ben set according to a traditional Taylor rule. Instead a long-term relationship between the Federal funds rate, the unemployment rate and the long-term interest rate is found. Deviations from this relationship are mainly corrected via changes in the Federal funds rate. This implies that in this small system the Federal funds rate can be considered the endogenous variable, indicating that the relationship has the character of a monetary policy rule. Rates are set as if FOMC reacts to unemployment and long-term interest rates. From a decision-making point of view a likely interpretation is a reaction to activity expressed by the unemployment rate and the information derived from financial markets expressed by the long-term interest rate.

We are fully aware that the decision-making process in real time has been far more complicated that a literal reading of our results suggest. Forecasts of inflation and activity using different models have been important as has a careful digestion of recent statistics. As a simple way to summarize factors entering the interest rate setting using *ex post* data the results nevertheless provide a better description than the traditional Taylor rule.

The analysis is carried out using a cointegrated vector autoregression, allowing for a simultaneous modelling of the long-term relationships and short-run dynamics. When testing against a more traditional Taylor-rule specification, our model suggests that inflation enters the relationship via its impact on expected inflation through the long-term interest rate. We are unable to find a significant role for inflation beyond that. A specification without information from the financial market is clearly statistically rejected, and the dynamic adjustment indicates that although such a relation looks like a simple Taylor (1993) rule, it cannot be interpreted as a policy reaction function because the Federal funds rate in that case is weakly exogeneous with respect to the long-run parameters.

References

Ball, L., and R. R. Tchaidze (2002): "The FED and the New Economy," *American Economic Review*, 92(2), 108–114.

Bernanke, B. S., and A. S. Blinder (1992): "The Federal Funds Rate and the Channels of Monetary Transmission," *American Economic Review*, 82(4), 901–921.

Boswijk, H. P. (1995): "Identifiability of Cointegrated Systems," *Working Paper, Tinbergen Institute and Department of Actuarial Science and Econometrics.*

Carey, K. (2001): "Testing for Stabilizing Monetary Policy Rules: How Robust to Alternative Specifications?," *Topics in Macroeconomics*, 1(1), 1–16.

Christensen, A. M. (2002): "The Real Interest Rate Gap: Measurement and Application," *Danmarks Nationalbank, Working Paper, WP 6/2002.*

Clarida, R., J. Galí, and M. Gertler (1998): "Monetary Policy Rules in Practice Some International Evidence," *European Economics Review*, 42, 1033–1067.

——— (2000): "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *The Quarterly Journal of Economics*, 115(1), 147–180.

Doornik, J. A. (1998): "Approximations to the Asymptotic Distribution of Cointegration Tests," *Journal of Economic Surveys*, 12(5), 573–593.

——— (2001): *Object-Oriented Matrix Programming Using Ox.* Timberlake Consultants Press, London, 4th edn.

Doornik, J. A., and H. Hansen (1994): "An Omnibus Test for Univariate and Multivariate Normality," *Working Paper, Nuffield College, Oxford.*

Doornik, J. A., and D. F. Hendry (1997): *Modeling dynamic systems using Pc-Fiml 9.0 for Windows.* International Thomson Publishing, London.

English, W. B., W. R. Nelson, and B. P. Sack (2003): "Interpreting the Significance of the Lagged Interest Rate in Estimated Monetary Policy Rules," *Contributions to Macroeconomics*, 3(1), Article 5.

Estrella, A., and G. A. Hardouvelis (1991): "The Term Structure as a Predictor of Real Economic Activity," *The Journal of Finance*, 46(2), 555–575.

Estrella, A., and F. S. Mishkin (1996): "The Yield Curve as a Predictor of U.S. Recessions," *Current Issues in Economics and Finance*, 2(7), 1–6.

Evans, C. L. (1998): "Real-time Taylor rules and the federal funds futures market," *Federal Reserve Bank of Chicago, Economic Perspectives*, 1998(3), 44–55.

Hansen, H., and S. Johansen (1999): "Some tests for parameter constancy in cointegrated VAR-models," *The Econometrics Journal*, 2, 306–333.

Hendry, D. F., and G. Mizon (1993): "Evaluating Dynamic Econometric Models by Encompassing the VAR," in *Models, Methods and Applications of Econometrics*, ed. by P. Phillips, pp. 272–300. Basil Blackwell, Oxford.

Johansen, S. (1996): *Likelihood-based Inference in Cointegrated Autoregressive Models.* Oxford University Press, Oxford, 2nd edition edn.

——— (2002): "A small sample correction for the test of cointegration rank in the vector autoregressive model," *Econometrica*, Forthcoming.

Johansen, S., and K. Juselius (2001): "Controlling inflation in a cointegrated vector autoregressive model with an application to US data," *EUI Working Paper ECO No. 2001/2.*

Judd, J. P., and G. D. Rudebusch (1998): "Taylor's Rule and the FED: 1970–1997," *Federal Reserve Bank of San Francisco, Economic Review*, 3, 3–16.

Kongsted, H. C. (1998): "Modelling Price and Quantity Relations for Danish Manufacturing Exports," *Journal of Business and Economic Statistics*, 16(1), 81–91.

Mehra, Y. P. (2001): "The bond rate and estimated monetary policy rules," *Journal of Economics and Statistics*, 53, 345–358.

Mishkin, F. S. (1990): "What does the term structure tell us about future inflation?," *Journal of Monetary Economics*, 25(1), 77–95.

Orphanides, A. (2001): "Monetary POlicy Rules Based on Real-Time data," *American Economic Review*, 91(4), 964–985.

Orphanides, A., and J. C. Williams (2002): "Robust Monetary Policy Rules with Unknown Natural Rates," *Brookings Papers on Economic Acticity*, 2, 63–145.

Rahbek, A., E. Hansen, and J. Dennis (2002): "ARCH Innovations and their Impact on Cointegration Rank Testing," *Working Paper no.22, Centre for Analytical Finance, University of Copenhagen.*

Schiller, R. S. (1990): "The Term Structure of Interest Rates," in *Handbook of Monetary Economics, Vol. I*, ed. by B. E. Friedman, and F. H. Hahn, chapter 13, pp. 626–722. North-Holland, Amsterdam.

Svensson, L. E. O. (2003): "What Is Wrong with Taylor Rules? Using Judgment in Monetary Policy through Targeting Rules," *Journal of Economic Literature, Forthcoming.*

Taylor, J. B. (1993): "Discretion versus policy rules in practice," *Carnegie-Rochester Conference Series on Public Policy*, 39, 195–214.

Woodford, M. (2002): "A Neo-Wicksellian Framework for the Analysis of Monetary Policy," in *Interest and Prices: Foundations of a Theory of Monetary Policy*, chapter 4. In preparation for Princeton University Press, Princeton.