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INFLATION, INFLATION UNCERTAINTY, AND MARKOV REGIME SWITCHING HETEROSKEDASTICITY: EVIDENCE FROM EUROPEAN COUNTRIES

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Abstract
We use a Markov regime-switching heteroskedasticity model in order to examine the association between inflation and inflation uncertainty in four European countries over a forty-year period. This approach allows for regime shifts in both the mean and variance of inflation in order to assess the association between inflation and its uncertainty in short and long horizons. We find that this association differs (i) between transitory and permanent shocks to inflation and (ii) across countries. In particular, the association is positive or zero for transitory shocks and negative or zero for permanent shocks. Hence, Friedman's belief that inflation is positively associated with inflation uncertainty is only partially supported in this study, i.e., with short-run inflation uncertainty.

JEL Classification: C22, C51, C52, E0
Keywords: Inflation, Inflation uncertainty, Markov process, regime-switching heteroskedasticity

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1. Introduction

The issue of the welfare costs of inflation has drawn the attention of macroeconomists for many years at both theoretical and empirical levels. In fact, the recent emphasis on price stability, expressed for practical purposes as low and stable inflation, among the world's major Central Banks, including the Federal Reserve System and the European Central Bank (ECB), is predicated on the assumed adverse impact of inflation on economic efficiency. Lucas (2000) estimates the welfare gain of reducing inflation from 14% to 3% at about 0.8% of US real GDP irrespective of the explicit form assumed by the money demand function[1]. It is widely accepted that the focus of monetary policy on price stability is the main cause of the low inflation rates achieved by several industrialized countries (Greenspan, 2004).

Considerable ambiguity surrounds the impact of the average rate of inflation on the rate of economic growth at the theoretical level. Furthermore, the impact of inflation on output growth may take place indirectly, via the inflation uncertainty channel. In his Nobel lecture, Friedman (1977) argues that a rise in the average rate of inflation leads to more uncertainty about the future rate of inflation, distorts the effectiveness of the price mechanism in allocating resources efficiently, and, thus, creates economic inefficiency and a lower level of output. Moreover, by affecting interest rates, inflation uncertainty also impacts the intertemporal allocation of resources. Hence, a comprehensive empirical study that tests for the real effects of inflation should control for the impact of inflation uncertainty on output. The positive correlation between inflation and inflation uncertainty reported in empirical studies can also arise from a positive causal effect of inflation uncertainty on inflation. Cukierman and Meltzer (1986) provide a theoretical model that explains such a causal effect. In the presence of more inflation uncertainty, less conservative central bankers have an incentive to surprise the public and generate unanticipated inflation, hoping for output gains.

The empirical assessment of the relationship between inflation uncertainty and inflation may be based on various approaches. Early studies focus on the variability (as opposed to uncertainty) of inflation and test for the correlation between inflation and inflation variability. The consensus reached by these studies is that inflation variability is positively correlated with inflation. Following Engle's (1982) pathbreaking paper on Autoregressive Conditional Heteroskedasticity (ARCH) models, researchers measured uncertainty by the conditional variance of unanticipated shocks to inflation. This allowed for a time-varying measure of inflation uncertainty. Engle

1. Most estimates of the cost of inflation are less than 1% of output suggesting that the costs of inflation are very low. An exception is that of Bullard and Russell (2004) who find that the annual cost of a 10% inflation rate is 11.2% of output.

(1983) finds that a rise in inflation in the current quarter does not lead to an increase in uncertainty in the next quarter. Subsequent studies summarised by Holland (1993) and Davis and Kanago (2000) find mixed evidence regarding the association between inflation and inflation uncertainty using a variety of methodologies. More recently, Grier and Perry (1998), using the Generalised ARCH (GARCH) approach, test for bidirectional causality between inflation and inflation uncertainty in the G7. The authors find that, first, inflation positively affects inflation uncertainty in all countries and, second, there is mixed evidence across countries regarding the effect of inflation uncertainty on inflation. However, Fountas and Karanasos (2007) find mixed evidence regarding the causal relationship between inflation and inflation uncertainty.

The approaches mentioned above, regarding the association between inflation and inflation uncertainty, usually examine this association at either short run or long-run horizons. For instance, pre-GARCH studies test for the effects of inflation on its uncertainty variability over several years whereas many GARCH studies test for the short-run (or next-quarter) effect. Ball and Cecchetti (1990) argue that association between inflation and its uncertainty may differ between short-run and long-run horizons. Some simple correlation analyses between the mean and variance of US inflation in the 1954-89 period reported by the authors indicates that these correlations become larger as the horizon considered increases. These results are confirmed by a more formal approach that distinguishes between permanent and temporary shocks to inflation. Motivated by the Ball and Cecchetti (1990) approach, Kim (1993) proposes a model of Markov-switching heteroskedasticity, which is deemed superior to the GARCH approach for three reasons. First, this approach allows for the possibility of regime shifts. Second, the Markov regime-switching approach permits the consideration of temporary and permanent shocks to inflation, thus allowing examination of the effects of inflation on short run and long-run uncertainty about inflation. Third, in contrast to the GARCH approach, this model allows for nonconstant unconditional variance.

In this paper, the relationship between inflation uncertainty and inflation are analyzed empirically using a model that allows for Markov regime-switching heteroskedasticity concerning four European countries. Our chosen econometric model is similar to that employed by Kim (1993) and it is applied to quarterly inflation data over a forty-year period. Our results are likely to shed some light on the empirical relationship between inflation and inflation uncertainty. In particular, they will indicate whether inflation uncertainty is associated with inflation, as predicted by Friedman (1977). This is a necessary requirement for welfare costs of inflation that work via the inflation uncertainty channel. Moreover, the results will show whether there is evidence that higher inflation is associated with more uncertainty about long-run inflation or short-run inflation or both. Finally, our methodological approach will indicate whether short-run and long-run inflation uncertainty positively or negatively affects the rate of inflation, as predicted by Cukierman and Meltzer (1986) and Holland (1995), respectively.

The paper is outlined as follows: Section 2 discusses the theoretical basis for the relationship between inflation and inflation uncertainty. Section 3 summarizes empirical literature to date on the association between inflation and uncertainty about the rate of inflation. Section 4 presents our econometric model and section 5 reports and discusses our results. Finally, Section 6 summarizes our main conclusions and draws some policy implications.

2. Theoretical background

2.1 The impact of inflation on inflation uncertainty

Economists have appealed to the uncertainty about the future rate of inflation in order to account for the welfare loss that monetary economics has associated with inflation. Predictable inflation should not lead to welfare loss since indexation will allow agents to minimize the costs of inflation. However, uncertainty about future inflation distorts efficient allocation of resources based on the price mechanism. Friedman (1977) presents an informal argument regarding the real effects of inflation; his argument represents one of the few existing arguments on the rationalization of welfare effects of inflation and comes in two parts. In the first leg of Friedman hypothesis, an increase in inflation may induce an erratic policy response by the monetary authority and, therefore, lead to more uncertainty about the future rate of inflation. As Friedman (1977, p. 466) wrote: "A burst of inflation produces strong pressure to counter it. Policy goes from one direction to another, encouraging wide variation in the actual and anticipated rate of inflation... Everyone recognizes that there is great uncertainty about what actual inflation will turn out to be over any specific future interval." The second part of Friedman's hypothesis predicts that increased inflation uncertainty would increase the rates of unanticipated inflation observed and, hence, will be associated with the costs of unanticipated inflation. Such costs arise from the effect of inflation uncertainty on both intertemporal and intratemporal allocation of resources. Combining the link of inflation to inflation uncertainty and the link of inflation uncertainty to output, a testable hypothesis is obtained, i.e., that higher inflation leads to lower output, i.e., a positively sloped Phillips curve[2].

2. The effect of inflation uncertainty on output was formally addressed by Dotsey and Sarte (2000). In a cash-in-advance model, which allows for precautionary savings and risk aversion, they show that more inflation uncertainty can have a positive output growth effect. According to the authors' argument, an increase in the variability of monetary growth, and, therefore, inflation, makes the return to money balances more uncertain and leads to a fall in demand for real money balances and consumption. Hence, agents increase precautionary savings, and the pool of funds available to finance investment increases. This result is analogous to literature finding that indicates fiscal policy uncertainty is conducive to growth by encouraging precautionary savings.

Subsequently, Friedman's intuitive result was formally derived by Ball (1992) in an asymmetric information game, in which the public faces uncertainty about the type of the policymaker (monetary authority). The two policymaker types differ in terms of their willingness to bear the economic costs of reducing inflation. In periods of low inflation, the tough type will apply contractionary monetary policy. Ball assumes that the two types of policymakers alternate in office in a stochastic manner. Therefore, a higher current inflation rate creates more uncertainty about the level of future inflation since it is not known whether the tough type will gain power and fight inflation.

2.2 The impact of inflation uncertainty on inflation

The opposite direction of causality to that examined by Friedman in the inflation/inflation uncertainty relationship has also been addressed in theoretical literature that examines the impact of a change in inflation uncertainty on the average rate of inflation. Cukierman and Meltzer (1986) employ a Barro-Gordon model, in which agents face uncertainty about the rate of monetary growth and, therefore, inflation. In the presence of this uncertainty, the policymaker applies an expansionary monetary policy in order to surprise agents and enjoy output gains. This argument implies a positive causal effect from inflation uncertainty to inflation and has been dubbed 'the Cukierman-Meltzer hypothesis' by Grier and Perry (1998). Holland (1995) supplied a different argument based on the stabilization motive of the monetary authority, the so-called "stabilizing Fed hypothesis". He claims that, as inflation uncertainty rises due to increasing inflation, the monetary authority responds by contracting money supply growth, in order to eliminate inflation uncertainty and the negative welfare effects associated with it. Hence, Holland's argument supports the opposite sign in the causal relationship, i.e., a negative causal effect of inflation uncertainty on inflation. The theoretical ambiguity surrounding this causal relationship necessitates an empirical investigation of the sign of the effect.

3. The empirical evidence

Early empirical studies on the relationship between inflation and its uncertainty used the variance (or standard deviation) as a measure of uncertainty and, hence, measured inflation variability as opposed to uncertainty. The use of the autoregressive conditional heteroskedasticity (ARCH) and generalized ARCH (GARCH) approaches, introduced by Engle (1982) and Bollerslev (1986), respectively, allows us to proxy uncertainty using the conditional variance of unpredictable shocks to the inflation rate. Engle (1983) and Bollerslev (1986), making use of the ARCH techniques, do not perform a statistical test of the Friedman-Ball hypothesis but only compare the conditional variance series estimated with the US average inflation rate over various time periods. Engle (1983), in an application of the

ARCH approach, finds that US inflation is not related to inflation uncertainty, which is inconsistent with the Friedman-Ball hypothesis[3]. Grier and Perry (1998) use the estimated conditional variance from a GARCH model and employ Granger-causality tests to test for the direction of causality between average inflation and inflation uncertainty. Baillie et al. (1996) perform these tests simultaneously in a single model by including lagged inflation in the conditional variance equation and conditional standard deviation in the inflation equation. More specifically, using G7 data, Grier and Perry (1998) find that inflation has a significant and positive effect on inflation uncertainty in all countries[4]. On the other hand, Baillie *et al.* (1996) find no significant relationship between inflation and inflation uncertainty. More recently, Karanasos *et al.* (2004), using a GARCH-in-Mean (GARCH-M) model enriched with lagged inflation in the conditional variance equation, find that US inflation positively affects inflation uncertainty, a result supporting the Friedman-Ball hypothesis. A similar model applied by Fountas (2001), using historical UK data, shows support for the Friedman-Ball hypothesis.

The causal impact of inflation uncertainty on inflation is tested empirically, using the GARCH approach, in Baillie *et al.* (1996), Grier and Perry (1998, 2000), Grier *et al.* (2004) and Fountas *et al.* (2004). Grier and Perry (2000) and Grier *et al.* (2004) use only US data, whereas the rest of the studies use international data. In general, the evidence is mixed. Baillie *et al.* (1996) find evidence supporting the link between the two variables for the UK and some high-inflation countries, whereas Grier and Perry (1998), in their G7 study, find evidence in favor of the Cukierman-Meltzer hypothesis for some countries and in favor of the Holland hypothesis for other countries. Fountas *et al.* (2004) also obtain mixed evidence. Finally, Grier and Perry (2000) and Grier *et al.* (2004) find evidence for a zero and negative effect of inflation uncertainty on inflation in the US, respectively.

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3. The evidence on the impact of inflation uncertainty on growth is more limited and is summarized in Holland (1993). GARCH studies on this matter, which represent a more accurate test of the hypothesis that inflation uncertainty has negative welfare effects, are mostly based on US data (e.g., Coulson and Robins, 1985; Jansen, 1989; Grier and Perry, 2000, Grier *et al.* 2004). Exceptions are the studies by Fountas and Karanasos (2007), Fountas *et al.* (2006) and Fountas *et al*. (2004). The first two studies use data on the G7 and the last one uses data on six European countries. The evidence is rather mixed. Grier and Perry (2000) and Grier *et al.* (2004) find evidence indicating a negative effect. In contrast, Coulson and Robins (1985) and Jansen (1989) find evidence pointing to a positive and zero effect, respectively. Fountas *et al.* (2004) and Fountas and Karanasos (2006) find mixed evidence using a two-step approach that combines the estimation of a GARCH model with the implementation of Granger-causality tests.
4. Using a Component GARCH-M model of inflation, which includes lagged inflation in the conditional variance, Grier and Perry (1998) simultaneously estimate the relationship between inflation and inflation uncertainty. They find that inflation has a positive effect on inflation uncertainty (the Friedman-Ball hypothesis), but uncertainty has no significant impact on inflation.

GARCH models have a potential disadvantage: they cannot account for regime shifts that may affect both the mean and the variance of inflation. Bhar and Hamori (2004), applying the Kim (1993) model for the G7 for the 1961-1999 period, find that inflation is positively related to long-run uncertainty in some countries and positively or negatively related to short-run uncertainty (depending on the country considered).

4. Econometric Methodology

We adopt the Kim (1993) approach, according to which two different volatility regimes, conditional and unconditional, are determined by two different Markov-switching processes. The following equation decomposes inflation into its two components:

$$\pi_t = \mathrm{T}_t + \mu_2 S_{1,t} + \mu_3 S_{2,t} + \mu_4 S_{1,t} S_{2,t} + (h_0 + h_1 S_{2,t}) e_t \quad (1)$$

$$T_t = T_{t-1} + (Q_0 + Q_1 S_{1,t}) v_t \quad (2)$$

In the two equations above, both v_t and e_t are N(0,1). The empirical model in equations (1) and (2) was first discussed by Ball and Cecchetti (1990). It decomposes inflation into two components, a stochastic and a stationary one with shocks to these two components represented by v_t and e_t, respectively. For example, trend inflation is determined by trend money growth and examples of shocks may include a rise in trend inflation to take account of supply side shocks. The effect of shocks to the stochastic trend feed through to inflation via equation (2) above. Transitory shocks (e_t) are also represented and take account of any shock resulting in inflation deviating from its trend. These may be demand (e.g., monetary policy) shocks or supply shocks. In equations (1) and (2), $S_{1,t}$ and $S_{2,t}$ are unobserved state variables that determine the regime for the trend and temporary component, respectively. It is assumed that $S_{1,t}$ and $S_{2,t}$ evolve independently of each other. A two-state Markov switching process is adopted with values of 0 taking account of the low-variance state and values of 1 of the high-variance one. The two-state Markov process takes on the following transition probabilities:

$$Pr[S_{1,t} = 0 \mid S_{1,t-1} = 0] = p_{00},\ Pr[S_{1,t} = 1 \mid S_{1,t-1} = 1] = p_{11},$$

$$Pr[S_{2,t} = 0 \mid S_{2,t-1} = 0] = q_{00},\ Pr[S_{2,t} = 1 \mid S_{2,t-1} = 1] = q_{11} \quad (3)$$

where regime 1 is characterized by low Q_t and low h_t, ($S_{1,t} = 0$, $S_{2,t} = 0$), regime 2 by a low Q_t and high h_t, ($S_{1,t} = 0$, $S_{2,t} = 1$), regime 3 by high Q_t and low h_t, ($S_{1,t} = 1$, $S_{2,t} = 0$) and, finally, regime 4 characterized by high Q_t and high h_t, ($S_{1,t} = 1$, $S_{2,t} =$

1). For example, in equation 3, p_{00} is the probability that the trend component will remain in regime 1. The effect of uncertainty on inflation is represented by μ_2, μ_3 and μ_4. μ_2 indicates the effect of uncertainty associated with the high inflation state for the permanent (long- run) component, while μ_3 indicates the effect of uncertainty associated with the high inflation state for the temporary (short-run) component. It may be the case that the effect on inflation may be non-linear, and, as a result, we also include the interaction between the two, μ_4. This term captures the effect of a change in both short-run and long-run uncertainty on inflation. Finally, Q_1 (Q_0) represents the increase in the variance of the trend component during the high (low) variance state and h_1 (h_0) represents the increase in the variance of the temporary component during the high (low) variance state.

5. Data and results

5.1 Data

We use quarterly data on the GDP deflator as a proxy for the price level (the only exception being Italy, where, in the absence of a long time series, CPI is used instead). The data refer to four European countries, namely, Germany, Italy, Holland, and the UK. The sample starts in 1966 (except for Holland and Italy, for which it starts in 1977 and 1960, respectively) and ends in the first quarter of 2005. All data are taken from the International Financial Statistics published by the IMF. Inflation is measured by the quarterly difference of the logarithm of the GDP deflator $[\pi_t = \log(\frac{PI_t}{PI_{t-1}})]$. We first test for the stationarity properties of our data using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The results of these tests (not reported) indicate that we can treat the inflation rate in each country as a nonstationary process[5].

5.2 Results

Table 1 reports estimates of the Markov regime-switching model of inflation. Specifically, we include estimates of the transition probabilities, the Q_s, the hs and the μ_s. With very few exceptions, all probabilities estimated are close to one and statistically significant, a finding consistent with regime switching. In two of the four countries (Italy and the UK), μ_2 is negative and significant at 5% implying that an increase in long-run uncertainty leads to lower inflation, which supports the theoretical argument of Holland (1995). In contrast, in two of the four countries (Holland and the UK), μ_3 is positive and significant at 5% implying that an increase in short-run uncertainty raises average inflation, supporting the Cukierman-Meltzer hypothesis. In half of the countries examined, both short-run and long-run

5. Results are made available by the authors upon request.

uncertainty regarding inflation have no impact on inflation. Finally, parameter μ_4 is positive and significant in three of the four cases considered implying that an increase in both long-run and short-run uncertainty raises average inflation.

Figures 1-8 plot the inflation rate and the probability of being in the high-variance state for permanent and transitory (temporary) shocks in the four countries. Inflation (the probability of the high-variance state) is measured along the left-hand (right-hand) side vertical axis. A close look at the figures representing inflation and the probability of a high-variance state for permanent shocks leads to the following observations:

(1) The probability of a high-variance state varies widely across countries. However, in some countries (the UK and Italy) it is observed that these probabilities are quite high (close to one) during the times of oil price shocks, namely, 1973-74 and 1979. In addition, the probability for Italy is close to zero in 1979, the year the country joined the European Monetary System.

(2) There is evidence for structural change in several countries. For example, in the UK, the probability of high-income state is close to one in the second half of the 1970s. Similarly, this probability is very high for Italy in 1973-79 and in 1962 and in Holland for several years in the early 1990s. In contrast, for Germany the probability is never lower than 0.5, most likely indicating the absence of regime changes. This evidence supports the choice of Markov regime-switching heteroskedasticity methodology.

(3) In Italy and the UK there seems to exist a negative association between inflation and the probability of a high-variance state for permanent shocks. In other words, inflation and long-run inflation uncertainty are negatively related. This agrees with the negative sign of μ_2. This finding contradicts the Friedman-Ball hypothesis.

A close look at the figures that plot the rate of inflation and the probability of a high-variance state for the transitory shocks reveals the following:

(1) The probability of a high variance state for transitory shocks varies significantly across countries. This probability is quite high (close to 1) for the UK in 1974, for Germany in the early 1970s and early 1990s (post-reunification years). In contrast, the probability is close to zero for Italy in 1979, the year it joined the EMS.

(2) There is evidence for structural change in several countries. For example, in Germany the probability is close to 1 for several quarters in the early 1970s, for Italy the probability is close to zero in 1979, and for Holland the probability is close to zero in 1998 and quite low in the following quarters.

(3) A positive association between inflation and the probability of the high-variance state for transitory shocks is evident for Holland and the UK. This is consistent with the positive sign of μ_3. Similarly, inflation and uncertainty about short-run

inflation are positively related. This evidence is consistent with the Friedman-Ball hypothesis. As inflation rises above normal, the public is facing more uncertainty regarding the response of the monetary authority, which may be accommodating or dis-inflating.

6. Conclusions

We use a Markov regime-switching heteroskedasticity model in order to examine the association between inflation and inflation uncertainty in four European countries over a forty-year period. This approach allows for regime shifts in both mean and variance of inflation in order to assess the association between inflation and its uncertainty in short and long horizons. We find that this association differs (i) between transitory and permanent shocks to inflation and (ii) across countries. In particular, the association is positive or zero for transitory shocks and negative or zero for permanent shocks. Hence, Friedman's belief that inflation is positively associated with inflation uncertainty is only partially supported in this study, i.e., with short- run inflation uncertainty. The evidence for regime shifts highlights the advantage of such an approach as compared to the GARCH methodology, according to which such regime changes are not accounted for.

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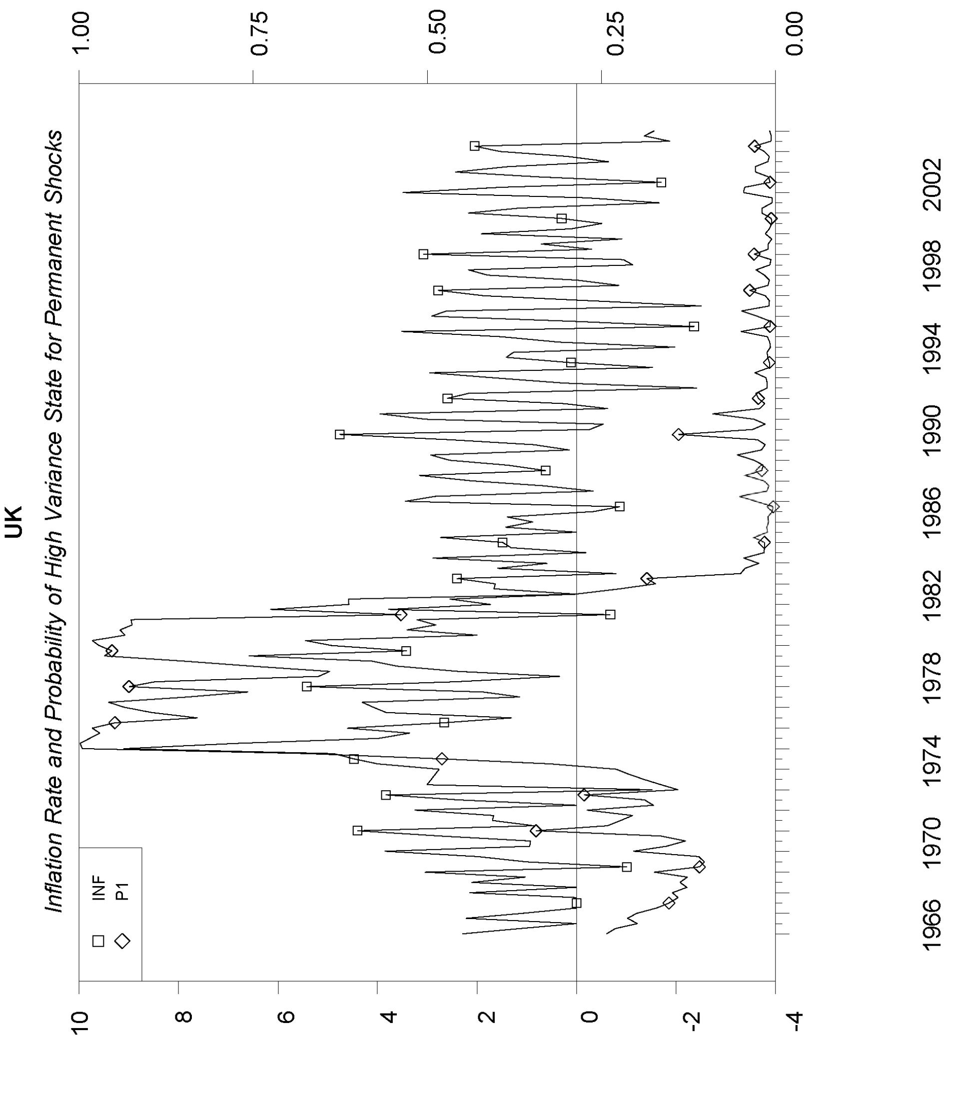
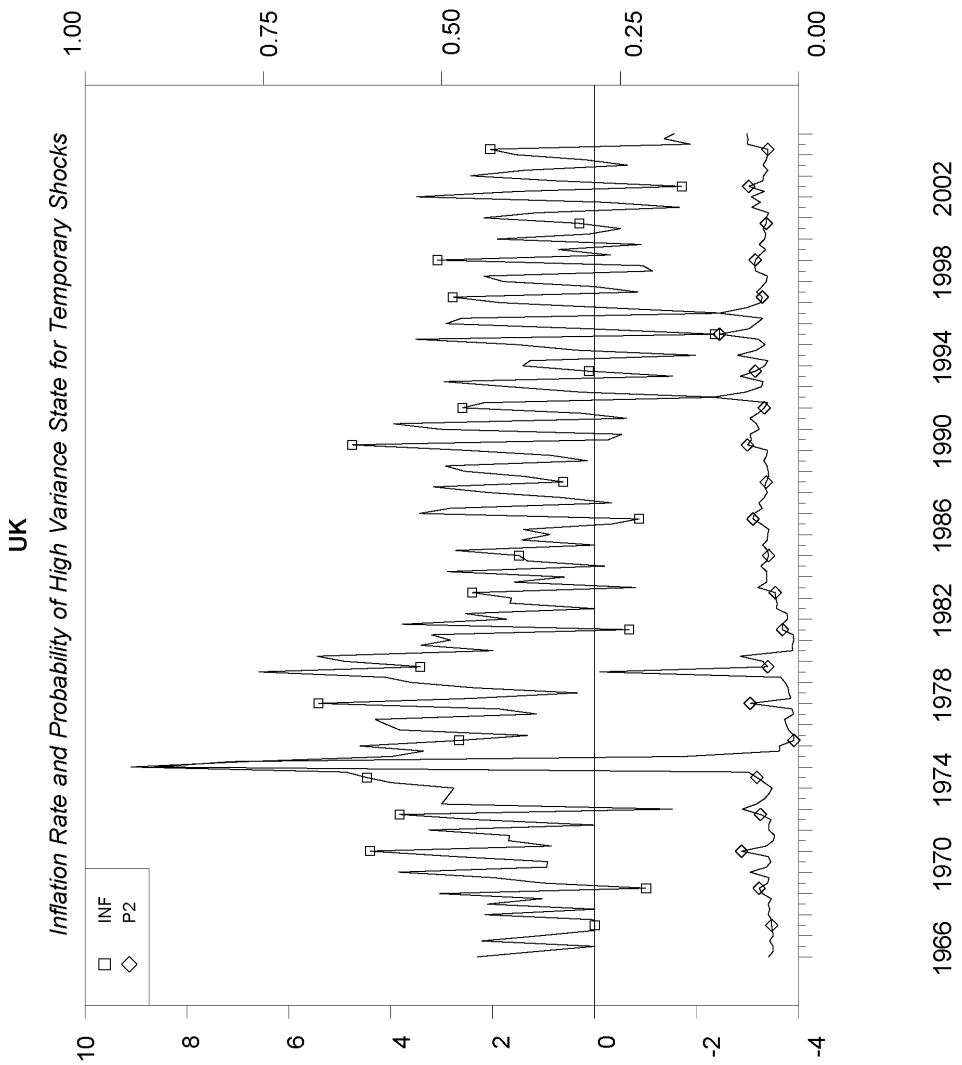
Table 1. Markov Switching Model of Inflation

	Germany	Holland	Italy	UK
	(1966.I-2005.I)	(1977.I-2005.I)	(1966.I-2005.I)	(1966.I-2005.I)
Q_0	0.001	0.0001	0.1245*	0.0599
	(0.0777)	(0.0225)	(0.0374)	(0.0532)
Q_1	0.0600	0.0001	1.2329*	0.0001
	(0.0825)	(0.0014)	(0.2247)	(0.0001)
$h0$	0.3729*	0.4442*	0.0001	1.5367
	(0.0363)	(0.0545)	(0.0015)	(0.0975)
$h1$	0.7491*	1.2693*	0.4546*	0.3415
	(0.1322)	(0.4159)	(0.0369)	(0.5634)
$\mu2$	0.4171	0.2217	-2.3195*	-0.1350*
	(0.5647)	(0.4566)	(0.5397)	(0.0002)
μ_3	-0.2157	0.5896*	0.1266	1.9422*
	(0.3646)	(0.1802)	(0.2540)	(0.5722)
μ_4	0.0812	3.6081*	1.2855*	3.4291*
	(0.8829)	(1.2543)	(0.4257)	(0.0003)
$p00$	0.9805*	0.8635*	0.8821*	0.9726*
	(0.0711)	(0.1343)	(0.0633)	(0.0306)
$p11$	0.9550*	0.9758*	0.9745*	0.9910*
	(0.1038)	(0.0217)	(0.0162)	(0.0082)
$q00$	0.9365*	0.3270	0.9930*	0.4303
	(0.0445)	(0.2207)	(0.0068)	(0.3852)
$q11$	0.9769*	0.9132*	0.9445*	0.9665*
	(0.0173)	(0.0533)	(0.0599))	(0.0431)

Full details on each of the parameters are discussed in the methodology section in the text.
Standard errors are in parenthesis.
Significance at the 5% level is indicated by a *.


UK
Inflation Rate and Probability of High Variance State for Permanent Shocks
INF
P1
1.00
0.75
0.50
0.25
0.00
10
8
6
4
2
0
-2
-4
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002


UK
Inflation Rate and Probability of High Variance State for Temporary Shocks
INF
P2
10
8
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4
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0
-2
-4
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0.25
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1970
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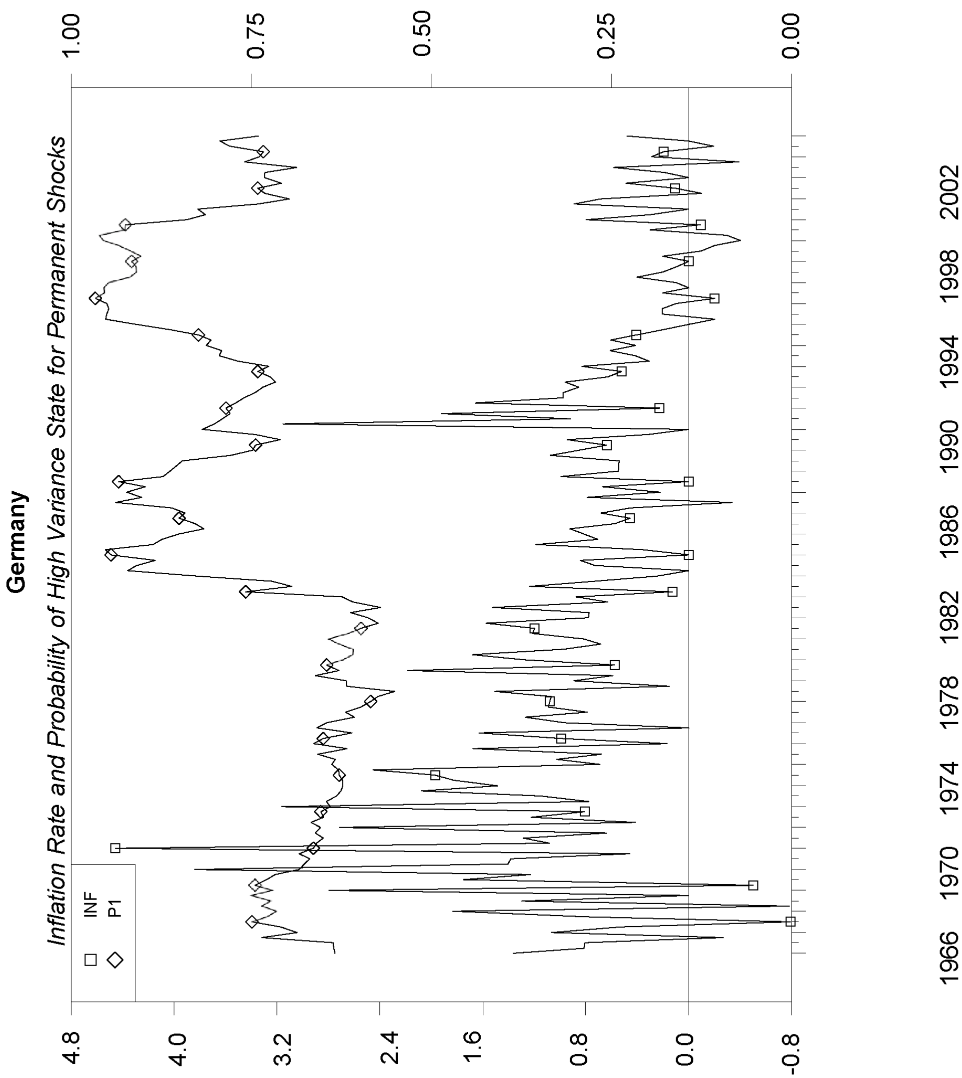
2002


Germany
Inflation Rate and Probability of High Variance State for Permanent Shocks
INF
P1
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4.0
3.2
2.4
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-0.8
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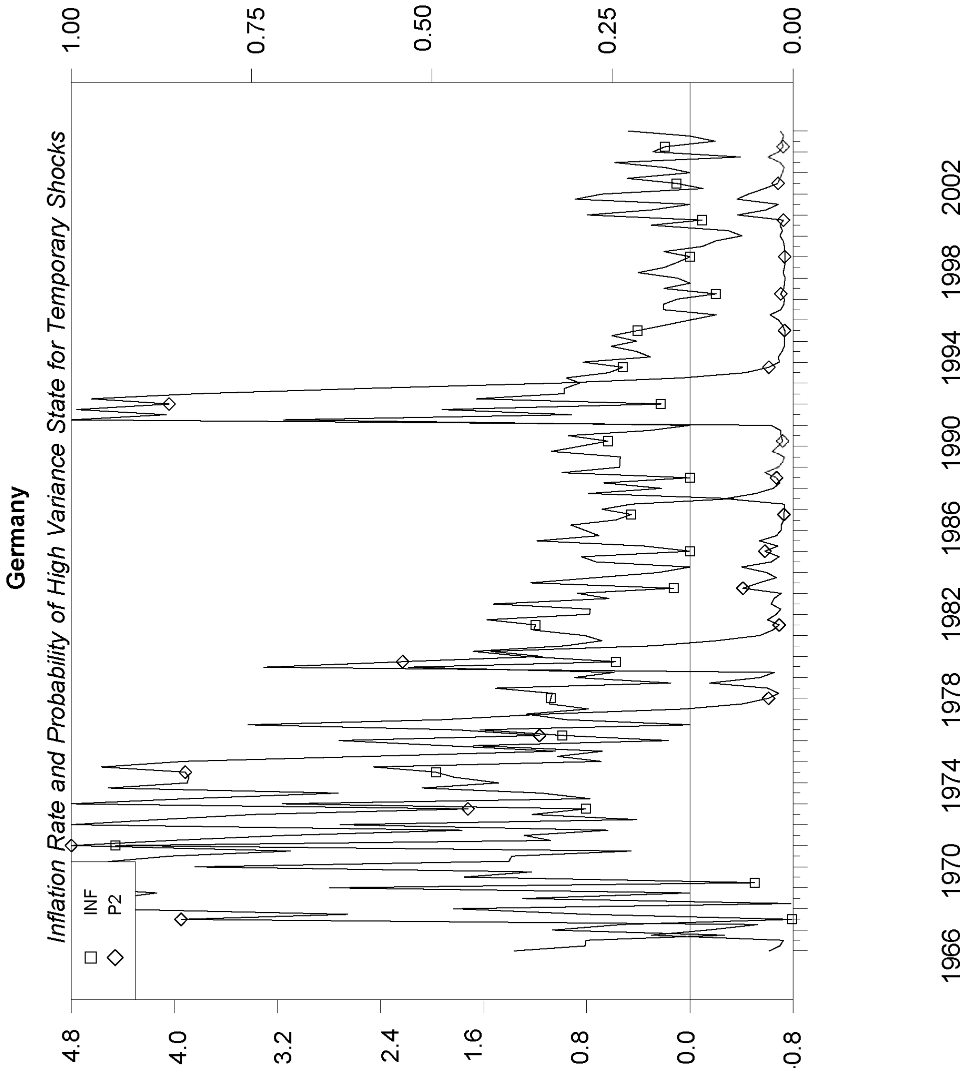
Germany
Inflation Rate and Probability of High Variance State for Temporary Shocks
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P2
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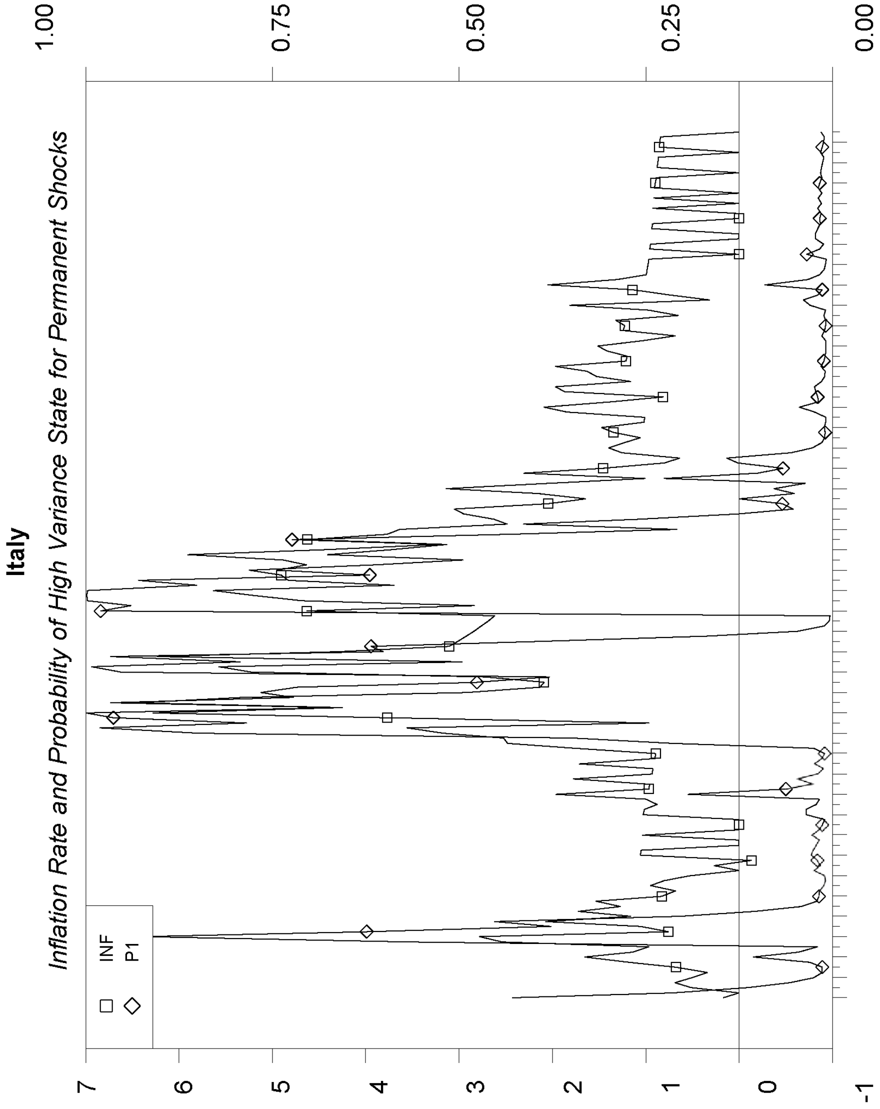
Italy
Inflation Rate and Probability of High Variance State for Permanent Shocks
INF
P1
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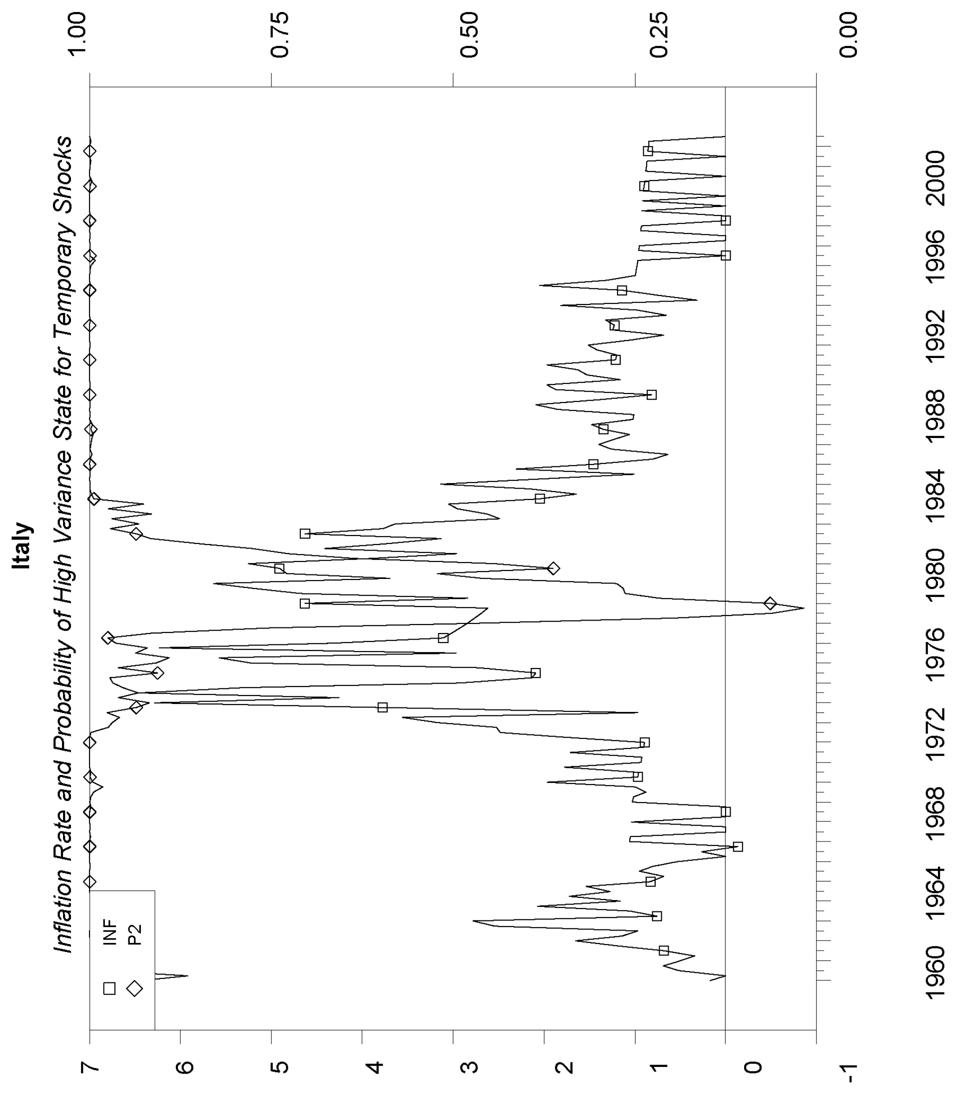

Italy
Inflation Rate and Probability of High Variance State for Temporary Shocks
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P2
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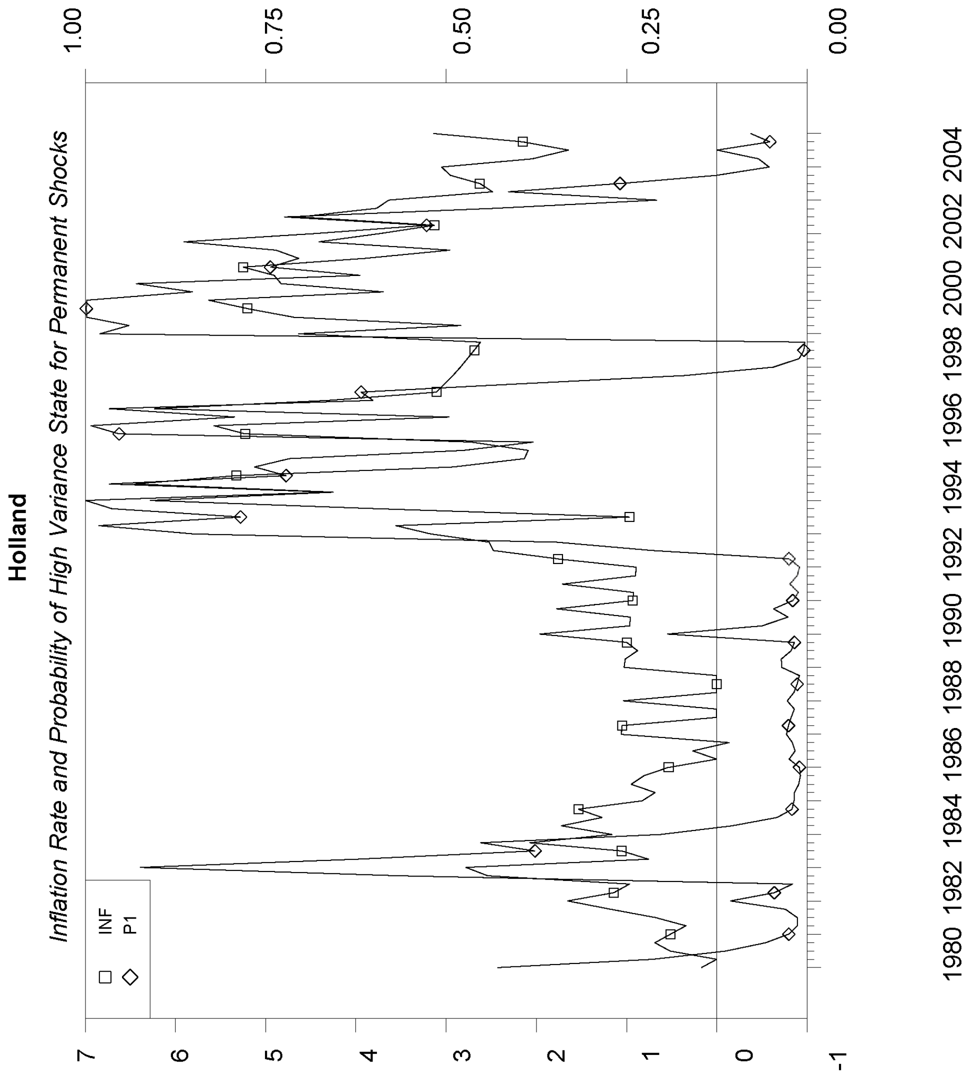

Holland
Inflation Rate and Probability of High Variance State for Permanent Shocks
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P1
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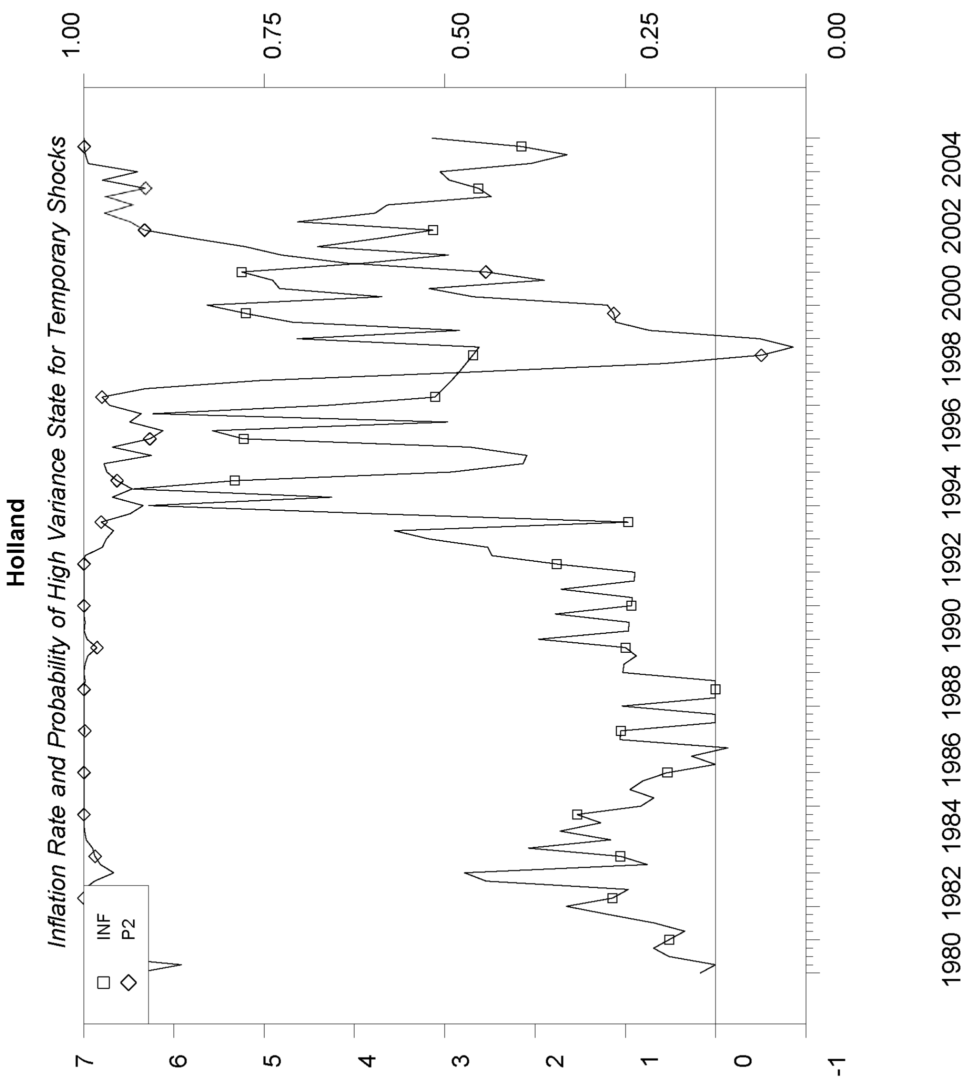
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004


Holland
Inflation Rate and Probability of High Variance State for Temporary Shocks
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0.75
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0.25
0.00
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004