Threshold effects in the monetary policy reaction function of the Deutsche Bundesbank *

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Abstract

We estimate a Taylor-type monetary policy reaction function with threshold effects for the Deutsche Bundesbank from real-time data. Estimates using the deviation of inflation from the Bundesbank's implicit inflation target as threshold variable suggest a switch to a stronger inflation response and increased persistence in the interest rate if inflation exceeds the Bundesbank's implicit inflation target. The reaction function in the regime with higher inflation implies an overall more contractionary monetary policy stance than that for the low inflation regime.

Keywords: monetary policy reaction function, threshold regression, instrumental variables, real-time data

JEL Classification: E52, E58, C22, C24

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1 Introduction

In this study we investigate nonlinearities in the monetary policy reaction function of the Deutsche Bundesbank by extending a standard forward-looking Taylor rule by shifts in the coefficients depending on current inflation. Our results show that the Bundesbank's reaction function associated with excess inflation implies a more restrictive monetary policy stance than the reaction function that prevailed in times of low inflation.

Nonlinearities in form of threshold effects so far have only been studied in a small number of empirical papers on monetary policy reaction functions.[1] Generally, this literature finds evidence for significant threshold effects in the monetary policy reaction functions of various central banks. If inflation exceeds a certain threshold the central banks tend to react more aggressively to both inflation and to the output gap. Theoretically, shifting to a more aggressive monetary policy regime if inflation becomes too high not only affects inflation through the direct effects of disproportionally higher interest rates on economic activity but also through inflation expectations if economic agents expect the central bank to respond more aggressively to inflation in case of a pronounced deviation of inflation.

This paper contributes to the literature in three directions. First, so far there is no empirical study on threshold effects related to inflation for the Deutsche Bundesbank. In the two decades before monetary policy in Germany was finally handed over to the European Central Bank (ECB) the Bundesbank established a reputation for successfully maintaining price stability even when faced with adverse shocks as in the late 1970s and early 1990s. Since nonlinear interest rate responses have been well documented in the literature for other central banks it is of interest to investigate whether such regime-shifts can also be found for the Bundesbank and whether the effects of these

[1]Univariate threshold models were introduced by Tong (1978) and Tong and Lim (1980) and allow for the coefficients in an estimated equation to shift dependent on the value of a threshold variable. See Tong (1990) for an extensive survey.

regime-shifts differ systematically from those found for other central banks. Second, in contrast to most of the literature our estimates are based on real-time data including the Bundesbank's own estimates of potential output. Third, while the available literature presents estimates for threshold effects in forward-looking monetary policy reaction functions, i.e. reaction functions based on forecasts of inflation and of the output gap, the usual GMM estimator is not adjusted for the presence of the threshold effect. Estimates in this paper are derived using the threshold instrumental variable estimator by Caner and Hansen (2004) which takes into account the endogeneity of the explanatory variables not only in the estimation of the reaction coefficients but also in testing for the presence of threshold effects.

Most closely related to this paper is the recent study by Bunzel and Enders (2010). They estimate Taylor rules for the Federal Reserve (Fed) with threshold effects using real-time data but consider only reaction functions in which the Fed reacts to current inflation and output gaps. They show an increase in the Fed's reaction to current inflation and to the current output gap if lagged inflation exceeds the estimated threshold. The empirical literature, however, suggests that forward-looking monetary policy reaction functions in which the central bank responds to forecasts of future inflation and output gaps are more appropriate descriptions of monetary policy (e.g. Clarida et al. 1998).

Bec et al. (2002) estimate Taylor rules with threshold effects for the Banque de France, the Deutsche Bundesbank and the U.S. Fed using revised data. They study threshold effects depending on the sign of the output gap and assume a regime switch in the monetary policy reaction functions occurring if the output gap is zero. In contrast, our focus is on inflation as the variable triggering regime changes in monetary policy and we estimate the numerical threshold value instead of just assuming it.

As in our paper, Castro (2008) focuses on regime changes in monetary policy caused by inflation. Similarly to Petersen (2007) he estimates smooth transition models for the monetary policy reaction functions of the Fed and the ECB. He shows that Euro area inflation in excess of the ECB's inflation target of 2% leads to a stronger response of the ECB to inflation and the output gap but does not derive his results from real-time data. Martin and Milas (2004) and Taylor and Davradakis (2006) use threshold models to study the Bank of England's monetary policy reaction function. Both studies present evidence for the Bank of England to tighten monetary policy in a non-linear way if inflation moves out of a zone around the inflation target. Estimates in both studies are derived from revised data instead of real-time data. Furthermore, while all these studies except for Petersen (2007) estimate forward-looking reaction functions none accounts for the implications of using ex-post realized data instead of actual central bank forecasts in testing for the presence of threshold effects.

Our paper proceeds as follows: Section 2 presents the threshold version of the the monetary policy reaction function while Section 3 provides some information on the data. Section 4 presents the empirical results and Section 5 concludes.

2 The threshold model for the Bundesbank's reaction function

As a starting point for investigating the Bundesbank's monetary policy reaction function we use a forward-looking Taylor rule with partial adjustment of the actual interest rate (Clarida et al., 1998). The Taylor rule specifies how the short-term interest rate controlled by the central bank responds to forecasts of inflation and of the output gap and can be written in reduced form as

$$i_t = \gamma_0 + \gamma_\pi \left(E_t \pi_{t+n} - \pi^*_{t+n} \right) + \gamma_y E_t y_{t+m} + \gamma_i i_{t-1} + \nu_t, \tag{1}$$

with γ_0, γ_π, γ_y and γ_i as coefficients. n and m are the central bank's forecast horizons for the inflation rate π and for the output gap y. π^* represents the central banks target for the inflation rate. The autoregressive term captures the gradual adjustment of the interest rate to the level desired by the central bank.

If the central bank's own internal forecasts for inflation and for the output gap are not observable, they can be replaced by their initial (unrevised) estimates in quarters $t+n$ and $t+m$, $(\pi_{t+n|t+n}, y_{t+m|t+m})$

$$i_t = \gamma_0 + \gamma_\pi \left(\pi_{t+n|t+n} - \pi^*_{t+n}\right) + \gamma_y y_{t+m|t+m} + \gamma_i i_{t-1} + \epsilon_t. \tag{2}$$

The error term ϵ_t summarizes both the approximation error ν_t and the forecast errors for the inflation rate and for the output gap and, hence, is correlated with the explanatory variables ($\pi_{t+n|t+n}$ and $y_{t+m|t+m}$) in (2),

$$\epsilon_t = \gamma_\pi(E_t\pi_{t+n} - \pi_{t+n|t+n}) + \gamma_y(E_t y_{t+m} - y_{t+m|t+m}) + \nu_t. \tag{3}$$

In order to account for this endogeneity in the regressors, the parameters of (2) can be estimated using the generalized methods of moments (GMM) and appropriate instruments.

Estimating a monetary policy reaction function like equation (2) possibly conceals important nonlinearities. One cause of such nonlinearities might be asymmetries in the central bank's loss function, such as e.g. the central bank attaching different importance to positive deviations of inflation from its target compared to negative deviations of the same size (e.g. Bunzel and Enders, 2010, pp. 936). Another explanation for a nonlinear monetary policy reaction function is explored by Aksoy et al. (2006) and Orphanides and Wilcox (2003). They propose a loss function for the central bank that implies a target zone for the inflation rate. As long as inflation remains within the target zone monetary policy remains passive. If a shock, however, pushes inflation above this range the central bank responds vigorously. A further motivation for a nonlinear response to inflation is based on theoretical models by Cukierman (1992) and Cukierman and Meltzer (1992). They argue that concerns of the central bank about a loss of public confidence in its commitment to the inflation target cause a more aggressive central bank response to sizable inflationary excesses than to small ones.

One way to model empirically such a dependence of the central bank's reaction function on inflation is a threshold model. Threshold effects represent endogenous regime shifts in the reaction cofficients depending on the state of the economy. Using (2) as a starting point, a threshold reaction function with two regimes can be written as

$$\begin{aligned} i_t &= (\alpha_0 + \alpha_1 \left(\pi_{t+n|t+n} - \pi^*_{t+n}\right) + \alpha_2 y_{t+m|t+m} + \alpha_3 i_{t-1}) I_t(x_{t-d} \leq \tau) \\ &\quad + (1 - I_t(x_{t-d} \leq \tau))(\beta_0 + \beta_1 \left(\pi_{t+n|t+n} - \pi^*_{t+n}\right) + \beta_2 y_{t+m|t+m} + \beta_3 i_{t-1}) + \eta_t. \end{aligned} \quad (4)$$

I_t is an indicator which takes on the value of one if the threshold variable x_{t-d} does not exceed the threshold value τ in period $t - d$ and zero otherwise. The model (4) implies two piecewise linear reaction functions. If the threshold variable is less than or equal to τ the reaction function is given by $\alpha_0 + \alpha_1 \left(\pi_{t+n|t+n} - \pi^*_{t+n}\right) + \alpha_2 y_{t+m|t+m} + \alpha_3 i_{t-1} + \eta_t$ otherwise it is given by $\beta_0 + \beta_1 \left(\pi_{t+n|t+n} - \pi^*_{t+n}\right) + \beta_2 y_{t+m|t+m} + \beta_3 i_{t-1} + \eta_t$.

A test for the presence of threshold effects is a test of the hypothesis $H_0 : \alpha_0 = \beta_0$, $\alpha_1 = \beta_1$, $\alpha_2 = \beta_2$, $\alpha_3 = \beta_3$. Since the threshold value τ is an unidentified nuisance parameter under the null hypothesis it is not possible to employ a standard F-test. Following Hansen (1996, 1997) and Caner and Hansen (2004) we construct a Wald statistic (*supW*) for the null hypothesis of no threshold effects as the supremum of Wald statistics for H_0 for each potential threshold value. P-values are obtained from the empirical distribution of *supW* constructed by Monte-Carlo simulation (Caner and Hansen, 2004, pp. 823).

For a given threshold variable x_{t-d} the threshold estimate $\hat{\tau}$ is selected by a grid search over all potential thresholds using the sum of squared residuals as selection criterion. An adequate number of observations on each side of the threshold is ensured by considering only those candidate values which leave at least 15% of the observations in each regime.

Bunzel and Enders (2010) estimate such a model for the Fed with real-time observations for inflation and for the output gap. They try to avoid the problem of correlation between the explanatory variables and the error term by using current inflation rate and output gap as right-hand-side variables. However, information on the output gap is not available within the current quarter. Using its current observation as an explanatory variable not only overstates the central bank's information set but also does not remove the correlation between the regressor and the error term. A similar but less severe problem applies to using the current quarter's inflation rate for which at least observations for the first two months in the quarter are available. In contrast, in this paper we estimate the forward-looking version of the threshold model as shown in (4) using the threshold instrumental variable estimation approach by Caner and Hansen (2004). This approach accounts for the correlation between the explanatory variables both in testing for the presence of threshold effects and to achieve consistent estimates of the coefficients .

3 Data

Most of the early estimates of monetary policy reaction functions (e.g. Clarida et al., 1998) relied on ex-post revised data, i.e. on the latest data vintage available to the researchers. Orphanides (2001, 2003) and others showed the estimates of the reaction coefficients of the Fed to change considerably if the estimation was based on real-time data, i.e. realizations of macroeconomic variables which were available at the point in time the monetary policy decisions were taken.

Estimates of monetary policy reaction functions for the Bundesbank based on real-time data were presented by Clausen and Meier (2005) and Gerberding et al. (2005). Clausen and Meier compiled real-time observations on GDP from Bundesbank publications and derived real-time output gap estimates by statistical filtering. Gerberding et al. (2005) collected real-time observations for potential output, consumer prices and money growth rates from the Bundesbank's own publications and internal briefing documents. These real-time estimates of potential output enabled them to construct real-time observations of the output gap as perceived by the Bundesbank in place of a filtered output series.[2]

Using the very same data set we study the Bundesbank's reaction function including the possibility of threshold effects. As in the other literature we estimate the reaction function from quarterly observations since information on the output gap is only available at this frequency. Following Gerberding et al. (2005) we use for the right-hand side variables quarterly averages of the annual percentage change in the consumer price index and quarterly estimates of the output gap. The dependent variable (i_t) is the average overnight interest rate in the final month of each quarter. Our sample period is 1979Q1 to 1998Q4. This excludes the turbulent period before the introducion of the European Exchange Rate Mechanism and the years in which the Bundesbank's strategy of monetary targeting had not settled down yet.
One important advantage of this data is that it also includes information on the Bundesbank's implicit target rate of inflation. This allows us to estimate a threshold model with switches in the reaction function dependent on the deviation of inflation from target instead of using only the level of inflation as in previous studies (e.g. Bunzel and Enders, 2010; Castro, 2008). We approximate the implicit inflation target by the Bundesbank's "price norm" which entered the derivation of the Bundesbank's growth target for the money stock: Based on the quantity theory the money growth target for year t ($\hat{M}_t^*$) was derived as

$$\hat{M}_t^* = \pi_t^* + \hat{Y}_t^{pot} - \hat{V}_t^{trend}.$$

$\hat{Y}_t^{pot}$ is the expected growth rate of potential output over year t, $\hat{V}_t^{trend}$ is the long-run (trend) change in the velocity of circulation and π_t^* is the "price norm", i.e. the change in the price level that is considered to be consistent with maintaining price stability (Deutsche Bundesbank, 1995, p. 83).

[2]For details on the construction of the data set, see Gerberding et al. (2005), pp. 279.

Based on the implicit inflation target π_t^* we define as threshold variable the first estimate of the current quarter's year-on-year inflation rate from the price norm $(\pi_{t|t} - \pi_t^*)$. Figure 1 shows the time series of the inflation rate, the price norm and their difference. From the late 1970s on the Bundesbank gradually lowered its implicit inflation target to two percent from the mid 1980s onwards. Actual inflation exceeded this target strongly in the late 1970s up to the early 1980s and again from the late 1980s to the mid 1990s. From 1986 to 1988 inflation fell considerably short of the target.

As explained in Section 2 we require a set of instruments in order to estimate the forward-looking Taylor rule (4), since replacing unobservable forecasts of inflation and output gap with realized observations implies that the these variables will be correlated with the error term η. The instruments should be correlated with the explanatory variables but not with the error term. When assuming rational forecasts, variables observable by policymakers at time t are uncorrelated with η_t. Hence, we use as instruments four lags of the interest rate, the period t estimate of inflation in the current quarter, the period t estimates of inflation and of the output gap in the previous four quarters and the value of the price norm. We cannot use the current quarter's output gap as an instrument because this information only becomes available with a lag of one quarter. The overidentifying restrictions imposed by the instruments are tested with Hansen's J-statistic.

4 Results

Since we found evidence of significant autocorrelation in the residuals when including just one lag of i_t, we estimate a threshold monetary policy reaction function as a forward-looking Taylor rule in inflation and in the output gap as in equation (4) but augmented by a second autoregressive term in the interest rate since.[3] Table 1

[3]An AR(2) specification is also used in Bunzel and Enders (2010) for the Fed and in Beyer et al. (2009) for the Bundesbank, although the latter study does not consider threshold effects. We also include a dummy variable for 1981Q1 to account for a jump in the interest rate when the Bundesbank

	$\hat{\tau}$	α_1	β_1	α_2	β_2	$\alpha_3+\alpha_4$	$\beta_3+\beta_4$	$P(J_\alpha)$	$P(J_\beta)$	SSR	prob
$n=3, m=0$	-0.400	0.120	0.293	-0.150	0.019	0.757	0.867	0.96	0.39	16.01	0.06
		(0.058)	(0.117)	(0.063)	(0.036)	(0.145)	(0.038)				
		(**)	(***)	(**)		(***)	(***)				
$n=4, m=0$	-0.400	-0.007	0.437	-0.115	-0.036	0.758	0.828	0.88	0.60	19.16	0.02
		(0.158)	(0.108)	(0.065)	(0.040)	(0.169)	(0.031)				
			(***)	(*)		(***)	(***)				
$n=5, m=0$	-0.400	-0.132	0.516	0.017	-0.078	0.922	0.870	0.74	0.87	22.92	0.10
		(0.132)	(0.136)	(0.067)	(0.050)	(0.166)	(0.038)				
			(***)		(***)	(***)	(***)				
$n=3, m=1$	0.267	0.065	0.176	-0.180	0.071	0.669	0.877	0.74	0.56	18.17	0.04
		(0.137)	(0.105)	(0.045)	(0.038)	(0.070)	(0.088)				
			(*)	(***)	(**)	(***)	(***)				
$n=4, m=1$	-0.400	0.040	0.398	-0.234	-0.022	0.522	0.831	0.99	0.62	19.31	0.08
		(0.161)	(0.111)	(0.083)	(0.046)	(0.149)	(0.035)				
			(***)	(***)		(***)	(***)				
$n=5, m=1$	-0.400	-0.009	0.468	-0.215	-0.054	0.554	0.843	0.99	0.78	22.08	0.12
		(0.142)	(0.140)	(0.079)	(0.055)	(0.146)	(0.041)				
			(***)	(***)		(***)	(***)				
Average	2M										
$n=4, m=0$	-0.092	0.114	0.328	-0.168	-0.011	0.734	0.846	0.95	0.72	19.37	0.04
		(0.248)	(0.108)	(0.064)	(0.040)	(0.121)	(0.029)				
			(***)	(***)		(***)	(***)				
Imposed	0.650										
$n=4, m=0$	0.650	0.171	0.447	-0.085	0.059	0.921	0.834	0.63	0.90	21.67	
		(0.182)	(0.116)	(0.053)	(0.042)	(0.059)	(0.035)				
			(***)	(*)	(*)	(***)	(***)				

Standard errors in parentheses. */**/*** denotes significance at the 10%/5%/1% level. Estimation period 1979:1-1998:4. Estimation by threshold IV. Threshold variable is inflation gap in current quarter. $\hat{\tau}$: estimated threshold value. $\alpha_3+\alpha_4$, $\beta_3+\beta_4$: sum of AR coefficients. $P(J)$: P-value of J-statistic. SSR: sum of squared residuals (AR2 model). *prob*: Simulated P-value of supWald statistic for null hypothesis of no threshold effect (5000 replications).

Table 1: Estimated threshold models (Taylor rules) with two regimes using the inflation gap as threshold variable

presents estimates for six versions of forward-looking Taylor rules with different forecast horizons for inflation (n) and for the output gap (m). As shown in the last column, threshold effects are significant at the 10% level for most model specifications.[4] The threshold estimates for five of the six Taylor rule variants in the top panel are identical exept for the version with $n = 3, m = 1$ are identical and imply a break in the reaction function if inflation is higher than the inflation target minus 0.4 percentage points.

Considering the time series of the threshold variable in Figure 1 the second regime clearly is associated with the high inflationary episodes in the late 1970s/early 1980s and in the early 1990s. The point estimates for the inflation coefficients (α_1, β_1) show a strong increase after crossing the threshold from below ($\alpha_1 < \beta_1$). These changes in the Taylor rule's inflation coefficent exceed two standard deviations in most cases - except for the models with $n = 3$. Furthermore, for five out of the six specifications in the top panel the coefficients on the output gap also increase in the above threshold regime ($\alpha_2 < \beta_2$).[5] While the coefficient estimate on the output gap is often significantly negative in the below threshold regime the estimates for the above threshold regime mostly are either insignificant or significantly positive. Finally, the Taylor rule in the high inflation regime implies more persistence in the interest rate as the sum of the AR coefficients is higher than for the low inflation regime in almost all cases. As shown in the theoretical literature, persistence is an important feature of optimal monetary policy reaction functions (e.g. Woodford, 1999). A high degree of autocorrelation in the interest rate leads to a smaller increase in inflation expectations after an inflationary shock since agents know that the increase in the interest rate by the central bank will persist for some time. This dampening of inflation expectations in turn affects actual inflation through the forward-looking Phillips curve. Thus, persistence in the central

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changed its operating procedures, see Gerberding et al. (2005), notes to Table 1. Since the IV threshold estimator requires identical specifications in both subsamples, we introduce the dummy variable - which is only present in one of the subsamples - by ignoring the effects of the 1981Q1 observation on coefficient estimates and all test statistics.

[4]The exception are models with a forecast horizon of $n = 5$ for inflation which also display a much inferior fit compared to the other specifications.

[5]The exception is the fourth specification with $n = 3$ and $m = 1$.

bank's interest rate response to an inflationary shock makes monetary policy more efficient.

Our benchmark specification with $n = 4$ and $m = 0$ which exhibits the strongest threshold effect (lowest p-value) assumes a forecast horizon of four quarters for the inflation rate. If the inflation rate in the current quarter was more than 0.4 percentage points below the Bundesbank's inflation target the reaction function is estimated as (with standard errors in parentheses)

$$\begin{array}{ccccccccccc} i_t & = & \underset{(0.504)}{0.667} & - & \underset{(0.158)}{0.007}(E_t\pi_{t+4} - \pi^*_{t+4}) & - & \underset{(0.065)}{0.115}E_t y_t & + & \underset{(0.106)}{1.187}i_{t-1} & - & \underset{(0.204)}{0.429}i_{t-2}. \end{array} \tag{5}$$

The estimated reaction function for the inflation rate in the preceding quarter in excess of the threshold estimate of $\pi^* - 0.4$ percentage points is

$$\begin{array}{ccccccccccc} i_t & = & \underset{(0.169)}{0.865} & + & \underset{(0.108)}{0.437}(E_t\pi_{t+4} - \pi^*_{t+4}) & - & \underset{(0.040)}{0.036}E_t y_t & + & \underset{(0.120)}{1.350}i_{t-1} & - & \underset{(0.111)}{0.522}i_{t-2}. \end{array} \tag{6}$$

The estimate of the corresponding linear Taylor rule without threshold effects is[6]

$$\begin{array}{ccccccccccc} i_t & = & \underset{(0.190)}{0.686} & + & \underset{(0.113)}{0.257}(E_t\pi_{t+4} - \pi^*_{t+4}) & - & \underset{(0.036)}{0.019}E_t y_t & + & \underset{(0.125)}{1.343}i_{t-1} & - & \underset{(0.116)}{0.477}i_{t-2}. \end{array} \tag{7}$$

Both the full-sample estimates of the constant and the coefficient on the inflation deviation fall in between the estimates for the two regimes while the estimate for the output gap coefficient is not significantly different from zero - as in the high inflation regime. These results for estimating the reaction function without the threshold effect mask important differences between the two regime dependent Taylor rules, in particular, in the high inflation regime an increase in the constant for the high inflation regime, a more pronounced response to the inflation deviation, as well as an increase in the persistence of the interest rate.

[6]The results are obtained from GMM estimation using an optimal weighting matrix

The results on the inflation response coefficient is consistent with the results in studies for other central banks such as the Fed (Bunzel and Enders, 2010; Castro, 2008), the ECB (Castro, 2008), and the Bank of England (Martin and Milas, 2004; Taylor and Davradikis, 2006) which present estimates of a stronger response to inflation in the high inflation regime. Evidence concerning the coefficient on the output gap is more mixed. The results in Castro (2008) indicate for the ECB a decline in the response to the output gap when inflation becomes too high. For the Bank of England, Martin and Milas (2004) and Castro (2008) show no significant output response in either regime while Taylor and Davradakis (2006) report a significantly stronger response to the output gap in the high inflation regime. For the Fed, the estimated reaction coefficients for the output gap are not significantly different from zero in Castro (2008), Petersen (2007) finds no evidence for a significant change in the coefficient while Bunzel and Enders (2010) present results qualitatively similar to ours, i.e. an increase in the output gap coefficient in the high inflation regime.
Concerning our results of a more pronounced persistence of the interest rate in the high inflation regime the results in the literature are mixed, as well. For the Bank of England, Martin and Milas (2004) estimate an increase in the autoregressive coefficient while Taylor and Davradakis (2006) report a decrease in the estimate. Similarly, Bunzel and Enders (2010) show the estimated Taylor rule for the Fed to imply less persistence in the Federal Funds Rate when switching to the high inflation regime.

Turning back to the estimated Bundesbank reaction functions from the threshold model (5) and (6) we now ask, how do they compare to each other in terms of monetary policy tightness? Figure 2 presents the fitted interest rates for both the below and above threshold reaction functions. The shaded area indicates the time periods in which the high inflation regime prevailed. It is obvious that the Bundesbank reaction function estimated for the high inflation regime implies a higher level of the interest rate compared to the one if the Bundesbank had followed the reaction function estimated for the low inflation regime. This result is robust across all model specifications in

Table 1 and is qualitatively consistent with those in the other studies discussed above.

The bottom panel of Table 1 gives the results for two robustness checks. In the first one (*Average 2M*) we use as threshold variable the average inflation rate in the first two months of each quarter instead of the average across the whole quarter as one might argue that the inflation rate in the final month of the quarter was not known to the Bundesbank when setting the interest rate. The thresold effect remains significant and the threshold estimate is close to zero indicating that, empirically, the price norm was the important determinant for the Bundesbank switching between reaction functions. All the other results from the top panel remain qualitatively unchanged.
The second robustness excercise (*imposed*) is derived from the fact that, while the estimates for $\hat{\tau}$ in Table 1 represent those values which minimize the residual sum of squares for the threshold model, there is a range of other possible threshold estimates that do not lead to a significantly worse fit. In Figure 3, which presents the results for the LR test suggested in Caner and Hansen (2004), all threshold values on the horizontal axis for which the likelihood ratio is below the horizontal line are possible threshold estimates that do not differ significantly from the best estimate of -0.4 %. To check the sensitivity of our results to this choice the final specification in Table 1 shows the results from imposing a threshold value of 0.65% in estimating the Taylor rule (4) with qualitatively similar results as before, although for this specification the persistence of the interest rate falls if the Bundesbank switches to the reaction function for the high inflation regime. In both robustness excercises the reaction function for the high inflation regime still implies a more restrictive monetary policy if inflation is high, i.e. we obtained interest rate paths similar to those in Figure 2.

5 Conclusions

This paper presented evidence on significant threshold effects in the monetary policy reaction function of the Deutsche Bundesbank with a special focus on using appropriate real-time data to model the information set available to the Bundesbank's policy-makers. Using past deviations of inflation from the Bundesbank's inflation target as threshold variable we showed systematic shifts in the reaction functions across regimes. Specifically, we found that the reaction function triggered by high deviations of inflation from target implied a much stronger response to the deviation of the inflation rate from the Bundesbank's target, a mostly insignificant response to the output gap and an increased persistence in the interest rate. The final effect is an important difference to results for the Fed (Bunzel and Enders, 2010) and is an interesting result because increasing persistence will have a stabilizing effect on inflation through its impact on inflation expectations. Comparing the implied interest rate paths across the reaction functions in the two regimes we found the coefficient estimates in the high inflation regime to imply a more restrictive monetary policy, i.e. a higher level of the interest rate in the high inflation regime.

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Figure 1: Inflation rate, price norm and inflation gap.

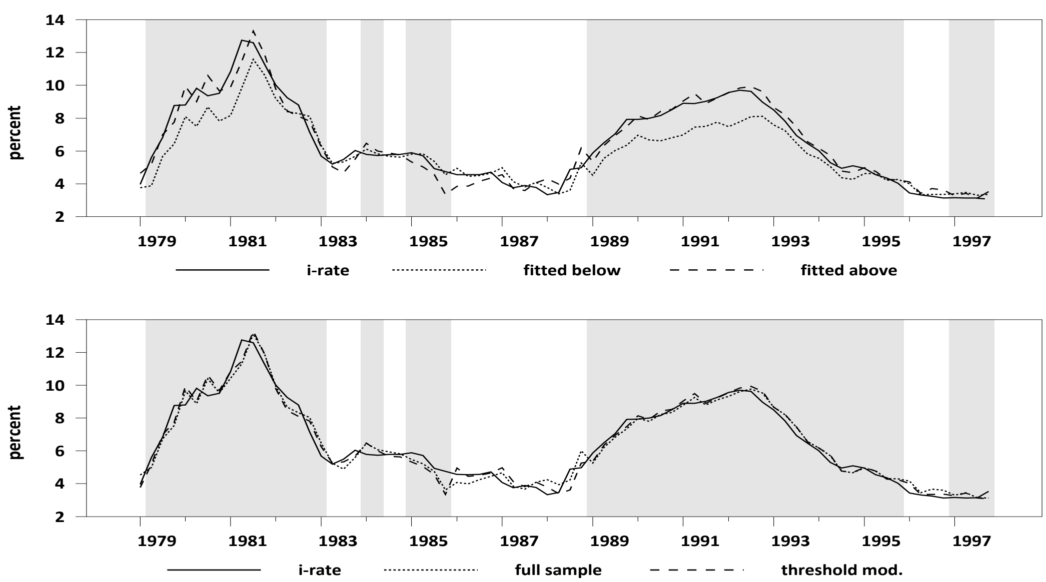

Figure 2: observed interest rate and fitted values from both regimes (n=4,m=0), inflation gap threshold.

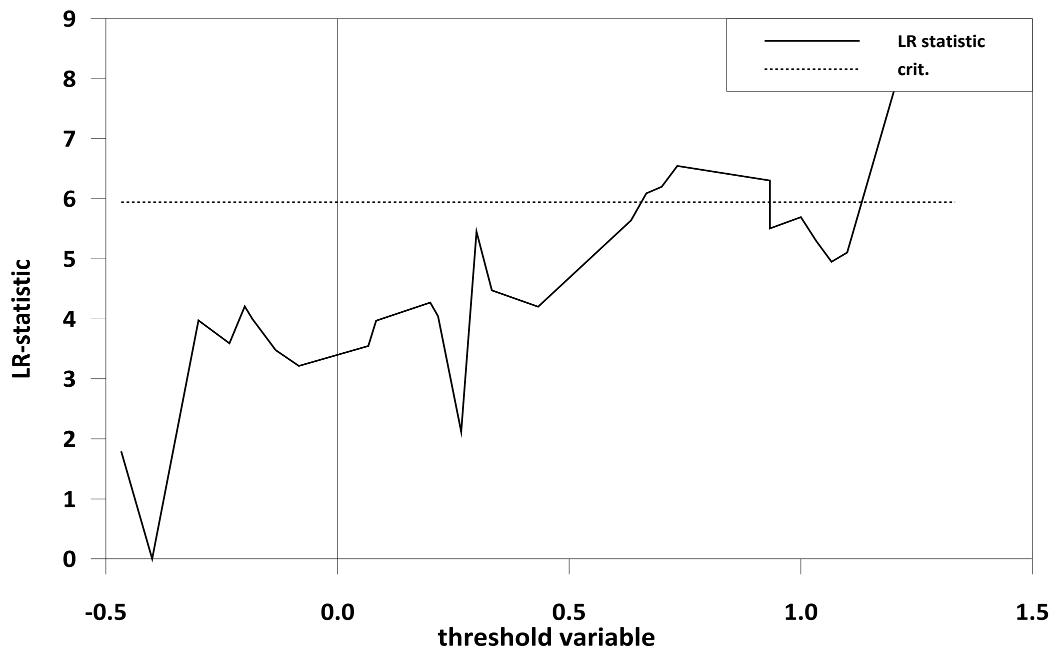

Figure 3: LR-test for range of of threshold values (specification n=4,m=0.