THE ROLE OF THE TERM SPREAD IN AN AUGMENTED TAYLOR RULE. An empirical investigation*

Jesús Vázquez†
Universidad del País Vasco

April 2003

Abstract

Using US data for the period 1967:5-2002:4, this paper empirically investigates the performance of an augmented version of the Taylor rule (ATR) that (i) allows for the presence of switching regimes, (ii) considers the long-short term spread in addition to the typical variables, (iii) uses an alternative monthly indicator of general economic activity suggested by Stock and Watson (1999), and (iv) considers interest rate smoothing. The estimation results show the existence of switching regimes, one characterized by low volatility and the other by high volatility. Moreover, the scale of the responses of the Federal funds rate to movements in the term spread, inflation and the economic activity index depend on the regime. The estimation results also show robust empirical evidence that the ATR has been more stable during the term of office of Chairman Greenspan than in the pre-Greenspan period. However, a closer look at the Greenspan period shows the existence of two alternative regimes and that the response of the Fed funds rate to inflation has not been significant during this period once the term spread is considered.

Key words: Fed funds rate, switching regimes, term spread
JEL classification numbers: C32, E43

*Financial support from Ministerio de Ciencia y Tecnología and Universidad del País Vasco (Spain) through projects BEC2000-1393 and 9/UPV00035.321-13511/2001, respectively, is gratefully acknowledged.

†Correspondence to: Jesús Vázquez, Dpto. Fundamentos del Análisis Económico II, Universidad del País Vasco, Av. Lehendakari Aguirre 83, 48015 Bilbao, Spain. Phone: (34) 94-601-3779, Fax: (34) 94-601-3774, e-mail: jepvapej@bs.ehu.es

1 INTRODUCTION

Taylor (1993) shows that a simple rule (called the Taylor rule) based on inflation and the output gap characterizes the evolution of the US Federal funds rate well for the first five years (1987-1992) of the term of office of Fed Chairman Greenspan. Recently, a strand of literature (for instance, Svensson (1997), Clarida, Galí and Gertler (1999)) has shown that this rule can be obtained from the optimizing behavior of a central bank that seeks to minimize a loss function that includes expected deviations of the rate of inflation from a target level and the output gap. Moreover, Rotemberg and Woodford (1998a) derive a Taylor rule from optimizing individual behavior. Related to this literature, a number of papers (for instance, Benhabib, Schmitt-Grohé and Uribe (2001, 2003), Bernanke and Woodford (1997) and Carlstrom and Fuerst (2000)) have proven the advisability of backward-looking interest rules to avoid self-fulfilling fluctuations and thus macroeconomic instability.

More recently, several papers (for example, Dolado, María-Dolores and Naveira (2000), Dolado, María-Dolores and Ruge-Murcia (2002) and Bec, Ben Salem and Collard (2002)) have found evidence of an asymmetric reaction function by the US Fed, among other central banks.

The aim of this paper is to study empirically an augmented version of the Taylor rule (ATR) that generalizes the Taylor rule with four additional features in order to provide a better understanding of how US monetary policy has been reacting to aggregate variables over a long period of time. First, the ATR allows for the presence of switching regimes to capture asymmetries in the reaction function. Second, the ATR considers the long-short term spread in addition to inflation and a real activity index as a simple way of capturing market expectations of both future real activity and inflation. Among others, Mishkin (1990) and Estrella and Mishkin (1997) have shown robust empirical evidence that the term spread contains useful information concerning market expectations of both future real activity and inflation and that the spread summarizes predictive information that is not captured by the variables entering into a standard Taylor rule. Third, I use an alternative definition of general economic activity. The economic activity index considered is the CFNAI-MA3. This index is the three-month moving average of the *Chicago Fed National Activity* index, which is computed using the methodology suggested by Stock and Watson (1999).[1] The CFNAI-

[1] More precise, the Chicago Fed National Activity index is the first pricipal component of 85 existing, monthly real indicators of economic activity. These 85 monthly indicators can be classified in five groups: production and income (21 series), employment, unemployment and labor hours (24 series), personal consumption and housing (13 series), manufacturing

MA3 is a monthly index, so it allows us to consider monthly data instead of quarterly data, as is the case when a GDP measure of economic activity is used.[2] As shown by Stock and Watson (1999), this type of economic activity index is a good indicator of future inflation. Therefore, the ATR is able to capture the presence of forward-looking components by considering the CFNAI-MA3 and the term spread, which are not present in the standard Taylor rule. Finally, following Rotemberg and Woodford (1998b) among others, interest rate smoothing is introduced into the ATR by considering the lagged interest rate.

I follow two approaches for studying the performance of the ATR. First, I carry out a multiple time series analysis by estimating a two-state four-variable Markov-switching VAR model that includes the term spread, the short rate, the CFNAI-MA3 and inflation. Second, I estimate the single equation described by the ATR. A comparison of the results from the two approaches allows us to assess the robustness of the ATR empirical analysis.

The estimation results show the existence of two regimes displaying very different features. One regime is characterized by low volatility and the other by high volatility. Moreover, the scale of the responses of the Federal funds rate to movements in the term spread, inflation and the economic activity index is much smaller in the low volatility regime than in the other. Moreover, the estimation results show robust evidence that the ATR, which includes the term spread, has remained stable in explaining the dynamics of the funds rate during the term of office of Chairman Greenspan, in sharp contrast with the pre-1987 period, when frequent switches between the two alternative regimes show up.

This paper also studies the Greenspan period alone. The idea is that the asymmetries in the monetary policy reaction function during the Greenspan era may be concealed when studying the full sample because the pre-Greenspan period was characterized by great macroeconomic volatility. The estimation results of the ATR for this period also show evidence of two regimes but, as expected, the differences between the two regimes are not so dramatic as those found when considering the whole sample. The most

---

and trade sales (11 series) and inventories and orders (16 series). Therefore, neither the term spread nor inflation is considered in building the CFNAI-MA3. For more details on this index and demostrations of how well it works both in forecasting inflation and identifying recessions as defined by the NBER, see also Fisher (2000) and Evans, Liu and Pham-Kanter (2002).

[2] A number of studies consider an industrial production index in order to avoid this shortcoming. However, the use of such an index can also be questioned on the grounds that the share of domestic output represented by industrial output has been reduced steadily in all industrial countries, including the US, over the last 30 years.

striking feature found in the Greenspan period is that once the term spread and interest rate smoothing are included in the Taylor rule the funds rate no longer responds to current inflation under any regime, in sharp contrast with the results obtained in previous studies and in the full sample analysis.

The rest of the paper is structured as follows. Section 2 introduces and estimates the two-state four-variable Markov-switching VAR model considered. Section 3 estimates the single equation ATR. The results from the two approaches are also compared. Section 4 analyzes the stability of the Taylor rule during the Greenspan period. Section 5 concludes.

2 THE MARKOV-SWITCHING VAR

In this section, I estimate a two-state Markov-switching VAR model that includes the variables entering a standard Taylor rule (i.e., the short-term rate, the economic activity index and inflation) and the term spread. Formally,

$$Z_t = \Upsilon(s_t) + B(s_t)Z_{t-1} + \Omega(s_t)^{1/2}\xi_t, \tag{1}$$

where $Z_t = (R_t - r_t, r_t - r_{t-1}, \Delta p_t, y_t)'$ and $\xi_t \sim N(0, I)$. R_t is the long-term rate, r_t is the short-term rate, $R_t - r_t$ is the long-short term spread, Δp_t is current inflation and y_t is an index of economic activity. Notice that I have imposed the unit root restriction on the short-term rate when writing system (1). As shown in the Appendix, the estimation results obtained when considering the level of the short-term rate instead of its first differences robustly confirm the presence of a unit root governing the short rate process and the conclusions are identical to those obtained from (1). Moreover, these findings provide strong empirical support for the existence of an interest rate smoothing policy suggested on theoretical grounds by Rotemberg and Woodford (1998b).[3] The regime variable s_t is either 1 or 2 and follows a first-order two-state Markov process with $prob(s_t = 1|s_{t-1} = 1) = p$ and

[3] Several authors have shown that a smoothing coefficient greater than unity has good properties. Thus, Rotemberg and Woodford (1999b) show that this feature guarantees the existence of a locally unique equilibrium. More recently, Benhabib, Schmitt-Grohé and Uribe (2003) show that a smoothing coefficient greater than unity ensures global stability. Interestingly, the point estimate of the lagged interest rate is greater than unity for most of the regressions considering the levels of the funds rate (see coefficients $b_{22}(s_t)$ at Tables A.1-A.3 and coefficients $\rho_4(s_t)$ at Tables A.4-A.6 in the Appendix). In 10 out of 12 cases the point estimate is greater than unity, although in all cases it is not significantly different from unity at any standard critical value. These estimation results support the assumption of the unit-root restriction imposed in the main text.

$prob(s_t = 2|s_{t-1} = 2) = q$.[4] We estimate the Cholesky decomposition $\Psi(s_t)$ of $\Omega(s_t)$ where $\Omega(s_t) = \Psi(s_t)\Psi(s_t)'$.

The second equation of system (1) can be viewed as an ATR where instead of current inflation and economic activity the lagged values of these two variables appear.

The short-term rate considered is the US Federal funds rate. We study the performance of the ATR for three alternative specifications of the term spread. Thus, I use the following rates as the long-term rates: the one-year, three-year and ten-year Treasury constant maturity rates. Inflation is determined from the consumer price index. The interest rate and inflation data were collected from the websites of the Federal Reserve Bank of St. Louis and the Bureau of Labor Statistics, respectively. As mentioned in the Introduction, the economic activity index considered is the CFNAI-MA3. The period studied runs from May, 1967 to April, 2002.

The maximum likelihood estimation of the alternative Markov-switching models considered in this paper follows the procedures suggested by Hamilton (1994, ch. 22).

Tables 1-3 show the estimation results when the long-term rate is defined by the 1-year, 3-year and 10-year rate, respectively. The estimation results can be summarized as follows. First, regime 1 is more persistent than regime 2 (i.e., p is significantly greater than q). Second, the volatility of innovations in the system (1) is much higher in the second regime than in the first, as can be shown by computing the eigenvalues of $\Omega(1)$ and $\Omega(2)$. The eigenvalues of $\Omega(1)$ are 0.0666, 0.0470, 0.0315 and 0.0271, whereas the eigenvalues of $\Omega(2)$ are 1.5336, 0.4074, 0.1663 and 0.0897.[5] Therefore, the first regime can be identified as the low volatility regime and the second as the high volatility regime. Third, the term spread is more persistent in the first regime than in the second (i.e., $b_{11}(1) > b_{11}(2)$).

Fourth, the lagged term spread positively determines changes in the funds rate in the first regime (i.e., $b_{21}(1) > 0$). Notice that the coefficient associated with the lagged term spread is significantly larger in the second regime than in the first ($b_{21}(2) > b_{21}(1)$). Moreover, the response of the funds rate decreases as the difference in maturity in defining the spread increases. These estimation results suggest a different policy reaction function depending on

---

[4] The two-regime Markov-switching VAR model considered may seem quite restrictive but it is the most the data can bear without extreme problems in estimation. For instance, dealing with the two-regime VAR model implies the cumbersome task of estimating 62 coefficients, whereas the estimation of the three-regime VAR model would imply the estimation of 96 coefficients.

[5] The point estimates for these eigenvalues are obtained using the 1-year rate. Similar results are obtained when using the 3-year and 10-year rates.

the predicted inflationary tensions captured by the term spread. Thus, the funds rate behaves in a smooth manner during periods characterized by low, stable interest rates in which the term spread is also low, stable as in the first regime. Contrariwise, the funds rate responses are larger in the second regime when the term spread is high, volatile since a high, volatile spread indicates the need for restrictive monetary policy (an increase in the funds rate) in order to fight inflation.

Fifth, changes in the funds rate are positively determined by the level of economic activity in the first regime but not in the second (i.e., $b_{24}(1) > 0$, $b_{24}(2) = 0$). Sixth, current inflation is negatively determined by lagged spread in the second regime but not in the first (i.e., $b_{31}(1) = 0$, $b_{31}(2) < 0$). Moreover, the scale of this effect decreases with the increase of the difference in maturity between the long and short-term bonds. Finally, the level of economic activity is positively determined by the lagged spread in the two states (i.e., $b_{41}(1) > 0$, $b_{41}(2) > 0$).

A general conclusion from these estimation results is that term spreads with differences in maturities over a year or more contribute to explaining movements in the funds rate, inflation and economic activity. Therefore, it seems useful to consider the term spread in evaluating the performance of any monetary policy reaction function.

Figures 1-3 show the allocation of time periods for the first regime based on the smoothed probabilities using the information over the whole sample of size T (i.e., $prob[s_t = 1|I_T]$) for the three alternative definitions of the term spread used, respectively. The three figures display similar features. Thus, they clearly indicate that the funds rate dynamics are characterized by frequent switches between regimes during the pre-Greenspan period (1967:5 to 1987:8) whereas the term of office of Chairman Greenspan can be entirely attributed to the low volatility regime (regime 1).

The correlation between the smoothed probabilities of regime 1 (2) and inflation is -0.4616 (0.4616) whereas the correlation between the smoothed probabilities of regime 1 (2) and the output gap is 0.3518 (-0.3518). Roughly speaking, regime 1 (2), characterized by low (high) volatility, can be viewed also as one state related to low (high) inflation and expansions (recessions). Thus the nineties, being a stable, expansionary and low inflationary period, belong to the first regime whereas the periods 1973-1976 (first oil crisis) and 1979-1983 (second oil crisis and the Fed's monetary experiment) are robustly attributed to the second.

Table 1. Estimation results for the unrestricted four-variable VAR model (1). 1-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\gamma_1(1)$	0.0207	0.0316	$b_{31}(2)$	−0.1112	0.0264
$\gamma_2(1)$	−0.0252	0.0249	$b_{32}(2)$	0.0291	0.0385
$\gamma_3(1)$	0.1362	0.0358	$b_{33}(2)$	0.2433	0.1420
$\gamma_4(1)$	0.0230	0.0244	$b_{34}(2)$	−0.0034	0.0308
$\gamma_1(2)$	−0.0467	0.1689	$b_{41}(2)$	0.1505	0.0485
$\gamma_2(2)$	−0.1029	0.2064	$b_{42}(2)$	0.0018	0.0454
$\gamma_3(2)$	0.3876	0.0816	$b_{43}(2)$	−0.1355	0.1722
$\gamma_4(2)$	0.2516	0.1598	$b_{44}(2)$	0.9444	0.0636
$b_{11}(1)$	0.9146	0.0273	$\psi_{11}(1)$	0.2009	0.0107
$b_{12}(1)$	−0.0561	0.0451	$\psi_{12}(1)$	−0.0084	0.0140
$b_{13}(1)$	−0.0494	0.0608	$\psi_{13}(1)$	−0.0299	0.0185
$b_{14}(1)$	−0.0087	0.0290	$\psi_{14}(1)$	0.0674	0.0148
$b_{21}(1)$	0.0739	0.0185	$\psi_{22}(1)$	0.1675	0.0233
$b_{22}(1)$	0.3081	0.0405	$\psi_{23}(1)$	0.0226	0.0272
$b_{23}(1)$	0.0087	0.0857	$\psi_{24}(1)$	0.0075	0.0255
$b_{24}(1)$	0.1231	0.0233	$\psi_{33}(1)$	0.2091	0.0105
$b_{31}(1)$	−0.0261	0.0274	$\psi_{34}(1)$	0.0021	0.0159
$b_{32}(1)$	0.0877	0.0552	$\psi_{44}(1)$	0.2324	0.0126
$b_{33}(1)$	0.5897	0.0970	$\psi_{11}(2)$	0.8272	0.0937
$b_{34}(1)$	0.0518	0.0299	$\psi_{12}(2)$	−0.6157	0.1622
$b_{41}(1)$	0.0801	0.0304	$\psi_{13}(2)$	−0.0108	0.0302
$b_{42}(1)$	0.0844	0.0646	$\psi_{14}(2)$	0.0178	0.0447
$b_{43}(1)$	−0.1207	0.0821	$\psi_{22}(2)$	0.9132	0.1531
$b_{44}(1)$	0.9026	0.0362	$\psi_{23}(2)$	0.0609	0.0287
$b_{11}(2)$	0.7131	0.1096	$\psi_{24}(2)$	0.1610	0.0482
$b_{12}(2)$	−0.3349	0.1601	$\psi_{33}(2)$	0.3130	0.0340
$b_{13}(2)$	−0.2107	0.3114	$\psi_{34}(2)$	−0.0704	0.0421
$b_{14}(2)$	−0.0353	0.0912	$\psi_{44}(2)$	0.4082	0.0427
$b_{21}(2)$	0.3680	0.1445	p	0.9842	0.0065
$b_{22}(2)$	0.3667	0.1250	q	0.9330	0.0128
$b_{23}(2)$	0.6627	0.2836	log		
$b_{24}(2)$	0.1681	0.1237	likelihood	469.91	

Notes: $\gamma_i(s_t)$ denotes a generic element of vector $\Upsilon(s_t)$, $b_{ij}(s_t)$ denotes a generic element of matrix $B(s_t)$ and $\psi_{ij}(s_t)$ denotes a generic element of matrix $\Psi(s_t)'$.

Table 2. Estimation results for the unrestricted four-variable VAR model (1). 3-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\gamma_1(1)$	0.0147	0.0335	$b_{31}(2)$	−0.0545	0.0157
$\gamma_2(1)$	−0.0609	0.0179	$b_{32}(2)$	0.0334	0.0248
$\gamma_3(1)$	0.2293	0.0325	$b_{33}(2)$	0.5042	0.0883
$\gamma_4(1)$	−0.0547	0.0237	$b_{34}(2)$	−0.0324	0.0233
$\gamma_1(2)$	0.1970	0.1569	$b_{41}(2)$	0.0792	0.0300
$\gamma_2(2)$	−0.3536	0.1815	$b_{42}(2)$	0.0411	0.0409
$\gamma_3(2)$	0.2810	0.0539	$b_{43}(2)$	−0.2228	0.1558
$\gamma_4(2)$	0.1996	0.0912	$b_{44}(2)$	0.9700	0.0557
$b_{11}(1)$	0.9880	0.0263	$\psi_{11}(1)$	0.2500	0.0177
$b_{12}(1)$	−0.1990	0.0576	$\psi_{12}(1)$	−0.0247	0.0107
$b_{13}(1)$	0.0383	0.0961	$\psi_{13}(1)$	0.0190	0.0209
$b_{14}(1)$	−0.0723	0.0251	$\psi_{14}(1)$	0.0426	0.0184
$b_{21}(1)$	0.0480	0.0129	$\psi_{22}(1)$	0.1467	0.0082
$b_{22}(1)$	0.1468	0.0314	$\psi_{23}(1)$	0.0171	0.0149
$b_{23}(1)$	0.0474	0.0439	$\psi_{24}(1)$	0.0477	0.0133
$b_{24}(1)$	0.1641	0.0156	$\psi_{33}(1)$	0.2331	0.0119
$b_{31}(1)$	−0.0342	0.0198	$\psi_{34}(1)$	−0.0330	0.0127
$b_{32}(1)$	0.1221	0.0612	$\psi_{44}(1)$	0.1903	0.0081
$b_{33}(1)$	0.3160	0.0895	$\psi_{11}(2)$	0.7890	0.0746
$b_{34}(1)$	0.0703	0.0255	$\psi_{12}(2)$	−0.7636	0.1667
$b_{41}(1)$	0.0656	0.0162	$\psi_{13}(2)$	−0.0079	0.0225
$b_{42}(1)$	0.0373	0.0405	$\psi_{14}(2)$	−0.0136	0.0364
$b_{43}(1)$	0.0325	0.0682	$\psi_{22}(2)$	0.6519	0.0732
$b_{44}(1)$	0.8463	0.0229	$\psi_{23}(2)$	0.0406	0.0206
$b_{11}(2)$	0.7601	0.0791	$\psi_{24}(2)$	0.1688	0.0429
$b_{12}(2)$	−0.3892	0.1255	$\psi_{33}(2)$	0.2290	0.0165
$b_{13}(2)$	−0.5260	0.2641	$\psi_{34}(2)$	0.0507	0.0411
$b_{14}(2)$	−0.0403	0.0780	$\psi_{44}(2)$	0.4138	0.0293
$b_{21}(2)$	0.2078	0.0996	p	0.9769	0.0048
$b_{22}(2)$	0.4360	0.1229	q	0.9384	0.0108
$b_{23}(2)$	0.7491	0.3203	log		
$b_{24}(2)$	0.1135	0.1023	likelihood	438.02	

Table 3. Estimation results for the unrestricted four-variable VAR model (1). 10-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\gamma_1(1)$	0.0348	0.0332	$b_{31}(2)$	−0.0384	0.0129
$\gamma_2(1)$	−0.0478	0.0195	$b_{32}(2)$	0.0184	0.0217
$\gamma_3(1)$	0.2439	0.0341	$b_{33}(2)$	0.5639	0.0929
$\gamma_4(1)$	−0.0464	0.0254	$b_{34}(2)$	−0.0374	0.0242
$\gamma_1(2)$	0.2076	0.1725	$b_{41}(2)$	0.0876	0.0226
$\gamma_2(2)$	−0.3899	0.1736	$b_{42}(2)$	0.0397	0.0391
$\gamma_3(2)$	0.2481	0.0563	$b_{43}(2)$	−0.0916	0.1554
$\gamma_4(2)$	0.1115	0.0925	$b_{44}(2)$	0.9618	0.0546
$b_{11}(1)$	0.9763	0.0156	$\psi_{11}(1)$	0.2326	0.0122
$b_{12}(1)$	−0.2508	0.0841	$\psi_{12}(1)$	−0.0571	0.0097
$b_{13}(1)$	0.0333	0.0837	$\psi_{13}(1)$	0.0258	0.0189
$b_{14}(1)$	−0.1140	0.0270	$\psi_{14}(1)$	0.0325	0.0160
$b_{21}(1)$	0.0264	0.0091	$\psi_{22}(1)$	0.1395	0.0085
$b_{22}(1)$	0.1914	0.0388	$\psi_{23}(1)$	0.0171	0.0143
$b_{23}(1)$	0.0184	0.0445	$\psi_{24}(1)$	0.0567	0.0155
$b_{24}(1)$	0.1663	0.0156	$\psi_{33}(1)$	0.2291	0.0120
$b_{31}(1)$	−0.0263	0.0137	$\psi_{34}(1)$	−0.0370	0.0135
$b_{32}(1)$	0.1448	0.0726	$\psi_{44}(1)$	0.1952	0.0082
$b_{33}(1)$	0.3099	0.0969	$\psi_{11}(2)$	0.9074	0.1134
$b_{34}(1)$	0.0656	0.0269	$\psi_{12}(2)$	−0.8936	0.1681
$b_{41}(1)$	0.0373	0.0110	$\psi_{13}(2)$	−0.0065	0.0214
$b_{42}(1)$	0.1106	0.0566	$\psi_{14}(2)$	−0.0584	0.0317
$b_{43}(1)$	0.0020	0.0701	$\psi_{22}(2)$	0.4670	0.0448
$b_{44}(1)$	0.8475	0.0259	$\psi_{23}(2)$	0.0512	0.0182
$b_{11}(2)$	0.8213	0.0652	$\psi_{24}(2)$	0.1405	0.0421
$b_{12}(2)$	−0.4281	0.1261	$\psi_{33}(2)$	0.2292	0.0152
$b_{13}(2)$	−0.4530	0.2849	$\psi_{34}(2)$	0.0489	0.0388
$b_{14}(2)$	−0.0494	0.0855	$\psi_{44}(2)$	0.4087	0.0312
$b_{21}(2)$	0.1645	0.0713	p	0.9785	0.0052
$b_{22}(2)$	0.4276	0.1132	q	0.9363	0.0120
$b_{23}(2)$	0.7435	0.3038	log		
$b_{24}(2)$	0.1096	0.1032	likelihood	479.59	

3 ESTIMATION OF THE AUGMENTED TAYLOR RULE

In this section, I estimate the ATR that allows for the presence of a Markov-switching process characterizing the parameters of the rule and considers the term spread and interest rate smoothing in addition to the variables included in the standard Taylor rule. Formally, the ATR is given by

$$r_t - r_{t-1} = \rho_0(s_t) + \rho_1(s_t)(R_{t-1} - r_{t-1}) + \rho_2(s_t)\Delta p_t + \rho_3(s_t)y_t + \sigma(s_t)u_t, \quad (2)$$

where u_t is a standard normal random variable. Notice that I have imposed the unit-root restriction. The estimation results using the level of the Fed funds rate are displayed in the Appendix and the conclusions are identical to those obtained from (2).

Table 4. Estimation results for the ATR (2). The 1-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0691	0.0191	$\rho_3(1)$	0.1728	0.0190
$\rho_0(2)$	-0.5539	0.2686	$\rho_3(2)$	0.5518	0.1385
$\rho_1(1)$	0.0751	0.0342	$\sigma(1)$	0.1626	0.0094
$\rho_1(2)$	0.3766	0.1205	$\sigma(2)$	1.1389	0.0956
$\rho_2(1)$	0.1211	0.0383	p	0.9846	0.0076
$\rho_2(2)$	1.5439	0.4603	q	0.9004	0.0289
log	likelihood	-38.09			

Table 5. Estimation results for the ATR (2). The 3-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0591	0.0181	$\rho_3(1)$	0.2024	0.0140
$\rho_0(2)$	-0.6875	0.2745	$\rho_3(2)$	0.4507	0.1245
$\rho_1(1)$	0.0188	0.0113	$\sigma(1)$	0.1536	0.0085
$\rho_1(2)$	0.2170	0.0888	$\sigma(2)$	1.1406	0.0871
$\rho_2(1)$	0.0887	0.0327	p	0.9805	0.0082
$\rho_2(2)$	1.4785	0.4654	q	0.8948	0.0271
log	likelihood	-42.91			

Table 6. Estimation results for the ATR (2). The 10-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0484	0.0204	$\rho_3(1)$	0.2124	0.0132
$\rho_0(2)$	-0.6400	0.2820	$\rho_3(2)$	0.4445	0.1154
$\rho_1(1)$	0.0029	0.0085	$\sigma(1)$	0.1523	0.0091
$\rho_1(2)$	0.1472	0.0711	$\sigma(2)$	1.1468	0.0883
$\rho_2(1)$	0.0747	0.0364	p	0.9799	0.0083
$\rho_2(2)$	1.3311	0.4724	q	0.8937	0.0267
log	likelihood	-44.83			

Tables 4-6 show the estimation results for the ATR (2) when the long-term rate is defined by the 1-year, 3-year and 10-year rates, respectively. The estimation results can be summarized as follows. First, regime 1 is more persistent than regime 2 (i.e., p is significantly greater than q). Moreover, these estimated probabilities are similar to those obtained when estimating the two-state four-variable Markov-switching VAR model (1).

Second, the best fit measured by the maximized value of the likelihood function is obtained when the term spread is defined using the 1-year rate. Moreover, the changes in the funds rate are determined by the term spread under the two regimes only for this definition of the term spread. In this case, the response of the funds rate is five times greater in the second regime than in the first (i.e., $\rho_1(2) \simeq 5\rho_1(1)$). Furthermore, the response of the funds rate decreases as the difference in maturity in defining the spread increases. These estimation results are similar to those obtained when estimating (1). I further estimate the model imposing the restrictions that the term spread does not determine the changes in the funds rate under any regime. The likelihood ratio test statistic associated with the null hypothesis that the changes in the funds rate are not determined by the term spread in any regime takes the value 180.36. This statistic is distributed as a $\chi^2(2)$, which implies overwhelming rejection of the null hypothesis.

Third, changes in the funds rate are positively determined by current inflation and the scale of the response is more than ten times higher for the second regime than for the first for any definition of the term spread. Notice that the typical result found in estimating a standard Taylor rule that the inflation coefficient is greater than unity only occurs for the second (high volatility) regime in the ATR framework.

Fourth, changes in the funds rate are also positively determined by the economic activity indicator and the scale of the response is more than twice as high for the second regime as for the first.

Fifth, the standard deviation of the innovation process is seven times greater in the second regime than in the first. Finally, the funds rate response to inflation is greater than the response to the economic activity indicator in the second regime. The opposite is true in the first regime.

Confirming the estimation results found above, these results suggest the existence of an asymmetric monetary policy reaction function. Thus, monetary policy is quite smooth when the volatility of innovations is low (regime 1) since the scale of the response of the funds rate to the term-spread, inflation and the economic activity index is small. Moreover, there is a more aggressive behavior toward output stabilization than inflation. However, when the volatility of innovations is high (regime 2) the response of the funds rate to each of the three variables is much greater than in the other regime. In addition, there is a more aggressive behavior toward inflation than output stabilization in this high volatility regime.

Figures 4-6 show the allocation of time periods for the first regime based on the smoothed probabilities using the information over the whole sample of size T. These four figures are similar and one can draw the same conclusions as those described above when analyzing Figures 1-3.

3.1 Are two regimes sufficient?

We have assumed up to now the existence of two alternative regimes. In this subsection, we estimate the ATR considering three regimes. Therefore, the regime variable s_t is either 1, 2 or 3 and follows a first-order three-state Markov process with the transition matrix given by

$$P = \begin{pmatrix} p_{11} & p_{21} & 1 - p_{33} - p_{32} \\ p_{12} & p_{22} & p_{32} \\ 1 - p_{11} - p_{12} & 1 - p_{21} - p_{22} & p_{33} \end{pmatrix},$$

where the row j, column i element of P is the transition probability p_{ij} that gives the probability that regime i will be followed by regime j. The estimation results of the ATR with three regimes are displayed in Table 7.[6]

We can test the hypothesis of two regimes versus three regimes using the likelihood ratio test. In this case, the likelihood ratio test statistic is distributed as a $\chi^2(9)$. This statistic takes the value 193.5, which implies overwhelming rejection of the two-regime hypothesis. A comparison of the estimation results from Tables 4 and 7 clearly points out that (i) the third

[6]For the sake of brevity, Table 7 only shows the estimation results for the term spread defined using the 1-year rate as the long-term rate. Similar results are found when using the alternative definitions of the term spread. They are available from the author upon request.

regime is close to describing the high volatility regime identified in the previous two-regime analysis and (ii) the low volatility regime identified in the two-regime analysis is a combination of the first two regimes detected in the three-regime analysis. These results indicate that considering an additional regime basically helps to distinguish a regime with very low volatility (regime 1) from one with moderate volatility (regime 2) without affecting the basic conclusions obtained from the two-regime analysis. This conclusion is further supported by Figures 7-9, which show the smoothed probabilities for the three alternative regimes. Thus, we can observe that the Greenspan period, which is attributed entirely to the low volatility regime in the two-regime analysis, is described by two regimes in the three-regime analysis. One regime is characterized by low volatility, whereas the other is characterized by moderate volatility. The next section confirms these results by analyzing the Greenspan period alone.

Table 7. Estimation results for the ATR (2) with three regimes. The 1-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	−0.0102	0.0084	$\rho_3(3)$	0.4899	0.1339
$\rho_0(2)$	−0.0678	0.0202	$\sigma(1)$	0.0484	0.0034
$\rho_0(3)$	−0.6117	0.2399	$\sigma(2)$	0.1427	0.0082
$\rho_1(1)$	0.0139	0.0063	$\sigma(3)$	1.1625	0.0905
$\rho_1(2)$	0.1878	0.0178	p_{11}	0.9948	0.0057
$\rho_1(3)$	0.2892	0.1163	p_{12}	0.0044	0.0050
$\rho_2(1)$	0.0292	0.0183	p_{21}	0.0883	0.0199
$\rho_2(2)$	0.1985	0.0394	p_{22}	0.8939	0.0216
$\rho_2(3)$	1.4925	0.4287	p_{32}	0.0544	0.0202
$\rho_3(1)$	0.0340	0.0069	p_{33}	0.8748	0.0286
$\rho_3(2)$	0.2431	0.0137	log	likelihood	58.66

4 THE GREENSPAN PERIOD

In this section, I estimate the ATR considering two regimes for the period 1987:8-2002:4. Table 8 shows the estimation results when the term spread is defined by the 1-year rate. As pointed out above, the differences detected between the two regimes in the Greenspan period are much less pronounced than those detected for the whole sample period. However, the likelihood ratio statistic for testing the null hypothesis of the existence of only one regime versus the alternative of two regimes, which is distributed as a

$\chi^2(6)$, takes the value 39.0914, which implies the rejection of the one-regime hypothesis in favor of the two-regime hypothesis at any standard critical value.

Table 8 also highlights that the response of the funds rate to inflation is not significant under any regime during the Greenspan period, whereas the term spread and the economic activity index responses are significant in the two regimes.[7] Moreover, the response of the funds rate to both the term spread and the economic activity index is three times greater in the moderate volatility regime than in the low volatility regime.

Table 8. Estimation results for the ATR (2) for the Greenspan period. The 1-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0192	0.0090	$\rho_3(1)$	0.0888	0.0133
$\rho_0(2)$	-0.0541	0.0420	$\rho_3(2)$	0.2795	0.0463
$\rho_1(1)$	0.0456	0.0202	$\sigma(1)$	0.0469	0.0034
$\rho_1(2)$	0.1441	0.0522	$\sigma(2)$	0.2105	0.0182
$\rho_2(1)$	0.0194	0.0251	p	0.9838	0.0149
$\rho_2(2)$	0.1446	0.1118	q	0.8557	0.0359
log	likelihood	42.57			

Figure 10 shows the allocation of time periods for the first regime based on the smoothed probabilities using the information over the Greenspan period. This figure is rather similar to Figure 7 during the Greenspan period and it clearly points to the existence of frequent switches between the two regimes detected in the Greenspan era. On the one hand, the first five years (1987:8-1992:8), 1994 and the period 1999:6-2001:10 are attributed with high probability to the moderate volatility regime (regime 2). On the other hand, the years 1993 and 1995, and the period 1996:6-1999:4 are attributed with high probability to the low volatility regime.

[7] Since the funds rate does not seem to respond to inflation under any regime during the Greenspan period, we re-estimate the ATR by imposing the restriction that the response of the funds rate to inflation is identical under the two regimes in order to assess the robustness of the latter result. As shown in Table 9, the estimation results confirm that the funds rate does not respond to inflation during the Greenspan period once the term spread, interest rate smoothing and the economic activity index are considered (i.e., ρ_2 is not significant).

Table 9. ATR (2) estimation results for the Greenspan period imposing the restriction $\rho_2(1) = \rho_2(2) = \rho_2$. The 1-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0208	0.0091	$\rho_3(1)$	0.0890	0.0113
$\rho_0(2)$	-0.0192	0.0276	$\rho_3(2)$	0.2829	0.0467
$\rho_1(1)$	0.0475	0.0204	$\sigma(1)$	0.0465	0.0033
$\rho_1(2)$	0.1355	0.0516	$\sigma(2)$	0.2120	0.0184
ρ_2	0.0254	0.0253	p	0.9828	0.0157
			q	0.8559	0.0360
log	likelihood	42.40			

5 CONCLUSIONS

This paper implements Markov regime switching procedures *à la Hamilton* to analyze the stability of the Taylor rule over the last thirty-five years. The estimation results show the existence of two different regimes. One (say regime 1) is characterized by low volatility and the other (regime 2) by high volatility. Moreover, the scale of the responses of the funds rate to movements in the term spread, inflation and the economic activity index is much smaller in the first regime than in the second. The first regime is also associated with expansionary and low inflationary periods. These estimation results suggest an asymmetric monetary policy reaction function where the funds rate responses are sharply different depending on the economic conditions.

The estimation results also show robust empirical evidence that an augmented version of the Taylor rule that includes the term spread has remained relatively stable in explaining the dynamics of the funds rate during the term of office of Chairman Greenspan. However, for the pre-Greenspan period the estimation results of the augmented Taylor rule show frequent switches between two quite different regimes. A closer look at the Greenspan period shows the existence of two alternative regimes characterized by low and moderate volatility and indicates that the response of the funds rate to inflation has not been significant in this period once the term spread and interest rate smoothing are considered.

APPENDIX

Table A.1. Estimation results for the unrestricted four-variable VAR model (1). 1-year rate defines the long-term rate. Fed funds rate in levels.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\gamma_1(1)$	0.1714	0.1282	$b_{31}(2)$	−0.1007	0.0296
$\gamma_2(1)$	−0.0543	0.0697	$b_{32}(2)$	0.0130	0.0117
$\gamma_3(1)$	−0.0316	0.2002	$b_{33}(2)$	0.2523	0.2025
$\gamma_4(1)$	0.0547	0.1648	$b_{34}(2)$	0.0335	0.0822
$\gamma_1(2)$	0.3713	0.2912	$b_{41}(2)$	0.0880	0.0411
$\gamma_2(2)$	−0.2891	0.2974	$b_{42}(2)$	−0.0316	0.0177
$\gamma_3(2)$	0.2413	0.1357	$b_{43}(2)$	−0.1634	0.1673
$\gamma_4(2)$	0.5221	0.1379	$b_{44}(2)$	0.9540	0.0550
$b_{11}(1)$	0.8779	0.0596	$\psi_{11}(1)$	0.1948	0.0315
$b_{12}(1)$	−0.0280	0.0269	$\psi_{12}(1)$	−0.0148	0.0180
$b_{13}(1)$	0.0240	0.0539	$\psi_{13}(1)$	−0.0288	0.0503
$b_{14}(1)$	−0.0025	0.0620	$\psi_{14}(1)$	0.0571	0.0215
$b_{21}(1)$	0.0908	0.0334	$\psi_{22}(1)$	0.1693	0.0090
$b_{22}(1)$	1.0036	0.0129	$\psi_{23}(1)$	0.0225	0.0263
$b_{23}(1)$	0.0231	0.0601	$\psi_{24}(1)$	0.0507	0.0175
$b_{24}(1)$	0.1945	0.0283	$\psi_{33}(1)$	0.2106	0.0125
$b_{31}(1)$	0.0300	0.0564	$\psi_{34}(1)$	0.0006	0.0237
$b_{32}(1)$	0.0290	0.0401	$\psi_{44}(1)$	0.2071	0.0183
$b_{33}(1)$	0.5652	0.0744	$\psi_{11}(2)$	0.8173	0.0875
$b_{34}(1)$	0.0160	0.1073	$\psi_{12}(2)$	−0.6794	0.1416
$b_{41}(1)$	0.0865	0.0410	$\psi_{13}(2)$	−0.0095	0.0250
$b_{42}(1)$	−0.0138	0.0333	$\psi_{14}(2)$	0.0019	0.0414
$b_{43}(1)$	0.0248	0.0828	$\psi_{22}(2)$	0.8724	0.1157
$b_{44}(1)$	0.8677	0.0586	$\psi_{23}(2)$	0.0736	0.0264
$b_{11}(2)$	0.7173	0.1102	$\psi_{24}(2)$	0.1506	0.0447
$b_{12}(2)$	−0.0435	0.0325	$\psi_{33}(2)$	0.2966	0.0377
$b_{13}(2)$	−0.2545	0.2655	$\psi_{34}(2)$	−0.0532	0.0634
$b_{14}(2)$	−0.2057	0.0794	$\psi_{44}(2)$	0.3974	0.0456
$b_{21}(2)$	0.2793	0.1439	p	0.9813	0.0067
$b_{22}(2)$	1.0099	0.0377	q	0.9387	0.0204
$b_{23}(2)$	0.6795	0.2798	log		
$b_{24}(2)$	0.2932	0.1063	likelihood	455.29	

Table A.2. Estimation results for the unrestricted four-variable VAR model (1). 3-year rate defines the long-term rate. Fed funds rate in levels.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\gamma_1(1)$	0.2107	0.1025	$b_{31}(2)$	−0.0483	0.0192
$\gamma_2(1)$	−0.0531	0.0632	$b_{32}(2)$	0.0036	0.0088
$\gamma_3(1)$	0.1600	0.0654	$b_{33}(2)$	0.5677	0.1131
$\gamma_4(1)$	0.0219	0.0586	$b_{34}(2)$	−0.0248	0.0259
$\gamma_1(2)$	0.2561	0.2870	$b_{41}(2)$	0.0744	0.0405
$\gamma_2(2)$	−0.3669	0.3073	$b_{42}(2)$	−0.0200	0.0176
$\gamma_3(2)$	0.1917	0.1290	$b_{43}(2)$	−0.0884	0.2036
$\gamma_4(2)$	0.3021	0.1591	$b_{44}(2)$	0.9700	0.0674
$b_{11}(1)$	0.9704	0.0293	$\psi_{11}(1)$	0.2508	0.0164
$b_{12}(1)$	−0.0311	0.0156	$\psi_{12}(1)$	−0.0342	0.0201
$b_{13}(1)$	0.0241	0.0927	$\psi_{13}(1)$	0.0127	0.0230
$b_{14}(1)$	−0.1169	0.0238	$\psi_{14}(1)$	0.0485	0.0212
$b_{21}(1)$	0.0298	0.0159	$\psi_{22}(1)$	0.1513	0.0170
$b_{22}(1)$	1.0022	0.0124	$\psi_{23}(1)$	0.0136	0.0335
$b_{23}(1)$	0.0379	0.0585	$\psi_{24}(1)$	0.0384	0.0251
$b_{24}(1)$	0.1997	0.0168	$\psi_{33}(1)$	0.2307	0.0145
$b_{31}(1)$	−0.0352	0.0218	$\psi_{34}(1)$	−0.0361	0.0166
$b_{32}(1)$	0.0143	0.0122	$\psi_{44}(1)$	0.1889	0.0093
$b_{33}(1)$	0.2830	0.0903	$\psi_{11}(2)$	0.8748	0.0972
$b_{34}(1)$	0.0973	0.0241	$\psi_{12}(2)$	−0.8578	0.1594
$b_{41}(1)$	0.0430	0.0151	$\psi_{13}(2)$	−0.0204	0.0221
$b_{42}(1)$	−0.0099	0.0091	$\psi_{14}(2)$	−0.0363	0.0382
$b_{43}(1)$	0.0309	0.0785	$\psi_{22}(2)$	0.6500	0.0814
$b_{44}(1)$	0.8640	0.0228	$\psi_{23}(2)$	0.0471	0.0191
$b_{11}(2)$	0.8115	0.0827	$\psi_{24}(2)$	0.1618	0.0407
$b_{12}(2)$	−0.0120	0.0356	$\psi_{33}(2)$	0.2428	0.0252
$b_{13}(2)$	−0.4009	0.3124	$\psi_{34}(2)$	0.0819	0.0457
$b_{14}(2)$	−0.1957	0.0920	$\psi_{44}(2)$	0.4086	0.0334
$b_{21}(2)$	0.1588	0.1083	p	0.9754	0.0060
$b_{22}(2)$	1.0018	0.0394	q	0.9366	0.0138
$b_{23}(2)$	0.7390	0.3183	log		
$b_{24}(2)$	0.2934	0.1164	likelihood	417.11	

Table A.3. Estimation results for the unrestricted four-variable VAR model (1). 10-year rate defines the long-term rate. Fed funds rate in levels

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\gamma_1(1)$	0.1192	0.0996	$b_{31}(2)$	−0.0511	0.0239
$\gamma_2(1)$	−0.0206	0.0632	$b_{32}(2)$	−0.0035	0.0140
$\gamma_3(1)$	0.1060	0.0801	$b_{33}(2)$	0.5183	0.1133
$\gamma_4(1)$	0.0190	0.0903	$b_{34}(2)$	−0.0202	0.0227
$\gamma_1(2)$	0.2427	0.3398	$b_{41}(2)$	0.0562	0.0355
$\gamma_2(2)$	−0.3595	0.3413	$b_{42}(2)$	−0.0152	0.0189
$\gamma_3(2)$	0.2933	0.1764	$b_{43}(2)$	−0.2100	0.1897
$\gamma_4(2)$	0.2909	0.2143	$b_{44}(2)$	0.9492	0.0535
$b_{11}(1)$	0.9767	0.0223	$\psi_{11}(1)$	0.2411	0.0150
$b_{12}(1)$	−0.0123	0.0133	$\psi_{12}(1)$	−0.0701	0.0134
$b_{13}(1)$	0.0051	0.0877	$\psi_{13}(1)$	0.0042	0.0219
$b_{14}(1)$	−0.1784	0.0208	$\psi_{14}(1)$	0.0218	0.0226
$b_{21}(1)$	0.0104	0.0141	$\psi_{22}(1)$	0.1466	0.0161
$b_{22}(1)$	0.9962	0.0088	$\psi_{23}(1)$	0.0302	0.0181
$b_{23}(1)$	0.0600	0.0504	$\psi_{24}(1)$	0.0544	0.0164
$b_{24}(1)$	0.2098	0.0164	$\psi_{33}(1)$	0.2367	0.0140
$b_{31}(1)$	−0.0189	0.0162	$\psi_{34}(1)$	−0.0221	0.0181
$b_{32}(1)$	0.0212	0.0122	$\psi_{44}(1)$	0.1949	0.0106
$b_{33}(1)$	0.3315	0.0944	$\psi_{11}(2)$	1.0244	0.1285
$b_{34}(1)$	0.0817	0.0279	$\psi_{12}(2)$	−1.0125	0.1723
$b_{41}(1)$	0.0240	0.0143	$\psi_{13}(2)$	−0.0119	0.0227
$b_{42}(1)$	−0.0128	0.0137	$\psi_{14}(2)$	−0.0811	0.0345
$b_{43}(1)$	0.1112	0.0805	$\psi_{22}(2)$	0.4743	0.0481
$b_{44}(1)$	0.8801	0.0309	$\psi_{23}(2)$	0.0652	0.0266
$b_{11}(2)$	0.8652	0.0761	$\psi_{24}(2)$	0.1484	0.0442
$b_{12}(2)$	−0.0101	0.0391	$\psi_{33}(2)$	0.2339	0.0275
$b_{13}(2)$	−0.3534	0.3376	$\psi_{34}(2)$	0.0421	0.0616
$b_{14}(2)$	−0.2104	0.0921	$\psi_{44}(2)$	0.4242	0.0329
$b_{21}(2)$	0.1160	0.0895	p	0.9781	0.0074
$b_{22}(2)$	1.0019	0.0389	q	0.9305	0.0163
$b_{23}(2)$	0.6843	0.3411	log		
$b_{24}(2)$	0.2796	0.1060	likelihood	457.25	

Tables A.4-A.6 show the estimation results for the ATR written in levels. Formally,

$$r_t = \rho_0(s_t) + \rho_1(s_t)(R_{t-1} - r_{t-1}) + \rho_2(s_t)\Delta p_t + \rho_3(s_t)y_t + \rho_4(s_t)r_{t-1} + \sigma(s_t)u_t, \tag{3}$$

Table A.4. Estimation results for the ATR (3). The 1-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0711	0.0387	$\rho_3(1)$	0.1715	0.0167
$\rho_0(2)$	-0.9147	0.3869	$\rho_3(2)$	0.6156	0.1320
$\rho_1(1)$	0.0769	0.0301	$\sigma(1)$	0.1620	0.0089
$\rho_1(2)$	0.4209	0.1201	$\sigma(2)$	1.1263	0.0935
$\rho_2(1)$	0.1195	0.0424	p	0.9847	0.0075
$\rho_2(2)$	1.3884	0.4571	q	0.9025	0.0284
$\rho_4(1)$	1.0003	0.0064	$\rho_4(2)$	1.0498	0.0405
log	likelihood	-37.54			

Table A.5. Estimation results for the ATR (3). The 3-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0741	0.0491	$\rho_3(1)$	0.2032	0.0137
$\rho_0(2)$	-0.8845	0.4537	$\rho_3(2)$	0.4769	0.1458
$\rho_1(1)$	0.0228	0.0157	$\sigma(1)$	0.1531	0.0094
$\rho_1(2)$	0.2349	0.1005	$\sigma(2)$	1.1379	0.0867
$\rho_2(1)$	0.0855	0.0341	p	0.9800	0.0083
$\rho_2(2)$	1.4431	0.4687	q	0.8947	0.0271
$\rho_4(1)$	1.0023	0.0073	$\rho_4(2)$	1.0231	0.0456
log	likelihood	-42.74			

Table A.6. Estimation results for the ATR (3). The 10-year rate defines the long-term rate.

Parameter	Estimate	Stand. error	Parameter	Estimate	Stand. error
$\rho_0(1)$	-0.0018	0.0420	$\rho_3(1)$	0.2069	0.0127
$\rho_0(2)$	-0.9654	0.4916	$\rho_3(2)$	0.5055	0.1337
$\rho_1(1)$	-0.0040	0.0099	$\sigma(1)$	0.1560	0.0079
$\rho_1(2)$	0.1984	0.0866	$\sigma(2)$	1.1527	0.0885
$\rho_2(1)$	0.0950	0.0368	p	0.9819	0.0081
$\rho_2(2)$	1.2699	0.4647	q	0.8951	0.0276
$\rho_4(1)$	0.9921	0.0059	$\rho_4(2)$	1.0445	0.0468
log	likelihood	-44.20			

References

[1] Bec, Frédérique, Mélika Ben Salem, and Fabrice Collard (2003) Asymmetries in Monetary Policy Reaction Function: Evidence for U.S. French and German Central Banks, *Studies in Nonlinear Dynamics and Econometrics* 6 (2), article 3 (http://www.bepress.com/snde).

[2] Benhabib, Jess, Stephanie Schmitt-Grohé, and Martin Uribe (2001) Monetary Policy and Multiple Equilibria, *American Economic Review* 91, 167-186.

[3] Benhabib, Jess, Stephanie Schmitt-Grohé, and Martin Uribe (2003) Backward-Looking Interest-Rate Rules, Interest-Rate Smoothing and Macroeconomic Instability, NBER Working Paper Series no. 9558.

[4] Bernanke, Ben S., and Michael Woodford (1997) Inflation Forecasts and Monetary Policy, *Journal of Money, Credit, and Banking* 29, 653-684.

[5] Carlstrom, Charles T., and Timothy S. Fuerst (2000) Forward-Looking Versus Forward-Looking Taylor Rules, Federal Reserve Bank of Cleveland Working Paper no. 0099.

[6] Clarida, Richard, Jordi Galí, and Mark Gertler (1999) The Science of Monetary Policy: A New Keynesian Perspective, *Journal of Economic Literature* 37, 1661-1707.

[7] Dolado, Juan J., Ramón María-Dolores, and Manuel Naveira (200) Asymmetries in Monetary Policy: Evidence for Four Central Banks, CEPR Discussion Paper Series no. 2441.

[8] Dolado, Juan J., Ramón María-Dolores, and Francisco J. Ruge-Murcia (2002) Non-Linear Monetary Policy Rules: Some New Evidence for the U.S., CEPR Discussion Paper Series no. 3405.

[9] Estrella, Arturo, and Frederic S. Mishkin (1997) The Predictive Power of the Term Structure of Interest Rates in Europe and the United States: Implications for the European Central Bank, *European Economic Review* 41, 1375-1401.

[10] Evans, Charles L., Chin T. Liu, and Genevieve Pham-Kanter (2002) The 2001 Recession and the Chicago Fed National Activity Index: Identifying Business Cycle Turning Points, *Economic Perspectives*, Federal Reserve Bank of Chicago 26, third quarter, 26-43.

[11] Fisher, Jonas D.M. (2000) Forecasting Inflation with a Lot of Data, *Chicago Fed Letter*, Federal Reserve Bank of Chicago (March) 151.

[12] Hamilton, James D. (1994) *Time Series Analysis.* Princeton University Press, New Jersey.

[13] Mishkin, Frederick S. (1990) The Information in the Longer Maturity Term Structure about Future Inflation, *Quarterly Journal of Economics* 105, 815-828.

[14] Rotemberg, Julio J., and Michael Woodford (1998a) An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy: Expanded Version, NBER Technical Working Paper Series no. 233.

[15] Rotemberg, Julio J., and Michael Woodford (1998b) Interest-Rate Rules in an Estimated Sticky Price Model, NBER Working Paper Series no. 6618.

[16] Svensson, Lars E.O. (1997) Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets, *European Economic Review* 41, 1111-1146.

[17] Stock, James, and Mark Watson (1999) Forecasting Inflation, *Journal of Monetary Economics* 44, 293-335.

[18] Taylor, John B. (1993) Discretion Versus Policy Rules in Practice, *Carnegie-Rochester Series on Public Policy* 39, 195-214.

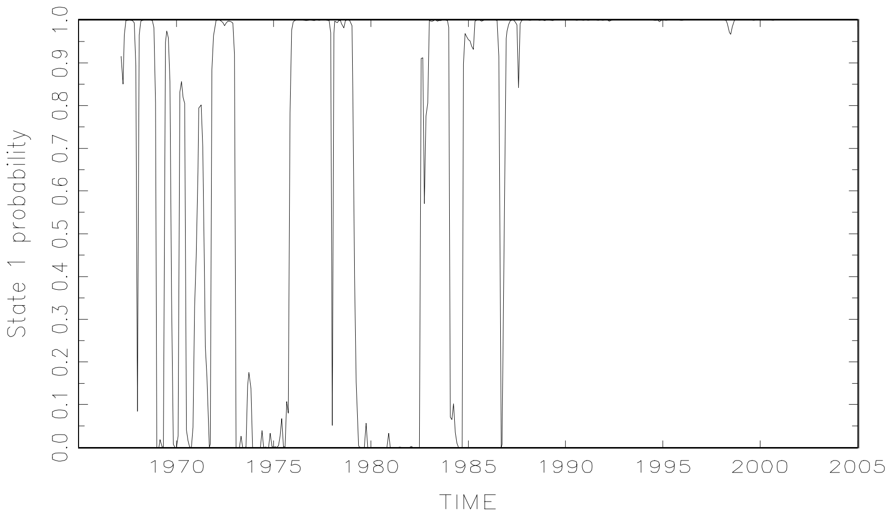

Figure 1: System (1). Long-term rate defined by the 1-year rate

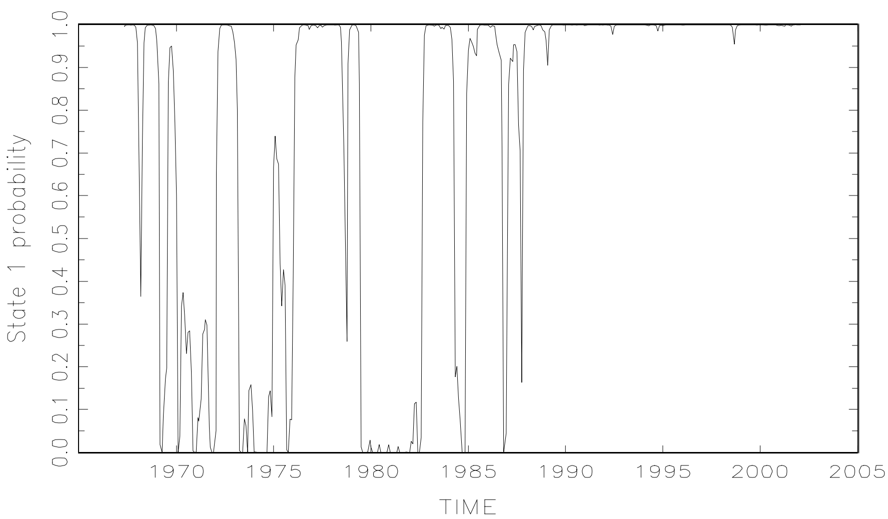

Figure 2: System (1). Long-term rate defined by the 3-year rate

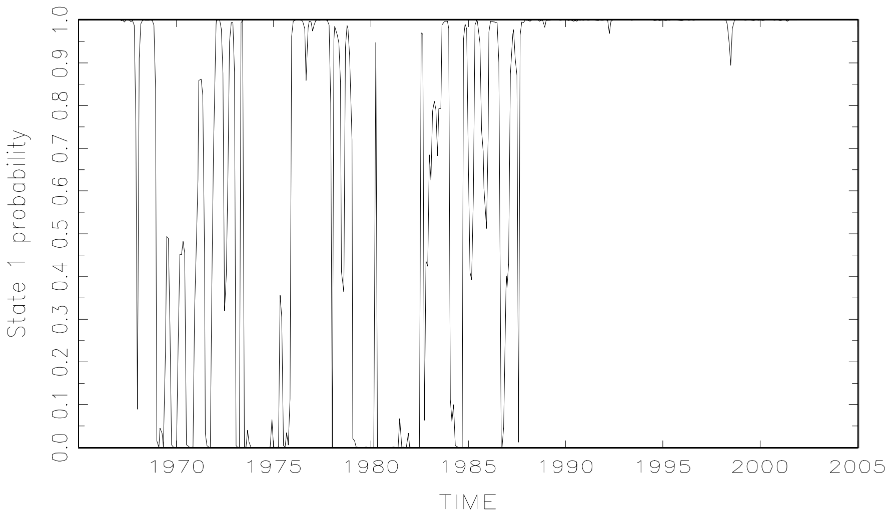

Figure 3: System (1). Long-term rate defined by the 10-year rate

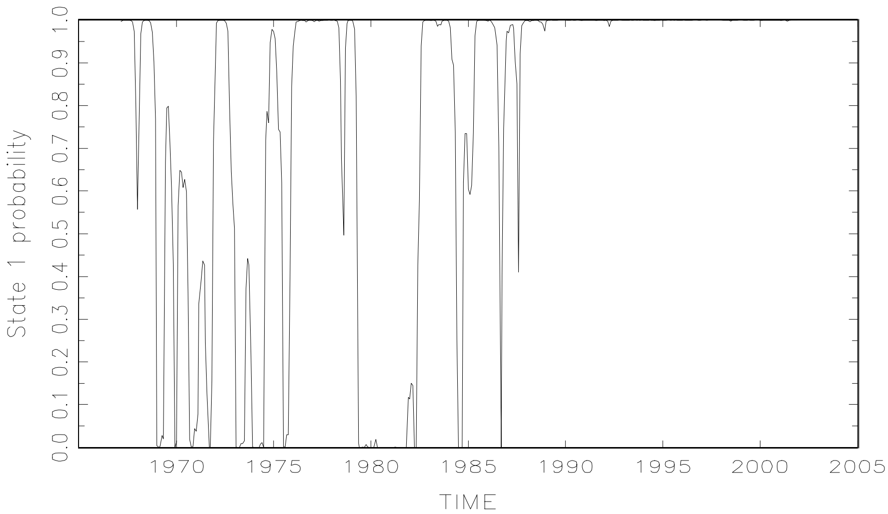

Figure 4: ATR (2). The long-term rate is defined by the 1-year rate

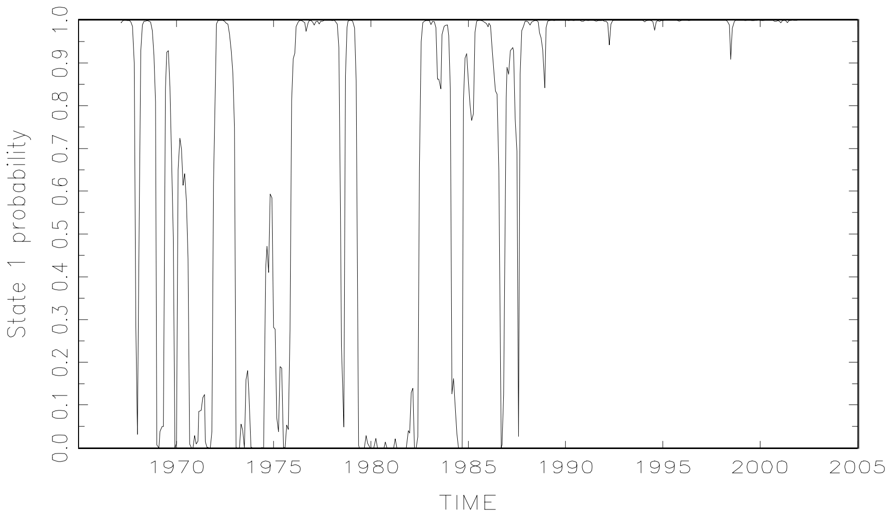

Figure 5: ATR (2). The long-term rate is defined by the 3-year rate

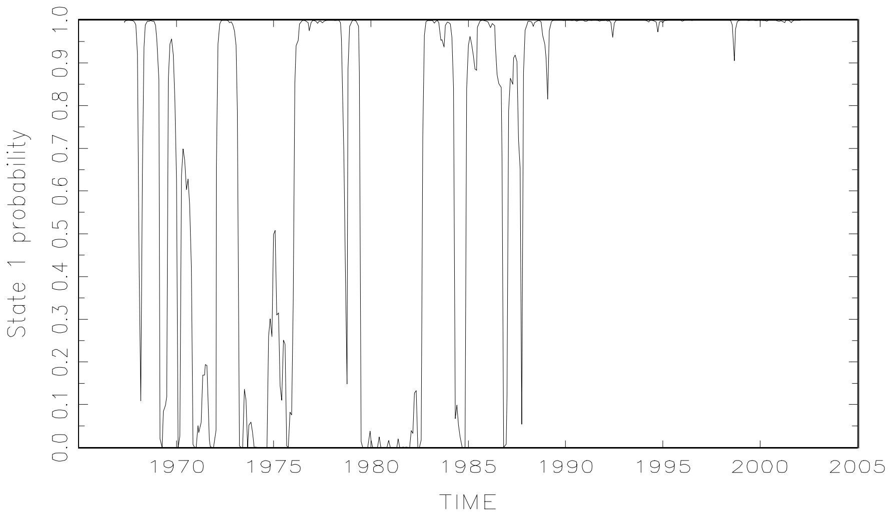

Figure 6: ATR (2). The long-term rate is defined by the 10-year rate

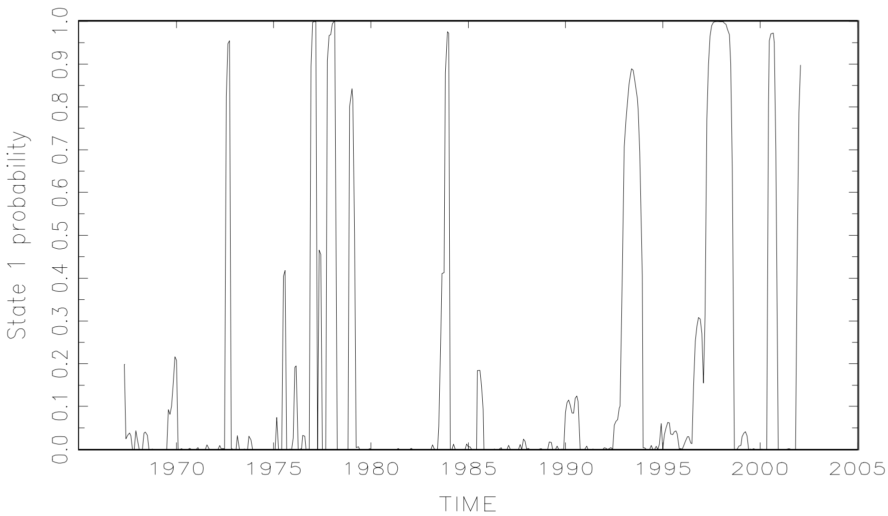

Figure 7: First regime smoothed probabilities for the ATR (2) with three regimes. The long-term rate is defined by the 1-year rate

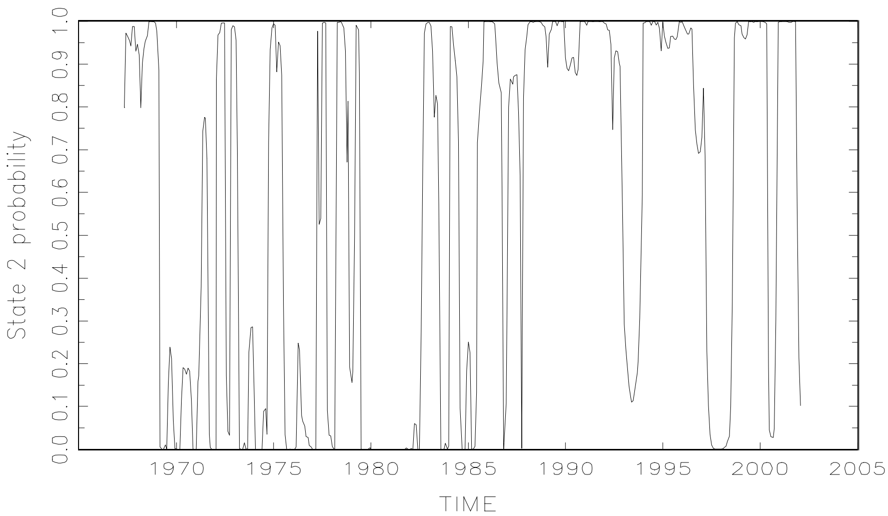

Figure 8: Second regime smoothed probabilities for the ATR (2) with three regimes. The long-term rate is defined by the 1-year rate

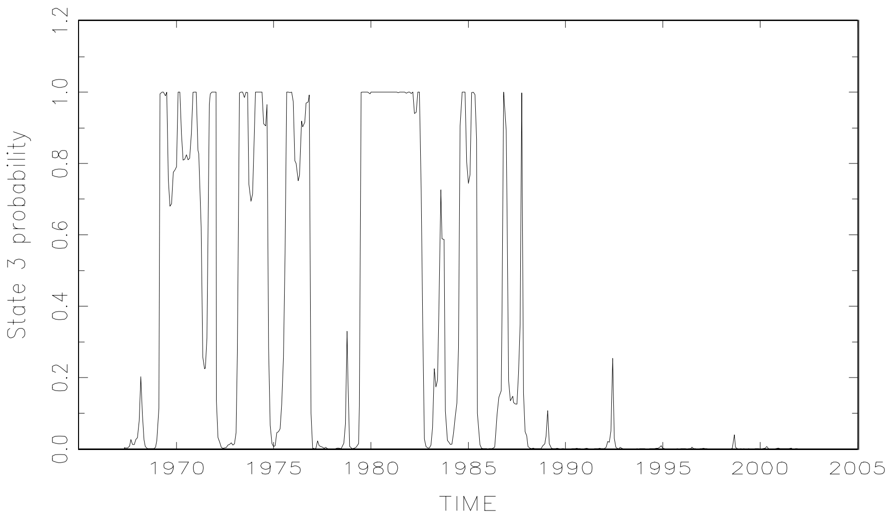

Figure 9: Third regime smoothed probabilities for the ATR (2) with three regimes. The long-term rate is defined by the 1-year rate

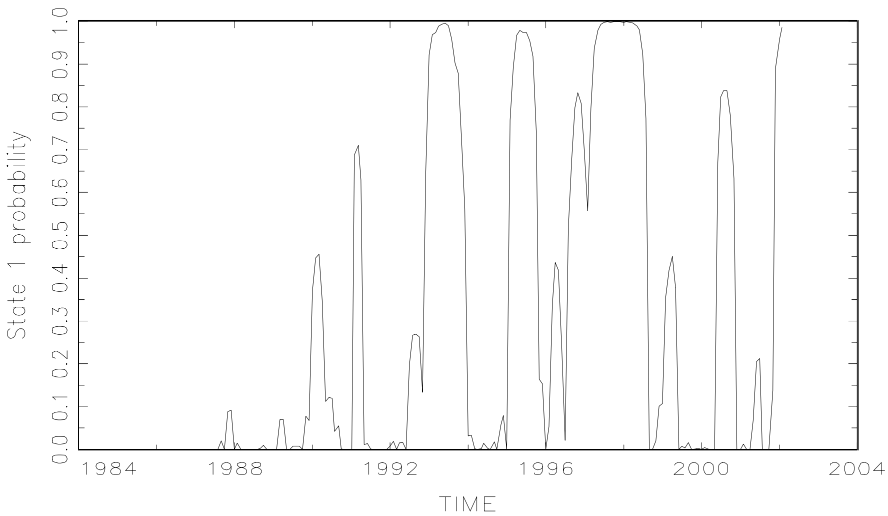

Figure 10: ATR (2) for the Greenspan period. The long-term rate is defined by the 1-year rate