Kiel Institute for World Economics
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Kiel Working Paper No. 1180

Did the Bundesbank Follow a Taylor Rule? An Analysis Based on Real-Time Data

by

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August 2003

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Abstract:
Using a real-time data set for German GDP over the period from 1973 to 1998 we calculate various measures of real-time output gaps and use these to calibrate and estimate Taylor-type reaction functions for the Bundesbank. Most of the reaction functions we find fit the Bundesbank's actual policy, as represented by the short-run interest rate, quite well. In contrast to previous findings based on ex post revised data for the output gap, we find the reaction coefficients to resemble quite closely those originally proposed by Taylor for some of our real-time measures of the output gap. Broad monetary aggregates such as M3, in contrast, only played a small role for the Bundesbank's interest rate decisions. Given the good record of the Bundesbank in fighting inflation, the results give support to the use of the Taylor rule for monetary policy.

Keywords: German real-time data, output gap, monetary policy rules
JEL-Classification: E52, E32

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The authors would like to thank Joachim Benner, Kai Carstensen, Juergen B. Donges, Sandra Eickmeier, Christophe Kamps, Harmen Lehment, Peter Tillmann and Joachim Scheide for helpful comments at different stages of this paper. Remaining errors are of course our own. Jens Clausen would also like to thank the Business Cycle Department of the Kiel Institute for World Economics for the hospitality enjoyed when he was visiting the Institute. Financial support by the Fritz-Thyssen-Foundation is also gratefully acknowledged.

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1 Introduction

Taylor rules in different shapes and forms have become very popular in describing monetary policy strategies. Part of their popularity stems from their apparent success in duplicating interest rate decisions ex post in a positive sense. Taylor (1993), in his seminal paper, shows that the monetary policy decisions of the U.S. Federal Reserve Board between 1982 and 1992 can be described well by the simple equation he proposes. For the period from 1965 to 1980, however, his rule cannot duplicate the Fed's historic decisions; the rule recommends a much higher interest rate than that actually set by the Fed. From this positive observation, Taylor (1999b) reaches the normative conclusion that the high inflation rates, which the United States experienced in the 1970s, had likely been avoided, had the Fed followed his rule.

Normative implications with respect to monetary policy rules may, however, not only be drawn from the historical experience of the United States. In Europe, the Deutsche Bundesbank conducted monetary policy largely independently from the Fed from 1973 to 1998 – with quite different results. Unlike the Fed, the Bundesbank by and large kept inflation tamed, even in the shock-ridden 1970s and early 1980s. In fact, in the 1970s and 1980s German inflation was lower than in any other OECD country (Clarida and Gertler 1996). Moreover, with the Bundesbank's formal independence and with its policy to publicly announce explicit targets for monetary growth (as well as implicit targets for inflation, termed the "unavoidable" or "normative" inflation), some important institutional features of German monetary policy during the Bundesbank's "active" period already coincided with the institutional setting many economists today regard as desirable for controlling inflation and which meanwhile have in modified ways found their ways into the institutional designs of other central banks such as the Bank of England or the European Central Bank.

Officially, the monetary strategy with which the Bundesbank managed to reach its impressive results, however, was different from the kind of "inflation targeting" described by the rule Taylor (1993) devised for the Fed under Alan Greenspan. The Bundesbank always emphasised that it pursued monetary targeting, a strategy that implies changing the interest rate when the growth rate of some broad monetary aggregate deviates from its target value or range but not necessarily in response to short-term changes in inflation or the output gap. Still, while the Bundesbank publicly announced growth targets for its preferred monetary aggregate each year between 1975 and 1998, the role monetary growth actually played for its monetary policy decisions is not clear. Interestingly, while the inflation record of the Bundesbank was remarkable by international standards and its credibility for low inflation was high, they were so despite the fact that the Bundesbank frequently missed its monetary target, in some cases by a long mark.[1] The decisive factor for the Bundesbank's credibility may, thus, not have been its rather "pragmatic"

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[1] The Bundesbank missed 11 out of the 24 targets for monetary growth it announced. In each case, monetary growth exceeded the target value. Still the Bundesbank never attempted to overcompensate for overexpansion in one year by setting a lower value for the next year. See Schächter (1999), Bofinger (1994).

way of monetary targeting but its commitment to low inflation, implemented by an inflation targeting strategy that included annual announcements of inflation targets (Bofinger 1994). This view is broadly supported by von Hagen (1999) who, after analysing minutes from the Central Bank Council of the years 1971-8, concludes with respect to the role of monetary targeting in the Bundesbank's policy at that time:

> "A two-stage nature of the decisions - which would have implied during the course of the year that monetary policy considerations focus on achieving the monetary target - is not evident from the discussions in the Central Bank Council. Equally, the Council in no way resisted the temptation to direct individual monetary policy measures to short-term employment-related goals [...]. The discussions in the Central Bank Council consistently reflected efforts to check out various 'motivational fields' for monetary policy to see whether a change in the current stance was called for. In the period considered here these fields regularly included the development of the real economy, international trends, developments in the money and capital markets and price trend." (Von Hagen 1999, p.434f)

From this description of the decision making process at the Bundesbank — at least in the 1970s — it is difficult to see large differences to the Fed's practice under Greenspan. We, therefore, set out to evaluate whether the Taylor rule is an appropriate description of monetary policy in Germany between 1973 and 1998. In light of the record of the Bundesbank in controlling inflation, finding German short-term interest rates to lie indeed close to those implied by the Taylor rule would imply that the rule is helpful in achieving low inflation.

The relevance of the Taylor rule for the Bundesbank's policy has been analysed by a number of studies before (see Clarida and Gertler 1996, Clarida et al. 1998, Deutsche Bundesbank 1999, Kamps and Pierdzioch 2003). A major drawback of these studies is that they do not acknowledge the informational problems associated with monetary policy rules. As argued by Orphanides (1998, 2002), calculating or estimating the weights in a monetary policy rule on the basis of the ex post revised data available to the research today can yield misleading descriptions of historical policy with questionable normative implications. Historical evaluations of monetary policy rules, in his view, need to be based exclusively on data that was actually available to the decision makers at the time of the decision. To show what difference it makes when different "vintages" of data are used, Orphanides (2002) recalculates the path of the federal funds target implied by the Taylor rule on the basis of such real-time data for the 1970s. Quite in opposite to Taylor (1999b), he finds the path of the Taylor rate to be very similar to the interest rate path observed in reality. Given these findings we base our assessment of the Bundesbank's policy on a real-time data set that we constructed for that purpose.

The paper is structured as follows. The next section describes the construction of our real-time data for GDP and potential output and points out the differences between real-time and ex post revised data for Germany. Section 3 then presents our estimates of dynamic Taylor rules, and the last section draws some conclusions.

2 Construction of the Data Set

In assessing whether a Taylor-type rule can adequately describe the Bundesbank's interest rate decisions, it is important to rely exclusively on data that was available to Bundesbank officials at the time of their decisions. Accordingly, the use of historical data currently available from the German statistical office is ruled out for all series that undergo substantial revisions. In particular, we cannot use the currently available "vintage" of historical real GDP data. Moreover, we cannot rely on ex post estimates for potential output, both because GDP data has been revised and because the full sample estimate of the medium-term trend in GDP, regardless of the concrete estimation procedure, is likely to be different from the trend estimated using the confined data set available at the historical time of decision. Put differently, the outlook for medium-term growth of the German economy in, say, early 1973 (before the first oil price shock) most likely looked very different from what the growth rate looks like from today's perspective. For the data on inflation, in contrast, the difference between revised and real-time is much less relevant since revisions are of minor magnitude and there is no need for trend estimates. In fact, in what follows, we treat the inflation rate and, of course, the interest rate as unrevised variables and thus use the last available vintage in the calculations and estimations of policy reaction functions. The construction of the real-time set is confined to real GDP and potential output.

2.1 Real GDP/GNP

Our real-time data for GDP contains seasonally adjusted quarterly data of the vintages 1973Q1 to 1998Q4, collected from the Deutsche Bundesbank's monthly publication "Saisonbereinigte Wirtschaftszahlen". In total there are 104 time series on real GDP/GNP in our database, one for each vintage. Each series reaches back to 1962Q1 but ends in a different period (the first vintage, for example, ends 1972Q4). Consequently, the longest series, which is that of the vintage 1998Q4, has 147 observations (1962Q1 to 1998Q3). The data set can be thought of as a 147 x 104 matrix, each entry of which represents a real-time data point. Each column vector of the matrix represents a new vintage of data, representing the data available for policy-makers at that vintage date. For example, the first column contains the data on real GNP available to the Bundesbank in the first quarter of 1973. It starts in 1962Q1 and ends in 1972Q4, as the data is only available with a lag of one (and a half) quarter.

Since the series published in "Saisonbereinigte Wirtschaftszahlen" underwent some changes, we needed to make some assumptions when constructing the data set. First, each issue of "Saisonbereinigte Wirtschaftszahlen" only contains quarterly data for the last ten years. To let each series reach back to 1962Q1, we appended data from the most current available longer vintage. We believe that this flaw of our data set is negligible with respect to the analysis of policy rules. For the estimation of potential output or dynamic monetary reaction patterns, for which historical data of the respective vintage is, of course, important, the effect of a possible difference between the actual real-time data, that we do not have and the near real-time series we have in our data set is likely to be extremely small. Second, until the early 1990s the data in our source refers to real seasonally and trading day adjusted GNP, after that it refers to the respective GDP figure. We treat the data from the two definitions as the same series, as the differences between GNP and GDP are generally small in Germany. Third, between 1975Q2 and 1991Q1 the published series was not trading day-adjusted. However, trading day-adjusted growth rates were given in addition, albeit rounded to half or full percentage points. We undertook our own trading-day adjustment[2] and compared the growth rates of the adjusted series with the published but rounded growth rates, finding only small differences; in the following we use the self-adjusted data. Finally, the data up to 1995Q1 refers to West Germany only. Beginning with the vintage of 1995Q2, we use data for unified Germany. To avoid a jump due to reunification, within the vintages from 1995Q2 onwards we link the data for West Germany with that of the reunified country by using West Germany's growth rates from 1993Q4 backwards (see for a similar approach SVR 2001, Zf. 459).

The difference between our real-time data for GNP/GDP and the ex post revised data can be seen from Figure 1. The figure depicts the growth rate of real GNP/GDP against the respective quarter in the previous year in percent, both for the ex post revised data and for our real-time data. The two series are generally quite close, so the magnitude of the revisions is not very large. Striking differences between the series occur only in two periods, 1975Q1 and 1991Q1. These two exceptions apart, data revisions do not seem to play much of a role for German GNP/GDP data.

2.2 Potential Output

The Taylor rule does not incorporate information on real GNP/GDP directly, but on its deviation from potential output, the output gap. Real-time estimates of the output gap may deviate from ex post estimates for two reasons. First, because of the use of unrevised data. Second, because the information set used today to estimate potential output for a historical data point is bigger than the one available at that time. Virtually all estimation methods for potential output rely on measures that separate the non-cyclical from the cyclical component of some economic variable. Applied in real time, where the future of the series is still unknown, these methods suffer from an end-of-sample problem, which makes the separation of trend and cycle at the end of the series much less reliable than it is ex post, where the complete series is known to the researcher. Therefore, one would expect real-time output gap estimates to be subject to revisions even if the underlying data were not revised at all. Table 1 illustrates the differences between real-time output gaps and ex post output gaps. Series a_t denotes the *real-time* output gap series, calculated on

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[2] We obtained "quasi-Bundesbank" trading-day adjustment factors for 1975-91 by regressing the annual change of the trading-day adjustment factors the Bundesbank currently publishes for real GDP from 1992Q1 to 2002Q2 on the annual change of the number of working days. We then "backcasted" these factors on the basis of the estimated coefficients and the number of working days in 1975Q2-1991Q1.

the basis of real-time GNP/GDP and real-time estimates of potential output. The series c_t, in contrast, is the *ex post* output gap series calculated on the basis of ex post revised GDP figures and estimates of potential output estimated using all information available today. Finally, the series b_t corresponds to a "*quasi-real-time*" (Orphanides and van Norden, 2002) output gap series, a measure in-between the former two. It is based on ex post revised real GDP figures, but the estimates for potential output are obtained recursively, that is, by exclusively using information (on ex post revised real GDP) up to the respective real-time data point.

The Bundesbank estimated potential output in Germany using a production function approach. Unfortunately, consistent real-time data on the Bundesbank's estimates of the level of potential output are not available.[3] To obtain real-time estimates of potential output, we use univariate time series-based measures. The advantage of these rather simple measures is that they require no other information than past (and possibly future) values of real GDP.[4] Following Orphanides and van Norden (2002), we employ a linear trend, a quadratic trend and the filter proposed by Hodrick and Prescott (1997). Both for the linear and the quadratic trend, we estimate two versions. In the first version, the trend is estimated on a sample that is fixed to start in 1962, whereas in the second version, the trend regressions are estimated using rolling samples with ten years of data. The second version serves to account for changes in the trend that are likely to have occurred since the 1960s.[5] To solve the end-of-sample problem of the Hodrick–Prescott filter, we follow Baxter and King (1995) and base the calculation of the filter at the end of the sample on data including forecasts over the next 12 quarters. The forecasts are generated from an $AR(8)$ model for the change in real GNP/GDP that is estimated recursively with the real-time data available.

To compute real-time output gaps, we estimate potential output for each data vintage using exclusively the information available at that point in time and subtract its logarithm from the logarithm of the respective real-time GNP/GDP figure. For example, in 1979Q1 we subtract the (log of the) estimate for potential output in 1978Q4 from actual output in 1978Q4, being the (log of the) latest realization of output available at that time. Repeating this process for all of our 104 series of real GNP/GDP and recording the most recently estimated output gap, we get a real-time output gap series consisting of output gaps computed only with data available in each time period.

As regards the estimated ex post output gaps, we find some differences between the individual procedures, especially for a period in the middle of the 1980s and in the early 1990s (Figure 2). Still, even the differences for the mid 1980s are small compared to the differences produced by the five real-time measures of the

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[3] The Bundesbank published an estimate of the expected growth rate of potential output at the beginning of each year when presenting its target range for monetary growth. However, it did not give an estimate of the level of potential output or on capacity utilisation. Estimates of the level of potential output based on a production function approach were published in three articles in the Bundesbank's monthly bulletin, see Deutsche Bundesbank (1973, 1981, 1995).

[4] We do not consider more sophisticated multivariate measures here because Orphanides and van Norden (2002) found them not to be superior to univariate measures for U.S. data.

[5] A similar approach has been applied to U.S. data by Ghysels et al. (2002).

output gap (Figure 3). These differences occur both between the individual real-time output gaps series and between the real-time and the ex post series (solid lines). The differences between the individual real-time output gap estimates are particularly pronounced for the recession of 1974/75 and for the unification boom in the early 1990s, two periods where there were also large revisions in the underlying data for real GDP. For 1990, as an example, the real-time output gap based on a fixed-sample linear trend is close to zero while its counterparts based on a rolling-sample linear trend and on a fixed-sample quadratic trend are 6 percent and 8 percent, respectively.

The methods used for estimating potential output not only differ in their assessment of the current state of the business cycle as given by the output gap, but also in the magnitude of the revisions of their output gap estimates. The latter are measured by the deviation of the real-time output gaps from the ex post output gaps. Some summary statistics on the revisions of the output gap estimates are given in Table 2. The first column shows the mean of the revisions. Note that apart from the fixed sample quadratic trend all measures tend to underestimate the magnitude of a positive output gap and overestimate the magnitude of a negative gap in real time. The mean revision is highest for the linear detrending based on a fixed sample. The magnitude of this bias, which is responsible for the high root mean squared error (RMSE) of 5.99 and which is also evident from the upper part of Figure 3, casts some doubt on the fact that such a measure has in fact been used in real-time. The same conclusion holds for the rolling sample quadratic trend, which has a lower RMSE than the fixed sample linear trend but seems to be virtually uncorrelated with the final estimate of the output gap from this procedure. Judged from the correlation and the RMSE, rolling sample linear detrending seems to be the most consistent output gap estimator, followed by HP filtering and, with some distance, by the fixed sample quadratic detrending. Contrasting the *real-time* output gap series with this *quasi-real* output gap series in Figure 4, we largely confirm the findings of Orphanides and van Norden (2002) for the U.S. case.[6] The data revisions only explain a rather small fraction of the differences between *real-time* and *ex post* output gap estimates. The end-of-sample characteristics involved with the methods to estimate potential output constitute the major problem.

As a final check of our time series-based real-time measures of the output gap, we compare them to the real-time estimates from a completely different but influential source Since the early 1960s, the *Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung* (SVR, German Council of Economic Experts) in its annual reports has been publishing estimates of the growth rate of potential output, of the aggregate rate of capacity utilization as well as of the deviation of the aggregate rate of capacity utilization from its long-run average.[7] The latter figure is the one we use for comparison here, since in contrast to our time series-

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[6] We also provide justification for Rünstler (2002), who estimates what he calls "real-time" output gaps for the euro area, which are in fact quasi-real output gaps.

[7] According to the SVR reports, the SVR's real-time estimate of the long-run average or "normal" aggregate capacity utilization was 97.5 percent between 1971 and 1985, 96.5 between 1986 and 1994 and 96.75 from 1995 to 1998.

based measures which define potential output as the average or trend output over some period, in the concept of the SVR potential output is defined as the output maximal attainable at full utilization of the capital stock: The SVR estimated potential output by multiplying the average annual capital stock by an estimate of potential capital productivity which, in turn, was obtained by extrapolating capital productivity observed at the last cyclical peak by the average growth rate of capital productivity over a complete productivity cycle (see e. g. SVR 1974).

The SVR's estimates were published in November and referred to the average for the respective calendar year They included a forecast for GDP growth in the fourth quarter of the year. For comparison, we calculated real-time calendar year averages for each of our five time series-based measures by taking the average over the four output gaps of a calendar year as they had been observed in the first quarter of the following year. While strictly speaking this sets the SVR estimates at a slight informational disadvantage and makes the measures incomparable, this way we avoid having to produce forecasts for fourth quarter GDP.

The SVR's annual real-time estimates of the deviation of the aggregate rate of capacity utilization from its long-run average — taken from the reports of the respective years — are shown as solid lines in Figure 5 alongside the annual averages for our five time series-based measures. As is evident from the graph, the time series-based measures that seemed to be the most consistent in the analysis above also come closes to the SVR's measure. The output gap measure based on moving-window linear detrending tracks the SVR's measure quite closely. Calculating some of the deviation statistics used in Table 2, we find that the latter measure has the lowest deviation from the SVR's measure (as quantified by the RMSE) and also the highest correlation with the SVR gap. The measure based on Hodrick-Prescott filtering comes second in terms of the RMSE but has a lower correlation than the measure based on fixed sample quadratic detrending. Fixed sample linear and moving sample quadratic detrending, again, are far off.

Overall, we conclude that the choice of the detrending procedure plays a substantial role for estimating output gaps in Germany, especially when real-time series are used. Given this result, we expect a significant impact of the detrending procedure on coefficient estimates of the Bundesbank's monetary policy rule.

3 Taylor Rules for the Bundesbank

Given our real-time output gap series, we are now in the position to investigate whether the Bundesbank's monetary policy over the period of 1973 to 1998 can be characterized as following a Taylor rule. Specifically, we ask whether the German three-month money market rate (Frankfurt Interbank Offer Rate, FIBOR) can be described as a linear combination of the deviation of the inflation rate from the Bundesbank's implicit target rate and the (real-time) output gap and, if so, which weights of these two factors fit the Bundesbank's policy best.

3.1 Calibration

As a first point in our analysis, we use the various output gap series described above to calibrate simple backward-looking Taylor rules of the form

$$r_t = rr - (\beta - 1)\pi_t^* + \beta\pi_t + \gamma(y_{t-1|t} - y_{t-1|t}^*) \tag{1}$$

where r_t is the short-term interest rate targeted by the central bank, rr is the equilibrium real interest rate, π_t is the current inflation rate, β and γ are weights, π_t^* the time-varying normative inflation rate of the Bundesbank and $y_{t-1|t} - y_{t-1|t}^*$ is the output gap in $t-1$ as observed at time t. All variables are measured in percent. As inflation rate we choose the change in the consumer price index.[8] The Bundesbank's implicit target inflation rates π_t^* are the "unavoidable" or "normative" rates of inflation the Bundesbank presented in its annual announcements of the target range for monetary growth.[9] For the equilibrium real interest rate rr we assume a value of 2 percent since this is close to the average rate of GDP growth in Germany over the sample period. Note that in (1) we allow the inflation differential to affect the interest rate contemporaneously whereas the output gap affects interest rate decisions with a lag of one quarter. The reason is that data on inflation was usually available at the end of the reported month. GDP data, in contrast, was only available one quarter after the end of the reported quarter. While this may seem to advocate a lag of two quarters for the output gap, this would probably underestimate the information available to Bundesbank decision makers as monthly indicators on industrial production and some other activities as well as survey based indicators such as ifo Institute's business climate allowed them to roughly estimate last quarter's GDP some weeks before the official data were actually published.

Figure 6 shows the three-month FIBOR in comparison to the calibrated rates based on three real-time measures of potential output, the moving window linear trend, the fixed window quadratic trend and the trend based on a Hodrick-Prescott filter with autoregressive forecast. In each case, the standard weights proposed by Taylor (1993, 1999) of 1.5 for β and 0.5 for γ have been chosen. Evidently, all three calibrated rates track the FIBOR more or less closely, except for the spikes in 1973 and 1981 and the year 1987, after the fall in energy prices. Overall, the calibration exercise seems to support the proposition that a Taylor rule can duplicate the Bundesbank's policy quite well. However, the short-run variation of the calibrated rule is generally higher than that of the FIBOR, indicating interest smoothing on the side of the Bundesbank.

3.2 Dynamic Estimates of the Bundesbank's Rule

We now go one step further and estimate the parameters of a Taylor-type rule for the Bundesbank. Again, different measures of real-time output gaps are used in order to

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[8] Using the GNP/GDP deflator gave a similar fit of the calibrated Taylor rule except for the period 1985 to 1987 when falling energy prices caused the two indicators to move in opposite directions.

[9] The Bundesbank's annual implicit inflation targets were taken from table II.3 in Schächter (1999) and interpolated to obtain a quarterly series.

judge the robustness of the estimates. Previous research, based on ex post revised data, has found the Taylor rule to be a good approximation for German short-run interest rates, with coefficient estimates lying somewhat below those proposed by Taylor (1993). For instance, Clarida et al. (1998) find a value of 1.31 for β and 0.25 for γ, Faust et al. (2001) report values of 1.31 and 0.18, respectively and Kamps and Pierdzioch (2003) of estimate values of 1.18 and 0.18, respectively.[10] These estimates, however, refer to a specification were equation (1) is augmented by a one-period lagged short-run interest rate to account for interest rate inertia. More importantly, π_t is usually replaced by $E_t(\pi_{t+4})$, its expected value one year from now, to account for forward-looking decisions, implying that the Bundesbank was looking at inflation one year ahead when setting the interest rate. Because of the expectational variable appearing on the right-hand side of the regression, estimation is to be carried out by the Generalized Method of Moments (GMM).

While central banks usually act forward-looking because of the lags in the transmission of monetary policy impulses to inflation, the forward-looking interest rate rules estimated in the literature are not without problems. The inclusion of an expectational regressors at some lead, as for instance $E_t(\pi_{t+4})$, brings about autocorrelated residuals which in the usual dynamic equations with a lagged interest rate as a regressor may well cause biased estimates. In addition, this autocorrelation makes the correct specification of the dynamics of the estimated difficult. All of the existing studies assume very simple dynamics by introducing only one lagged short-term interest rate term. Residual autocorrelation beyond the order that is introduced by the leading regressors $E_t(\pi_{t+4})$ is not tested, although it may give an indication whether a more complicated dynamic specification is needed. The fact that higher order lags of the interest rate as well as of the output gap and the inflation rate from further in the past may also have directly affected the central bank's decisions is precluded by these specifications. Again, misspecification of these dynamic effects may well lead to autocorrelated residuals with the consequence of biased estimates of the coefficient standard errors and — since a lagged endogenous variable is among the regressors — even the coefficients themselves.

In addition, recent theoretical research has raised doubt on the way "forecasts" are generally accounted for in forward-looking Taylor rules. Woodford and Giannoni (2002) find that optimal rules may in the case of inflation inertia be forecast-based, but that the forecasts enter the rule in a more complicated way than usually assumed.[11] Moreover, in their model, it is the forecast for the current and the next quarter that matters most, forecasts for later periods are barely relevant. Overall, the authors conclude that forecasts play a relatively small role in the optimal monetary policy rule.

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[10] For the Fed from the 1980s on, Clarida et al. (1998, 2000) compute values in the range of 1.79 to 2.15 for β and in the range of 0.07 to 0.93 for γ whereas Orphanides (2001) calculates values in the range of 1.80 to 1.95 for β and 0.17 to 0.27 for γ. For a fictitious euro area central bank, Gerdesmeier and Roffia (2003) find a coefficient for the inflation gap in the range of 1.9 to 2.2, for the output gap of 0.1 to 0.5.

[11] For instance, a higher inflation forecast may at times result in a *lower* current interest rate, in order to cause higher current inflation to avoid sudden changes in inflation which in their model cause the greatest welfare losses. See Woodford and Giannoni (2002, 30f.).

To avoid the potential pitfalls in the estimation of forward-looking rules, we will in the following estimate dynamic non-forward-looking rules for the Bundesbank. Still, our estimates do not preclude that the Bundesbank acted forward-looking. In fact, the estimated functions can be interpreted as reduced forms of forward-looking rules. While we cannot attach a structural interpretation to each of the coefficients, in the sense that we can, for instance, determine whether the lagged output gap is significant because the Bundesbank attempted to stabilize the business cycle or simply because it served to forecast future inflation, the coefficients nevertheless show the overall importance of contemporaneous and lagged inflation and lagged output gap data for the Bundesbank's decisions.

To allow for a more complicated dynamics in the interest setting process, we introduce further lags of the difference between actual and target inflation and of the output gap in our empirical equation. As shown by Aoki (2003), lags of the order p of the interest rate, the inflation rate and the output gap enter a reduced form policy rule when the random shocks to inflation and output follow $AR(p)$ processes. Without restricting the lag order p to be the same across all variables a priori our dynamic Taylor rule reads

$$r_t = \delta_0 + \pi_t^* + \sum_{i=1}^{p_1} \delta_{1i} r_{t-i} \sum_{i=0}^{p_2} \delta_{2i} \pi_{t-i} + \sum_{i=1}^{p_3} \delta_{3i} (y_{t-i|t} - y_{t-i|t}^*) \ . \qquad (2)$$

Note that as above, we allow inflation to affect the interest rate contemporaneously while the output gap enters with a lag of one quarter. Notice further that the second sub index at the lags of the real-time output gap $y_{t-i|t} - y_{t-i|t}^*$ is fixed at date t. This way we ensure that the lags of this variable always refer to the most recent vintage of output gap data.

Unfortunately, coefficient estimates from this dynamic Taylor rule are not easily compared directly to the Taylor rules proposed in the literature, which are usually static or contain only a single lag of the interest rate to account for interest rate smoothing. Comparability is, however, easily established by re-parameterizing (2) as an error-correction model, that is[12]

$$\begin{aligned} \Delta r_t &= \theta_0 + \theta_1 r_{t-1} + \theta_2 \pi_t^* + \theta_3 \pi_t + \theta_4 (y_{t-1|t} - y_{t-1|t}^*) \\ &\quad + \sum_{i=1}^{p_1-1} \theta_{1i} \Delta r_{t-i} + \sum_{i=0}^{p_3-1} \theta_{3i} \Delta \pi_{t-i} + \sum_{i=1}^{p_4-1} \theta_{3i} \Delta (y_{t-i|t} - y_{t-i|t}^*) \qquad (3) \end{aligned}$$

where Δ is the first-difference operator ($\Delta x_t = x_t - x_{t-1}$) and the long-run parameters of the static rule (1) are easily recovered as $rr = \frac{\theta_0}{\theta_1}$, $\beta^* = \frac{\theta_2}{\theta_1} = -(\beta - 1)$, $\beta = \frac{\theta_3}{\theta_1}$ and $\gamma = \frac{\theta_4}{\theta_1}$. As an alternative to calculating the long-run coefficients from the estimated coefficients of the error-correction equation, the long-run coefficients can be estimated directly together with their standard errors using the so-called Bewley-transform of the error-correction equation (Wickens and Breusch 1988). This method will be employed below.

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[12] For a similar error-correction approach applied to U.S. data, see Judd and Rudebusch (1998).

A particular role is played by the coefficient θ_1 in this error-correction framework. First, it can be interpreted as $\rho - 1$, where ρ is the sum of the coefficients on the lagged interest rate. As such it is directly comparable to the lagged interest rate coefficients estimated from more restrictive approaches in the literature. Second, in case the variables in the equation are integrated, the standard t-statistic of θ_1 can be used to test the hypothesis that the two series are not cointegrated (see Kremers et al. 1992). However, testing for non-stationarity using the DF-GLS test of Elliott et al. (1996) with a constant term and five autoregressive lags included, we were able to reject the null hypothesis of non-stationarity for the short-run interest rate at the 1% level and for the inflation rate at the 5% level of significance. We could also reject non-stationarity for all of the real-time output gap measures at least on the 10% level; the ex post measures are stationary by construction. Thus, testing for cointegration is not relevant in the present context.

For the estimation, the maximum lag order of the error-correction model is chosen to be 4 ($p_1 - 1 = p_2 - 1 = p_3 - 1 = 5$), since that lag order should be sufficient to remove any residual autocorrelation due to seasonality. Tests for autocorrelation applied to each equation supported this view, implying that all estimated equations are free of autocorrelation. To reach a parsimonious specification and consequently low coefficient standard errors, first-differenced variables with a marginal significance level of their t-statistic of below 7.5 percent were restricted to zero, implying that the actual lag order of a particular equation may well be lower than 5. Heteroscedasticity-robust standard errors are used for calculating t-statistics.

The OLS long-run estimates for our eight measures of the output gap are presented in Table 3 together with the $\bar{R}^2$, which measures how much of the variance of the *change* in the three-month-market rate is explained by the regression[13] and the results of the Exp$F$ test for a structural break at an unknown break point proposed by Andrews and Ploberger (1994). The test procedure is to generate LM statistics of the hypothesis of no structural break for each data point in the sample, except from a trimming region of 15 percent at the start and the end, and to use either the minimum or an exponentially weighted average of these LM statistics as the final statistic. P-values for the non-standard distribution of this test (given in squared brackets) were obtained using the method proposed by Hansen (1997). The test rejects the null hypothesis of no structural break at a 10% percent level of significance for the fixed sample linear and the rolling sample quadratic detrending procedures. For the remaining models, the test does not indicate any parameter instability.

For each of the three detrending procedures, the first line gives the results for the ex post revised data. Note that the coefficient estimates are very close for these data across the detrending procedures. A researcher working with ex post revised data would, thus, have concluded that the choice of the detrending procedure does not matter much for estimating the Bundesbank's reaction function. In addition, the researcher would have concluded that the Bundesbank did not look at the output gap when taking its decisions, not even when forecasting inflation, since, regardless of the detrending procedure, the estimated coefficients of the output gap γ are not

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[13] The $\bar{R}^2$ refers to the error-correction parametrisation (3), not to the Bewley-transform since the latter is estimated by instrumental variables.

significantly different from zero. Thus, while the researcher had found the coefficient estimates of the inflation rate β to be close to the value of 1.5 suggested by Taylor (1993) — implying that the Bundesbank controlled real short-term interest rates by varying nominal interest rates by more than the change in inflation —, she had rejected the Taylor rule as a description of the decision making process at the Bundesbank for the insignificant output gap coefficient.

With real-time data for the output gap, the evidence is more favorable for the Taylor rule. While the estimates of all coefficients vary more widely across the detrending procedures compared to the ex post revised output gap data, the estimates of the inflation coefficient associated with the different procedures are still close to 1.5. In contrast to the ex post data based estimates, however, depending on the detrending procedure, there are now also some statistically significant output gap coefficients. The three models with the highest explanatory power as gauged by their $\bar{R}^2$ all have estimates for γ that are significantly different from zero. The best-fitting model, the one based on rolling-sample linear detrending, and likewise the model based on fixed-sample quadratic detrending even give coefficient estimates close to Taylor's suggestion of 0.5. For the Hodrick-Prescott filter-based output gap, however, the estimate is substantially higher, reflecting the fact that real-time output gaps based on this detrending procedure are less volatile than those based on other two procedures (see Figure 3). This divergence of the estimated coefficients highlights their dependence on the detrending method which only becomes apparent when real time data are used in the analysis since pronounced differences in the volatility of the output gap estimates only appear with real-time data, the volatility of the ex post revised output gaps is relatively similar across the detrending methods.

The parameter estimates, moreover, indicate substantial inertia in Bundesbank interest rate setting, as can be seen from the significant estimates for the adjustment coefficient $\rho - 1$. By and large in line with previous studies, we find an estimate for ρ — which measures the sum of all lagged interest rate coefficients — of about 0.8, implying that only 20 percent of the current level of the interest rate was influenced by the most recent developments concerning inflation and output, the rest was determined before. In contrast to previous studies, however, the dynamic specification often involved more than one lag of the interest rate. This finding of a strong backward-looking element in the Bundesbank's implicit decision is interesting since recent research on optimal interest rate rules has shown that optimal rules also have such a backward-looking character. Woodford (1999, 2000) argues that when private agents with rational expectations act forward-looking and the decisions of these private agents determine the economy's future path, optimal monetary policy cannot act purely forward-looking, that is, it cannot act only upon those aspects of the state of the economy that are relevant for forecasting the inflation. Instead, it must also act in response to past shocks and change the interest rate in the way that brings about the development of the economy it wishes the private sector to expect in order to fulfil its commitments and retain the credibility that ultimately makes its policy more effective. The optimal interest rate rules calculated by Woodford and Giannoni (2002) often involve more than one lag of the interest rate.

Somewhat astonishing is the estimate for β^* which should be equal to $-(\beta - 1)$ but is substantially higher for all detrending procedures. However, this result disappears when ”outliers” are controlled for. We find three poorly modelled observations, as indicated by a studentized residual with a t-value of more than 3.0, which we model by a 0/1 dummy. Two of the dummies ”model” the episode in the first half of 1981 where the Bundesbank partly followed the interest rate hike in the United States during the Volcker disinflation. The other dummy captures the extraordinary sharp fall in German interest rates in early 1975. We re-estimate the error-correction model for the output gap based on linear detrending including these dummies, impose the restriction $\beta^* + \beta = 1$ and get (long-run parameters and their absolute, heteroscedasticity-robust t-statistics obtained from the Bewley-transform shown in squared brackets):

$$\begin{aligned} \Delta r_t \quad = \quad & 0.82 - 0.23 \Big[r_{t-1} - 0.32\pi_t^* + 1.32\pi_t + 0.70(y_{t-1|t} - y^*_{t-1|t}) \Big] \\ & (5.94) \quad (7.49) \qquad\qquad (2.23) \quad\; (9.23) \quad\; (8.91) \\ & +0.24\Delta r_{t-1} - 0.11\Delta r_{t-3} - 1.96D75Q1 + 1.98D81Q1 + 1.79D81Q2 \\ & (3.39) \qquad\quad (1.41) \end{aligned} \tag{4}$$

Again, non-cointegration is rejected and the long-run coefficient estimates are highly significant and close to the original Taylor rule. An F-test of the restriction $\beta^* + \beta = 1$ yields a marginal significance level of 0.06. Interest rate inertia are substantial with changes of the lagged interest rate significant with a lag of one and three quarters. Stability of the long-run parameters over the sample is largely confirmed by (forward and backward) recursive estimation (figure 7); apart from some instability in 1994 shown in the backward recursion, the parameters do not deviate much from the full-sample estimates.

Overall, our analysis supports the view that the Bundesbank by and large followed a Taylor rule. In case some form of flexible linear detrending is employed to estimate the output gap, the coefficients on the inflation gap and the output gap are even quite close to the values originally proposed by Taylor (1993) for the United States. In all cases we find a substantial interest rate smoothing component.

3.3 The Role of Money

Minford et al. (2002) have recently argued that finding the output gap and the inflation gap significant in an interest rate regression such as ours need not necessarily imply that the central bank followed a Taylor rule. The authors show that a Taylor-type reaction function could also arise if the central bank followed quite different monetary policy rules such as monetary targeting.[14] In this case, the empirically estimated Taylor-type reaction function is a reduced form of the actual monetary policy rule, with the money supply hidden in the residual. Since the Bundesbank has always emphasised monetary targeting as its monetary policy strategy, we analyze in the following whether there is an additional role for money in our estimated

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[14] See also Taylor (1999) on the relation between his rule and monetary targeting.

Bundesbank reaction function. Specifically, we will test whether deviations of the Bundesbank's preferred monetary aggregate from its announced target value led to changes in the 3-month money market rate over and above those implied by the Taylor rule.

As our measure of the deviation of the money stock from its target, we take the difference between the annualised quarter-to-quarter change of the target monetary aggregate $\widehat{M}_t$ to the annual rate of change of the money stock announced for (the fourth quarter of) that year $\widehat{M}^*_t$. Unfortunately, in this part of the study we have to rely on ex-post revised data as we neither have real-time data on the central bank money stock, the monetary aggregate the Bundesbank targeted between 1975 and 1987 nor on M3, the aggregate the Bundesbank's announced annual targets or corridors for between 1988 and 1998.[15] The targets or corridors usually referred to the rate of monetary growth in the fourth quarter of the respective year as compared to the fourth quarter of the year before. To obtain a time series of point targets, we convert corridors into point targets by taking the average between the upper and lower bound of the corridor as the target rate. From this we construct the deviations $(\widehat{M}-\widehat{M}^*)_t$ the lags of which we use as an additional regressor in equation (4). After some experimentation we find (again imposing the restriction $\beta^* + \beta = 1$ on the long-run estimates)[16]

$$\begin{aligned}
\Delta r_t \quad = \quad & 0.84 - 0.21[r_{t-1} - 0.23\pi^*_t + 1.23\pi_t + 0.72(y_{t-1|t} - y^*_{t-1|t}) \\
& (4.04) \quad (6.68) \qquad\quad (1.42) \quad\; (7.51) \quad\; (9.75) \\
& \qquad\qquad\qquad +0.04(\widehat{M} - \widehat{M}^*)_{t-3} + 0.07(\widehat{M} - \widehat{M}^*)_{t-4}] \\
& \qquad\qquad\qquad\quad (2.21) \qquad\qquad\qquad\quad (4.03) \\
& +0.13\Delta r_{t-1} - 0.24\Delta\pi_{t-2} \\
& (1.64) \qquad\quad (2.90) \\
& +1.39D79Q2 + 1.20D79Q4 + 1.98D81Q1 + 1.79D81Q2 \quad . \qquad (5)
\end{aligned}$$

Apart from the new regressors $(\widehat{M} - \widehat{M}^*)_{t-3}$ and $(\widehat{M} - \widehat{M}^*)_{t-4}$, the reaction function has not changed much. The long-run coefficient of the output gap is nearly the same as in (4), the long-run coefficient of the inflation rate is slightly smaller, and the coefficient of the target inflation rate is now only marginally significant. The long-run coefficients for the money stock deviations are statistically significant with correct signs, so on average there was an impact of money on the Bundesbank's interest rate decisions. Note however, that in economic terms this impact was small. Adding the coefficients of $(\widehat{M} - \widehat{M}^*)_{t-3}$ and $(\widehat{M} - \widehat{M}^*)_{t-4}$ gives a value of only 0.11, implying that when M3 exceeded its announced target value by one percentage point, the Bundesbank on average increased interest rates only by 0.11 percentage points.

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[15] See Baltensberger (1999) for a detailed review of the Bundesbank's policy in the 1980s and 1990s.

[16] Since the Bundesbank introduced monetary targeting in 1975 and we employ up to 4 lags of the monetary deviation measure, the sample starts now starts in 1975Q4. We omit the observation for 1991Q1 for which no growth rate of M3 can be calculated due to the change in the statistic from western German to pan-German data.

We, therefore, conclude that while monetary aggregates also played a role in the Bundesbank's interest rate decisions, the main impulses came from variables that figure in the Taylor rule. This conclusion seems to be in line with the evidence from the Bundesbank minutes presented above. One caveat to our conclusion is that it relies on ex post revised data for the money stock, not on the monetary data Bundesbank officials had actually at hand when taking their decisions.

4 Conclusions

This paper has taken a fresh look at the evidence concerning the underpinnings of the monetary strategy of the Deutsche Bundesbank, a central bank with the best inflation record in the post-Bretton Woods period and an institution often regarded as a model for the European Central Bank. We investigated whether the Bundesbank's interest rate decisions during the period of 1973 to 1998 can be approximated by a simple interest rate rule of the type proposed by Taylor (1993). In contrast to previous studies, we took the informational requirements of the rule explicitly into account and based our analysis on real-time data. This distinction is important since there are significant differences between output gaps estimated ex post and in real-time that, in turn, affects the size of the output gap coefficient in our estimated monetary reaction functions.

Monetary reaction functions employing real-time output gaps generated by a number of different detrending methods indicate that a Taylor-type rule can track the Bundesbank's actual policy quite well. Movements in German short-run interest rates are thus broadly consistent with a policy aiming at keeping inflation close to the Bundesbank's announced target, possibly also at retaining a stable level of output around its trend. Taylor rules calibrated and estimated on the basis of the calculated real-time output gaps have an acceptable fit and for some detrending methods the estimated coefficients show an astonishing analogy to the coefficients proposed in the original publication of Taylor (1993), except for a significant interest smoothing component. Monetary aggregates, in contrast, only played a minor role for interest rate decisions. Thus, while one has to keep in mind that the correlation between the actual short-term interest rates and those suggested by the Taylor rule does not necessarily imply that the Bundesbank had this form of policy rule in mind when setting interest rates, in effect it acted as if it did so.

A number of simulation studies[17] have recently shown that an interest rate rule with a parameterisation close to Taylor's original proposal, usually including some interest rate smoothing component, has a number of superior properties. Our empirical results for Germany point into the same direction. Part of the success of the Bundesbank in fighting inflation during the 1970s to 1990s seems to be attributable to the fact that it reacted in a way to shocks to inflation and GDP that was quite similar to a Taylor rule augmented by interest rate inertia. Overall our results, thus, strengthen the evidence in favor of a modified Taylor rule for practical monetary policy.

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[17] See the papers in Taylor (1999a).

In addition, our estimates shed new light on the discussion whether the poorer performance of the German economy relative to the United States in terms of output growth and employment over the last decades can be attributed to a tighter monetary policy in Germany. Our estimates reveal that the Bundesbank over the period 1973 to 1998 acted more or less in the same manner as the Fed did under Alan Greenspan. Despite German historic experiences with two hyperinflations, the "anti-inflation bias" of the Bundesbank does not seem to have been stronger than that of the Fed. There is, thus, no indication, that German monetary policy has been systematically more restrictive than its U.S. counterpart.

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Table 1: Real-Time Data

	1973Q1	....	....	....	....	1998Q4
1962Q1						c_t
....						c_t
1972Q4	a_t					$b_t; c_t$
....		a_t				$b_t; c_t$
....			a_t			$b_t; c_t$
....				a_t		$b_t; c_t$
....					a_t	$b_t; c_t$
1998Q3						$a_t = b_t = c_t$

Table 2: Summary Statistics on Output Gap Revisons

	Mean of Revison	St. Dev. of Revision	RMSE of Revision	St. Dev. Ex Post Gap	Corr
Linear Trend					
fixed sample	-5.29	2.83	5.99	2.26	33.12
rolling sample	-1.01	2.20	2.41	"	68.34
Quadratic Trend					
fixed sample	1.47	4.46	4.67	3.30	12.27
rolling sample	-0.17	4.35	4.33	"	-4.12
Hodrick Prescott					
Filter	-0.09	1.67	1.66	1.58	20.86

All figures are given in percent. Revisions are the differences between the real-time and the ex post output gaps. RMSE is the mean squared error of the revision. Corr is the correlation of the real-time series with the ex post series.

Table 3: Long-Run Coefficients of Dynamic Bundesbank Rules 1974Q2-1998Q4

	β^*	β	γ	$\rho - 1$	$\bar{R}^2$	exp$F$
			Linear Trend			
ex post	-1.43	1.47	0.23	-0.18	0.44	6.76
	(3.73)	(5.80)	(1.36)	(4.98)		[0.17]
fixed sample	-1.36	1.31	0.08	-0.16	0.37	6.28
	(3.49)	(5.26)	(0.61)	(3.75)		[0.08]
rolling sample	-1.03	1.50	0.52	-0.25	0.53	5.80
	(3.81)	(9.72)	(5.55)	(6.32)		[0.43]
			Quadratic Trend			
ex post	-1.47	1.44	-0.10	-0.20	0.44	6.78
	(4.01)	(5.38)	(1.03)	(5.18)		[0.17]
fixed sample	-0.61	1.34	0.35	-0.22	0.47	6.46
	(1.38)	(6.55)	(3.18)	(5.48)		[0.21]
rolling sample	-1.36	1.29	-0.04	-0.19	0.43	7.78
	(3.57)	(4.59)	0.25	(4.78)		[0.09]
			Hodrick Prescott Filter			
ex post	-1.22	1.24	0.23	-0.20	0.44	5.86
	(2.79)	(4.79)	(1.07)	(5.13)		[0.30]
ex ante	-2.36	1.85	1.30	-0.17	0.48	6.51
	(5.24)	(7.76)	(3.71)	(5.16)		[0.30]

Figures in round brackets are absolute t-statistics. Figures in squared brackets are the p-values of the expF test.

Figure 1: Growth of Real GDP Over Previous Year: Ex Post and Real-Time

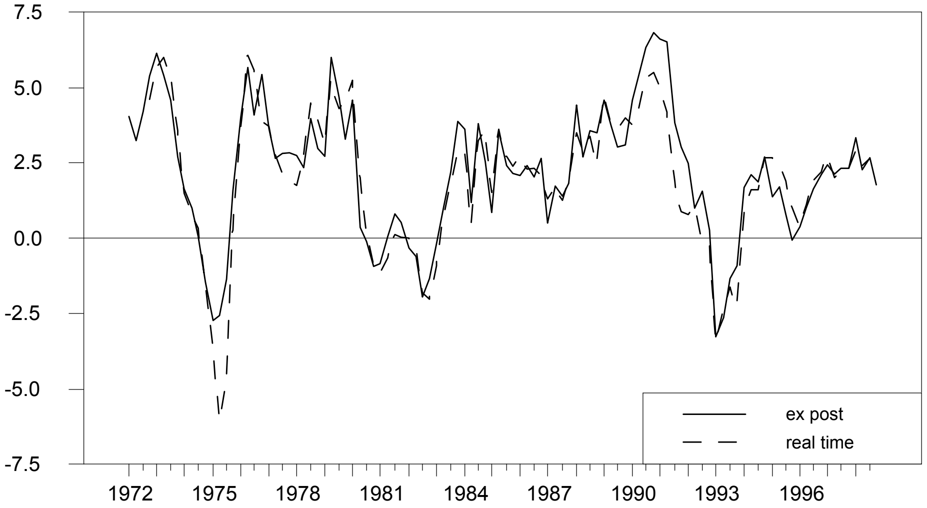


Figure 2: Ex Post Estimates of the Output Gap

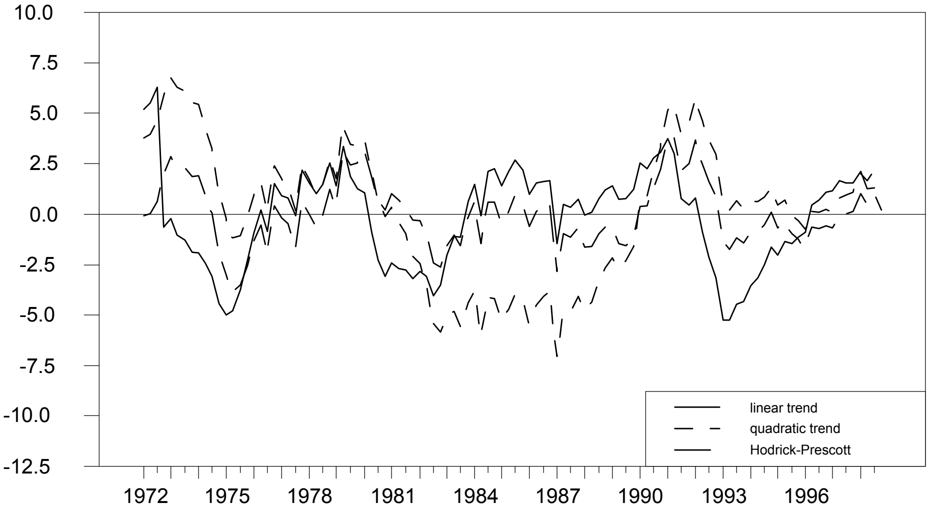


Figure 3: Real-Time Estimates of the Output Gap

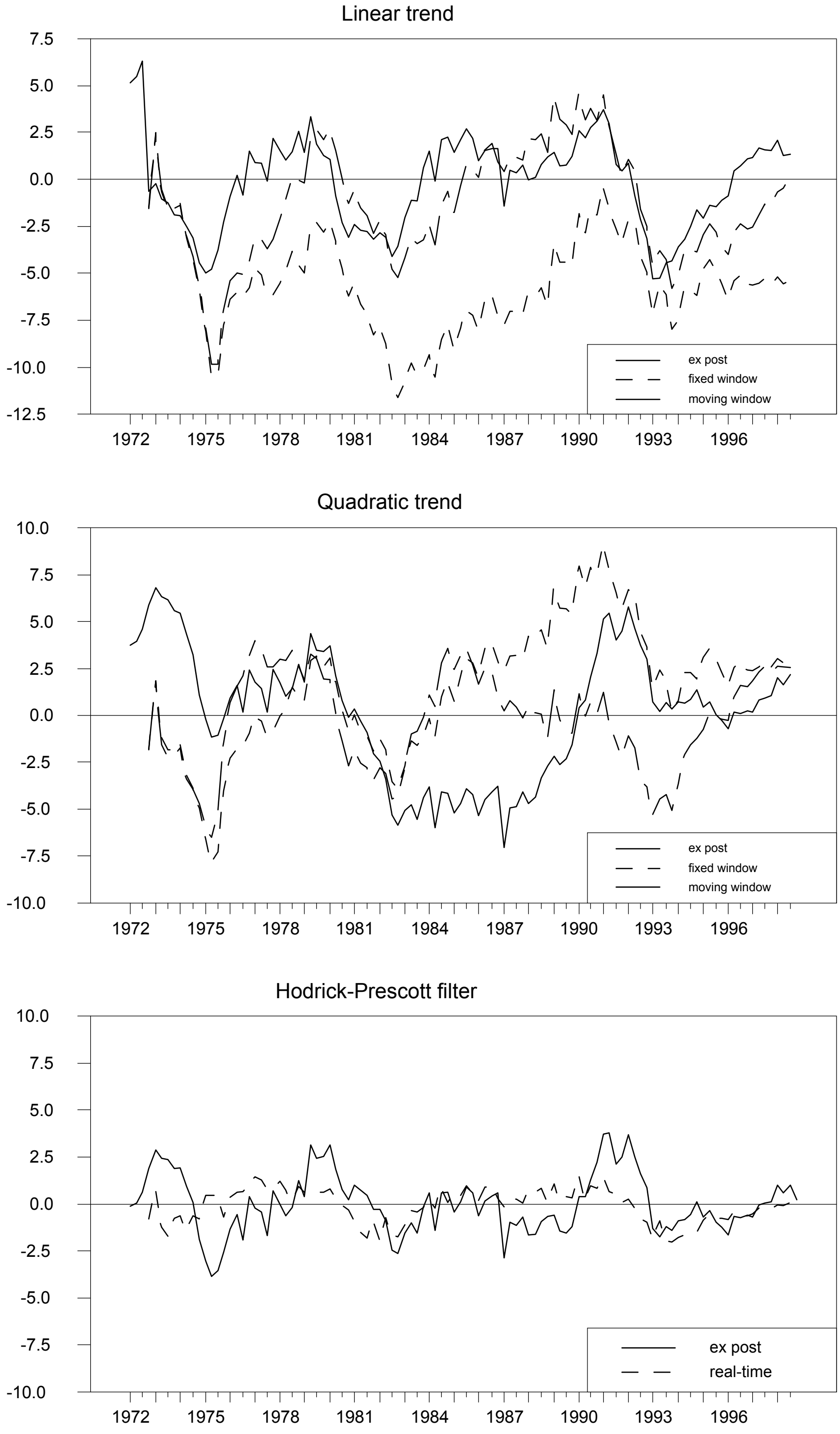
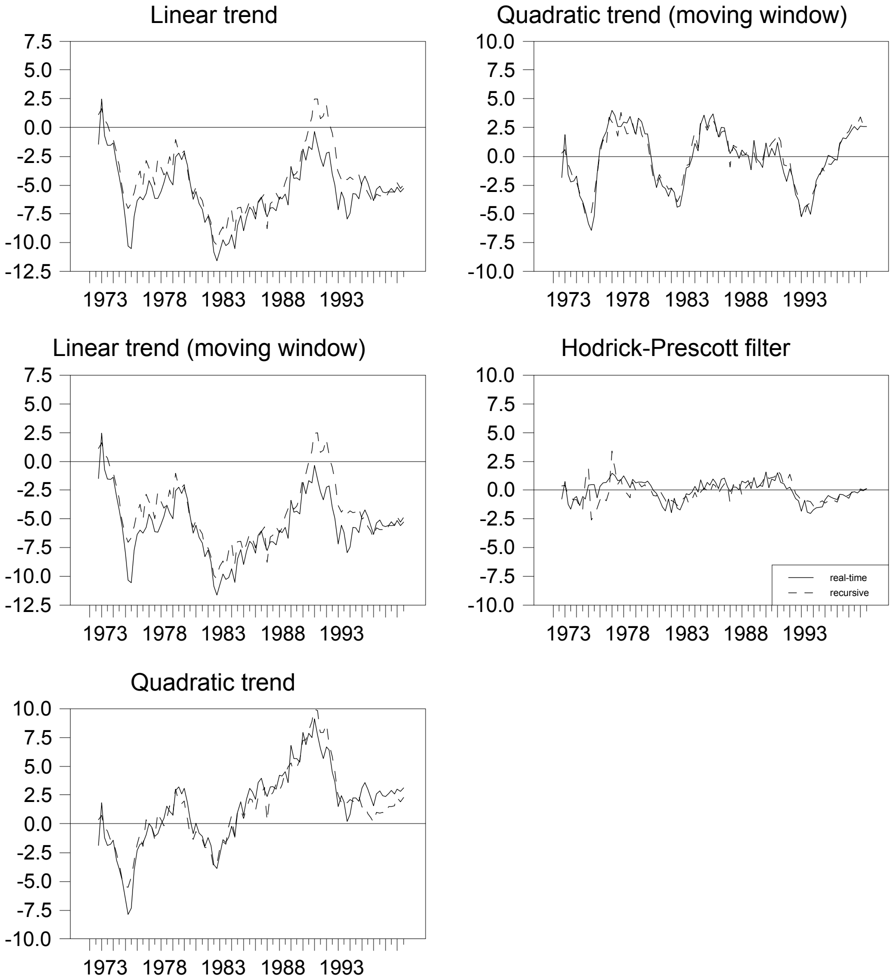


Figure 4: Real-Time Versus Ex Post Recursive Output Gap Estimates



Linear trend

Quadratic trend (moving window)

Linear trend (moving window)

Hodrick-Prescott filter

Quadratic trend

Figure 5: Real-time SVR output gap measure versus time series-based measures

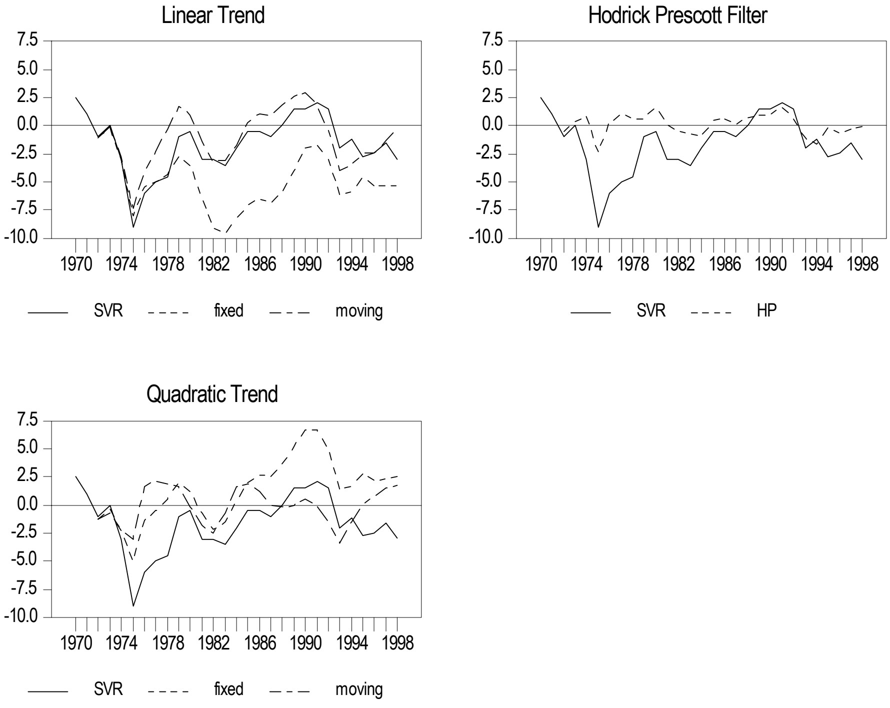


Figure 6: Calibrated Taylor Rates and the FIBOR

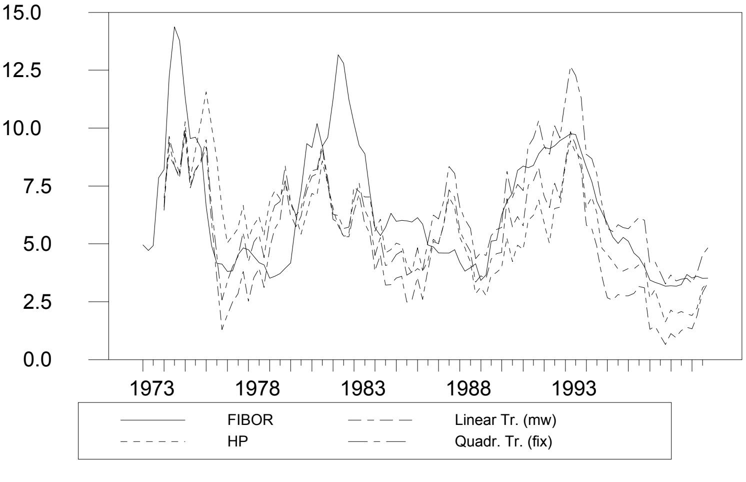


Figure 7: Recursive Coefficient Estimates ±2 Standard Errors