Taylor Rules with Real-Time Data: A Tale of Two Countries and One Exchange Rate

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Abstract

Most studies which focus on explaining central bank behavior using interest rate reaction functions fit a single specification of a monetary policy rule using the longest available span of historical data. This data, however, is revised and does not reflect the information available to monetary authorities at the time they are formulating policy. We find that differences in estimated Taylor rules based on revised and real-time data are more important for Germany than for the U.S., Taylor rules using real-time data suggest significant differences between U.S. and German monetary policies, and Taylor rules for the U.S. using inflation forecasts are nearly identical to those using lagged inflation rates. We then investigate the implications of the use of real-time data for evaluating out-of-sample exchange rate predictability. Using a model for the dollar/mark nominal exchange rate with forecasts based on Taylor rule fundamentals, we find strong evidence of predictability of exchange rate changes at the one-quarter horizon using real-time, but not revised, data. The evidence of predictability with real-time data does not increase if inflation forecasts, rather than lagged inflation rates, are used in the forecasting equation.

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1. Introduction

John Taylor's (1993) paper, "Discretion versus Policy Rules in Practice," has inspired voluminous empirical research on interest rate reaction functions using a variety of specifications. The simplest monetary policy rule states that the central bank adjusts its short-term nominal interest rate in response to changes in inflation and the output gap.[1] Subsequently, policy rules that incorporate inertia and relate the interest rate to expectations of inflation, the output gap, and output gap growth have been found to be more successful than Taylor's original specification.[2] Although these rules are modifications of the original specification, referring to them as Taylor rules has become standard in the literature.

The first papers to estimate Taylor rules, such as Clarida, Gali, and Gertler (1998), (CGG), fit specifications to the longest available span of historical data. However, as argued by Orphanides (2001), revised data does not reflect the information available to monetary authorities and is therefore a poor guide to understanding their behavior. He finds that U.S. monetary policy is less accommodative to inflation when Taylor rules are estimated using real-time data rather than revised data. The logic that monetary policy evaluation should be conducted by using only information available to policymakers at the time they are formulating policy seems compelling and recent papers, such as Rudebusch (2006), tend to use real-time data. Interest rate reaction functions using real-time data have also been estimated by Nelson (2003) for the United Kingdom and Clausen and Meier (2003) and Gerberding, Worms, and Seitz (2005) (GWS) for Germany.

While data revisions for inflation and output both create differences between the data available to researchers and the data available to policymakers, the differences are more substantial for output. For inflation, the differences are only caused by the data revisions themselves. For

[1] This form of the Taylor rule naturally arises under the assumption that the Federal Reserve minimized the intertemporal loss function consisting of the loss due to deviation of (expected) inflation from its target and the output gap (see, for example, Woodford (2001)).

[2] Orphanides (2007) provides a recent survey of various types of Taylor rules.

output, since the relevant variable is the output gap, the differences are also caused by revisions to potential output. Another distinction involves real-time data that, while not available to the public, is available to policymakers. This data, including Greenbook forecasts of inflation and internal Federal Reserve estimates of the output gap and forecasts of output gap growth, has been extensively used by Orphanides (2001, 2003, 2004) to estimate Taylor rules that incorporate the information available to the FOMC at the time of monetary policy decisions.

Taylor rules also provide a framework for modeling exchange rate determination. By specifying Taylor rules for two countries and subtracting one from the other, an equation is derived with the interest rate differential on the left-hand-side and the inflation and output gap differentials on the right-hand-side. By using uncovered interest rate parity (UIRP), where the interest rate differential equals the expected rate of depreciation, and solving expectations forward, an exchange rate equation is derived. Engel and West (2006) and Mark (2007) have examined the empirical performance of Taylor-rule based exchange rate models.

The Taylor-rule based exchange rate model can also be evaluated out-of-sample. If the UIRP assumption is maintained, an exchange rate forecasting equation can be derived because an increase in either the inflation or the output gap differential would lead to an expected depreciation of the currency. An extensive literature, however, has shown that regressing exchange rate changes on interest rate differentials not only does not produce coefficients equal to one, it often produces negative coefficients. This is consistent with the recent "carry trade" literature, where countries with high interest rates appear to have appreciating currencies. In addition, as argued by Clarida and Waldman (2007), if an unexpected increase of the inflation rate above its target creates the expectation that the central bank will respond by raising the interest rate, the exchange rate will appreciate, rather than depreciate, in response to the news. We therefore use Taylor rule fundamentals to forecast exchange rate changes, but remain agnostic regarding the direction of the forecasts.

Since the seminal work of Meese and Rogoff (1983), it has proven very difficult for models to forecast exchange rates better than a na ve no change (random walk) model. Cheung, Chinn, and Pascual (2005), for example, conclude that no model does statistically better than the random walk. Virtually all existent literature on exchange rate predictability has used fully revised data to assess the out-of-sample performance of empirical exchange rate models. Although the argument for using real-time data seems at least as compelling for exchange rate forecasting as for Taylor rule modeling, the only paper, to our knowledge, that uses real-time data to evaluate nominal exchange rate predictability is Faust, Rogers and Wright (2001). They examine the predictive ability of Mark's (1995) monetary model using real-time data for Japan, Germany, Switzerland and Canada vis-a-vis the U.S. dollar and conclude that, while the models consistently perform better using real-time data than fully revised data, they do not perform better than the random walk model.

One potential reason for the failure of empirical exchange rate models to forecast better than a random walk out-of-sample is that the tests commonly used to compare predictive ability, those of Diebold and Mariano (1995) and West (1996) are, as demonstrated by Clark and McCracken (2001), severely undersized when used with nested models. Molodtsova and Papell (2007), exploiting recent econometric work by Clark and West (2006), test the out-of-sample predictability of nominal exchange rate changes using Taylor rule fundamentals model for 12 countries from 1973 to 2006. While real-time data is not available during the post-Bretton Woods period for most of the countries, they construct output gaps as deviations from "quasi-revised" trends in potential output, where the trends, while incorporating data revisions, are updated each period so as not to incorporate *ex post* data. Although they find strong evidence of short-run predictability with semirevised data for most of the considered currencies using Taylor rule fundamentals, they do not produce forecasts with real time data.[3]

The objective of this paper is to estimate Taylor rule interest rate reaction functions with real-time data for the United States and Germany from 1979, the beginning of the European Monetary System, through 1998, the advent of the Euro, and to use these specifications as fundamentals for evaluating out-of-sample forecasting of the United States Dollar/Deutsche Mark (USD/DM) nominal exchange rate with real-time data. The reasons for the choice of countries and exchange rate are twofold. First, the USD/DM exchange rate, along with the dollar/yen rate, was the centerpiece of the post-Bretton Woods pre-Euro international monetary system. Second, Germany and the United States are the two countries for which the highest quality real-time data are available over this period.

We first use real-time datasets for both the U.S. and Germany to estimate interest rate reaction functions of similar form as in Orphanides (2003) for the U.S. and CGG for Germany, and then use these reaction functions to forecast the USD/DM exchange rate out-of-sample. While we take it as self-evident that real-time data should be used for Taylor rule estimation and forecasting, the same real-time data should not be used for both purposes because the data available to policymakers is not necessarily available to market participants. These issues are particularly important for the U.S. Greenbook inflation forecasts and internal Federal Reserve estimates of potential output are not available to the public for a minimum of five years so, while they are real-time data for the purpose of Taylor rule estimation, they are clearly not real-time data for the purpose of forecasting. For Germany, while the real-time output gap can be constructed based on potential output taken from the Bundesbank real-time database, it is not clear how available this data

[3] Engel, Mark and West (2007) use a more constrained version of the Molodtsova and Papell (2007) specification with fully revised data. They find less evidence of short-horizon predictability, but more evidence of long-horizon predictability, than Molodtsova and Papell.

was to market participants in real time. For the purpose of forecasting, but not estimation, we therefore construct real-time output gap estimates obtained by applying a quadratic trend to real-time output in addition to using real-time estimates of potential output only contemporaneously available to policymakers. We also use inflation forecasts from the Survey of Professional Forecasters (SPF), which are available to market participants in real time, in addition to Greenbook inflation forecasts.

We estimate the "standard" Taylor rule, where only inflation and the output gap appear as regressors, and find relatively small difference in the monetary policy rule coefficients obtained with revised and real-time data for the U.S. The response of the interest rate to increases in inflation is always greater than one, indicating the monetary policy is stabilizing, and fairly close to Taylor's (1993) postulated value of 1.50. The coefficients on the output gap are small and insignificant. The implications of using revised data for Germany are more substantial. With interest rate smoothing and the Bundesbank's output gap measure, monetary policy is only stabilizing with respect to inflation if real-time data is used for policy evaluation. Following CGG, we augment the standard rule by allowing the German money market rate to respond to the changes in the real Deutsche Mark/United States Dollar (DM/USD) exchange rate, and find a significant response of the interest rate to the real exchange rate.

It is often argued that forward-looking monetary policy rules provide a superior description of the Federal Reserve's behavior than rules based on the most recent estimates of inflation, and we therefore estimate both contemporaneous and forward-looking monetary policy rules with Greenbook inflation forecasts up to four quarters ahead for the U.S. We do not find any difference between using lagged and forecasted inflation for estimation of Taylor rules with real-time data. This is in accord with the argument in Taylor (1999) that, since forecasts of the future are based on current and lagged data, inflation forecast rules are no more forward-looking than rules explicitly based on current and lagged data.[4] Following Orphanides (2001, 2003), we also estimate forward-looking rules with forecasts of output gap growth. In accord with his results, these natural-growth targeting rules produce larger coefficients on inflation, significant output gap growth (but not output gap level) coefficients, and a somewhat better fit (measured in terms of the R-squared) than the rules without forecasts of output gap growth. Since there is no analog to Greenbook forecasts for Germany, we cannot estimate forward-looking monetary policy rules using real-time data for the Bundesbank.[5]

We proceed to investigate how the use of real-time data affects conclusions about exchange rate predictability with Taylor rule fundamentals by focusing on the USD/DM nominal exchange rate. In many cases, such as forecasting GDP, the rationale for using real-time data is to avoid giving an informational advantage to the econometrician by the use of revised data that wasn't available to market participants. Because the exchange rate is an asset price, the rationale here is different. If the market's forecast of the exchange rate changes in response to new information, market participants will trade currencies so the forecast becomes self-fulfilling. With short-horizon forecasts, data revisions will provide the econometrician with information that is not available to market participants either when the forecast is made or when it is realized. The use of this additional information has the potential to make "forecasts" with revised data inferior to forecasts conducted in real time. The same rationale applies to information available to the Federal Reserve but not to the market.

The out-of-sample forecasting results illustrate the importance of both real-time data and Taylor rule specification. In the context of standard Taylor rules, models that allow differential inflation and output coefficients in the Federal Reserve and Bundesbank reaction functions and

[4] With real-time data, inflation forecasts are necessarily made with lagged data, and include "forecasts" of the contemporaneous inflation rate.

[5] CGG estimate forward-looking rules with revised data by using ex post realized values for inflation and instrumental variables techniques. This methodology, however, cannot be applied with real-time data.

include the exchange rate in the Bundesbank reaction function provide greater predictive ability than the random walk model with real time but not revised data. Models that impose identical coefficients and/or do not include the exchange rate in the Bundesbank reaction function do not provide evidence of predictability of exchange rate changes with either revised or real-time data. These results are in accord with the Taylor rule estimates, where the coefficients are different between the countries and the exchange rate enters significantly into the Bundesbank reaction function, and with the intuition that forecasts of asset price changes might be worse with revised than with real-time data. The models with either Greenbook or SPF inflation forecasts do not outperform the standard Taylor rule models with lagged inflation rates, in accord with Taylor's (1999) point that inflation forecast rules are no more forward looking than rules with lagged inflation. Finally, the models that include output gap growth forecast worse out-of-sample than the other models, despite having a better in-sample fit, in accord with the intuition that using information that was not available to market participants has the potential to worsen forecasts.[6]

2. Taylor Rules

2.1 The Standard Taylor Rule

Taylor (1993) postulates a simple monetary policy rule to be followed by central banks,

$$i_t^* = \pi_t + \delta(\pi_t - \pi_t^*) + \gamma y_t + r^* \quad (1)$$

where i_t^* is the target for the short-term nominal interest rate, π_t is the inflation rate, π_t^* is the target level of inflation, y_t is the output gap, or percent deviation of actual real GDP from an estimate of its potential level, and r^* is the equilibrium level of the real interest rate. It is assumed that the target for the short-term nominal interest rate is achieved within the period so there is no distinction between the actual and target nominal interest rate.

6 These comparisons are all with the random walk model, not between alternative models.

According to the Taylor rule, the central bank raises the target for the short-term nominal interest rate if inflation rises above its desired level and/or output is above potential output. The target level of the output deviation from its natural rate y_t is 0 because, according to the natural rate hypothesis, output cannot permanently exceed potential output. The target level of inflation is positive because it is generally believed that deflation is much worse for an economy than low inflation. Taylor assumed that the output and inflation gaps enter the central bank's reaction function with equal weights of 0.5 and that the equilibrium level of the real interest rate and the inflation target were both equal to 2 percent.

The parameters π_t^* and r^* in equation (2) can be combined into one constant term $\mu = r^* - \delta\pi_t^*$, which leads to the following equation,

(2) $$i_t^* = \mu + \lambda\pi_t + \gamma y_t$$

where $\lambda = 1 + \delta$.

The condition that 1 + δ > 1 is known as the Taylor Principle, according to which when inflation exceeds its target level, the central bank raises its nominal interest rate more than one-for-one with inflation, so that the real interest rate increases. This has been emphasized by many academics and policymakers, including Greenspan (2004), as a crucial condition for economic stability.

Besides the baseline specification, which includes only inflation and the output gap, we estimate an augmented model for Germany which includes a vector of additional variables z_t. Based on the results of CGG and GWS, the variables that we consider are the real DM/USD exchange rate and the deviation of the annual money growth rate from the targeted money growth rate.

(3) $$i_t^* = \mu + \lambda\pi_t + \gamma y_t + \delta z_t$$

We also estimate a specification of the Taylor rule which allows for the possibility that the interest rate adjusts gradually to achieve its target level.[7] Following CGG, we assume that the actual observable interest rate i_t partially adjusts to the target as follows:

(4) $$i_t = (1-\rho)i_t^* + \rho i_{t-1} + v_t$$

Substituting (3) into (4) gives the following equation that can be estimated by nonlinear least squares.

(5) $$i_t = (1-\rho)(\mu + \lambda\pi_t + \gamma y_t + \delta z_t) + \rho i_{t-1} + v_t$$

Even in the context of the standard Taylor rule, there is a distinction between the use of revised and real-time data. With revised data, contemporaneous values are used for inflation, the output gap, and the real exchange rate. With real-time data, since the variables are not known contemporaneously, one-quarter lagged values are used. Variables dated time *t*, while not known to policymakers until time *t*, measure data at time *t-1*.

2.2 Forward-Looking Policy Rules

Given the interest that the Federal Reserve has paid to forecasts of economic indicators, it is reasonable to think that forecast-based monetary policy rules could provide a better description of policy than the standard Taylor rule. Orphanides (2003) considers two specifications of forward-looking monetary rules using real time data. The first replaces one-quarter lagged inflation by forecasts of inflation, but retains the one-quarter lagged output gap. The second adds the forecasted rate of growth of the output gap (which is equivalent to the forecasted rate of output growth minus the forecasted rate of potential output growth) to the specification. We take forecasts of inflation over a one-to-four quarter horizon starting from the quarter for which we have the latest available

[7] Woodford (1999) develops a model where interest rate smoothing is endogenously obtained as a part of the optimal solution.

data. Given a one-quarter lag in data releases, this suggests that we use forecasts of inflation made in period *t* with data through period *t–1* for periods *t*, *t+1*, *t+2*, and *t+3*.[8]

We estimate forecast-based variants of monetary policy rules with real-time data for the U.S.,

(6) $$i_t = (1-\rho)(\mu + \lambda\pi_{t-1+i} + \gamma y_t + \delta z_t) + \rho i_{t-1} + v_t$$

where *i* ranges from 1 to 4, the π's are inflation forecasts, and y_t is the output gap. The vector of alternative regressors in the forward-looking specification for the U.S. contains the four-quarters-ahead forecasted growth rate of the output gap. Because the data is in real time, the inflation forecasts, output gap, and output gap forecasts are calculated in period *t* with data released through period *t-1*. This specification is similar to the one considered in Orphanides (2003), except that we examine the rule with various inflation horizons instead of fixing it at four quarters ahead.[9] Since the real-time forecasts are based only on information available contemporaneously, it is not necessary to use instrumental variables techniques.

3. Data

We use quarterly data from 1979:Q1 to 1998:Q4. The start of the period was, following CGG, chosen to correspond with the beginning of the European Monetary System for Germany and the approximate start of the Volcker-Greenspan era for the United States. The end of the period was dictated by the end of independent Bundesbank monetary policy with the advent of the Euro.[10] For both countries we use the GDP deflator to measure inflation and real GDP to measure output.[11] The real DM/USD exchange rate is calculated from the nominal exchange rate and the two

[8] The "forecast" of inflation made for and in period *t* with period *t-1* information is not literally a forecast.
[9] Orphanides (2003) shows how this rule relates to monetary growth targeting.
[10] CGG use monthly data for Germany from March 1979 to December 1994. We extend their sample by including observations up to 1998:Q4 and use the same data period for both countries.
[11] If the focus of this paper was to estimate Taylor rules for the U.S. during the Greenspan period, we would, following Blinder and Reis (2005), use core CPI inflation instead of headline inflation. Since, in order to consider exchange rate predictability, we need a sample that begins and ends earlier, the choice of the GDP deflator seems more appropriate.

countries' GDP deflators.[12] Following Taylor (1993), the inflation rate is the rate of inflation over the previous four quarters.

Real-time datasets have been compiled for the United States by Croushore and Stark (2001) at the Federal Reserve Bank of Philadelphia and for Germany by GWS at the Bundesbank. Both data sets have a triangular format with the vintage date on the horizontal axis and dates on the vertical. The term vintage denotes each date for which we have data as they appeared at the time. Because inflation, GDP, and real exchange rate data are not contemporaneously available, we pair vintage dates with the last available observations, generally one quarter earlier. The revised data is constructed from the1999 :Q1vintage (the last available for Germany) of both real-time datasets.

For estimation of the Taylor rules, we use real-time potential output data available to both countries' monetary authorities at the time they were formulating policy. The U.S real-time estimates and four-quarter-ahead forecasts of the output gap are from Orphanides (2003), who constructed a real-time output gap dataset using real-time output and estimates of potential output that were available to the FOMC at the time of FOMC meetings by the middle month of each quarter.[13] The revised Central Bank output gap for the U.S. is from the January 1999 Congressional Budget Office issue of "Budget and Economic Outlook: Fiscal Years 2000-2009". The German Central Bank real-time and revised output gap is constructed based on potential output from the Bundesbank real-time database. The Bundesbank real-time dataset provides annual data on forecasted potential output which becomes available to the public in December of the previous year and is revised in June of the current year. We convert annual data into quarterly using quadratic interpolation between annual forecasts.

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[12] We use GDP deflators because Consumer Price Indexes are not available in real time for our sample. The real exchange rate is calculated in the usual manner, the nominal DM/USD exchange rate plus the U.S. price level minus the German price level (all in logarithms), so that an increase represents a real depreciation of the mark.

[13] Taylor (2000) has criticized Orphanides' use of the potential GDP series produced by the Council of Economic Advisors in the 1960s and 1970s on the grounds that it was politicized and not used by serious economic analysts. These concerns are not an issue for this paper because our data start in 1979.

We use real-time Greenbook inflation forecasts and "median forecasts" of inflation from the SPF. Both data files contain annualized quarterly GDP deflator inflation forecasts, which are calculated as quarter over-quarter inflation forecasts multiplied by four. For our purposes, we need year-over-year annual inflation forecasts. To convert those values into yearly inflation forecasts, we take an average of the last four quarters to correspond with our calculation of actual inflation. For example, all inflation forecasts made in 1997:1 use information released through 1996:4. The inflation "forecast" made in 1997:1 for 1997:1 (period *t*) is an average of four annualized quarter-over-quarter inflation rates: actual inflation in 1996:2, 1996:3, and 1996:4 and contemporaneously "forecasted" inflation for 1997:1. The inflation forecast made in 1997:1 for 1997:2 (period *t+1*) is an average of actual inflation in 1996:3 and 1996:4, contemporaneously "forecasted" inflation for 1997:1, and inflation forecasted in 1997:1 for 1997:2. The inflation forecast made in 1997:1 for 1997:3 (period *t+2*) is an average of actual inflation in 1996:4, contemporaneously "forecasted" inflation for 1997:1, and inflation forecasted in 1997:1 for 1997:2 and 1997:3. The inflation forecast made in 1997:1 for 1997:4 (period *t+3*) is an average of contemporaneously "forecasted" inflation for 1997:1 and inflation forecasted in 1997:1 for 1997:2, 1997:3, and 1997:4. The only true forecast is the period *t+3* forecast because the others combine actual inflation rates with forecasts. The SPF and Greenbook inflation forecast data are available on the Philadelphia Fed website.

While it is clear that the Orphanides (2003) and Greenbook data were not available to market participants in real time, the picture is cloudier with the Bundesbank potential output data. As described by GWS, Bundesbank estimates of expected growth of potential output can usually be found semi-annually in the official statements on the target range for the monetary aggregate published in December (for the upcoming year) and reviewed in July. Bundesbank estimates of the level of potential output, in contrast, were only published twice between 1980 and 1998. In order to construct their estimates of the level of potential output, GWS used internal briefing documents on the estimated level for at least one data point of each vintage. Since the estimates of the Bundesbank potential output data contain a mixture of public and internal material, it is not clear to what extent these estimates were available to market participants in real time.

In the context of exchange rate forecasting with Taylor rule fundamentals, we also construct the output gap by taking deviations of log output from its quadratic trend. For constructing the revised dataset, we use the full-sample trend by fitting a quadratic time trend to the last GDP vintage in each dataset. The last vintage is chosen to be 1999:Q1 for both countries. It contains information up to 1998:Q4, when the euro was formed and the DM effectively ceased to exist. For constructing the real-time dataset, we estimate the output gap in real-time. For each vintage, potential output is estimated using only information available at this point in time in order to mimic as closely as possible the information available to market participants at the time the forecasts would have been made. Thus, in each period the OLS regression is re-estimated adding one additional observation to the sample and revising the others. The German dataset contains a number of missing observations at the beginning of each vintage. Following Orphanides and van Norden (2002), we fill the missing values in each vintage by using the most recently previously published vintage.

For data that is not revised, we can use standard sources. The interest rate is the money market rate (call money rate) for Germany and the Federal Funds Rate for the U.S. The source for the German money market rate is the IMF International Financial Statistics Database (line 60B). The Federal Funds Rate and the nominal USD/DM exchange rate are taken from the Federal Reserve Bank of Saint Louis database. An increase in the USD/DM exchange rate is a depreciation of the dollar.

4. Empirical Results

We first examine the real-time inflation and output gap variables by looking at the graphs of both series for the U.S. and Germany. Figures 1 and 2 compare U.S. and German real-time inflation and output gaps with those available from the revised data in 1999:Q1. The left panels graph U.S. variables, while the right panels present the same variables for Germany. Three observations are apparent: First, while U.S. real-time and revised inflation have tracked each other quite closely during the studied period, the differences between the two series are more pronounced for Germany. In particular, revised inflation was higher during the period following reunification than was apparent at the time. Second, the discrepancies between real-time and revised output gaps are larger for the U.S. than for Germany during the 1980s, with the recession of the early 1980s appearing less severe with revised than with real-time data. Third, the differences between real-time and revised output gaps are larger than those between real-time and revised inflation for both the U.S. and Germany.[14]

41 Specifications of the Taylor Rule

Estimates of Federal Reserve and Bundesbank interest rate reaction functions from 1979:Q1 to 1998:Q4 obtained using revised and real-time data are presented in Tables 1 and 2. The estimates are for variants of Equation (5), with coefficients described in Equations (3) and (4). Our baseline specification includes inflation, the output gap, and (with smoothing) the lagged interest rate. The data for the output gap was, as described above, taken from Orphanides (2003) for the U.S. and GWS for Germany to replicate, as closely as possible, the information available to the Federal Reserve Board and Bundesbank at the time that policy decisions were made.

We first consider estimation results for the U.S. The first two columns in Table 1 show the estimates for the model with revised data. The estimated inflation coefficient is 1.39 without partial adjustment of the federal funds rate ($\varrho = 0$ in equation (5)), which corresponds to Taylor's original specification of the rule, and 1.50 with interest rate smoothing. The latter estimate is exactly equal to Taylor's (1993) postulated value. Both estimated inflation coefficients are highly significant and

[14] These results can be found in Orphanides (2003) for the U.S. and in GWS for Germany.

greater than one, which indicates that the Federal Reserve was following the Taylor principle. The coefficients on the output gap are positive but insignificant. The smoothing coefficient is 0.55 and significant. These results are in accord with much previous work.

The second two columns in Table 1 show the estimates with real-time data. The estimated inflation coefficient is 1.32 without partial adjustment of the federal funds rate and 1.36 with interest rate smoothing. The coefficients on the output gap are nearly zero and insignificant. The decrease in the estimated coefficients with real-time data is consistent with the hypothesis that measurement error caused by the presence of noise in the data would produce biased parameter estimates for the revised data. Although the estimated inflation coefficients fall with real-time data, they are still consistent with the Taylor principle. The smoothing coefficient is 0.54 and significant, nearly identical to the result with revised data.

Using Taylor's (1993) original span of data (1987:1 – 1992:4), Orphanides (2001) finds that using real-time, rather than revised, data produces very large differences in the estimated inflation coefficients for the baseline specification, with the coefficients decreasing from 1.57 to 0.79 without smoothing and 1.15 to 0.10 with smoothing. Taken literally, these results imply that the Federal Reserve was not stabilizing inflation during this period, and lead Orphanides to conclude that the baseline model is not specified properly. Using a much larger span of data, our conclusions are very different. The estimates of the inflation coefficient are greater than one in all cases, consistent with the Federal Reserve following the Taylor principle when policy evaluation is conducted using real time as well as revised data. While the estimates of the U.S. output gap coefficient obtained with real time data are smaller than with revised data, they are not significant in either case. The estimates of the partial adjustment coefficient ϱ confirm the existence of interest rate smoothing with both types of data. There are no important differences in the inflation, output gap, or partial adjustment coefficients obtained with revised and real-time data.

Table 2 reports estimates of interest rate reaction functions for the Bundesbank. In addition to our baseline specification for the U.S. that includes inflation, the output gap, and (with smoothing) the lagged interest rate, we consider an extended model that includes the log of the real DM/USD exchange rate and/or the deviation of the annual money growth rate from the targeted money growth rate. CGG find evidence supporting the importance of the real exchange rate, but not money growth deviations, for the Bundesbank's estimated Taylor rule between 1979 and 1994 using revised data. GWS, in contrast, find evidence supporting the inclusion of money growth deviations between 1979 and 1998 using real-time data.

The first two columns in the left panel of Table 2 show the estimates for the baseline model with revised data while the first two columns in the right panel show the estimates with real-time data. It is immediately apparent that the inclusion of the lagged interest rate has a much larger affect on the estimates for Germany than for the U.S. The smoothing coefficients are about 0.88 for Germany and 0.55 for the U.S., the R-squared rises from about 0.70 to 0.95 for Germany and 0.73 to 0.82 for the U.S., and the parameter estimates for inflation and the output gap change substantially. Since the fit of the model obviously improves substantially with the inclusion of the real interest rate, we focus on estimates of the coefficients for the monetary policy rule that includes interest rate smoothing.

In addition to the baseline model, Table 2 reports specifications which include the real exchange rate, the money growth deviation, and both additional variables for revised and real-time data. The most important result is that, across all four specifications, the coefficient on inflation increases from about 0.85 using revised data to about 1.20 using real-time data. Taken literally, an inflation coefficient of 0.85 would indicate that German monetary policy was not stabilizing during the period. Our interpretation, in contrast, is that the Bundesbank interest rate reaction function is misspecified with revised data. Based on real-time data, the Bundesbank stabilized inflation much more than one would conclude based on revised data.

There is much stronger evidence of output stabilization for Germany than for the U.S. With real-time data, the coefficients on the output gap are about 1.00 for specifications that include the real exchange rate and 0.78 for specifications that do not include the real exchange rate, and are all significant. With revised data, the coefficients are larger but the significance level becomes more marginal. The evidence of interest rate smoothing is also stronger for Germany than for the U.S. The smoothing coefficients range from 0.80 to 0.89 and are all highly significant and even the smallest values, 0.80 for the specifications that use real-time data and include the real exchange rate, are considerably larger than found for the U.S.

The coefficient on the log real DM/USD exchange rate is 0.09 with revised and 0.08 with real-time data, and significant in both cases, indicating that the Bundesbank raised the interest rate in response to a depreciation of the real DM/USD exchange rate. The coefficients on the money growth deviations are insignificant with revised data and nearly zero with real-time data. When both the real exchange rate and the money growth deviation are included in the regression, the coefficients are very similar to when only the real exchange rate is included. These results are in accord with those of CGG, who report significant coefficients on the real exchange rate, but not money growth deviations, in Taylor rules for Germany.[15]

The results of our estimation suggest that there are both significant similarities and significant differences in the way the two central banks conducted monetary policy. We focus on the results with real-time data, which corresponds most closely with the information used by the central banks at the time that policy decisions were made. The most important similarity is that the coefficient on inflation in the Taylor rule is greater than one for both countries, indicating that both

[15] GWS report significant coefficients on money growth deviations. They include *ex post* values of growth rates and instrumental variables techniques, and are therefore not actually using real-time data.

central banks followed the Taylor principle. The response of the interest rate to inflation, however, is greater for the U.S. than for Germany. The second similarity is that both central banks smoothed interest rates, although the magnitude of the interest rate smoothing was larger for Germany than for the U.S. The most important difference is that the output gap coefficients were large and significant for Germany and small and insignificant for the U.S. In addition, the Bundesbank raised the interest rate in response to real exchange rate depreciation.

Figures 3 and 4 compare the actual interest rate (bold solid line) with the interest rate implied by the real-time rule (large dashed line), the interest rate implied by the comparable rule estimated using revised data (small dashed line) for the Federal Reserve and the Bundesbank, respectively. The implied interest rates for the U.S. obtained from the rules using real-time and revised data do not seem to differ substantially. The estimates of the German interest rate implied by both real-time and revised data appear to track the actual rate closer than their U.S. counterparts.

42 Forward-Looking Taylor Rules

Tables 3 and 4 report the results of ordinary least squares estimation of forward-looking specifications of U.S. monetary policy rules with real-time data. Table 3 replicates the specification of the last column of Table 1, which includes interest rate smoothing, with inflation forecasts from the Greenbook replacing the actual inflation rate. These forecasts are for periods t, $t+1$, $t+2$, and $t+3$, using inflation data through period $t-1$ that is available in period t. The estimates of the inflation, output gap and smoothing coefficients are similar to those obtained with contemporaneously available inflation. The coefficients on the inflation forecasts are between 1.30 and 1.34 and the coefficients on the output gap are small and insignificant. These results is in accord with Taylor's (1999) view that, because they incorporate the same information, inflation forecast rules are no more forward-looking than rules based on lagged data. Table 4 reports the same specifications as Table 3 with the addition of forecasted output gap growth. The coefficient on inflation significantly increases to between 1.95 and 2.28 and increases with the forecast horizon. The coefficient on output gap growth is positive, significant and increasing with the forecast horizon. The output gap coefficients rise but remain insignificant, and the models are characterized by a slightly better fit. These results are in accord with Orphanides (2003), and indicate that the differences between "standard" and "forward-looking" Taylor rules using real-time data come from the inclusion of an additional variable, forecasted output gap growth, in the latter specifications and not from the replacement of lagged inflation with forecasts of current or future inflation.

5. Out-of-Sample Exchange Rate Forecasting

5.1 Taylor Rule Fundamentals

We have estimated Taylor rules for the United States and Germany using revised and real-time data. We found significant similarities and differences, both between the countries and between the types of data. We proceed to show that, by subtracting the Taylor rule for Germany from that of the U.S., we can derive an exchange rate forecasting equation with Taylor rule fundamentals. Since the coefficients of the two countries' Taylor rules exhibit substantial differences, it might be useful in terms of exchange rate forecasting to use a specification of the exchange rate model with Taylor rule fundamentals that does not restrict inflation and output gap coefficients in both countries to be the same. In addition, since output gap growth and the real DM/USD exchange rate enter significantly in the estimated U.S. and German Taylor rules, respectively, inclusion of these variables may also be useful for forecasting.

One of the central questions we raise in this paper is how the use of the real-time data affects our conclusion about out-of-sample exchange rate predictability. We consider the fundamental-based model for USD/DM nominal exchange rate which includes two types of Taylor rules. The first specification assumes that both the U.S. and Germany determine their interest rates according to the same Taylor rule where the nominal interest rate responds to inflation, the output gap and (possibly) the lagged interest rate. The second specification includes a vector of additional variables z_t which, based on our estimation results, consists the real DM/USD exchange rate for Germany. We call the former specification symmetric and the later specification asymmetric. We also estimate specifications with real-time data where inflation known at time *t* is replaced with forecasts of current or future inflation and specifications where both forecasted inflation and forecasted output gap growth are included.

To derive the Taylor-rule based forecasting equation, we construct the interest rate differential by subtracting the interest rate reaction function for Germany from that for the U.S.:

(7) $$i_t - \tilde{i}_t = \alpha + \alpha_{u\pi}\pi_t - \alpha_{g\pi}\tilde{\pi}_t + \alpha_{uy}y_t - \alpha_{gy}\tilde{y}_t + \alpha_{uz}z_t - \alpha_{gz}\tilde{z}_t + \rho_u i_{t-1} - \rho_g \tilde{i}_{t-1} + \eta_t$$

where ~ denotes German variables, u and g are coefficients for the United States and Germany, α is a constant, and $\alpha_\pi = \lambda(1-\rho)$, $\alpha_y = \gamma(1-\rho)$, and $\alpha_z = \delta(1-\rho)$ for both countries. Based on the estimation results reported above, we do not impose equality of coefficients on the two countries' variables. The vector of additional regressors z_t includes output gap growth for the U.S. and the real DM/USD exchange rate.

The most direct way to derive a forecasting equation is to postulate that the expected rate of depreciation is proportional to theinterest rate differential:

(8) $$E(\Delta s_{t+1}) = \beta(i_t - \tilde{i}_t)$$

Assuming that UIRP holds, $\beta =$ 1 and (8) can be substituted into (7) to produce a forecasting equation.

(9) $$\Delta s_{t+1} = \alpha + \alpha_{u\pi}\pi_t - \alpha_{g\pi}\tilde{\pi}_t + \alpha_{uy}y_t - \alpha_{gy}\tilde{y}_t + \alpha_{uz}z_t - \alpha_{gz}\tilde{z}_t + \rho_u i_{t-1} - \rho_g \tilde{i}_{t-1} + \eta_t$$

There are two problems with this specification. First, UIRP does not hold in the short run, so we would not expect the coefficients in (9) to match the estimated Taylor rules. Based on empirical work on UIRP and (more recently) carry trade, it is not even clear whether β, which equals one by UIRP, is positive or negative. Second, there is very strong evidence that interest rates do not completely adjust to their target levels within the period. Suppose that the U.S. inflation rate (actual or forecasted) rises above its target. According to our results in Tables 1 and 3, this causes the Fed to raise the interest rate but also creates an expectation that the Fed will further raise the interest rate in the future. Since the increase in the interest rate may or may not cause expected depreciation of the exchange rate, and the expectation of further increases in the interest rate may cause expected appreciation of the exchange rate, we do not have a strong prior that even the signs of the coefficients in (9) are correct. Since a similar logic applies to an increase in the German inflation rate above its target, as well as to the other variables, we estimate Equation (9) as an exchange rate forecasting equation with Taylor rule fundamentals without restricting the signs or magnitudes of the coefficients.[16]

5.2 Tests of Equal Predictive Ability

In order to test the ability of our model to forecast the nominal USD/DM exchange rate, we use the Clark and West (2006) test of equal predictive ability (CW). The statistic is constructed for rolling regressions, moving the estimation window inside the sample from left to right, fitting the model, making an out-of-sample forecast, and comparing it to the actual realization of the data. The null model for both tests is a zero mean martingale difference process, $y_t = \varepsilon_t$, while the alternative is a linear model, $y_t = X_t^{'}\beta + \varepsilon_t$, where the vector X represents the Taylor rule fundamental variables. Suppose we have a sample of T+1 observations. The last P < T observations are used for the predictions. If we fix the moving window of size R at the beginning of the sample, then the first prediction is made for the observation R+1, the next for R+2, and so on; the final one for T+1.

[16] Clarida and Waldman (2007) construct a model that combines a Taylor rule with a Phillips curve to derive conditions under which a surprise increase in U.S. inflation will appreciate the exchange rate, and use event study methodology to test the model.

Thus, we have the equality T+1=R+P. We fix the window size R at 40 quarters (10 years). The one-step ahead prediction for y_{t+1} is 0 for the H_0, and $X_{t+1}\hat{\beta}_t$ for the alternative.

The CW test is a modification of the Diebold and Mariano (1995) and West (1996) tests (DMW) that is valid for nested models. We are interested in comparing the mean square prediction errors from two models. The sample forecast errors $\hat{e}_{1,t+1}$ and $\hat{e}_{2,t+1}$ from the model under H_0 and H_1 are $\hat{e}_{1,t+1} = y_{t+1}$ and $\hat{e}_{2,t+1} = y_{t+1} - X_{t+1}\hat{\beta}_t$ respectively. If we sum them up over the last P observations available for the forecast, we get the mean square prediction error (MSPE) for both models:

(10)
$$\hat{\sigma}_1^2 = P^{-1} \sum_{t=T-P+1}^{T} y_{t+1}^2$$
$$\hat{\sigma}_2^2 = P^{-1} \sum_{t=T-P+1}^{T} (y_{t+1} - X'_{t+1}\hat{\beta}_t)^2$$

We are interested in testing the null hypothesis that the population MSPE's are equal, $\sigma_1^2 - \sigma_2^2 = 0$, against the alternative hypothesis is that the linear model has a smaller MSPE. If we define

(11)
$$\hat{f}_t = \hat{e}_{1,t}^2 - \hat{e}_{2,t}^2$$
$$\bar{f} = P^{-1} \sum_{t=T-P+1}^{T} \hat{f}_{t+1} = \hat{\sigma}_1^2 - \hat{\sigma}_2^2$$
$$\hat{V} = P^{-1} \sum_{t=T-P+1}^{T} (\hat{f}_{t+1} - \bar{f})^2$$

The DMW test statistic can be computed in the following way:

(12)
$$DMW = \frac{\bar{f}}{\sqrt{P^{-1}\hat{V}}}$$

Although the DMW statistic is valid for non-nested models, it has been shown to be severely undersized when used to compare predictive ability of two nested models.[17] These considerations are important in the context of exchange rate forecasting because, since the null is a martingale difference process and the alternative is a linear model, the models are always nested. Use of undersize tests will bias the results towards non-rejection of the random walk null.

Clark and West (2006) propose an adjusted DMW statistic, which corrects the bias by taking into consideration that the sample difference between the two MSPE's is uncentered:

(13) $$\hat{\sigma}_1^2 - \hat{\sigma}_2^2 = P^{-1}\sum_{t=T-P+1}^{T}\hat{f}_{t+1} = P^{-1}\sum_{t=T-P+1}^{T}y_{t+1}^2 - P^{-1}\sum_{t=T-P+1}^{T}(y_{t+1} - X'_{t+1}\hat{\beta}_t)^2 = 2P^{-1}\sum_{t=T-P+1}^{T}y_{t+1}X'_{t+1}\hat{\beta}_t - P^{-1}\sum_{t=T-P+1}^{T}(X'_{t+1}\hat{\beta}_t)^2$$

Under the null, the first term is zero, while the second one is positive by construction. Therefore, under the null we expect the MSPE of the na ve no-change model to be smaller than that of a linear model. As a result, the sample MSPE of the alternative model will be higher by the amount of the estimation noise. Clark and West (2006) propose a simple correction, which results in the following asymptotically normally distributed statistics for rolling regressions, which have more desirable size and power properties,

$$\hat{f}_{t+1}^{ADJ} = \hat{e}_{1,t+1}^2 - \left[\hat{e}_{2,t+1}^2 - \left(X'_{t+1}\hat{\beta}_t\right)^2\right]$$

(14) $$\bar{f}^{ADJ} = P^{-1}\sum_{t=T-P+1}^{T}\hat{f}_{t+1}^{ADJ} = \hat{\sigma}_1^2 - \left[\hat{\sigma}_2^2 - P^{-1}\sum_{t=T-P+1}^{T}(X'_{t+1}\hat{\beta}_t)^2\right]$$

$$\hat{V} = P^{-1}\sum_{t=T-P+1}^{T}(\hat{f}_{t+1}^{ADJ} - \bar{f}^{ADJ})^2$$

$$CW = \frac{\bar{f}^{ADJ}}{\sqrt{P^{-1}\hat{V}^{ADJ}}}$$

[17] Clark and McCracken (2001, 2005) and McCracken (2006) provide extensive documentation of the size properties of the DMW test.

5.3 Empirical Results

The results for 1-quarter-ahead forecast comparisons using the CW test statistics with revised and real-time data are presented in Tables 5-7. These tables differ in how the output gaps are calculated for the two counties. Table 5 presents forecasting results with the Central Banks' measures of the output gaps, as used for estimation of the Taylor rules in Tables 1 and 2. These measures, however, are released with extensive delays and are therefore not appropriate for evaluating real-time forecasts. Table 6 presents results with output gaps constructed by quadratic detrending for the two countries. These measures are available to market participants and are appropriate for evaluating real-time forecasts. Table 7 presents results that use the quadratic detrended output gap for the U.S. and the Bundesbank output gap for Germany, reflecting the fact that, while the Federal Reserve's measure of the output gap is clearly not contemporaneously available to market participants, some of the information used to construct the Bundesbank's measure is contemporaneously available.

Panel A in the three tables shows the CW statistic and its corresponding p-values with revised and real-time data for the symmetric model with Taylor Rule fundamentals, which includes only inflation and the output gap (and possibly the lagged interest rate) for both countries, and the asymmetric model that includes the real DM/USD exchange rate for Germany.[18] The left two columns in each panel report results for the models that do not include partial adjustment of interest rates, while the right two columns contain results for the same models with smoothing. Contemporaneous values are used for inflation, the output gap, and the real exchange rate with revised data and one-quarter lagged values are used with real-time data

The results obtained with all the three output gap combinations are very similar. The revised data provides no evidence of exchange rate predictability, as neither the symmetric nor the

[18] Although money growth deviations did not significantly enter the Bundesbank Taylor rule estimates, we experimented with including them in Equation (9), but the forecasting results worsened.

asymmetric models significantly outperform the random walk based on the CW statistic. The results change drastically if we estimate the same models using real-time data. While the symmetric Taylor rule model fails to provide any evidence of exchange rate predictability using the CW statistic regardless of the output gap combination whether or not there is interest rate smoothing, all six asymmetric Taylor rule models with real-time data significantly outperform the random walk at the 5% level.

Panels B and C present forecasting results with real-time data when inflation forecasts, rather than lagged inflation rates, are used on the right-hand-side of Equation (10). Since the symmetric Taylor rule model fails to produce any evidence of exchange rate predictability, we focus on the asymmetric model. Panel B uses Greenbook forecasts, which correspond to the estimates reported in Table 3. The evidence of exchange rate predictability using period t (contemporaneous) and period $t+1$ Greenbook inflation forecasts is comparable to that obtained using lagged inflation rates, but weakens with longer-horizon forecasts. With three output gap measures and a choice between smoothing and no smoothing, there are six forecasts for each of four forecast horizons. The forward looking models with exchange rate targeting outperform the random walk at the 5% level in 19 out of 24 cases, six (out of six) in periods t and $t+1$, three in period $t+2$, and four in period $t+3$, and at the 10% level for the remaining cases. Another perspective comes from sorting by output gap measures. With four forecast horizons and a choice between smoothing and no smoothing, there are eight forecasts for each of three output gap measures. The forward-looking models with exchange rate targeting outperform the random walk at the 5% level in eight (out of eight) cases with quadratic detrended data, six cases with quadratic detrended data for the US and Central Bank data for Germany, and five cases with Central Bank data. It is interesting that the data that works best, using quadratic detrended output gaps for both countries, is most clearly available to market participants.

The Greenbook inflation forecasts, however, are not contemporaneously available to market participants and therefore cannot be used to evaluate the predictive accuracy of the models with real-time data. Panel C depicts the same statistics using SPF inflation forecasts, which are available to market participants. While considerable evidence of exchange rate predictability is found using SPF inflation forecasts, it is weaker than using either Greenbook forecasts or lagged inflation rates. The forward looking models with exchange rate targeting outperform the random walk at the 5% level in 10 out of 24 cases, four (out of six) in period *t*, three in period *t+1*, two in period *t+2*, and one in period *t+3*, and at the 10% level for 12 of the 14 remaining cases. Sorted differently, the forward looking models with exchange rate targeting outperform the random walk at the 5% level in four (out of eight) cases with quadratic detrended data, three cases with quadratic detrended data for the US and Central Bank data for Germany, and three cases with Central Bank. This provides another piece of evidence in support of Taylor's (1999) argument that inflation forecast rules are not necessarily superior to those that use inflation data.

Panels D and E present forecasting results with real-time data when output gap growth forecasts, as well as inflation forecasts, are used on the right-hand-side of Equation (10). Panel D uses Greenbook inflation forecasts, which correspond to the estimates reported in Table 4. Although the coefficients on output gap growth were significant in the regressions reported in Table 4, the evidence of exchange rate predictability using Greenbook inflation and output gap growth forecasts is clearly worse than that obtained using either lagged inflation rates or Greenbook inflation forecasts. None of the models with output gap growth outperform the random walk at the 5% level, and the forward-looking models with exchange rate targeting outperform the random walk at the 10% level in 14 of the 24 cases, five (out of eight) with quadratic detrended data, five with quadratic detrended data for the US and Central Bank data for Germany, and four with Central Bank data.

Since neither Greenbook inflation forecasts nor output gap growth forecasts are contemporaneously available to market participants, Panel E presents results with output gap growth forecasts and SPF inflation forecasts. The latter, but not the former, are contemporaneously available. The evidence of exchange rate predictability unambiguously worsens. None of the models with output gap growth and SPF inflation forecasts outperform the random walk at the 5% level, and the forward-looking models with exchange rate targeting outperform the random walk at the 10% level in only four of the 24 cases, one (out of eight) with quadratic detrended data, two with quadratic detrended data for the US and Central Bank data for Germany, and one with Central Bank data.

Why does exchange rate predictability worsen when output gap growth forecasts are included in the set of Taylor rule fundamentals despite entering significantly into the Taylor rule estimates? The estimates in Table 4, both the large size of the inflation coefficient and the inclusion of a large output gap growth coefficient, are very different from the usual Taylor rule estimates. One conjecture is that market participants use more conventional Taylor rule estimates, as reported in Tables 1 and 3, as an input into interest rate forecasts. If these interest rate forecasts affect exchange rates, then it would not be surprising to find more exchange rate predictability with Taylor rule fundamentals based only on conventional Taylor rule estimates.

An interesting question to explore is what are we forecasting when we find evidence of exchange rate predictability? Figure 6 shows the dynamics of five coefficients in the real-time forecasting equation that includes the real DM/USD exchange rate in addition to the levels of Taylor-rule fundamentals and uses the quadratic detrended output gap for the U.S. and the Central bank output gap for Germany.[19] The U.S. inflation coefficients, which are negative throughout the sample, decline and become significantly negative by the end of the sample. The German inflation

[19] Figures for the other two output gap combinations are very similar.

coefficients are positive and significant throughout the sample. An increase in inflation for either country is therefore associated with forecasted appreciation of its exchange rate. An increase in the U.S. output gap produces forecasts of depreciation, while the coefficients on the German output gap are never significant. The real DM/USD rate coefficient is also significantly negative, so that a real depreciation of the mark (real appreciation of the dollar) leads to forecasted appreciation of the dollar. The results for inflation and the real exchange rate are consistent with either a negative coefficient on the interest rate differential between the two countries (in violation of UIRP) and/or an effect where increases in inflation and real appreciation lead to expectations of higher interest rates and exchange rate appreciation.

6. Conclusions

The first purpose of the paper is to investigate how the use of real-time data affects our knowledge about interest rate reaction functions that guided Federal Reserve and Bundesbank monetary policy. We compare how estimated Taylor rules obtained with real-time data differ from those suggested by ex post revised data. Analyzing the period from 1979:Q1 to 1998:Q4, we find that the differences in the monetary policy rule coefficients obtained with revised and real-time data for the U.S. are much smaller than for Germany. While monetary policy is stabilizing and obeys the Taylor principle for the U.S. regardless of whether revised or real-time data is used, monetary policy for Germany only obeys the Taylor principle if evaluated in real time. The estimation results also suggest significant differences in the way the two central banks conducted their monetary policy. The output gap coefficients are low and not significant for the U.S., while they are large and highly significant for Germany. In addition, the real DM/USD exchange rate enters the Bundesbank's interest rate reaction function.

The second purpose of the paper is to investigate how the use of real-time data affects out-of-sample exchange rate predictability by looking at a model for the USD/DM nominal exchange rate with Taylor rule fundamentals. We find strong evidence of exchange rate predictability at the one-quarter-ahead horizon using real-time data when the real DM/USD exchange rate enters the Bundesbank's Taylor rule. No evidence of predictability is found with just the inflation and output gap series or when revised data is used. An important determinant of exchange rate predictability is that increases in inflation for both countries generate forecasts of exchange rate appreciation. This is consistent with the result in Clarida and Waldman (2007) that bad news about inflation is good news for the exchange rate.

An important focus of Taylor rule estimation has been the forward-looking nature of monetary policy. We estimate Taylor rules and forecast nominal exchange rates with models incorporating Taylor rule fundamentals which use inflation forecasts rather than actual inflation rates, and find little-to-no difference between forecast-based models and models with lagged inflation. While estimating natural-growth targeting versions of the forecast-based models produces significant coefficients on the rate of growth of the output gap, the out-of-sample predictability of the USD/DM exchange rate worsens. These results are in accord with the argument in Taylor (1999) that inflation forecast rules are no more forward-looking than rules based on current and lagged data.

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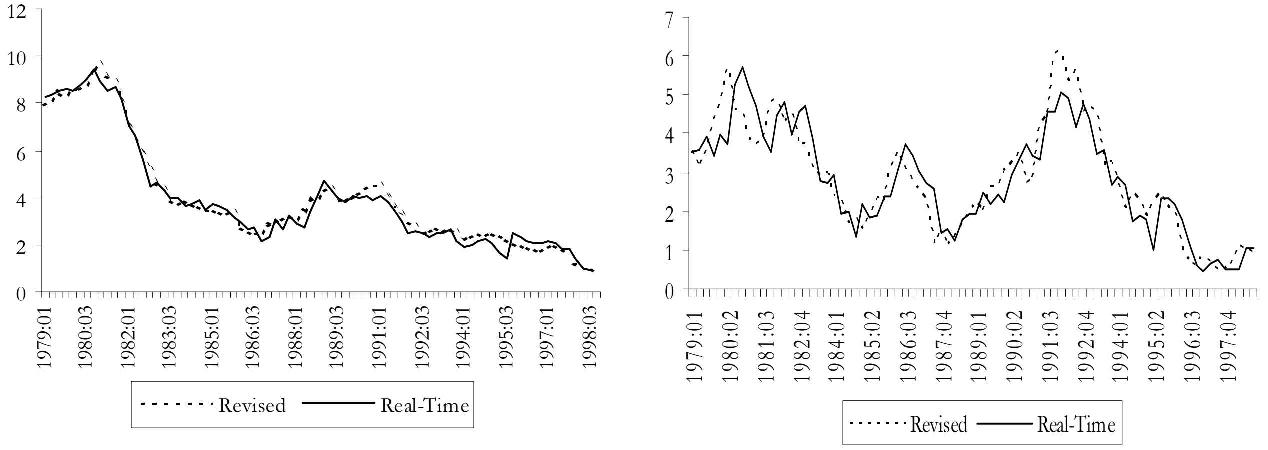
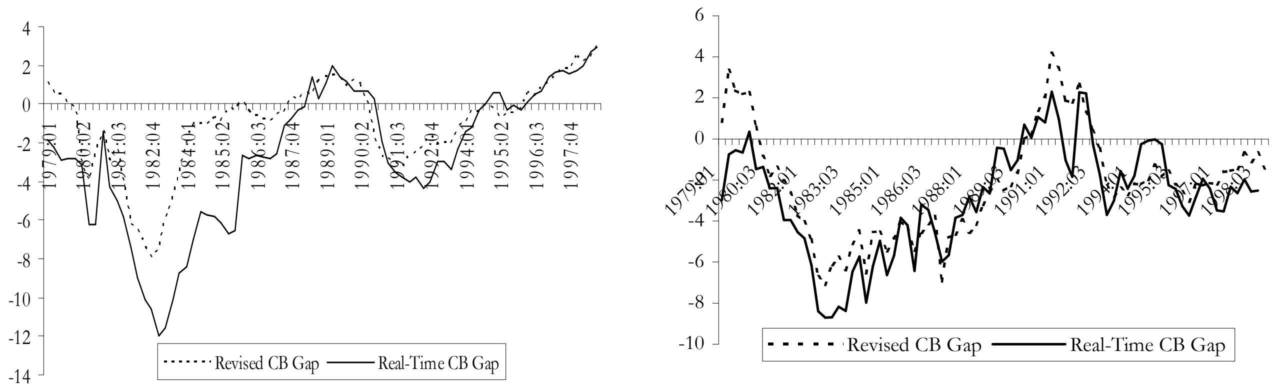


A. U.S. Inflation B. German Inflation

Figure 1. U.S. and German Inflation



A. U.S. Output Gap B. German Output Gap

Figure 2. U.S. and German Central Bank Output Gaps

Table 1. Estimated Taylor Rules for the United States

	Revised Data		*Real-Time Data*	
Inflation Coefficient, λ	1.39	1.50	1.32	1.36
	(0.17)	(0.21)	(0.16)	(0.21)
Output Gap Coefficient, γ	0.11	0.28	-0.01	0.01
	(0.15)	(0.20)	(0.08)	(0.12)
Smoothing Coefficient, ρ	-	0.55	-	0.54
		(0.18)		(0.18)
R-squared	0.73	0.82	0.73	0.82

Notes: The table reports nonlinear least squares estimates of the following equation, $i_t = (1-\rho)(\mu + \lambda\pi_t + \gamma y_t) + \rho i_{t-1} + v_t$, where i is the Federal Funds Rate, π is inflation, and y is the output gap. The sample size is 1979:Q1 – 1998:Q4. Standard errors are in parentheses.

Table 2. Estimated Taylor Rules for Germany

	Revised Data					*Real-Time Data*				
Inflation Coefficient, λ	1.36	0.84	0.84	0.88	0.86	1.37	1.19	1.19	1.19	1.20
	(0.15)	(0.51)	(0.36)	(0.43)	(0.34)	(0.14)	(0.48)	(0.27)	(0.48)	(0.27)
Output Gap Coefficient, γ	0.09	1.13	1.27	1.02	1.20	0.23	0.78	0.99	0.78	1.00
	(0.09)	(0.77)	(0.64)	(0.67)	(0.59)	(0.07)	(0.35)	(0.28)	(0.38)	(0.29)
Smoothing Coefficient, ρ	-	0.89	0.85	0.88	0.85	-	0.87	0.80	0.87	0.80
		(0.07)	(0.07)	(0.08)	(0.07)		(0.06)	(0.06)	(0.06)	(0.06)
Exchange Rate Coefficient, δ_1	-	-	0.09	-	0.08	-	-	0.08	-	0.08
			(0.05)		(0.05)			(0.03)		(0.03)
Money Growth Coefficient, δ_2	-	-	-	-0.23	-0.12	-	-	-	0.01	0.01
				(0.30)	(0.14)				(0.37)	(0.17)
R-squared	0.71	0.95	0.96	0.95	0.96	0.68	0.95	0.95	0.95	0.95

Notes: The table reports nonlinear least squares estimates of the following equation, $i_t = (1-\rho)(\mu + \lambda\pi_t + \gamma y_t + \delta z_t) + \rho i_{t-1} + v_t$, where i is the Federal Funds Rate, π is inflation, y is the output gap, and z is a vector containing the real DM/Dollar exchange rate and the money growth deviation.. The sample size is 1979:Q1 – 1998:Q4. Standard errors are in parentheses.

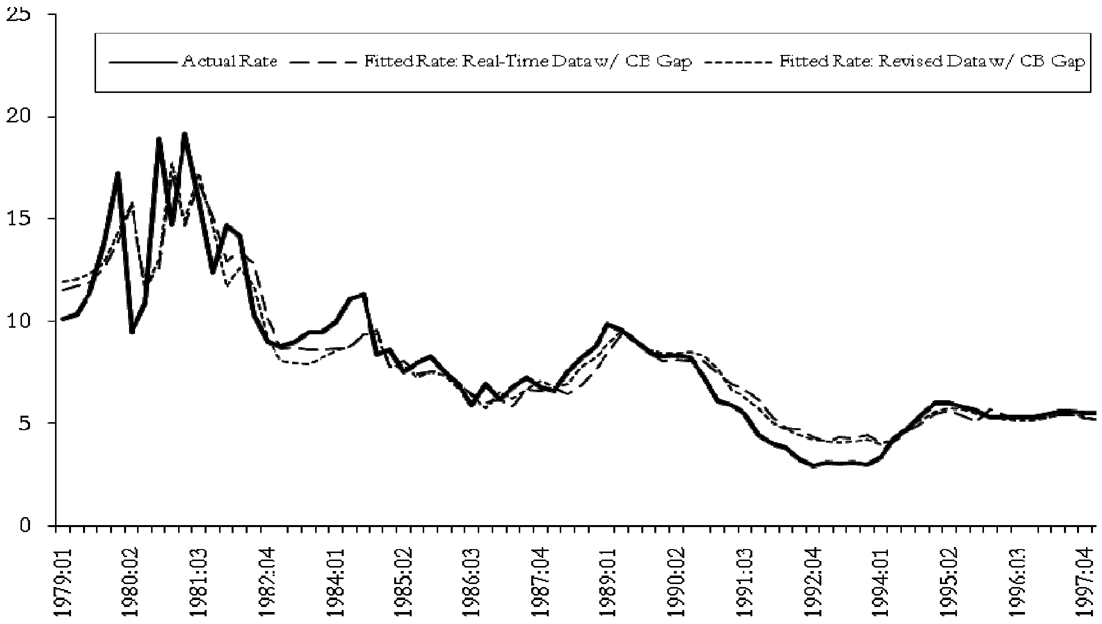


Figure 3. Actual and Fitted Values of U.S. Federal Funds Rate

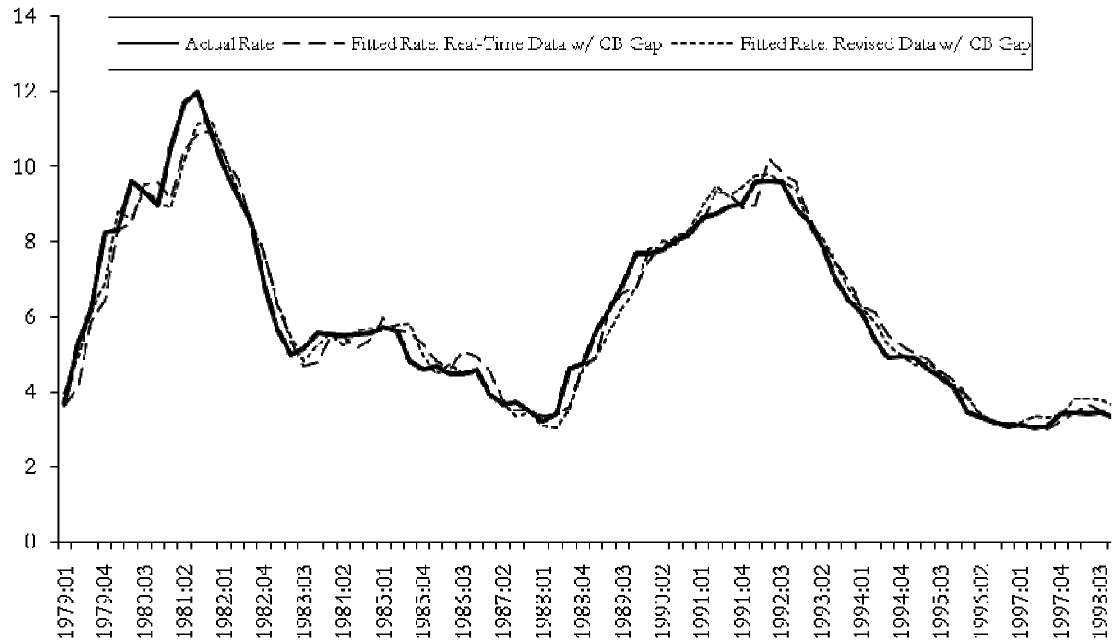


Figure 4. Actual and Fitted Values of German Money Market Rate

Table 3. Taylor Rules for the United States Using Real-Time Data and Greenbook Inflation Forecasts

	Period t Inflation	*Period t+1 Inflation*	*Period t+2 Inflation*	*Period t+3 Inflation*
Inflation Coefficient, λ	1.33	1.34	1.30	1.34
	(0.21)	(0.23)	(0.26)	(0.27)
Output Gap Coefficient, γ	-0.02	-0.05	-0.08	-0.10
	(0.11)	(0.11)	(0.11)	(0.10)
Smoothing Coefficient, ϱ	0.52	0.54	0.59	0.57
	(0.18)	(0.15)	(0.13)	(0.13)
R-squared	0.82	0.82	0.81	0.82

Notes: The table reports nonlinear least squares estimates of the following equation, $i_t = (1-\rho)(\mu + \lambda\pi_{t-1+i} + \gamma y_t) + \rho i_{t-1} + v_t$, where *i* is the Federal Funds Rate, π is forecasted inflation, and *y* is the output gap. The sample size is 1979:Q1 – 1998:Q4. Standard errors are in parentheses.

Table 4. Taylor Rules for the United States Using Real-Time Data, Greenbook Inflation Forecasts and Forecasted Output Gap Growth

	Period t Inflation	*Period t+1 Inflation*	*Period t+2 Inflation*	*Period t+3 Inflation*
Inflation Coefficient, λ	1.95	2.11	2.16	2.28
	(0.38)	(0.41)	(0.46)	(0.44)
Output Gap Coefficient, γ	0.17	0.17	0.14	0.11
	(0.14)	(0.14)	(0.15)	(0.13)
Output Gap Growth Coefficient	1.07	1.32	1.44	1.54
	(0.51)	(0.56)	(0.65)	(0.60)
Smoothing Coefficient, ϱ	0.54	0.57	0.61	0.59
	(0.16)	(0.13)	(0.12)	(0.12)
R-squared	0.84	0.84	0.83	0.84

Notes: The table reports nonlinear least squares estimates of the following equation, $i_t = (1-\rho)(\mu + \lambda\pi_{t-1+i} + \gamma y_t + \delta z_t) + \rho i_{t-1} + v_t$, where *i* is the Federal Funds Rate, π is forecasted inflation, *y* is the output gap, and *z* is forecasted output gap growth. The sample size is 1979:Q1 – 1998:Q4. Standard errors are in parentheses.

Table 5. CW Statistics: One-Quarter-Ahead USD/DM Exchange Rate Forecasts using Taylor Rules with Central Bank Output Gaps

	w/o Smoothing		*w/ Smoothing*	
	Symmetric	*Asymmetric*	*Symmetric*	*Asymmetric*
A. Revised and Real-Time Data				
Revised Data	0.358	0.548	0.258	-0.107
	(0.31)	(0.25)	(0.35)	(0.50)
Real-Time Data	-0.936	1.979**	-0.689	1.924**
	(0.77)	(0.02)	(0.70)	(0.03)
B. Real-Time Data with Greenbook Inflation Forecasts				
Period-t Greenbook Inflation Forecasts	-0.177	1.895**	0.493	1.849**
	(0.51)	(0.03)	(0.28)	(0.03)
Period-t+1 Greenbook Inflation Forecasts	-0.021	1.798 **	0.347	1.754**
	(0.43)	(0.03)	(0.32)	(0.04)
Period-t+2 Greenbook Inflation Forecasts	-0.321	1.484*	-0.136	1.561*
	(0.56)	(0.07)	(0.50)	(0.06)
Period-t+3 Greenbook Inflation Forecasts	0.115	1.672**	0.252	1.495*
	(0.40)	(0.05)	(0.36)	(0.07)
C. Real-Time Data with SPF Inflation Forecasts				
Period-t SPF Inflation Forecasts	-0.272	1.740**	0.317	1.667**
	(0.53)	(0.04)	(0.34)	(0.05)
Period-t+1 SPF Inflation Forecasts	-0.478	1.266*	-0.011	1.593**
	(0.62)	(0.10)	(0.45)	(0.05)
Period-t+2 SPF Inflation Forecasts	-0.530	1.035	-0.206	1.368*
	(0.64)	(0.14)	(0.52)	(0.08)
Period-t+3 SPF Inflation Forecasts	-0.133	1.194*	0.226	1.244*
	(0.48)	(0.10)	(0.36)	(0.10)
D. Real-Time Data with Greenbook Inflation Forecasts and Period-t+3 Output Gap Growth				
Period-t Greenbook Inflation Forecasts	-0.791	1.216*	0.165	1.513*
	(0.74)	(0.10)	(0.39)	(0.06)
Period-t+1 Greenbook Inflation Forecasts	-0.656	1.146	0.025	1.377*
	(0.68)	(0.12)	(0.43)	(0.08)
Period-t+2 Greenbook Inflation Forecasts	-1.028	0.717	-0.507	1.280*
	(0.80)	(0.22)	(0.63)	(0.10)
Period-t+3 Greenbook Inflation Forecasts	-0.469	1.095	-0.330	1.101
	(0.62)	(0.12)	(0.57)	(0.12)
E. Real-Time Data with SPF Inflation Forecasts and Period-t+3 Output Gap Growth				
Period-t SPF Inflation Forecasts	-0.864	1.076	-0.102	1.298*
	(0.75)	(0.12)	(0.49)	(0.09)
Period-t+1 SPF Inflation Forecasts	-1.140	0.545	-0.456	1.170
	(0.84)	(0.26)	(0.62)	(0.12)
Period-t+2 SPF Inflation Forecasts	-1.259	0.260	-0.636	1.046
	(0.86)	(0.35)	(0.69)	(0.13)
Period-t+3 SPF Inflation Forecasts	-0.783	0.587	-0.433	0.775
	(0.72)	(0.25)	(0.61)	(0.20)

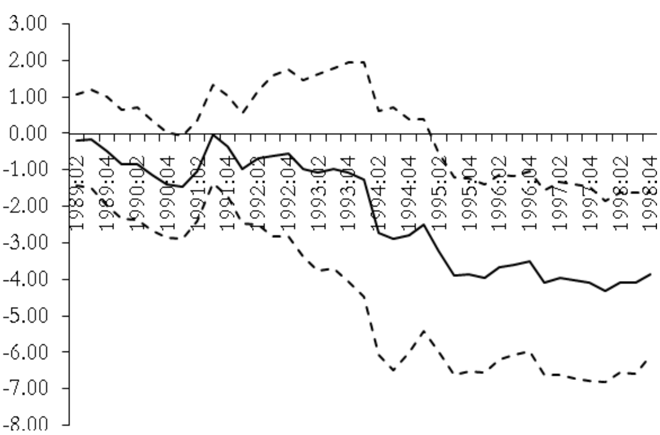
Notes to Tables 5-7. The tables report CW tests of equal predictive ability between the null of a martingale difference process and the alternative of a linear model with Taylor rule fundamentals. The sample starts in 1979:Q1 and rolling regressions are estimated with a 40 quarter window, so the forecasts are conducted for 1989:Q1 – 1998:Q4. The p-values in parentheses are calculated using bootstrap methods with the number of repetitions = 10,000. * ,**, and *** denote test statistics significant at 10, 5, and 1% level, respectively, based on critical values for the one-sided test.

Table 6. CW Statistics: One-Quarter-Ahead USD/DM Exchange Rate Forecasts using Taylor Rules with Quadratic Detrended Output Gaps

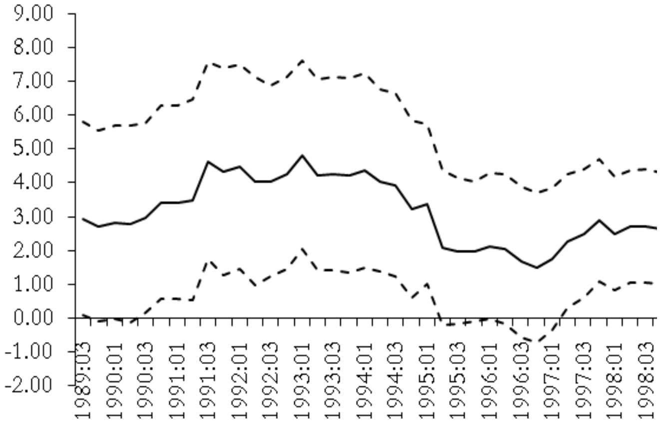
	w/o Smoothing		*w/ Smoothing*	
	Symmetric	*Asymmetric*	*Symmetric*	*Asymmetric*
A. Revised and Real-Time Data				
Revised Data	0.201	0.526	0.210	-0.178
	(0.36)	(0.37)	(0.36)	(0.47)
Real-Time Data	0.009	1.775**	0.314	1.754**
	(0.44)	(0.03)	(0.34)	(0.04)
B. Real-Time Data with Greenbook Inflation Forecasts				
Period-t Greenbook Inflation Forecasts	0.410	1.894**	0.493	1.849**
	(0.30)	(0.03)	(0.27)	(0.03)
Period-t+1 Greenbook Inflation Forecasts	0.514	1.772**	0.543	1.780**
	(0.26)	(0.04)	(0.26)	(0.04)
Period-t+2 Greenbook Inflation Forecasts	0.301	1.661**	0.155	1.707**
	(0.33)	(0.05)	(0.39)	(0.04)
Period-t+3 Greenbook Inflation Forecasts	0.630	1.820**	0.296	1.576**
	(0.22)	(0.03)	(0.35)	(0.05)
C. Real-Time Data with SPF Inflation Forecasts				
Period-t SPF Inflation Forecasts	0.415	1.652**	0.533	1.584*
	(0.29)	(0.05)	(0.26)	(0.06)
Period-t+1 SPF Inflation Forecasts	0.285	1.491*	0.373	1.803**
	(0.34)	(0.07)	(0.31)	(0.03)
Period-t+2 SPF Inflation Forecasts	0.191	1.400	0.161	1.636**
	(0.37)	(0.07)	(0.39)	(0.05)
Period-t+3 SPF Inflation Forecasts	0.469	1.604**	0.234	1.493*
	(0.27)	(0.05)	(0.36)	(0.07)
D. Real-Time Data with Greenbook Inflation Forecasts and Period-t+3 Output Gap Growth				
Period-t Greenbook Inflation Forecasts	-0.106	1.230*	0.300	1.255*
	(0.49)	(0.10)	(0.34)	(0.10)
Period-t+1 Greenbook Inflation Forecasts	0.039	1.305*	0.197	1.207
	(0.42)	(0.09)	(0.37)	(0.11)
Period-t+2 Greenbook Inflation Forecasts	-0.211	1.116	-0.199	1.284*
	(0.52)	(0.12)	(0.52)	(0.09)
Period-t+3 Greenbook Inflation Forecasts	0.180	1.379*	-0.211	1.058
	(0.39)	(0.07)	(0.53)	(0.13)
E. Real-Time Data with SPF Inflation Forecasts and Period-t+3 Output Gap Growth				
Period-t SPF Inflation Forecasts	-0.054	1.148	0.124	1.032
	(0.46)	(0.11)	(0.40)	(0.14)
Period-t+1 SPF Inflation Forecasts	-0.027	1.192	-0.154	1.051
	(0.45)	(0.11)	(0.51)	(0.14)
Period-t+2 SPF Inflation Forecasts	-0.266	0.931	-0.215	1.123
	(0.35)	(0.16)	(0.54)	(0.12)
Period-t+3 SPF Inflation Forecasts	0.037	1.209*	-0.270	0.817
	(0.43)	(0.10)	(0.52)	(0.19)

Table 7. CW Statistics: One-Quarter-Ahead USD/DM Exchange Rate Forecasts using Taylor Rules with U.S. Quadratic Detrended and German Central Bank Output Gaps

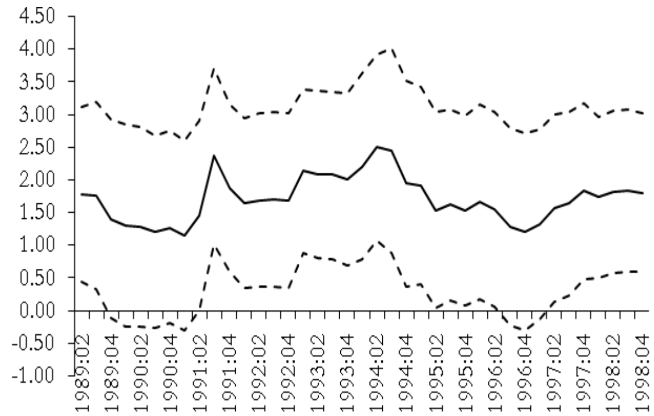
	w/o Smoothing		*w/ Smoothing*	
	Symmetric	*Asymmetric*	*Symmetric*	*Asymmetric*
A. Revised and Real-Time Data				
Revised Data	0.207	0.352	0.545	0.590
	(0.36)	(0.32)	(0.26)	(0.25)
Real-Time Data	-0.517	1.818**	-0.299	1.794**
	(0.63)	(0.03)	(0.56)	(0.04)
B. Real-Time Data with Greenbook Inflation Forecasts				
Period-t Greenbook Inflation Forecasts	0.032	1.795**	0.677	1.626**
	(0.41)	(0.04)	(0.22)	(0.05)
Period-t+1 Greenbook Inflation Forecasts	0.219	1.783**	0.615	1.683**
	(0.35)	(0.03)	(0.24)	(0.03)
Period-t+2 Greenbook Inflation Forecasts	-0.050	1.600*	0.289	1.689**
	(0.46)	(0.06)	(0.35)	(0.05)
Period-t+3 Greenbook Inflation Forecasts	0.341	1.771**	0.323	1.458*
	(0.31)	(0.04)	(0.33)	(0.07)
C. Real-Time Data with SPF Inflation Forecasts				
Period-t SPF Inflation Forecasts	-0.047	1.682**	0.611	1.521*
	(0.45)	(0.04)	(0.24)	(0.06)
Period-t+1 SPF Inflation Forecasts	-0.169	1.370*	0.532	1.767**
	(0.49)	(0.08)	(0.26)	(0.04)
Period-t+2 SPF Inflation Forecasts	-0.193	1.264*	0.319	1.611**
	(0.51)	(0.09)	(0.33)	(0.05)
Period-t+3 SPF Inflation Forecasts	0.144	1.526*	0.395	1.416*
	(0.39)	(0.06)	(0.30)	(0.07)
D. Real-Time Data with Greenbook Inflation Forecasts and Period-t+3 Output Gap Growth				
Period-t Greenbook Inflation Forecasts	-0.456	1.169	0.292	1.264*
	(0.63)	(0.11)	(0.35)	(0.09)
Period-t+1 Greenbook Inflation Forecasts	-0.293	1.223*	0.252	1.290*
	(0.55)	(0.10)	(0.36)	(0.09)
Period-t+2 Greenbook Inflation Forecasts	-0.556	0.938	-0.060	1.445*
	(0.66)	(0.15)	(0.47)	(0.07)
Period-t+3 Greenbook Inflation Forecasts	-0.158	1.253*	-0.156	1.116
	(0.50)	(0.10)	(0.51)	(0.11)
E. Real-Time Data with SPF Inflation Forecasts and Period-t+3 Output Gap Growth				
Period-t SPF Inflation Forecasts	-0.485	1.060	0.185	1.120
	(0.64)	(0.13)	(0.39)	(0.13)
Period-t+1 SPF Inflation Forecasts	-0.603	0.769	0.119	1.350*
	(0.66)	(0.19)	(0.41)	(0.08)
Period-t+2 SPF Inflation Forecasts	-0.651	0.619	-0.064	1.299*
	(0.68)	(0.24)	(0.47)	(0.09)
Period-t+3 SPF Inflation Forecasts	-0.359	0.966	-0.155	0.928
	(0.57)	(0.14)	(0.52)	(0.17)



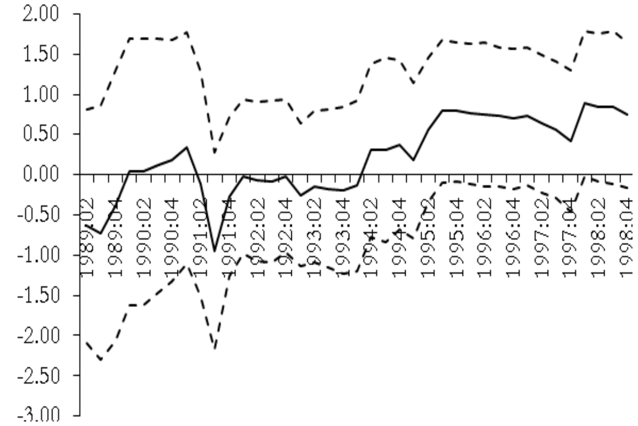
A. U.S. Inflation Coefficient



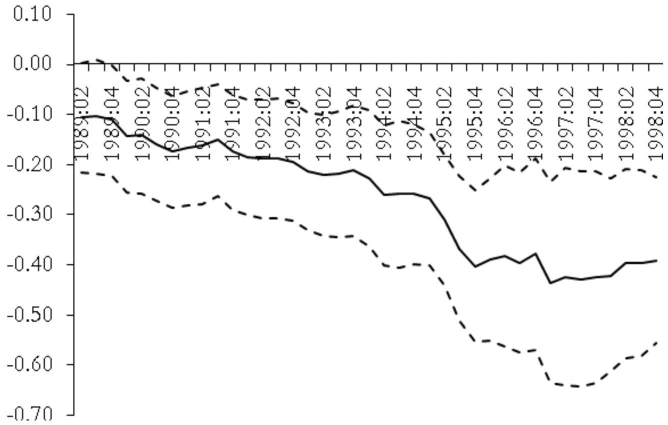
B. German Inflation Coefficient



C.U.S. Output Gap Coefficient



D.German Output Gap Coefficient



E. Real DM/USD Exchange Rate Coefficient

Figure 5. Dynamics of Forecasting Equation Coefficients: Taylor Rules with U.S. Quadratic Detrended and German Central Bank Output Gaps