Taylor Rules and the Euro[†]

Tanya Molodtsova[*], Alex Nikolsko-Rzhevskyy[**], and David H. Papell[***]

Abstract

This paper uses real-time data to show that the variables which normally enter central banks' Taylor rules for interest-rate-setting, can provide evidence of out-of-sample predictability for the U.S. Dollar/Euro exchange rate from the inception of the Euro in 1999 to 2007. The strongest evidence is found for specifications that constrain the coefficients on inflation and real economic activity to be the same for the U.S. and the Euro Area, do not incorporate interest rate smoothing, and do not include the real exchange rate in the forecasting regression. The evidence of predictability is found with both one-quarter-ahead and longer horizon forecasts.

Keywords: Out-of-sample exchange rate predictability, Euro/dollar exchange rate, Taylor rules

JEL Classification: E5, F3

[†] We thank Yu-Chin Chen, Luisa Corrado, Lutz Kilian, Sylvain Leduc, Michael McCracken, Barbara Rossi, Ken West, two anonymous referees, and participants at the EABCN Conference, Using Euro Area Data: Issues and Consequences for Economic Analysis, the 2008 CIRANO Workshop on Macroeconomic Forecasting, Analysis, and Policy with Data Revision, the 2008 SCCIE International Economics Conference, the Applied Econometrics and Forecasting in Macroeconomics and Finance Workshop at Federal Reserve Bank of St. Louis, Texas Camp Econometrics 2009, the 2009 North American Summer Meeting of the Econometric Society, the 2009 NBER Summer Institute International Finance and Macroeconomics Meeting, Ohio State University, the European Central Bank, and the Federal Reserve Bank of Atlanta for helpful comments and discussions.

[*] Tanya Molodtsova is Assistant Professor of Economics, Department of Economics, Emory University, Email: tmolodt@emory.edu

[**] Alex Nikolsko-Rzhevskyy is Assistant Professor of Economics, Department of Economics, University of Memphis, Email: nklrzhvs@memphis.edu

[***] David Papell is Professor of Economics, Department of Economics, University of Houston, Email: dpapell@uh.edu

1. Introduction

The behavior of exchange rates between Europe and the United States, either via multiple currencies until 1999 or via the Dollar/Euro exchange rate thereafter, has been one of the most studied topics in international economics. The results of this research have been less than stellar. The inability to connect exchange rates with macroeconomic fundamentals, characterized as the "exchange rate disconnect puzzle", has produced pessimism regarding the usefulness of empirical exchange rate models and focused attention on unquantifiable speculative and psychological factors.

A major contributing factor to this exchange rate pessimism has been the inability of empirical exchange rate models, starting with the seminal paper of Meese and Rogoff (1983), to forecast nominal exchange rates out-of-sample better than a naïve no-change, or random walk, forecast. While Mark (1995) provided hope that the models would forecast better at long horizons, more recent work such as Cheung, Chinn, and Pascual (2005) concludes that no model consistently does better than a random walk.

These models, however, do not reflect how monetary policy is currently conducted or evaluated. Starting with Taylor (1993), the interest rate reaction function known as the Taylor rule, where the nominal interest rate responds to the inflation rate, the difference between inflation and its target, the output gap, the equilibrium real interest rate, and (sometimes) the lagged interest rate and the real exchange rate, has become the dominant method for evaluating monetary policy. Following Clarida, Gali, and Gertler (1998), (hereafter CGG), Taylor rules have been estimated for a number of countries and time periods.

A major focus of Taylor rule estimation, pioneered by Orphanides (2001), is the use of real-time data that reflects the information available to central banks when they make their interest-rate-setting decisions. Although the argument for using real-time data seems at least as compelling for exchange rate forecasting as for Taylor rule modeling, almost all existent literature on exchange rate predictability uses fully revised data to assess the out-of-sample performance of empirical exchange rate models.[1]

Molodtsova and Papell (2009), exploiting recent econometric work by Clark and West (2006), test the out-of-sample predictability of nominal exchange rate changes using Taylor rule fundamentals 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 quasi-revised data for most of the considered currencies using Taylor rule fundamentals, they do not produce forecasts with real-time data.

In Molodtsova, Nikolsko-Rzhevskyy, and Papell (2008), we 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 (EMS), through 1998, the advent of the Euro, and use these specifications as fundamentals for evaluating out-of-sample predictability of the United States Dollar/Deutsche Mark nominal exchange rate. We find that evidence of predictability increases with the use of real-time, rather than revised, data and with models that allow differential inflation and output coefficients in the Federal Reserve and Bundesbank reaction functions and include the exchange rate in the Bundesbank reaction function.

This paper uses real-time data to evaluate out-of-sample predictability of the United States Dollar/Euro exchange rate from the inception of the Euro in 1999 to the end of 2007. We do not update the data because of the zero bound on the nominal interest rate. Once the Federal Funds rate

[1] Faust, Rogers and Wright (2003) was the first paper to use real-time data to evaluate exchange rate predictability.

approaches zero, it cannot be lowered further and future interest rate setting cannot be predicted by the Taylor rule.

Following the nomenclature in Molodtsova and Papell (2009), we consider a number of different specifications. While each specification has the interest rate differential on the left-hand-side, there are a number of possibilities for the right-hand-side variables.

1. Taylor posited that the Fed sets the nominal interest rate based on the current inflation rate, the inflation gap - the difference between inflation and the target inflation rate, the output gap - the difference between GDP and potential GDP, and the equilibrium real interest rate. Assuming that the ECB follows a similar rule, we construct a *symmetric* model with inflation and the output gap on the right-hand-side. Alternatively, we can posit that the ECB includes the difference between the exchange rate and the target exchange rate, defined by PPP, in its Taylor rule and construct an *asymmetric* model where the real exchange rate is also included.

2. It has become common practice, following CGG, to posit that the interest rate only partially adjusts to its target within the period. In this case, we construct a model with *smoothing* so that lagged interest rates appear on the right-hand-side. Alternatively, we can derive a model with *no smoothing* that does not include lagged interest rates. Models with and without smoothing can be symmetric or asymmetric.

3. If the Fed and ECB respond identically to changes in inflation and the output gap, so that the coefficients in their Taylor rules are equal, we derive a *homogeneous* model where relative (domestic minus foreign) inflation and the relative output gap are on the right-hand-side. If the response coefficients are not equal, a *heterogeneous* model is constructed where the domestic and

foreign variables appear separately. The homogeneous and heterogeneous models can be either symmetric or asymmetric, with or without smoothing.[2]

Using real-time data with Taylor rule fundamentals, we find very strong evidence of short horizon (one-quarter-ahead) out-of-sample predictability for the Dollar/Euro exchange rate. The strongest evidence comes from symmetric specifications with homogeneous coefficients without interest rate smoothing. The results are robust to whether the real-time output gap is constructed by Hodrick-Prescott (HP) filtering, taken from OECD estimates, or proxied by the difference between the unemployment rate and the natural rate of unemployment. Evidence of predictability is also found from symmetric specifications with heterogeneous coefficients without interest rate smoothing. Asymmetric specifications which include the real exchange rate in the forecasting regression and/or specifications with smoothing provide no evidence of predictability.

When estimating Taylor rules with real-time data, it is common practice to use forecasted, rather than realized, values of inflation and real economic activity. We use forecasted inflation with either the forecasted OECD output gap or the forecasted unemployment rate. The evidence of predictability with forecasted variables is comparable to, and in some cases stronger than, that found with realized values. We also investigate predictability with longer horizon exchange rate forecasts, and find somewhat stronger evidence of predictability with two-to-four quarter forecasts.

2. Taylor Rule Fundamentals

We examine the linkage between the exchange rate and a set of fundamentals that arise when central banks set the interest rate according to the Taylor rule. Following Taylor (1993) and CGG, the monetary policy rule postulated to be followed by the Fed or the ECB can be specified as

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

[2] If, in addition to having the same inflation response and interest rate smoothing coefficients, the two central banks have identical target inflation rates and equilibrium real interest rates, there is *no constant* on the right-hand-side. Otherwise, there is a *constant*. Since the restrictions necessary to eliminate the constant seem very unlikely to be fulfilled, we only estimate models with a constant.

where i_t is the short-term nominal interest rate, π_t is the inflation rate, y_t is the output gap, or percent deviation of actual real GDP from an estimate of its potential level, and q_t is the real exchange rate for the Euro Area. It is generally assumed that $\delta = 0$ for the United States. Alternatively, as in Blinder and Reis (2005), the difference between the natural rate of unemployment and the unemployment rate can replace the output gap. The constant term μ incorporates the inflation target and equilibrium real interest rate, and ρ measures partial adjustment of the interest rate to its target.

To derive the Taylor-rule-based forecasting equation, we first construct the interest rate differential by subtracting the interest rate reaction function for the Euro Area from that for the U.S. Based on empirical research on the forward premium and delayed overshooting puzzles and the results in Gourinchas and Tornell (2004) and Bacchetta and van Wincoop (2010), who show that an increase in the interest rate can cause sustained exchange rate appreciation if investors either systematically underestimate the persistence of interest rate shocks or make infrequent portfolio decisions, we postulate the following exchange rate forecasting equation:[3]

$$\Delta s_{t+1} = \omega - \omega_{u\pi}\pi_t + \omega_{e\pi}\tilde{\pi}_t - \omega_{uy}y_t + \omega_{ey}\tilde{y}_t + \omega_q\tilde{q}_t - \omega_{ui}i_{t-1} + \omega_{ei}\tilde{i}_{t-1} + \eta_t \tag{2}$$

where ~ denotes Euro Area variables and subscripts *u* and *e* denote coefficients for the United States and the Euro Area. The variable s_t is the log of the U.S. dollar nominal exchange rate determined as the domestic price of foreign currency, so that an increase in s_t is a depreciation of the dollar. The signs of the coefficients reflect the presumption that anything that causes the Fed and/or ECB to raise the U.S. interest rate relative to the Euro Area interest rate will cause forecasted dollar appreciation (a decrease in s_t).

[3] A more extensive discussion of the link between higher inflation and forecasted exchange rate appreciation can be found in Molodtsova and Papell (2009).

A number of different models can be nested in Equation (2). If the ECB doesn't target the exchange rate $\delta = \omega_q = 0$ and we call the specification symmetric. Otherwise, it is asymmetric. If the interest rate adjusts to its target level within the period $\omega_{ui} = \omega_{ei} = 0$ and the model is specified with no smoothing. Alternatively, there is smoothing. If the coefficients on inflation, the output gap, and interest rate smoothing are the same in the U.S. and the Euro Area, so that $\omega_{u\pi} = \omega_{e\pi}$, $\omega_{uy} = \omega_{ey}$, and $\omega_{ui} = \omega_{ei}$, inflation, output gap, and lagged interest rate differentials are on the right-hand-side of Equation (2) and we call the model homogeneous. Otherwise, it is heterogeneous.

3. Real-Time Data

We use real-time quarterly data from 1999:Q4 to 2007:Q3 for the United States and the Euro Area. The data is from the OECD Original Release Data and Revisions Database. It has a triangular format with the vintage date on the horizontal axis and calendar dates on the vertical. The term vintage denotes the date which a time series of data becomes known to the public.[4] The data for the first vintage starts in 1991:Q1. For each subsequent quarter, the new vintage incorporates newly released data and revisions to the historical data, thus providing all information known at the time.

We use the GDP Deflator to measure inflation for the U.S. and the Harmonized Index of Consumer Prices (HICP) to measure inflation for Euro Area. Following Taylor (1993), the inflation rate is the rate of inflation over the previous four quarters. We use two different measures of the real-time output gap. First, we construct quarterly measures of the output gap from internal OECD estimates. This data comes from the semi-annual issues of OECD Economic Outlook. Each issue contains past estimates as well as future forecasts of annual values of the output gap for OECD countries including the Euro Area. Since both estimates and forecasts are annual, we used quadratic

[4] There is typically a one-quarter lag before data is released, so real-time data, with the exception of nominal exchange rates and interest rates, dated time *t* actually represent data through period *t-1*.

interpolation to obtain quarterly estimates.[5] The second measure of the output gap uses real-time HP detrended real industrial production.[6] While applying the HP filter, we estimate the trend for the first vintage from 1991:Q1 to 1999:Q4. For each subsequent vintage, we update the trend by one quarter, taking account of the end-of-sample problem by forecasting and backcasting the series by 12 quarters in both directions assuming that growth rates follow an AR(4) process. The unemployment rates are from the OECD real-time database.

The forward-looking specifications for the U.S. also use the Philadelphia Fed Survey of Professional Forecasters (SPF) data, which consists of annualized quarter-over-quarter GDP deflator inflation and unemployment forecasts at different horizons. We convert them into year-over-year rates by taking the average of four consecutive forecasts. The data is available for the entire sample. For the Euro Area, the ECB publishes Euro Area SPF forecasts for the one-year-ahead HICP inflation rate. The first round of the survey was conducted in 1999:Q1. This means that we do not have the same year-over-year forecast for 1991:Q1, which is the starting point for our "vintage" regressions. To deal with this issue, we note that the first "vintage" regression which the public could have run using OECD real-time data was in 1999:Q4 when the first OECD vintage was published. At that time, inflation data for 1990:Q1-1999:Q3 was available. To construct the t+4 inflation forecast for any vintage, we use the realized t+4 values of inflation until 1998:Q4 and real-time Euro Area SPF forecasts from 1999:Q1 to 2007:Q3. The data for t+4 SPF forecasts of unemployment for Euro Are is constructed by the same method.[7]

The nominal exchange rate, defined as the U.S. dollar price of a Euro, is taken from daily exchange rates posted on the PACIFIC Exchange Rate Service website. While the actual exchange

[5] Since the data is updated semi-annually, we assume that, in the quarter following the period in which the estimates are released, the public uses the estimates and forecasts from the previous quarter. We interpolate between the current and immediate past release of the Economic Outlook.

[6] The industrial production data starts in 1990:Q1. We use industrial production instead of GDP because the latter does not start until 1995 for the Euro Area in the OECD database.

[7] Since the first forecasts are conducted in 1999:Q4, they are real-time forecasts even though realized t+4 values of inflation and unemployment are used through 1998:Q4.

rate is only available since the advent of the Euro in 1999, "synthetic" euro rates are available starting in 1993. We use point in time, rather than quarterly averaged, exchange rates to avoid inducing serial correlation in exchange rate changes. This, however, does not specify which point in time exchange rate should be used. Because of lags in data collection, real-time data reported for quarter t actually represents data through quarter $t-1$. While the release dates for the different real-time variables range from the end of the first month in the quarter (U.S. GDP) to the end of the third week of the second month in the quarter (U.S. unemployment), the majority of releases are clustered around the second week of the second month in the quarter. For the purpose of evaluating forecasts, we need to ensure that the data have been released (or else we wouldn't be using real-time data) and want to minimize the time between the release of the data and the start of the forecast (or else markets will have time to incorporate information before the forecasts are made). We therefore use the end of the second week of the second month as our exchange rate.

The short-term nominal interest rates, defined as the interest rate in the third month of each quarter, are taken from the OECD Main Economic Indicators (MEI) database. The short-term interest rate is the money market rate (EONIA) for Euro Area and the Federal Funds Rate for the U.S. Since interest data for the Euro Area does not exist prior to 1994:Q4, we use the German money market rate from the IMF International Financial Statistics Database (line 60B) for the earlier period. The real Euro/USD exchange rate is calculated as the percentage deviation of the nominal exchange rate from the target defined by Purchasing Power Parity, where the two countries' price levels are measured by the CPI for the U.S. and the HICP for the Euro Area.

4. Forecast Comparison Based on MSPE

We are interested in comparing the mean square prediction errors from two nested models. The benchmark model is a zero mean martingale difference process, while the alternative is a linear model.

Model 1: $y_t = \varepsilon_t$

Model 2: $y_t = X_t^{'}\beta + \varepsilon_t$, where $E_t(\varepsilon_{t+1}) = 0$

We want to test the null hypothesis that the MSPEs are equal against the alternative that the MSPE of Model 2 is smaller than the MSPE of Model 1. Under the null, the population MSPEs are equal. We need to use the sample estimates of the population MSPEs to draw the inference. The procedure introduced by Diebold and Mariano (1995) and West (1996) uses sample MSPEs to construct a t-type statistic which is assumed to be asymptotically normal.

McCracken (2007) shows that application of the DMW statistic with standard normal critical values to non-nested models results in severely undersized tests. Clark and West (2006) demonstrate analytically that the asymptotic distributions of sample and population difference between the two MSPEs are not identical, namely the sample difference between the two MSPEs is biased downward from zero. They show that the sample difference between the two MSPEs is uncentered under the null and, therefore, the MSPE of the naïve no-change model would be smaller than that of a linear model. The intuition behind this result is as follows. If the null is true, estimating the alternative model introduces noise into the forecasting process because it is trying to estimate parameters which are zero in population. Use of the noisy estimate will lead to a higher estimated MSPE and, as a result, the sample MSPE of the alternative model will be higher by the amount of estimation noise.

In order to test for predictability, we construct the corrected test statistic as described in Clark and West (2006) by adjusting the sample MSPE from the alternative model by the amount of the bias under the null hypothesis. This adjusted CW test statistic is asymptotically standard normal. When the null is a martingale difference series, Clark and West (2006, 2007) recommend adjusting the difference between MSPEs and using standard normal critical values for inference.[8]

[8] Because the null hypothesis for the CW statistic is a zero mean martingale difference process, we can only test the null that the exchange rate is a random walk, not a random walk with drift. Clark and McCracken (2009) consider the impact

It is important to understand the distinction between predictability and forecasting ability. We use the term "predictability" as a shorthand for "out-of-sample predictability" in the sense used by Clark and West (2006, 2007), rejecting the null of a zero slope in the predictive regression in favor of the alternative of a nonzero slope. The CW methodology tests whether the regression coefficient β is zero rather than whether the sample MSPE from the model-based forecast is smaller than the sample MSPE from the random walk forecast.

We also use McCracken's (2007) asymptotic critical values for the DMW test with nested models to produce correctly sized tests. The critical values depend on the ratio of the number of observations in the predictive regression to the number of forecasts and the number of additional estimated parameters in the unrestricted model. Since the null hypothesis is a random walk, with zero estimated parameters, the number of additional estimated parameters is given in Equation (2), ranging from three for the symmetric model with homogeneous coefficients and no smoothing to eight for the asymmetric model with heterogeneous coefficients and smoothing.[9]

One disquieting aspect of both tests is that it is possible to find evidence of predictability when the MSPE of the random walk forecast is smaller than the MSPE of the linear model forecast. The issue arises because, whether good size is achieved by adjusting the DMW statistic, as in Clark and West (2006), or by adjusting the critical values, as in McCracken (2007), the distribution of the critical values is not centered around the point where the two MSPEs are equal. This is not problematic in an econometric context because testing for predictability, whether the regression coefficient β is significantly different from zero, is not the same as whether the MSPE from the

---

of data revisions on tests of equal predictive ability. Because the nominal exchange rate is unrevised and a random walk under the null, even predictable real-time data revisions do not have an impact on the asymptotic distributions and the Clark and West results can be used.

[9] Since we have a relatively small number of observations, we also calculated bootstrapped critical values for the CW test, which made virtually no difference in the results and are not reported. We did not calculate bootstrapped critical values for the DMW test because, as described by McCracken (2007), the asymptotic distribution is not well-approximated by a standard normal distribution and so bootstrapping cannot be used to correct finite sample size distortions relative to an asymptotic standard normal distribution.

model is smaller than the MSPE from the random walk. It is, however, problematic if one wants to interpret evidence of predictability as evidence of forecasting ability. While we are certainly not going to solve the problem of testing for forecasting ability in nested models in this paper, we report the ratio of the MSPEs as well as the two test statistics.

5. Empirical Results

5.1 One-Quarter-Ahead Out-of-Sample Predictability

We now turn to the central question of our paper, whether Taylor rule fundamentals can provide evidence of out-of-sample predictability for the United States Dollar/Euro exchange rate. For each forecasting regression, we use 26 quarters to estimate the historical relationship between the Taylor rule fundamentals and the change in the exchange rate, and then use the estimated coefficients to forecast the exchange rate one-to-four quarters ahead. We use rolling regressions to predict 32 exchange rate changes from 1999:Q4 to 2007:Q3.[10] Since we use vintage data, the estimates and forecasts incorporate all information known at the time.[11]

Table 1 presents results for one-quarter-ahead forecast comparisons. The first row of each panel reports the ratios of the out-of-sample MSPE from the linear model with Taylor rule fundamentals to that of the random walk model. The second row reports test statistics using the CW test with asymptotic critical values. The third row reports test statistics using the DMW test with McCracken's (2007) critical values. For each specification, results are reported where real economic activity is measured by the HP filtered real-time output gap, the OECD estimates of the real-time

[10] The span of the data for estimating the forecasting regressions is limited to 26 quarters because the synthetic euro data is not available before 1993:Q1. With two, three, and four quarter-ahead forecasts, the number of predictions decreases to 31, 30, and 29, respectively.

[11] An alternative method of constructing real-time data is to use "diagonal" data that does not incorporate historical revisions. Since the vintages are not available before 1999 and we only have 32 forecast periods, we do not have that option for this paper.

output gap, and the real-time unemployment rate.[12] The exchange rate is for the end of the second week of the second month in the quarter which, as discussed above, minimizes the time between when the data for the right-hand-side variables has been released and the date of the forecast.

With a symmetric specification that does not include the real exchange rate in the forecasting regression and no interest rate smoothing, the MSPE of the Taylor rule model is smaller than the MSPE of the random walk model, so that the ratio is less than unity, for all three cases with homogeneous coefficients and for two of the three cases with heterogeneous coefficients. With homogeneous coefficients, the random walk (no predictability) null hypothesis is rejected in favor of the alternative hypothesis of out-of-sample predictability for the Euro/Dollar exchange rate with Taylor rule fundamentals at the 1 percent level when inflation and the unemployment rate, and at the 5 percent level when inflation and either the HP filtered output gap or the OECD estimated output gap, is included in the forecasting regression using either the CW or the DMW statistic.[13] With heterogeneous coefficients, the null hypothesis is rejected at the 5 percent level for inflation and the HP filtered output gap using both tests. With inflation and the unemployment rate, the null is rejected at the 5 percent level with the DMW statistic and at the 10 percent level with the CW statistic. With inflation and the OECD estimated output gap, where the MSPE of the linear model is larger than the MSPE of the random walk, the null hypothesis of no predictability cannot be rejected using either test. Summarizing the results for the symmetric model without smoothing, the MSPE for the model with Taylor rule fundamentals is smaller than the MSPE for the random walk model and the no predictability null hypothesis can be rejected for five of the six cases, while the MSPE for

[12] Because we use rolling regressions where the constant, as well as the coefficients, change each period, using the real-time unemployment rate is identical to using the real-time unemployment gap, as in Boivin (2006), where the natural rate of unemployment is measured as the backward moving average of the unemployment rate.

[13] Plots of the forecasting equation coefficients for the symmetric specification with homogeneous coefficients and no smoothing (not reported) show that the signs of both the inflation and real economic activity differential coefficients are in accord with the predictions of Equation (2), but only the inflation coefficients are significantly different from zero.

the model with Taylor rule fundamentals is larger than the MSPE for the random walk model and the no predictability null hypothesis cannot be rejected for the other case.

We illustrate these results in Figure 1, which depicts actual and predicted Dollar/Euro exchange rate changes for all six specifications of the symmetric model with no smoothing. Positive values represent depreciation of the dollar while negative values represent appreciation of the dollar. Since the "zero" line represents the random walk (no change) forecast, periods for which the actual and predicted values are both either positive or negative lower the MSPE ratio, while periods for which the actual and predicted values are of opposite sign raise the MSPE ratio. The predicted exchange rate changes display considerable variability, although not as much as the actual changes. While the predicted changes do not pick up the sharp quarter-by-quarter spikes of the actual changes, they track the pattern of dollar appreciation in 2000 and 2001, depreciation in 2002-2004, appreciation in 2005, and depreciation in 2006 and 2007 found in the data. Given the generally accepted view that exchange rates are unconnected with macroeconomic fundamentals, the figure provides strong collaboration of the statistical evidence that Taylor rule fundamentals can predict changes in the Dollar/Euro rate.

The results for the other models provide no evidence of predictability. The MSPE of the linear model is larger than the MSPE of the random walk for all specifications of asymmetric models without smoothing, symmetric models with smoothing, and asymmetric models with smoothing. The no predictability null hypothesis can only be rejected at the 10 percent level in two of the 18 cases with the CW statistic, about what you would expect to find from a correctly sized test under the null, and cannot be rejected in any of the cases with the DMW test.

Estimated Taylor rules for both the U.S. and the Euro Area almost universally include interest rate smoothing, and so we find it puzzling that the exchange rate forecasting results are so much stronger for the models with no smoothing. While we do not have a definitive answer, we can think of two possibilities. First, the models with smoothing add two more coefficients to be estimated, and the resultant increased standard errors could be important with only 26 quarters in each window. Second, in contrast to the academic literature, Taylor rules in the practitioner literature, including the Macroeconomic Advisors rule described by Meyer (2009) and the Bloomberg rule described by Rosenberg (2010), do not include lagged interest rates. Since we are evaluating forecasts that could have been made in real time, maybe the practitioner literature is more relevant for our results than the academic literature.

It is often argued that forward-looking monetary policy rules provide a superior description of central banks' behavior than rules based on the most recent estimates of inflation. Following Orphanides (2001, 2003), most of this literature uses Greenbook forecasts for the U.S. Since Greenbook forecasts are not publicly available past 2002 and there is no equivalent for the ECB, we use SPF forecasts for both. The bottom two rows of each panel in Table 1 report specifications with both forecasted inflation and four-quarter-ahead OECD output gap and unemployment rate forecasts. While these mostly provide evidence of predictability for the symmetric models without smoothing, the evidence is of comparable strength as with the realized inflation and measures of real economic activity. The use of unemployment rate forecasts also increases out-of-sample exchange rate predictability for almost all of the specifications for which no evidence of predictability is found with realized values.

5.2 Testing for Superior Predictive Ability

Since we are testing simultaneously hypotheses that involve 24 different alternative models, conventional p-values can be misleading. As a result of extensive specification search, we may mistake significant results generated by chance for genuine evidence of predictive ability. To address the issue of multiple hypothesis testing, we perform the test of superior predictive ability (SPA) proposed by Hansen (2005). The SPA test is designed to compare the out-of-sample performance of a benchmark model to that of a set of alternatives. This approach is a modification of the reality check for data snooping developed by White (2000). The advantages of the SPA test are that it is more powerful and less sensitive to the introduction of poor and irrelevant alternatives.[14]

The SPA test can be used for comparing the out-of-sample performance of two or more models. It tests the composite null hypothesis that the benchmark model is not inferior to any of the alternatives against the alternative that at least one of the linear economic models has superior predictive ability. In the context of using the CW statistic to evaluate out-of-sample predictability, rejecting the null indicates that at least one linear model is strictly superior to the random walk. SPA p-values take into account the search over models that preceded the selection of the model being compared to the benchmark. A low p-value suggests that the benchmark model is inferior to at least one of the competing models. A high p-value indicates that the data analyzed do not provide strong evidence that the benchmark is outperformed.[15]

Table 2 reports SPA p-values for nine sets of forecasts based on symmetric and asymmetric Taylor rule specifications that are compared to a random walk forecast. The SPA p-values strongly confirm the results in Table 1. Every symmetric specification without smoothing or with a combination of models with and without smoothing is significant at the 10 percent level or higher and no specification that includes only models with smoothing is significant at the same level. Within the class of symmetric specifications, the p-values are lower for the homogeneous and no smoothing specifications than for the heterogeneous and smoothing specifications and, not surprisingly, are lowest for the homogeneous specifications without smoothing. For the asymmetric

---

[14] Molodtsova and Papell (2009) use the SPA test for the same purpose. Hansen (2005) provides details on the construction of the test statistic and confirms the advantages of the test by Monte Carlo simulations. We use the publicly available software package MULCOM to construct the SPA-consistent p-values for each country. The code, detailed documentation, and examples can be found at http://www.hha.dk/~alunde/mulcom/mulcom.htm.

[15] We use the adjusted MSPE's from the linear models so that the tests have correct size. Hubrich and West (2010) develop a similar procedure based on the White (2000) test.

models, the null hypothesis of no predictability cannot be rejected at the 10 percent level for any combination of specifications.

5.3 Longer Horizon Out-of-Sample Predictability

Following Mark (1995), it has become standard practice to investigate long horizon out-of-sample exchange rate predictability, mostly in the context of studies where evidence of short horizon predictability cannot be found. Engel, Mark and West (2008) use a more constrained version of the Molodtsova and Papell (2009) specification with fully revised data. They find more evidence of long horizon (16-quarter) than short horizon (one-quarter) predictability. Engel, Mark, and West (2009) augment their models with factors constructed from a cross section of exchange rates. For the 1999:Q1-2007:Q4 sample, where their results are strongest, they again report more evidence of long horizon than of short horizon predictability. Wang and Wu (2009), using interval forecasts, also find more evidence of long horizon than of short horizon predictability using models with Taylor rule fundamentals. None of these papers, however, use real-time data.

We investigate longer horizon out-of-sample predictability by estimating two, three, and four-quarter-ahead exchange rate forecasting regressions.[16] Table 3 reports multiple-step-ahead out-of sample forecasts for models with realized variables that do not incorporate smoothing. For the symmetric models with homogeneous coefficients, where the evidence of predictability was strongest with one-step-ahead forecasts, the no predictability null can be rejected at the 5 percent level or higher for all forecast horizons and measures of real economic activity. For the symmetric models with heterogeneous coefficients, for which the evidence of predictability was next strongest when the forecast horizon h = 1, the evidence strengthens with h = 2 and h = 3, but then almost disappears with h = 4. For the asymmetric models with either homogeneous or heterogeneous

[16] We account for the serial correlation induced by multiple-period forecasts with overlapping data by using a mean-adjusted version of the estimator in Hodrick (1992). Using the Newey-West estimator does not affect the results. While Engel, Mark, and West (2007) consider 16-quarter-ahead forecasts, we focus on horizons up to four quarters because of the limited time span of our data.

coefficients, for which there was no evidence of predictability with $h = 1$, the evidence of predictability strengthens as h increases and is strongest with $h = 4$. Combining all models, the no predictability null hypothesis can be rejected at the 10 percent level in 6, 7, 9, and 10 cases (out of 12) with $h = 1, 2, 3$, and 4, respectively. At the 5 percent level, the number of rejections are 4, 7, 6, and 6 for h = 1,…,4. Overall, the evidence of predictability increases with the forecast horizon.

6. Conclusions

It has become standard practice for monetary policy evaluation of the Fed and ECB to be conducted via some variant of a Taylor rule where the short-term nominal interest rate responds to inflation and a measure of real economic activity. While neither the Fed nor the ECB follow a mechanical rule and there is much disagreement over the coefficients and variables that enter the rule that best describes their behavior, even a cursory reading of FOMC press releases and the ECB Monthly Bulletin makes it clear why Taylor rules have become so ubiquitous. This is clear from both the Fed's dual mandate and the concern by the Governing Council of the ECB with real economic activity as well as price stability.

In this paper, we analyze whether the variables that normally enter central banks' interest-rate-setting rules, which we call Taylor rule fundamentals, can provide evidence of out-of-sample predictability of the Dollar/Euro exchange rate. We use real-time data that was available to market participants at the point that their exchange rate forecasts were conducted and are careful to minimize the time between the release of the data and the start of the forecast.

The major result of the paper is that the null hypotheses of no predictability can be rejected against the alternative hypotheses of predictability with Taylor rule fundamentals for a wide variety of specifications that include inflation and a measure of real economic activity in the forecasting regression. The strongest evidence comes from the simplest specifications that closely resemble the original Taylor rule, where the interest rates set by the Fed and the ECB respond only to inflation and a measure of real economic activity. The results are robust to the inclusion of inflation and real economic activity forecasts, rather then realized values, in the forecasting regression and to testing for either short-horizon exchange rate predictability of one quarter or longer-horizon predictability of up to one year.

Rogoff and Stavrakeva (2008) have criticized recent studies that employ the Clark and West (CW) statistic because it does not necessarily satisfy their criterion for a "good" forecast – a forecast with a MSPE smaller than the MSPE of a driftless random walk. While the CW statistic is a test for predictability, not forecasting ability, the strongest results in this paper are not subject to their criticism. For every symmetric specification with homogeneous coefficients and without interest rate smoothing where the null hypothesis can be rejected by either the CW or the DMW statistic, the MSPE of the model with Taylor rule fundamentals is smaller than the MSPE of the random walk model.

References

Bacchetta, Philippe and Eric van Wincoop. (2010) "Infrequent Portfolio Decisions: A Solution to the Forward Discount Puzzle." *American Economic Review*, 100, 870-904.

Blinder, Alan S. and Ricardo Reis. (2005) "Understanding the Greenspan Standard." in *The Greenspan Era: Lessons for the Future*, pp.11-96. Kansas City: Federal Reserve Bank of Kansas City.

Boivin, Jean. (2006) "Has U.S. Monetary Policy Changed? Evidence from Drifting Coefficients and Real-Time Data." *Journal of Money, Credit and Banking*, 38, 1149-79.

Cheung, Yin-Wong, Menzie D. Chinn, and Antonio Garcia Pascual. (2005) "Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?" *Journal of International Money and Finance*, 24, 1150-75.

Clarida, Richard, Jordi Gali, and Mark Gertler. (1998) "Monetary Rules in Practice: Some International Evidence." *European Economic Review*, 42, 1033-67.

Clark, Todd E. and Michael W. McCracken. (2009) "Tests of Equal Predictive Ability with Real-Time Data." *Journal of Business and Economic Statistics*, 27, 441-54.

Clark, Todd and Kenneth D. West. (2006) "Using Out-of-Sample Mean Squared Prediction Errors to Test the Martingale Difference Hypothesis." *Journal of Econometrics*, 135, 155-86.

__________, (2007) "Approximately Normal Tests for Equal Predictive Accuracy in Nested Models." *Journal of Econometrics*, 138, 291-311.

Diebold, Francis and Robert Mariano. (1995) "Comparing Predictive Accuracy." *Journal of Business and Economic Statistics*, 13, 253-63.

Engel, Charles, Nelson C. Mark, and Kenneth D. West. (2008) "Exchange Rate Models Are Not as Bad as You Think." in *NBER Macroeconomics Annual 2007,* edited by Daron Acemoglu*,* Kenneth Rogoff, and Michael Woodford*,* pp.381-441. Chicago: University of Chicago Press.

___________, (2009) "Factor Model Forecasts of Exchange Rates." manuscript, University of Wisconsin.

Faust, Jon, John H. Rogers, and Jonathan H. Wright. (2003) "Exchange Rate Forecasting: the Errors We've Really Made." *Journal of International Economics*, 60, 35-59.

Gourinchas, Pierre-Olivier and Aaron Tornell. (2004) "Exchange Rate Puzzles and Distorted Beliefs." *Journal of International Economics*, 64, 303-33.

Hansen, Peter. (2005) "A Test for Superior Predictive Ability." *Journal of Business and Economic Statistics*, 23, 365-80.

Hodrick, Robert. (1992) "Dividend Yields and Expected Stock Returns: Alternative Procedures for Inference and Measurement." *Review of Financial Studies*, 5, 357-86.

Hubrich, Kirstin and Kenneth D. West. (2010) "Forecast Comparisons for Small Nested Model Sets." *Journal of Applied Econometrics*, 25, 574-94.

Mark, Nelson. (1995) "Exchange Rate and Fundamentals: Evidence on Long-Horizon Predictability." *American Economic Review*, 85, 201-18.

McCracken, Michael. (2007) "Asymptotics for Out-of-Sample Tests of Granger Causality." *Journal of Econometrics*, 140, 719-52.

Meese, Richard A. and Kenneth Rogoff. (1983) "Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample?" *Journal of International Economics*, 14, 3-24.

Meyer, Laurence. (2009) "Dueling Taylor Rules." *Monetary Policy Insights: Policy Focus*, Macroeconomic Advisors, August 20.

Molodtsova, Tanya and David H. Papell. (2009) "Exchange Rate Predictability with Taylor Rule Fundamentals." *Journal of International Economics*, 77, 167-80.

Molodtsova, Tanya, Alex Nikolsko-Rzhevskyy and David H. Papell. (2008) "Taylor Rules with Real-Time Data: A Tale of Two Countries and One Exchange Rate." *Journal of Monetary Economics*, 55, S63-S79.

Orphanides, Athanasios. (2001) "Monetary Policy Rules Based on Real-Time Data." *American Economic Review*, 91, 964-85.

Rogoff, Kenneth and Vania Stavrakeva. (2008) "The Continuing Puzzle of Short Horizon Exchange Rate Forecasting." National Bureau of Economic Research Working Paper 14071.

Rosenberg, Michael. (2010) "Financial Conditions Watch." Bloomberg, January 27.

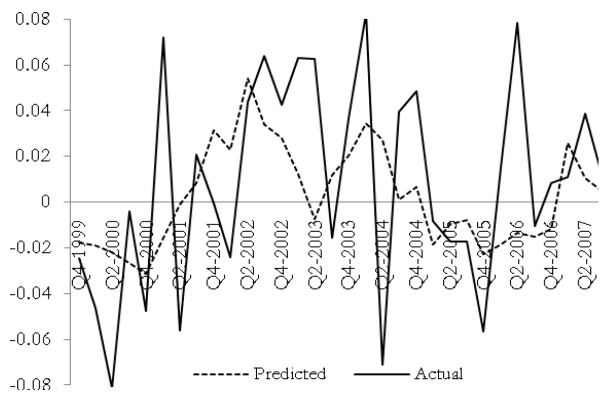
Taylor, John B. (1993) "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy*, 39, 195-214.

Wang, Jian and Jason Wu. (2009) "The Taylor Rule and Forecast Intervals for Exchange Rates" Federal Reserve Bank of Dallas Globalization and Monetary Policy Institute Working Paper No.22.

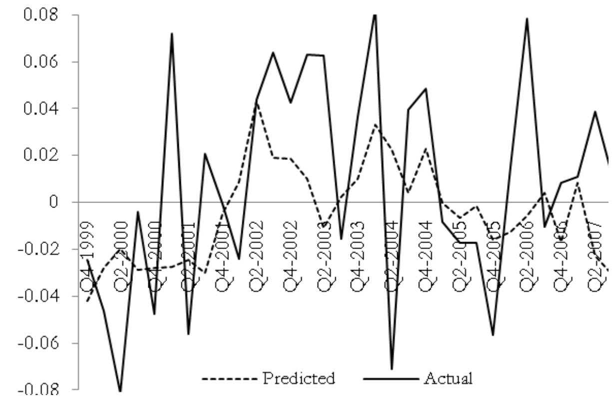
Wang, Jian and Jason Wu. (2009) "The Taylor Rule and Forecast Intervals for Exchange Rates"

West, Kenneth D. (1996) "Asymptotic Inference about Predictive Ability." *Econometrica*, 64, 1067-84.

White, Halbert L. (2000) "A Reality Check for Data Snooping." *Econometrica*, 68, pp.1097-1127.

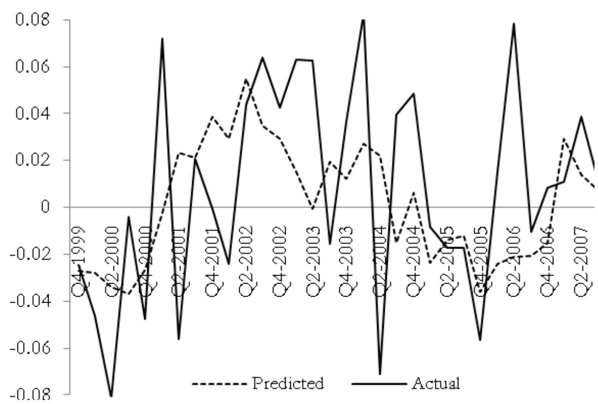


Homogeneous Coefficients

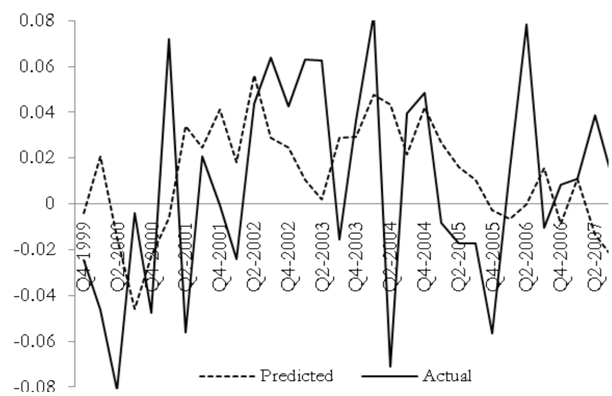


Heterogeneous Coefficients

A. HP Filtered Output Gap

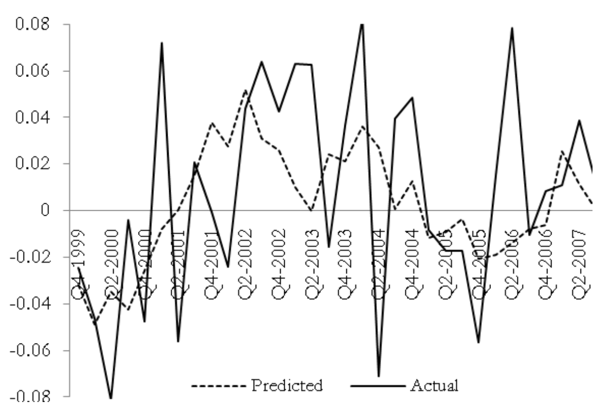


Homogeneous Coefficients

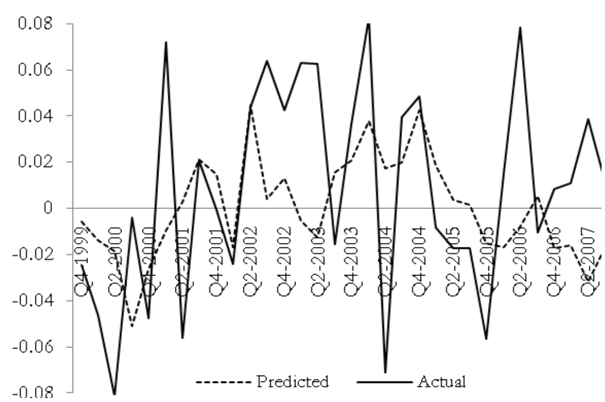


Heterogeneous Coefficients

B. OECD Estimates of Output Gap



Homogeneous Coefficients



Heterogeneous Coefficients

C. Unemployment Rate

Figure 1. Actual and Predicted Changes in the Dollar/Euro Exchange Rate Based on the Symmetric Model with No Smoothing

Table 1: One-Quarter-Ahead Out-of-Sample Predictability

	w/o Smoothing		*w/ Smoothing*	
	Symmetric	*Asymmetric*	*Symmetric*	*Asymmetric*
A. Homogenous Coefficients				
HP Filtered Output Gap	0.854	1.018	1.046	1.428
CW statistic	2.197**	1.506*	1.361*	-0.658
DMW statistic	0.955**	-0.114	-0.252	-1.849
OECD Estimates of Output Gap	0.903	1.363	1.161	1.496
CW statistic	2.202**	0.291	0.839	-0.596
DMW statistic	0.560**	-1.718	-0.828	-1.903
Unemployment Rate	0.832	1.037	1.137	1.429
CW statistic	2.526***	1.148	1.221	-0.981
DMW statistic	1.010***	-0.233	-0.632	-2.003
OECD Output Gap Forecasts	0.808	0.870	1.087	1.127
CW statistic	2.465***	2.164**	1.082	0.951
DMW statistic	1.383***	0.812**	-0.425	-0.602
Unemployment Rate Forecasts	0.904	0.797	1.007	0.965
CW statistic	2.476***	2.789***	1.810**	1.797**
DMW statistic	0.542**	1.049***	-0.026*	0.165**
B. Heterogeneous Coefficients				
HP Filtered Output Gap	0.927	1.378	1.119	1.999
CW statistic	1.731**	-0.411	1.092	-1.077
DMW statistic	0.455**	-1.640	-0.481	-3.031
OECD Estimates of Output Gap	1.085	1.565	1.666	1.691
CW statistic	1.186	0.933	0.004	0.159
DMW statistic	-0.414	-1.570	-2.080	-1.812
Unemployment Rate	0.965	1.597	1.259	1.603
CW statistic	1.626*	-0.572	0.511	-1.084
DMW statistic	0.244**	-2.405	-1.250	-2.853
OECD Output Gap Forecasts	1.041	1.235	1.328	1.527
CW statistic	1.339*	0.840	0.586	0.419
DMW statistic	-0.288	-0.915	-1.300	-1.496
Unemployment Rate Forecasts	0.975	0.895	1.080	1.198
CW statistic	2.307**	2.137**	1.358*	1.009
DMW statistic	0.115*	0.648***	-0.355*	-0.755

Notes: The table reports the ratio of the out-of-sample MSPEs of the linear model to that of the random walk model and the CW and DMW statistics for tests of equal predictability between the two models. Panel A contains the results for homogenous Taylor rule models that restrict coefficients on the inflation and output gap in the two countries to be the same, and Panel B contains the results for heterogeneous Taylor rule models. The statistics are reported for the following classes of models: Symmetric Taylor rule models that exclude real exchange rate from the forecasting regression equation, and Asymmetric Taylor rule models, that are subdivided into the models w/ Smoothing and w/o Smoothing that either include or exclude lagged interest rate. * ,**, and *** denote test statistics significant at 10, 5, and 1% level, respectively, based on standard normal critical values for the CW statistic and McCracken's (2007) critical values for the DMW statistic. We use real-time quarterly data from 1999:Q4 to 2007:Q3 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. Rolling regressions with a 26-quarter window are used to predict 32 exchange rate changes from 1999:Q4 to 2007:Q3 based on the models with Taylor rule fundamentals.

Table 2: Tests for Superior Predictive Ability

Models	*Symmetric*	*Asymmetric*
Homogenous w/ Smoothing	0.110	0.828
Homogenous w/o Smoothing	0.012**	0.127
Heterogenous w/ Smoothing	0.171	0.675
Heterogenous w/o Smoothing	0.055*	0.330
Homogenous	0.021**	0.128
Heterogenous	0.076*	0.388
Smoothing	0.188	0.741
No Smoothing	0.019**	0.227
All	0.029**	0.286

Notes: The table reports SPA p-values for the CW statistic for nine sets of forecasts based on *Symmetric* (without the real exchange rate) and *Asymmetric* (with the real exchange rate) Taylor rule specifications that are compared to a random walk forecast. * ,**, and *** denote test statistics significant at 10, 5, and 1% level, respectively. Each row contains the results for the following classes of models: *All*, all Taylor rule models, *Smoothing* and *No Smoothing*, models that include or exclude interest rate smoothing, *Homogenous* and *Heterogeneous*, models that restrict or do not restrict the coefficients on inflation and measures of economic activity to be the same for the U.S. and Euro Area.

Table 3: Longer Horizon Out-of-Sample Predictability for Models without Smoothing

Forecast Horizon, *h*	*h=1*	*h=2*	*h=3*	*h=4*
A. Homogenous Coefficients, Symmetric				
HP Filtered Output Gap	0.854	0.678	0.587	0.668
CW statistic	2.197**	2.214**	2.231**	1.976**
OECD Estimates of Output Gap	0.903	0.812	0.777	0.938
CW statistic	2.202**	2.176**	2.058**	1.785**
Unemployment Rate	0.832	0.628	0.471	0.440
CW statistic	2.526***	2.531***	2.491***	2.428***
B. Heterogeneous Coefficients, Symmetric				
HP Filtered Output Gap	0.927	0.775	0.759	1.313
CW statistic	1.731**	2.070**	1.976**	1.000
OECD Estimates of Output Gap	1.085	1.101	1.070	1.401
CW statistic	1.186	1.111	1.335*	1.033
Unemployment Rate	0.964	0.753	0.769	1.835
CW statistic	1.625*	2.141**	2.118**	1.365*
C. Homogenous Coefficients, Asymmetric				
HP Filtered Output Gap	1.018	0.804	0.790	0.670
CW statistic	1.506*	2.063**	2.153**	2.164**
OECD Estimates of Output Gap	1.363	1.379	1.567	1.249
CW statistic	0.291	0.991	1.194	1.542*
Unemployment Rate	1.037	0.812	0.781	0.637
CW statistic	1.148	2.012**	2.039**	2.135**
D. Heterogeneous Coefficients, Asymmetric				
HP Filtered Output Gap	1.378	0.992	1.331	1.547
CW statistic	-0.411	1.245	1.085	1.517*
OECD Estimates of Output Gap	1.565	1.885	2.780	1.629
CW statistic	0.933	0.721	1.038	1.657*
Unemployment Rate	1.597	1.493	2.194	1.268
CW statistic	-0.572	0.784	1.501*	2.078**

Notes: The table reports the ratio of the out-of-sample MSPEs of the linear model to that of the random walk model and the CW statistics for the tests of equal predictability respectively, between the two models. * ,**, and *** denote test statistics significant at 10, 5, and 1% level, respectively, based on standard normal critical values. For h>1, Hodrick (1992) adjustment is used. We use real-time quarterly data from 1999:Q4 to 2007:Q3 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. Rolling regressions with a 26-quarter window are used to predict 32 exchange rate changes from 1999:Q4 to 2007:Q3 based on the models with Taylor rule fundamentals.