

Phoenix Taylor Rule Exchange Rate Forecasting During the Financial Crisis

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December 17, 2010

Abstract

This paper evaluates out-of-sample exchange rate forecasting of Taylor rule models for the euro/dollar exchange rate with real-time data during the financial crisis of 2008-2009. The Taylor rule specifications outperform the random walk with forecasts ending between 2007:Q1 and 2008:Q2, but the evidence weakens in 2008:Q3 and falls precipitously at the peak of the crisis in 2008:Q4. Taylor rule forecasting, however, rises from the dead in 2009 and 2010. We also compare the out-of-sample performance of the Taylor rule specifications with conventional models. The model with interest rate differentials can only outperform the random walk before the crisis, and the monetary and purchasing power parity models cannot outperform the random walk for any forecast interval.

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1. Introduction

The past few years have seen a resurgence of academic interest in out-of-sample exchange rate forecasting. Gourinchas and Rey (2007), using an external balance model, Engel, Mark, and West (2008), using a panel monetary model, and Molodtsova and Papell (2009), using a heterogeneous symmetric Taylor rule model with smoothing, all report successful results for their models vis-à-vis the random walk null. There has even been the first revisionist response. Rogoff and Stavrakeva (2008) criticize the three above-mentioned papers for their reliance on the Clark and West (2006) statistic, arguing that it is not a minimum mean squared forecast error statistic.

An important problem with these papers is that none of them use real-time data that was available to market participants.¹ Unless real-time data is used, the “forecasts” incorporate information that was not available to market participants, and the results cannot be interpreted as successful out-of-sample forecasting. Faust, Rogers, and Wright (2003) initiated research on out-of-sample exchange rate forecasting with real-time data. They constructed data for five countries and, using the monetary model to forecast U.S. dollar exchange rates, found that the forecasts were better with real-time than with revised data, although not superior to the random walk. Molodtsova, Nikolsko-Rzhevskyy, and Papell (2008) use real-time data to estimate Taylor rules for Germany and the U.S. and to forecast the deutsche mark/dollar exchange rate out-of-sample for 1989:1 – 1998:4. Using a variety of specifications, the random walk null could be rejected in favor of the Taylor rule fundamentals alternative for real-time, but not revised, data.

Molodtsova, Nikolsko-Rzhevskyy, and Papell (2010), henceforth MNP (2010), use real-time data to show that inflation and either the output gap or unemployment, variables which normally enter central banks’ Taylor rules, can provide evidence of out-of-sample predictability for the U.S. Dollar/Euro exchange rate from 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. Evidence of predictability is found with both one-quarter-ahead and longer-horizon forecasts.

Engel, Mark, and West (2008) propose an alternative methodology for Taylor rule out-of-sample exchange rate forecasting. Using a Taylor rule with pre-specified coefficients for the inflation differential, output gap differential, and real exchange rate, they construct the interest rate differential implied by the policy rule and use the resultant differential for exchange rate forecasting. We use the single equation

¹ Gourinchas and Rey (2007) and Engel, Mark, and West (2008) use revised data. Ince (2010) shows that Engel, Mark, and West’s results are stronger with real-time data. Molodtsova and Papell (2009) use quasi-real-time data where the trend does not use ex post observations, but the data itself incorporates revisions.

version of their model which we call the Taylor rule differentials model.² For the reasons described above, we do not include the real exchange rate in the forecasting regression.³

Out-of-sample exchange rate forecasting with Taylor rule fundamentals received blogosphere, as well as academic, notice in 2008. On July 28 and September 9, Menzie Chinn posted on Econbrowser a discussion of in-sample estimates of one of the specifications used in an early version of MNP (2010).⁴ On August 17, he posted an article by Michael Rosenberg of Bloomberg, who discussed Taylor rule fundamentals as a foreign currency trading strategy. By December 22, however, optimism had turned to pessimism. Once interest rates hit the zero lower bound, they cannot be lowered further. With zero or near-zero interest rates for Japan and the U.S., and predicted near-zero rates for the U.K. and the Euro Area, the prospects for Taylor rule exchange rate forecasting were bleak. A second theme of the post, however, was that there was nothing particularly promising on the horizon. Going back to the monetary model, even in a regime of quantitative easing, faced doubtful prospects for success.⁵

Taylor rule exchange rate forecasting returned to the blogosphere in 2010. On September 30, John Taylor discussed an article by Matt Walcoff and Chris Fournier of Bloomberg on his Economics One blog, which in turn discussed a post by Camilla Sutton and Sacha Tihanyi, currency strategists at the Bank of Nova Scotia. Using the Taylor rule to estimate the ideal interest rate, they find that the Bank of Canada's benchmark rate should have been 1 percentage point higher, and the U.S. federal funds rate 1.75 percentage points lower, than it actually was, producing a 2.75 percentage point gap between ideal and actual interest rates. Since the federal funds rate cannot be lowered further, they forecast the Bank of Canada raising rates and the Federal Reserve providing stimulus, resulting in the U.S. dollar depreciating against the Canadian dollar.⁶

The purpose of this paper is to evaluate Taylor rule out-of-sample exchange rate forecasting for the euro/dollar exchange rate with real-time data during and following the financial crisis of 2008 – 2009. We estimate models with OECD estimates of the output gap and the unemployment gap and use both contemporaneous data and one-year-ahead forecasts for inflation and the measures of real economic activity. With two measures of real economic activity and either contemporaneous or forecasted data, we estimate four models with each Taylor rule specification. For the purpose of comparison, we also evaluate the performance of conventional monetary, Purchasing Power Parity (PPP), and interest rate differential models.

² Taylor (2010b) calls this model the policy rules differential model.

³ Engel, Mark, and West (2010) extend their panel models to include exchange rate factors. They do not include the real exchange rate in their Taylor rule specification.

⁴ The results are contained in Chinn (2008).

⁵ These posts are available on <http://www.econbrowser.com/> under “exchange rates”.

⁶ These posts are available on <http://www.johnbtaylorblog.blogspot.com/>.

Real-time data for the U.S. is available in vintages starting in 1966, with the data for each vintage going back to 1947. Real-time data for the Euro Area, however, is only available in vintages starting in 1999:Q4, with the data for each vintage going back to 1991:Q1. While the euro/dollar exchange rate is only available since the advent of the Euro in 1999, “synthetic” rates are available since 1993. We use rolling regressions to forecast exchange rate changes starting in 1999:Q4, with 26 observations in each regression. Keeping the number of observations constant, we report results ending in 2007:Q1, with 30 forecasts, through 2010:Q4, with 45 forecasts. We report three test statistics: the ratio of the mean squared prediction errors (MSPE) of the linear and random walk models, the CW test of Clark and West (2006) and the DMW test of Diebold and Mariano (1995) and West (1996) with McCracken’s (2007) critical values.

The results for the Taylor rule fundamentals model display a strikingly clear pattern. With contemporaneous variables and headline inflation, the MSPE of the Taylor rule model is smaller than the MSPE of the random walk model, and the random walk null can be rejected in favor of the Taylor rule model using the CW and DMW tests at the 5 percent level or higher for the initial set of forecasts ending in 2007:Q1. As the number of forecasts increases, so does the strength of the rejections, peaking in 2008:Q2. In the following quarter, 2008:Q3, the strength of the rejections starts to fall and, in 2008:Q4, at the peak of the financial crisis, the evidence in favor of the Taylor rule specification falls precipitously. If the trends of the previous two quarters had continued, the MSPE of the Taylor rule model would have risen above the MSPE of the random walk model in the next quarter and, by the end of 2008, it appeared that Taylor rule exchange rate forecasting was dead. But the trends did not continue. Starting in mid-2009, the “phoenix” Taylor rule forecasting started to rise from the ashes and the random walk can be rejected in favor of the Taylor rule models at the 1 percent significance level for all specifications between 2009:2 and 2010:4. The pattern of results with core inflation is similar to that with headline inflation, although the strength of the rejections is weaker. The results with forecasted variables are weaker than with contemporaneous variables. While the random walk can sometimes be rejected in favor of the Taylor rule model before the financial crisis, the rejections disappear during the crisis and do not return.

We proceed to delve more deeply into the reasons for this pattern. In 2008:Q3 and 2008:Q4, the dollar appreciated substantially against the euro, reversing almost all of the dollar depreciation from 2005 to mid-2008. This occurred during the “panic” period of the financial crisis, and is generally viewed as a manifestation of extreme risk avoidance unrelated to macroeconomic fundamentals. The Taylor rule specification, however, predicted further dollar depreciation. This was in accord with most private sector forecasts. Interest rates in the Euro Area were considerably higher than those in the U.S., and forecasters, betting against uncovered interest rate parity, also predicted further dollar depreciation. As the panic

period of the financial crisis started to abate in early 2009, the dollar depreciated sufficiently so that, by the end of 2009:Q3, most of the appreciation at the end of 2008 had been reversed. The Taylor rule specification, which continued to predict dollar depreciation, became re-aligned with the path of the euro/dollar exchange rate. In 2010, the Taylor rule specification correctly predicted both the dollar's initial appreciation and subsequent depreciation.

The results for the Taylor rule differentials models with headline inflation display a similar pattern to those of the Taylor rule fundamentals model for both measures of real economic activity. The MSPE ratio is below one and the random walk null can be rejected in favor of the Taylor rule differentials model throughout the entire sample. The evidence strengthens through 2008:Q2, weakens during the financial crisis, and strengthens again after the crisis. With forecasted variables, the results are much weaker. With the unemployment gap, the random walk null can only be rejected through 2008:Q3, and for the output gap, there is no evidence of predictability. A similar pattern is observed with core inflation and the output gap, although the results are weaker than those with headline inflation, and the random walk null is generally not rejected after 2008:Q3 with the unemployment gap.

We also compare the out-of-sample performance of the Taylor rule models with the monetary, PPP, and interest rate differentials models. The monetary and PPP models cannot outperform the random walk for any forecast interval. For the interest rate differentials model, the MSPE ratios are below one from 2007:Q1 to 2008:Q3 and the random walk can be rejected with the CW and DMW tests, although most of the rejections are at the 10 percent significance level. Starting in 2008:Q4, the MSPE ratios are above one, and the random walk null cannot be rejected. The evidence of out-of-sample exchange rate predictability is much stronger with the Taylor rule models than with the traditional models.

2. Exchange Rate Forecasting Models

Evaluating exchange rate models out of sample was initiated by Meese and Rogoff (1983), who could not reject the naïve no-change random walk model in favor of the existent empirical exchange rate models of the 1970s. Starting with Mark (1995), the focus of the literature shifted towards deriving a set of long-run fundamentals from different models, and then evaluating out-of-sample forecasts based on the difference between the current exchange rate and its long-run value. Another strand of the literature uses uncovered interest rate parity directly to produce exchange rate forecasts. Engel, Mark, and West (2008) use the interest rate implied by a Taylor rule, and Molodtsova and Papell (2009) use the variables that enter Taylor rules to evaluate exchange rate forecasts.

2.1 Taylor Rule Fundamentals Model

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

$$i_t = \pi_t + \phi(\pi_t - \bar{\pi}) + \gamma y_t + R \quad (1)$$

where i_t is the target for the short-term nominal interest rate, π_t is the inflation rate, $\bar{\pi}$ is the target level of inflation, y_t is the output gap, the 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.⁷

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 $\bar{\pi}$ and R in equation (1) can be combined into one constant term, $\mu = R - \phi\bar{\pi}$, which leads to the following equation,

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

where $\lambda = 1 + \phi$. Because $\lambda > 1$, the real interest rate is increased when inflation rises, and so the Taylor principle is satisfied.

We incorporate a number of modifications of the "classic" Taylor rule. The unemployment gap, the difference between the unemployment rate and the natural rate of unemployment, can replace the output gap in Equations (1) and (2) as in Blinder and Reis (2005) and Rudebusch (2010). In that case, the coefficient γ would be negative so that the Fed raises the interest rate when the unemployment rate is below the natural rate of unemployment. Following Clarida, Gali, and Gertler (1998), henceforth CGG (1998), inflation, output gap, and/or unemployment forecasts are often used on the grounds that Federal Reserve policy is forward looking. We will present forecasting results with contemporaneous and forecasted variables, using the output and unemployment gaps as measures of real economic activity.

⁷ While we do not explicitly incorporate time-varying inflation and/or equilibrium real interest rates, the use of rolling regressions allows for changes in the constant.

We do not incorporate other modifications of the Taylor rule. Following CGG (1998), lagged interest rates are usually included in estimated Taylor rules to account for either (1) partial adjustment of the federal funds rate to the rate desired by the Federal Reserve or (2) desired interest rate smoothing on the part of the Federal Reserve. Since the most successful exchange rate forecasting specifications for the dollar/euro rate in MNP (2010) did not include a lagged interest rate and Walsh (2010) shows that the Federal Reserve lowered the interest rate during the financial crisis faster than would be consistent with interest rate smoothing, we do not include lagged interest rates. Also following CGG (1998), the real exchange rate is often included in specifications that involve countries other than the U.S. Since there is no evidence that the ECB uses the real exchange rate as a policy objective and inclusion of the real exchange rate worsens exchange rate forecasts in MNP (2010), we do not include it.

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

$$i_t - i_t^* = \alpha + \alpha_\pi (\pi_t - \pi_t^*) + \alpha_y (y_t - y_t^*) + \eta_t \quad (3)$$

where asterisks denote Euro Area variables, subscripts π and y denote coefficients for inflation and output gap differentials, and α is a constant. It is assumed that the coefficients on inflation and the output gap are the same for the U.S. and the Euro Area, but the inflation targets and equilibrium real interest rates are allowed to differ (otherwise the constant would equal zero).⁸

Based on empirical research on the forward premium and delayed overshooting puzzles by Eichenbaum and Evans (1995), Faust and Rogers (2003) and Scholl and Uhlig (2008), 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:⁹

$$\Delta s_{t+1} = \omega - \omega_\pi (\pi_t - \pi_t^*) - \omega_y (y_t - y_t^*) + \eta_t \quad (4)$$

where asterisks denote Euro Area variables, subscripts π and y denote coefficients for inflation and output gap differentials, and ω is a constant. Alternatively, the unemployment gap differential can substitute for the output gap differential in Equation (4).

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 reversal of the signs

⁸ The assumption of equal coefficients is not necessary to produce a forecasting equation, and is made because, in MNP (2010), the results were consistently stronger with homogeneous coefficients than with heterogeneous coefficients.

⁹ A more extensive discussion of the link between higher inflation and forecasted exchange rate appreciation can be found in Molodtsova and Papell (2009).

of the coefficients between (3) and (4) reflects 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 the dollar to appreciate (a decrease in s_t). Since we do not know by how much a change in the interest rate differential (actual or forecasted) will cause the exchange rate to adjust, we do not have a link between the magnitudes of the coefficients in (3) and (4).

2.2 Interest Rate Differentials Model

Under UIRP, the expected change in the log exchange rate is equal to the nominal interest rate differential. If we were willing to assume that UIRP held, we could use it as a forecasting equation. Since empirical evidence indicates that, while exchange rate movements may be consistent with UIRP in the long-run, it clearly does not hold in the short-run, we need a more flexible specification. Following Clark and West (2006), we use the interest rate differential in a forecasting equation,

$$\Delta s_{t+1} = \alpha + \omega(i_t - i_t^*) \quad (5)$$

Since we do not restrict ω to be equal to 1, or even restrict its sign to be positive, (5) can be consistent with UIRP, where a positive interest rate differential produces forecasts of exchange rate depreciation, and the carry trade literature, where a positive interest rate differential produces forecasts of exchange rate appreciation.

2.3 Taylor Rule Differentials Model

Engel, Mark, and West (2008) propose an alternative Taylor Rule based model, which we call the Taylor rule differentials model to differentiate it from both the interest rate differentials model and the Taylor rule fundamentals model. They start with Equation (2) with Taylor's original coefficients, so that $\lambda = 1.5$ and $\gamma = 0.5$, and subtract the interest rate reaction function for the Euro Area from that for the U.S. to obtain implied interest rate differentials,

$$i_t - i_t^* = 1.5(\pi_t - \pi_t^*) + 0.5(y_t - y_t^*) \quad (6)$$

where the constant is equal to zero assuming that the inflation target and equilibrium real interest rate are the same for the U.S. and the Euro Area. Out-of-sample exchange rate forecasting is conducted according to Equation (5), where the implied Taylor rule interest rate differentials replace the actual interest rate differentials.¹⁰

We estimate the Taylor rule differentials model with two measures of economic activity, OECD estimates of the output gap and the unemployment gap. In order to obtain an implied interest rate differential that corresponds to the implied interest rate differential (6) with the unemployment gap as the

¹⁰ Engel, Mark, and West (2008) also include a coefficient on the real exchange rate and estimate a variant of their model with panel data.

measure of real economic activity, we use a coefficient of -1.0. This is consistent with a coefficient of 0.5 on the output gap if the Okun's Law coefficient is 2.0.

2.4 Monetary Fundamentals Model

Following Mark (1995), most widely used approach to evaluating exchange rate models out of sample is to represent a change in (the logarithm of) the nominal exchange rate as a function of its deviation from its fundamental value. Thus, the one-period-ahead change in the log exchange rate can be modeled as a function of its current deviation from its fundamental value.

$$\Delta s_{t+1} = \alpha + \omega z_t + v_t, \quad (7)$$

where

$$z_t = f_t - s_t$$

and f_t is the long-run equilibrium level of the nominal exchange rate determined by macroeconomic fundamentals.

We select the flexible-price monetary model as representative of 1970's vintage models. The monetary approach determines the exchange rate as a relative price of the two currencies, and models exchange rate behavior in terms of relative demand for and supply of money in the two countries. The long-run money market equilibrium in the domestic and foreign country is given by:

$$m_t = p_t + ky_t - hi_t \quad (8)$$

$$m_t^* = p_t^* + k^* y_t^* - hi_t^* \quad (9)$$

where m_t , p_t , and y_t are the logs of money supply, price level and income, and i_t is the level of interest rate in period t ; asterisks denote foreign country variables.

Assuming purchasing power parity, UIRP, and no rational speculative bubbles, the fundamental value of the exchange rate can be derived.

$$f_t = (m_t - m_t^*) - k(y_t - y_t^*) \quad (10)$$

We construct the monetary fundamentals with a fixed value of the income elasticity, k , which can equal to 0 or 1. We substitute the monetary fundamentals (10) into (7), and use the resultant equation for forecasting.

2.5 Purchasing Power Parity Fundamentals Model

As a basis of comparison, we examine the predictive power of PPP fundamentals. There has been extensive research on PPP in the last decade, and a growing body of literature finds that long-run PPP holds in the post-1973 period.¹¹ Since the monetary model is build upon PPP but assumes additional restrictions, comparing the out-of-sample performance of the two models is a logical exercise. Mark and

¹¹ See Papell (2006) for a recent example.

Sul (2001) use panel-based forecasts and find evidence that the linkage between exchange rates and monetary fundamentals is tighter than that between exchange rates and PPP fundamentals.

Under PPP fundamentals,

$$f_t = (p_t - p_t^*) \quad (11)$$

where p_t is the log of the national price level. We substitute the PPP fundamentals (11) into (7), and use the resultant equation for forecasting.

3. Forecast Comparison Based on MSPE

We are interested in comparing the mean squared 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 $E_{t+1}(\varepsilon_t) = 0$

We want to test the null hypothesis that the MSPEs are equal against the alternative that the MSPE of the linear model 2 is smaller than the MSPE of the random walk 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 statistics, which is assumed to be asymptotically normal.

The ideal test for evaluating exchange rate models out-of-sample does not exist. The null hypothesis for the DMW test is that the MSPE from the random walk model is equal to the MSPE from the linear model, and the alternative hypothesis is the MSPE from the linear model is smaller than the MSPE from the random walk model. Under the null hypothesis of a random walk, however, the MSPE of the linear model will be larger than the MSPE of the random walk model because the parameters, which have no predictive ability by definition, are being estimated. This biases MSPE comparisons towards favoring the random walk model and makes DMW tests undersized, also favoring the random walk model.¹² This is an example of the inappropriate application of MSPE comparisons and DMW tests to nested models, which is relevant because, if the null hypothesis is a random walk and the alternative hypothesis is a linear model, the two models are always nested.

Clark and West (2006) propose an adjustment to the DMW statistic, called the CW statistic, which corrects for the size distortions with nested models under the null. For the CW test, the null hypothesis is that the exchange rate follows a random walk while the alternative hypothesis is that the

¹² McCracken (2007) shows that using standard normal critical values for the DMW statistic results in severely undersized tests, with tests of nominal 0.10 size generally having actual size less than 0.02.

exchange rate can be described by a linear model. An alternative is to use the DMW statistic with McCracken's (2007) critical values, which are appropriate for nested models with one-period-ahead predictions. While these are tests of predictability, they are not tests of forecasting ability. With both statistics, it is possible to reject the random walk null in favor of the linear model alternative even though the MSPE of the random walk is smaller than the MSPE of the linear model.

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.

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. While this is not problematic in the context of testing for predictability, which is a test of whether the regression coefficient β is significantly different from zero, it is problematic in interpreting the results as evidence of forecasting ability, which is a test of whether the MSPE from the model is smaller than the MSPE from the random walk.

In the absence of an ideal test, we report three test statistics: the ratio of the MSPE of the linear model to that of the random walk model; the CW statistic; and the DMW statistic with McCracken's critical values. While rejecting the random walk null in favor of the linear model alternative with either statistic provides evidence of predictability for the model and reporting an MSPE ratio below one constitutes evidence that the model forecasts better than the random walk, the test results cannot provide evidence that that the model forecasts significantly better than the random walk.

4. Taylor Rules, the Fed, and the ECB

4.1 Real-Time Data

We use real-time quarterly data from 1999:Q4 to 2010:Q4 for the United States and the Euro Area. Most of the data is from the OECD Original Release and Revisions Database.¹³ The dataset has a triangular format with the vintage date on the horizontal axis and calendar dates on the vertical. The term

¹³ An alternative would be to use Euro Area Business Cycle Network dataset that is now maintained by the ECB Statistical Data Warehouse, but it does not start until 2001.

vintage denotes the date in which a time series of data becomes known to the public.¹⁴ For each subsequent quarter, the new vintage incorporates revisions to the historical data, thus providing all information known at the time.

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-quarter-ahead. The data for the first vintage starts in 1993:Q1. We use rolling regressions to predict 30 exchange rate changes from 1999:Q4 to 2007:Q1, 31 exchange rate changes from 2000:Q1 to 2007:Q2, etc., up to 45 exchange rate changes from 1999:Q4 to 2010:Q4. Since we use vintage data, the estimated coefficients are based on revised data, but the forecasts are conducted using real-time data.¹⁵

We use the Consumer Price Index (CPI) and the core Personal Consumption Expenditure (PCE) index to measure inflation for the U.S. and the Harmonized Index of Consumer Prices (HICP) and the core HICP to measure inflation for Euro Area. CPI and HICP data are from the OECD Original Release and Revisions Database. Real-time U.S. core PCE is from the Philadelphia Fed Real-Time Database for Macroeconomists described in Croushore and Stark (2001). Core PCE inflation has been emphasized by the Fed since 2004, while keeping HICP inflation below 2 percent has been the policy objective of the ECB since its inception. For the core HICP, we use the HICP index for all-items excluding energy and unprocessed food from the Euro Area Real-Time Data available from the ECB Statistical Data Warehouse. Since the first available vintage is 2001:Q1, we assume that the core HICP is not revised during the first five quarters of the sample. Following Taylor (1993), the inflation rate is the rate of inflation over the previous four quarters.

We construct quarterly measures of the output gap from internal OECD estimates. The data comes from semi-annual issues of the 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 prior to December 2003 are semi-annual, we used quadratic interpolation to obtain real-time quarterly estimates for early vintages.¹⁶

The unemployment rates are from the OECD Original Release and Revisions Database. We use the Non-Accelerating Inflation Rate of Unemployment (NAIRU) from semi-annual OECD Economic

¹⁴ There is typically a one-quarter lag before data is released, so real-time variables dated time t actually represent data through period $t-1$.

¹⁵ An alternative method of constructing real-time data is to use “diagonal” data that does not incorporate historical revisions. With that method, the estimated coefficients would also use real-time data. Since the vintages are not available before 1999 and we only have 45 forecast periods, we do not have that option for this paper.

¹⁶ 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.

Outlook issues to construct the unemployment gap for both the U.S. and the Euro Area. As with the output gap, quadratic interpolation is used to transform semiannual NAIRU series into quarterly before December 2003. The OECD Economic Outlook introduced the NAIRU variable in December 2001. For the U.S., we use Congressional Budget Office (CBO) Economic Outlook quarterly estimates of the NAIRU to complement OECD Economic Outlook data. Since there is no counterpart to CBO NAIRU estimates for the Euro Area, we assume that the Euro Area NAIRU has not been revised in the early vintages prior to December 2001, which does not appear to be a bad approximation for this series.

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 CPI 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 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:Q4. The data for $t+4$ SPF forecasts of unemployment for Euro Area is constructed by the same method.¹⁷

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

¹⁷ 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. We do not have real-time data on core inflation forecasts.

The short-term nominal interest rates, defined as the interest rate in the third month of each quarter, are taken from 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 price levels for calculating PPP fundamentals are measured by the CPI for the U.S. and HICP the Euro Area. The money supply is measured by seasonally adjusted M3 (broad money) in billions of national currency, and national income is measured by real GDP. Real-time price level, money supply, and real GDP are taken from the OECD Original Release and Revisions Database for both countries.

4.2 Taylor Rules for the Fed and ECB

We provide visual evidence of how closely interest rate setting by the Fed and the ECB can be characterized by a Taylor rule with real-time data. In Panel A of Figure 1, we depict the actual U.S. and Euro Area interest rate and the counterfactual interest rate implied by a Taylor rule with a coefficient of 1.5 on inflation, 0.5 on the output gap, an inflation target of 2 percent, an equilibrium real interest rate of 2 percent, and no smoothing. This is the exercise conducted in Taylor (1993) with different data and a different time period. We use CPI real-time inflation for the U.S., HICP real-time inflation for the Euro Area, and OECD estimates of the output gap.

The results for the U.S. show that, while the Federal Funds rate and interest rate implied by the Taylor rule are clearly positively correlated, the Federal Funds rate is consistently below the rate implied by the Taylor rule from 2003:Q1 to 2006:Q4, closely replicating the results reported by Taylor (2007) and Poole (2007). For the Euro Area, while the overall fit is closer, the actual Money Market Rate is below the rate implied by the Taylor rule from 2003:Q1 to 2006:Q4. While this is similar to the pattern found for the U.S., the magnitude of the gap is much smaller for the Euro Area than for the U.S. In 2008, as the oil price spike raises headline inflation, the implied Taylor rule interest rate rises sharply above the actual rate for both the U.S. and the Euro area.

Bernanke (2010) uses a similar figure to argue that inflation forecasts, rather than realized inflation rates, should be used to calculate prescribed Taylor rule interest rates for the U.S. In panel B of Figure 1, we depict forward-looking specifications, for which we use the t+4 SPF inflation forecasts for both the Euro Area and the U.S. Everything else, including the coefficients on inflation and the output gap, the inflation target of 2 percent, and the equilibrium real interest rate of 2 percent, is the same as with contemporaneous inflation and output gap. For the U.S., the pattern is similar to that found with contemporaneous inflation for 2002 to 2006. For the Euro Area, the actual rate with forecasted inflation is close to the rate implied by the Taylor rule for almost the entire 2002 – 2006 period. The differences between actual and forecasted headline inflation are much more dramatic starting in 2008, as the implied

Taylor rule rates with forecasted inflation are much closer to the actual rates than those with realized inflation.

Kohn (2007) argues that core, rather than headline, inflation should be used to calculate implied Taylor rule interest rates for the U.S. Panel C of Figure 1 depicts the implied and actual interest rates with core PCE inflation for the U.S. and core HICP inflation for the Euro Area. During 2002 – 2006, the gap between the implied and actual interest rates is smaller for the U.S. and about the same for the Euro Area with core inflation. Starting in 2008, the fit between the implied and actual interest rates is much closer with core than with realized inflation for both the U.S. and the Euro Area.

Since the Fed emphasizes core PCE inflation and the ECB emphasizes headline HICP inflation, we will report results with both core and headline inflation. While it may be argued, following Bernanke (2010), that the 2008 oil-price-spike makes headline inflation inappropriate for calculating prescribed Taylor rule interest rates for either the U.S. or the Euro Area, this is not a problem for our analysis. Both of the Taylor rule models use inflation differentials rather than individual country inflation rates, and the spikes in headline inflation mostly cancel out in differential form.

Using real-time data with visual methods that make no attempt to produce a good fit between the actual and implied interest rates, we have shown that the Taylor rule provides a reasonable approximation of interest rate setting by both the Fed and the ECB since 1999. We emphasize “reasonable approximation” over “exact fit.” If the central banks exactly followed a Taylor rule, there would be no difference between the interest rate and Taylor rule differentials models. If interest rate setting by the Fed and the ECB was unrelated to Taylor rule prescriptions, then it would be difficult to see how the Taylor rule models would be useful for euro/dollar exchange rate forecasting. It is the combination of Fed and ECB policy being broadly consistent with Taylor rule prescriptions, plus divergences in 2003 – 2005 and following the attainment of the zero lower bound for the federal funds rate in late 2008, which provides the potential for out-of-sample forecasting with the Taylor rule models.

5. Empirical Results

We evaluate out-of-sample exchange rate forecasting with Taylor rule fundamentals and Taylor rule differentials before, during, and after the financial crisis of 2008-2009. For the purpose of comparison, we also evaluate forecasting performance for interest rate, monetary, and PPP specifications. As discussed in Section 4.1, we conduct one-quarter-ahead exchange rate forecasts starting at the end of the second week of the second month of the quarter. For example, the forecast for 2008:4 predicts the exchange rate change from mid-August to mid-November, using the latest available data on inflation, output gaps, and unemployment gaps. This forecast spans what Taylor (2010a) calls the panic period of the crisis from late September through October 2008. The forecast for 2009:1 predicts the exchange rate

change from mid-November 2008 to mid-February 2009, corresponding to what Taylor calls the start of the post-panic period.

5.1 Taylor Rule Fundamentals

Panel A of Table 1 presents one-quarter-ahead out-of-sample forecasts of the euro/dollar exchange rate with contemporaneous headline inflation and two measures of real economic activity. The first column reports the ratio of out-of-sample MSPEs of the linear model to that of the random walk model, the second column reports the CW statistic, and the third column reports the DMW statistic. The left column reports results where economic activity is measured by OECD output gap estimates for the U.S. and the Euro Area, and the right column depicts results where economic activity is measured by OECD unemployment gap estimates. Real-time quarterly data is used throughout.

The first row reports test statistics for 30 forecasts from 1999:Q4 to 2007:Q1 with rolling regressions, using 26 quarters to represent the historical relationship between the Taylor rule fundamentals and the exchange rate changes. For each subsequent row, an additional forecast is included, so that the last row for 2010:Q4 reports statistics for 45 forecasts, but the rolling regressions still use 26 quarters to represent the historical relationship.

Several patterns emerge from the forecast statistics. The MSPE ratios for both specifications start under one with forecasts through 2007:Q1, so the forecast errors of the linear model are smaller than those of the random walk, and remain under one throughout the sample. Under the null hypothesis of a random walk, the MSPE of the linear model will be greater than the MSPE of the random walk model, so this represents favorable evidence for the Taylor rule model.¹⁸ The evidence strengthens through 2007 and early 2008, with the most favorable evidence coming from samples that end in 2008:2, before the onset of the financial crisis. The MSPE attains its lowest value, the CW and DMW statistics attain their highest values, and the no predictability null can be rejected at the 1 percent level with both tests using either the output gap or the unemployment gap as the measure of real economic activity. The MSPE ratios rise sharply in 2008:Q3 and (especially) 2008:Q4, and the no predictability null can only be rejected at the 5 percent level.

From the perspective of the end of 2008, exchange rate forecasting with Taylor rule fundamentals seemed finished. The federal funds rate for the U.S. was at the zero lower bound and the money market rate for the ECB was falling rapidly, seemingly breaking the link between the interest rate differential and future exchange rates. Although the policy rate for the Euro Area was above the policy rate for the U.S., the dollar appreciated sharply. Extrapolating trends from the previous two quarters, the MSPE ratio would be projected to rise above one in 2009:1 or 2009:2, accompanied by insignificant CW

¹⁸ In Meese and Rogoff (1983), the evidence that empirical exchange rate models could not forecast better than a random walk consisted of MSPE ratios that were greater than one.

and DMW statistics. But these trends did not continue. The MSPE ratios rise much more slowly, peaking below one in either 2008:4 or 2009:1, and the no predictability null can be rejected at the 1 percent level in all four cases by 2009:4.

The results with forecasted headline inflation are depicted in Panel B of Table 1. With the unemployment gap, the MSPE ratios are below one and the CW and DMW statistics are almost all significant at the 5 percent level or higher from 2007:1 to 2008:2. Starting in 2008:3, however, the evidence of out-of-sample exchange rate predictability disappears. The MSPE ratios exceed one and, with the exception of the CW statistic for 2008:3, neither the CW nor the DMW statistics are significant for the remainder of the sample. With the output gap, the results are even weaker. The MSPE ratios exceed one and there is no evidence of out-of-sample exchange rate predictability throughout the sample.

Some intuition for these results can be found in Figure 2, which depicts actual and forecasted exchange rate changes, using contemporaneous and forecasted variables with output gap and unemployment gap. Since the exchange rate is defined as dollars per euro, observations above the zero line represent dollar depreciation, while observations below the zero line represent dollar appreciation. The dollar depreciated against the euro for each quarter from 2006:Q1 to 2008:Q2. In 2008:Q3, the depreciation turned to appreciation and, in 2008:Q4, the dollar sharply appreciated at the peak of the financial crisis. The dollar depreciated in 2009, appreciated in the first half of 2010, and depreciated in the second half of 2010.

The success, failure, and rehabilitation of Taylor rule forecasting can be seen in Figure 2. The forecasts track the actual exchange rate movements very well (albeit by the low standards of out-of-sample exchange rate forecasting) through 2008:Q2. In 2008:Q3 and 2008:Q4, however, Taylor rule forecasting collapsed. By far the largest quarterly movement in the dollar/euro rate since 2000 occurred in 2008:Q4, when the dollar appreciated by more than 10 percent. As shown in Figure 2, all four Taylor rule specifications predicted continued dollar depreciation while, by definition, the random walk model predicted neither depreciation nor appreciation. While there is not much difference between the accuracy of the Taylor rule and random walk forecasts in 2009:Q1, the Taylor rule forecasts are generally more accurate than the random walk forecasts from 2009:2 to 2010:4. The forecasts from the model with the output gap closely match the dollar's depreciation in 2009:Q2 and 2009:Q3, while the forecasts from the model with the unemployment gap closely match the dollar's appreciation in the first half of 2010.

Table 2 reports results with core inflation. Since core inflation forecasts are not available for the Euro Area and core PCE forecasts are not available for the U.S., we only report results with realized inflation. The results with the output gap are similar to, although not as strong as, the results with headline inflation. The MSPE ratios are below one and the random walk can be rejected in favor of the Taylor rule fundamentals model at the 5 percent level or higher through 2008:3. In 2008:4 and 2009:1, the MSPE

ratio rises (although it does not exceed one) and the null can either no longer be rejected (CW) or can only be rejected at the 10 percent level (DMW). Starting in 2009:2, however, the MSPE ratio falls and the no predictability null can be rejected at the 5 percent level with both tests through 2010:Q4. The results with the unemployment gap are again weaker. While the MSPE ratio is below one and the null hypothesis of no predictability can be rejected by both the CW and DMW tests through 2008:Q4, the MSPE ratio exceeds one and the null cannot be rejected for the remainder of the sample.

Summing up the results for the Taylor rule fundamentals model, the strongest evidence of out-of-sample forecasting, in the form of MSPE ratios below one, and predictability, in the form of significant CW and DMW statistics, comes from the specifications with headline inflation and contemporaneous measures of inflation and real economic activity. The next strongest results come from using core inflation and contemporaneous measures of inflation and economic activity, while the weakest results come from using headline inflation and forecasted measures of inflation and economic activity.

5.2 Taylor Rule Differentials

Following Engel, Mark, and West (2008), we evaluate out-of-sample performance of the Taylor rule differentials model. As in the previous tables, MSPEs, the CW statistic, and the DMW statistic are reported for each model. The results for the Taylor rule differentials model are very similar to those of the Taylor rule fundamentals model. Panel A of Table 3 presents one-quarter-ahead out-of-sample forecasts of the euro/dollar exchange rate with contemporaneous headline inflation and both measures of economic activity. The MSPE ratio is below one and the random walk null can be rejected in favor of the Taylor rule differentials model throughout the entire sample when real economic activity is measured by either the output gap or the unemployment gap. The evidence strengthens through the early part of the sample, peaks in 2008:2, weakens during the financial crisis, and strengthens again after the crisis.

The results with forecasted headline inflation are depicted in Panel B of Table 3. With the unemployment gap, the MSPE ratios are below one and the CW and DMW statistics are generally significant from 2007:1 to 2008:3, with the strength of the rejections peaking in 2008:Q2. Starting in 2008:Q4, however, the MSPE ratio exceeds one and the random walk model cannot be rejected in favor of the Taylor rule differentials model for the remainder of the sample. With the output gap, the results are even weaker. The MSPE ratios exceed one and there is no evidence of out-of-sample exchange rate predictability for the entire sample.

Actual and predicted exchange rate changes in Figure 3 provide some intuition for these results. Forecasts with the contemporaneous Taylor rule differentials model with either the output gap or the unemployment gap and the forward-looking Taylor rule differentials model with the unemployment gap track actual exchange rate movements quite well through 2008:Q2. While all three models predict dollar

depreciation in 2008:Q3 and 2008:Q4, the fit between the forecasted and actual exchange rate changes for both contemporaneous models output gap recovers in 2009.

Table 4 reports results for the Taylor rule differentials model with core inflation. The results with the output gap are similar to, although not as strong as, the results with headline inflation. The MSPE ratios are below one and the random walk can be rejected in favor of the Taylor rule fundamentals model through 2008:Q3. Starting in 2008:Q4, the MSPE ratio rises (although it does not exceed one) and, while the no predictability null can generally be rejected with both tests, most of the rejections are at the 10 percent level. With the unemployment gap, the MSPE ratio is less than one and the null can be rejected through 2008:Q3. Starting in 2008:Q4, the MSPE ratios are either close to or exceed one and, except for 2009:Q3 and 2009:Q4, the random walk model cannot be rejected in favor of the Taylor rule differentials model for the remainder of the sample.

5.3 Interest Rate Differentials

The Taylor rule fundamentals and Taylor rule differentials models replace interest rate differentials with either (1) the variables that enter Taylor rules or (2) the interest rates implied by Taylor rules. We now evaluate the performance of out-of-sample exchange rate forecasting using the interest rate differentials themselves.

The results are shown in Table 5. The MSPE ratio is below one for the forecast intervals ending between 2007:Q1 and 2008:Q3, attaining its lowest point in 2008:Q2. The ratio rises between 2008:Q2 and 2008:Q3 and is greater than one for all intervals ending between 2008:Q4 and 2009:Q3. The null hypotheses of equal predictability can be rejected, using the CW and DMW tests, for all forecast intervals ending between 2007:Q1 and 2008:Q3, although most of the rejections are at the 10 percent significance level. For the forecast intervals ending between 2008:Q4 and 2010:Q2, however, neither the CW nor the DMW test provides any evidence against the random walk. Figure 4 illustrates the results. While the fit between the actual and predicted changes in the exchange rate are visually comparable to those from the Taylor rule models through 2005, the interest rate differentials model is slower to pick up the subsequent appreciation of the euro and performs worse than the others in late 2008.

There are two major differences between results with the Taylor rule models and with interest rate differentials. First, with Taylor rule fundamentals, evidence of predictability returns following the peak of the financial crisis with both the output gap and the unemployment rate as the measure of real economic activity and, with Taylor rule differentials, evidence of predictability returns with the output gap. With interest rate fundamentals, there are no rejections after 2008:Q3. Second, while the no predictability null hypothesis can be rejected with the interest rate differentials model before the financial crisis, the evidence of predictability is lower than with the Taylor rule models.

5.4 Monetary and PPP Fundamentals

The attainment of the zero lower bound for the federal funds rate for the U.S. in late 2008 and sharp fall of the money market rate for the Euro Area in early 2009 raises the question of whether more conventional specifications, with monetary or PPP fundamentals, might replace the interest rate differentials and Taylor rule models for out-of-sample exchange rate forecasting.

Table 5 reports one-quarter-ahead out-of-sample forecasts of the euro/dollar exchange rate with monetary and PPP fundamentals using the same statistics that were used to evaluate the Taylor rule and interest rate differential models. Results for the monetary model are presented with k equal to 0 and 1. The results for the monetary and PPP models are extremely clear. For all forecast intervals and all specifications, the MSPE ratios are greater than one, the null hypothesis of equal predictability cannot be rejected with the CW test (except for 2010:Q3 with the PPP model when the CW statistic is significant at the 10 percent level), and the null hypothesis of equal MSPEs cannot be rejected by the DMW test. Neither the monetary nor the PPP models provide any evidence whatsoever against the random walk.

Figure 4 depicts actual and forecasted exchange rate changes for the monetary and PPP models. There is very little variation in the forecasted exchange rate changes, and neither model forecasts the depreciation of the dollar from 2002 through 2004. While the models do a little better than the random walk starting in 2007, the improvement is not sufficient to provide any evidence of predictability.

5.5 Dynamics of Forecasting Equation Coefficients

What are we forecasting when we find evidence of out-of-sample exchange rate predictability? Figure 5 depicts the coefficients on inflation and real economic activity differentials for the Taylor rule fundamentals model with headline inflation. The coefficients are from the forecasting regressions for samples ending in 1999:4 through 2010:4, with each rolling regression using a 26 quarter window. As reported in Table 1, this model produces significant evidence of predictability throughout the entire sample, with weaker evidence during the crisis.

The coefficients on the inflation differentials, reported in Figure 5 along with 90% confidence interval bands, are always negative and almost universally significantly different from zero for both measures of real economic activity. The only exception is the period around the crisis, when the inflation coefficients, while still negative, become insignificant. Since the inflation differential equals U.S. inflation minus Euro Area inflation and the exchange rate is defined as dollars per euro, a negative coefficient means that when U.S. inflation rises relative to Euro Area inflation, out-of-sample exchange rate predictability is achieved by forecasting dollar appreciation as predicted by Equation (4). The evidence is much weaker for real economic activity. While the coefficients on the output gap differentials are mostly negative and the coefficients on the unemployment gap differentials are mostly positive, both consistent with the predictions of Equation (4), the confidence intervals never exclude zero.

Panel A in Figure 6 depicts the dynamics of the coefficients on the implied interest rate differentials for the model with contemporaneous headline inflation and output gap. The coefficients on the implied interest rate differential are always negative and almost always significantly different from zero. The confidence interval widens to include zero during the period the crisis. Panel B depicts the dynamics of the coefficient on the interest rate differential. It is negative and usually statistically significant before 2008:Q4, and becomes positive but not statistically significant starting in 2009:Q1. The negative coefficient on the implied and actual interest rate differentials, so that a positive interest rate differential forecasts exchange rate appreciation, is consistent with the empirical evidence that UIRP fails to hold over short-run horizons.

6. Conclusions

Interest rate setting for the Fed and ECB through 2008 can be described, although of course not exactly, by a Taylor rule. When the federal funds rate hit the zero lower bound in late 2008, it was widely assumed that the Taylor rule was no longer relevant for evaluating Fed policy. This assumption was incorrect, as the prescribed Taylor rule interest rate became a key element in the debate in 2009 and 2010 over how much quantitative stimulus the Fed should provide. Similarly, it was assumed that, starting in late 2008, the Taylor rule would not be useful for out-of-sample exchange rate forecasting. While Taylor rule forecasting for the euro/dollar exchange rate collapsed in late 2008, pronouncements of its demise proved to be premature. Like the phoenix rising from the ashes, Taylor rule models outperformed the random walk in 2009 and 2010.

The Taylor rule fundamentals model forecasts more accurately than the random walk using the MSPE ratio and the no predictability null hypothesis can be rejected in favor of the model using CW and DMW tests from 2007:Q1 to 2008:Q2, with the strongest evidence at the end. With contemporaneous headline inflation and either the output gap or the unemployment gap differential, the evidence weakens in 2008:Q4 and 2009:Q1 and strongly returns later in 2009 and in 2010. With contemporaneous core inflation and the output gap differential, the pattern is similar except that the evidence disappears in 2008:Q4 and 2009:Q1 and does not return quite as strongly. With either contemporaneous core inflation and the unemployment gap differential or forecasted headline inflation and the unemployment gap differential, the evidence disappears during the crisis and does not return. With forecasted headline inflation and the output gap differential, there is no evidence of predictability.

The Taylor rule differentials model also outperforms the random walk. With contemporaneous headline inflation and either output gap or unemployment gap differentials, the model forecasts more accurately than the random walk and the no predictability null can be rejected for the entire sample. As with the Taylor rule fundamentals model, the evidence peaks in 2008:Q2, weakens in 2008:Q4 and

2009:Q1, and strengthens later in 2009 and in 2010. With contemporaneous core inflation and output gap differentials, the model also outperforms the random walk for the entire sample, although the rejections are weaker with core than with headline inflation. For the models with unemployment gap differentials and either contemporaneous core or forecasted headline inflation, consistent evidence in favor of the models over the random walk can only be found through 2008:Q3 and, with forecasted headline inflation and output gap differentials, the Taylor rule differentials model does not outperform the random walk. Overall, the performance of the Taylor rule differentials model is similar to that of the Taylor rule fundamentals model.

Both of the Taylor rule models are much more successful than other specifications. While the interest rate differentials model provides some evidence of predictability through 2008:Q3, the evidence disappears during the crisis and does not return. The models with monetary and PPP fundamentals cannot outperform the random walk for any sample.

Taylor rules have proven to be successful at describing and prescribing interest rate setting at the Fed and other central banks. We have shown that, using models with Taylor rule fundamentals and Taylor rule differentials, we can forecast the euro/dollar exchange rate more accurately and provide more evidence of out-of-sample predictability than with the random walk benchmark. While none of the models predict the dollar's appreciation in late 2008, the Taylor rule models again achieve success in 2009 and 2010.

References

- Bacchetta, Philippe and Eric van Wincoop, "Infrequent Portfolio Decisions: A Solution to the Forward Discount Puzzle" *American Economic Review* 100, 2010, pp. 870-904
- Bernanke, Ben, "Monetary Policy and the Housing Bubble", paper delivered at the American Economic Association Meetings, January 3, 2010
- Blinder, Alan S. and Ricardo Reis, "Understanding the Greenspan Standard", in *The Greenspan Era: Lessons for the Future*, Federal Reserve Bank of Kansas City, 2005, pp. 11-96
- Cavallo, Michele and Fabio Ghironi, "Net Foreign Assets and the Exchange Rate: Redux Revived" *Journal of Monetary Economics* 49, 2002, pp.1057-1097
- Chinn, Menzie D., "Taylor Rules, Exchange Rates, and the Speculation about the Dollar/Euro Rate" [Weblog Entry], Econbrowser, http://www.econbrowser.com/archives/2008/07/taylor_rules_ex.html, 28 July 2008
- _____, "Taylor Rules, Synchronized Recession and the Potential for Competitive Depreciation" [Weblog Entry], Econbrowser, http://www.econbrowser.com/archives/2008/09/taylor_rules_sy.html, 9 September 2008
- _____, "ZIRP and the exchange rate...and other macro variables" [Weblog Entry], Econbrowser, 22 December 2008, http://www.econbrowser.com/archives/2008/12/zirp_and_the_ex.html, 22 December 2008
- _____, "Nonlinearities, Business Cycles and Exchange Rates" *Economic Notes* 37, 2008, pp. 219-239
- Chinn, Menzie D. and Richard Meese, "Banking on Currency Forecasts: Is Change in Money Predictable?" *Journal of International Economics* 38, 1995, pp. 161-78
- Clarida, Richard and Daniel Waldman, "Is Bad News About Inflation Good News for the Exchange Rate?", in John Y. Campbell (ed.), *Asset Prices and Monetary Policy*, University of Chicago Press, 2008
- Clarida, Richard, Jordi Gali, and Mark Gertler, "Monetary Rules in Practice: Some International Evidence" *European Economic Review* 42, 1998, pp. 1033-1067
- Clark, Todd and Michael W. McCracken, "Tests of Equal Predictive Ability with Real-Time Data" *Journal of Business and Economic Statistics* 27, 2009, pp. 441-454
- Clark, Todd and Kenneth D. West, "Using Out-of-Sample Mean Squared Prediction Errors to Test the Martingale Difference Hypothesis" *Journal of Econometrics* 135, 2006, pp. 155-186
- _____, "Approximately Normal Tests for Equal Predictive Accuracy in Nested Models" *Journal of Econometrics* 138, 2007, pp. 291-311
- Eichenbaum, Martin and Charles Evans, "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates" *Quarterly Journal of Economics*, November 1995, CX, pp. 975-1009.
- Engel, Charles and Kenneth D. West, "Taylor Rules and the Deutschmark-Dollar Real Exchange Rates" *Journal of Money, Credit, and Banking* 38, 2006, pp. 1175-1194

Engel, Charles, Nelson C. Mark, and Kenneth D. West, "Exchange Rate Models Are Not as Bad as You Think" *NBER Macroeconomics Annual 2007*, University of Chicago Press, 2008, pp. 381-441

Engel, Charles, Nelson C. Mark, and Kenneth D. West, "Factor Model Forecasts of Exchange Rates" manuscript, September 2010

Faust, Jon and John H. Rogers, "Monetary Policy's Role in Exchange Rate Behavior" *Journal of Monetary Economics* 50, 2003, pp. 1403-1424

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

Gourinchas, Pierre-Olivier and Helene Rey, "International Financial Adjustment" *Journal of Political Economy* 115, 2007, pp. 665-703

Gourinchas, Pierre-Olivier and Aaron Tornell, "Exchange Rate Puzzles and Distorted Beliefs" *Journal of International Economics* 64, 2004, pp. 303-333

Kohn, Donald L., "John Taylor Rules", *BIS Review* 116, 2007, pp. 1-7

Mark, Nelson, "Exchange Rate and Fundamentals: Evidence on Long-Horizon Predictability" *American Economic Review* 85, 1995, pp. 201-218

Mark, Nelson C. and Dongguy Sul, "Nominal Exchange Rates and Monetary Fundamentals: Evidence from a Small Post-Bretton Woods Panel", *Journal of International Economics* 53, 2001, pp. 29-52

McCracken, Michael, "Asymptotics for Out-of-Sample Tests of Granger Causality" *Journal of Econometrics* 140, 2007, pp.719-752

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

Molodtsova, Tanya and David H. Papell, "Exchange Rate Predictability with Taylor Rule Fundamentals" *Journal of International Economics* 77, 2009, pp. 167-180

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

_____, "Taylor Rules and the Euro", forthcoming, *Journal of Money, Credit, and Banking*, 2010

Papell, David H., "The Panel Purchasing Power Parity Puzzle" *Journal of Money, Credit, and Banking* 38, 2006, pp. 447-467

Poole, William, "Understanding the Fed" *Federal Reserve Bank of St. Louis Review*, 2007, pp. 3-13

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

Rudebusch, Glenn, “The Fed’s Exit Strategy for Monetary Policy” *Federal Reserve Bank of San Francisco Economic Letter* 18, June 14, 2010, pp. 1-5

Scholl, Almuth and Harald Uhlig, “New Evidence on the Puzzles: Results from Agnostic Identification on Monetary Policy and Exchange Rates” *Journal of International Economics* 76, 2008, pp. 1-13

Taylor, John B., “Discretion versus Policy Rules in Practice” *Carnegie-Rochester Conference Series on Public Policy* 39, 1993, pp. 195-214

_____, “Housing and Monetary Policy”, in *Housing, Housing Finance, and Monetary Policy*, Federal Reserve Bank of Kansas City, 2007

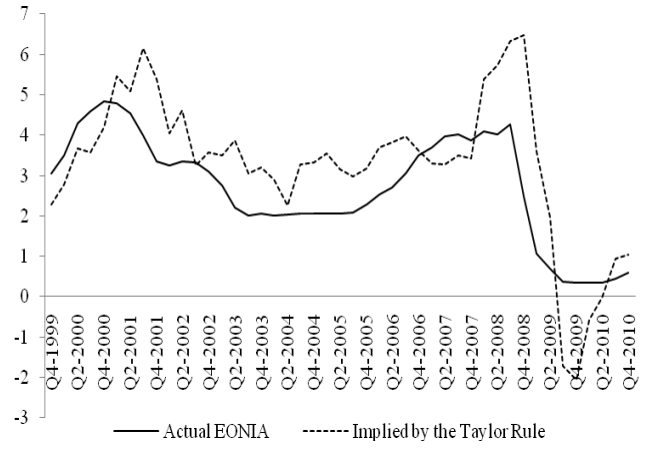
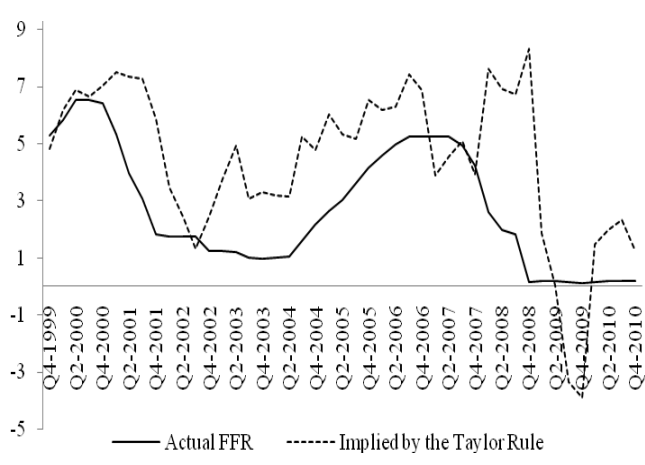
_____, “Empirically Evaluating Economic Policy in Real Time” *NBER Reporter* 3, 2009

_____, “Assessing the Federal Policy Response to the Economic Crisis” Testimony before the Committee on the Budget, United States Senate, 22 September 2010, 2010a

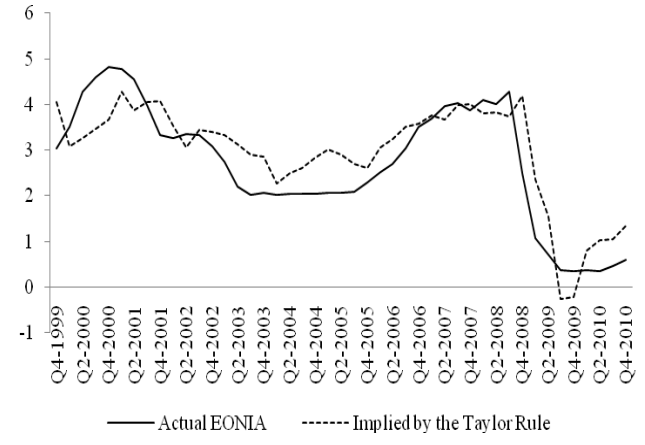
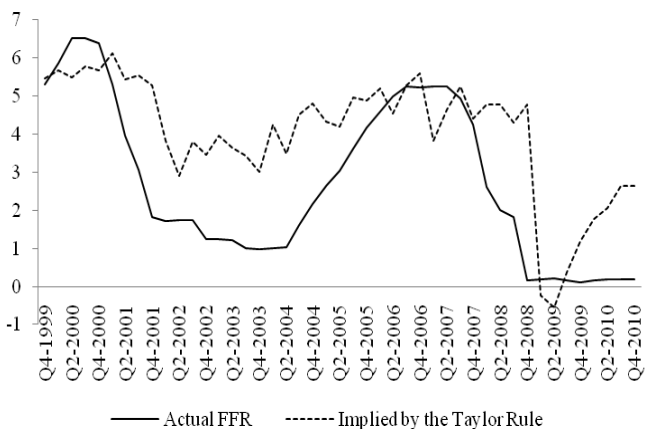
_____, “Policy Rule Gaps as Forecasts of Currency and Interest Rate Movements”, [Weblog Entry], *Economics One*, <http://johnbtaylorblog.blogspot.com/2010/09/policy-rule-gaps-as-forecasts-of.html>, 30 September 2010, 2010b

Taylor, John B. and John C. Williams, “A Black Swan in the Money Market” *American Economic Journal: Macroeconomics* 1, 2009, pp. 58-83

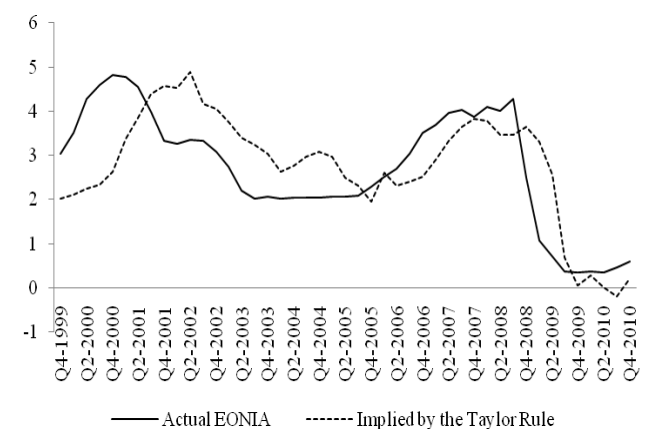
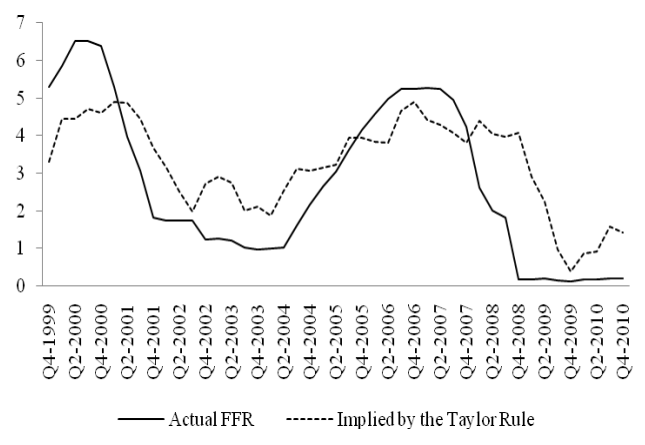
Walsh, Carl E., “Using Monetary Policy to Stabilize Economic Activity”, in *Financial Stability and Macroeconomic Policy*, Federal Reserve Bank of Kansas City, 2010, pp. 245-296



A. Headline Inflation: Contemporaneous

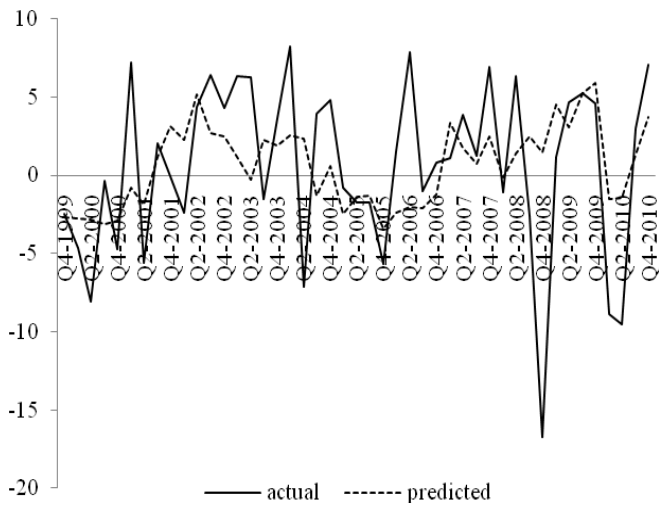


B. Headline Inflation: Forward-Looking

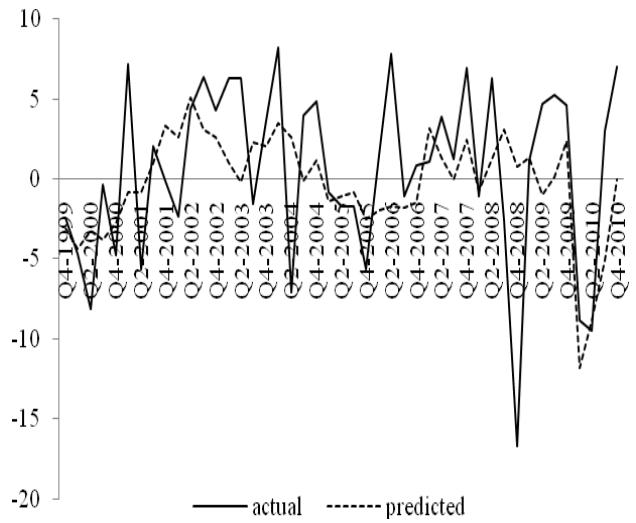


C. Core Inflation: Contemporaneous

Figure 1. Actual and Implied by the Taylor Rule Interest Rates for the US and Euro Area

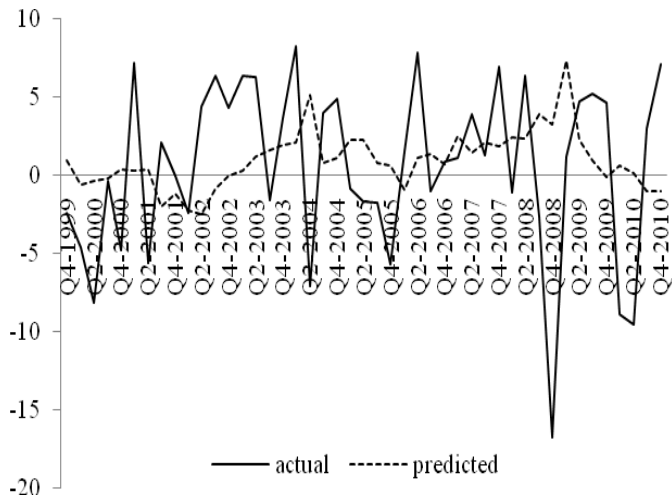


OECD Output Gap

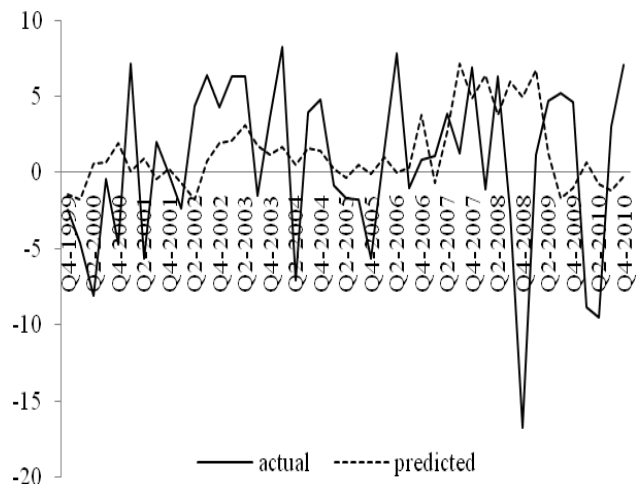


Unemployment Gap

A. Contemporaneous Taylor Rule Model



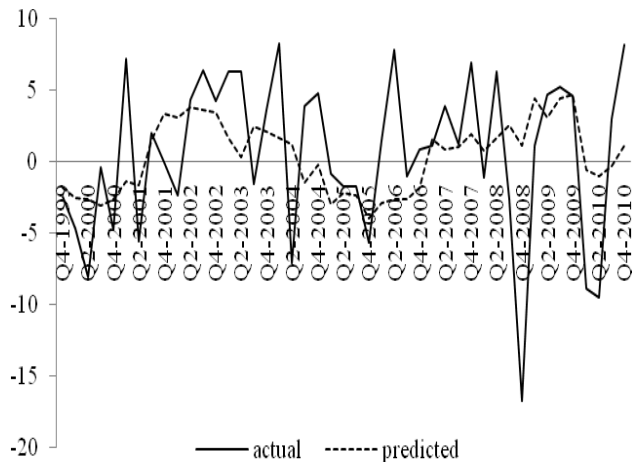
OECD Output Gap



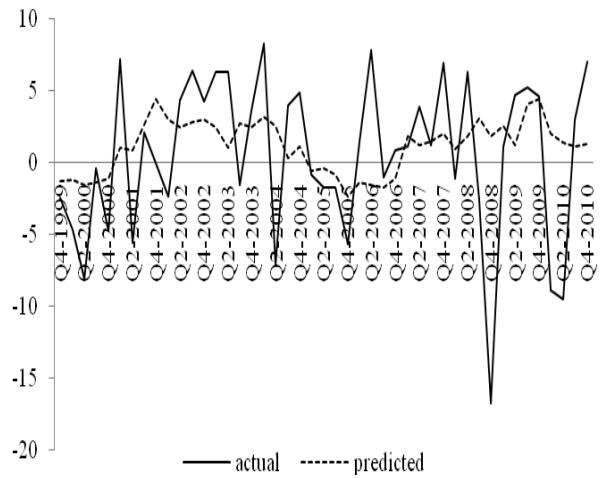
Unemployment Gap

B. Forward-Looking Taylor Rule Model

Figure 2. Actual and Predicted Changes in the Dollar/Euro Exchange Rate Taylor Rule Fundamentals Model

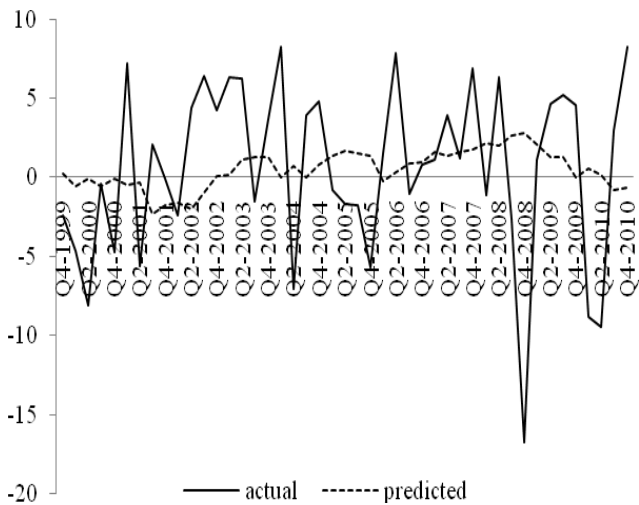


OECD Output Gap

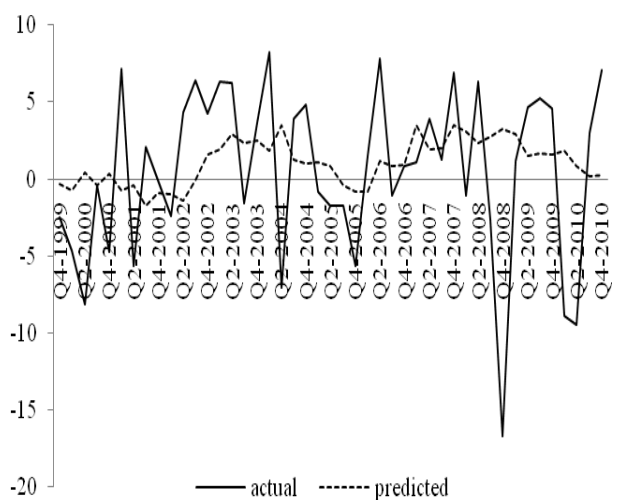


Unemployment Gap

A. Contemporaneous Taylor Rule Model



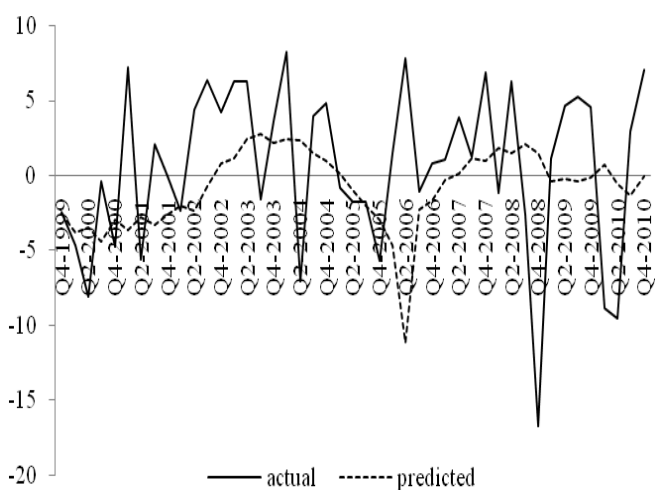
OECD Output Gap



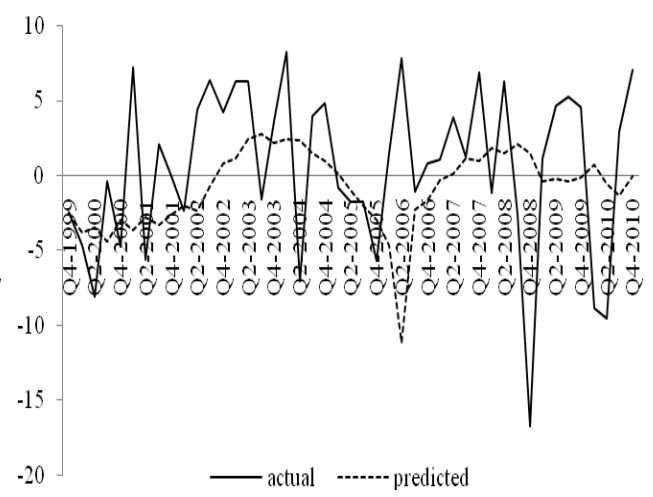
Unemployment Gap

B. Forward-Looking Taylor Rule Model

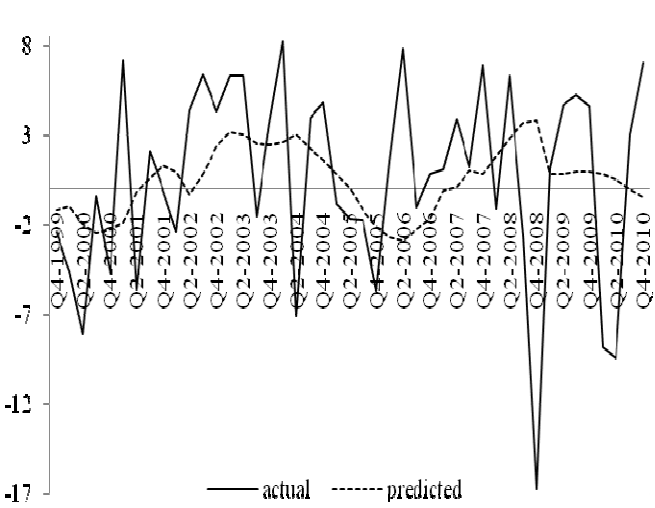
Figure 3. Actual and Predicted Changes in the Dollar/Euro Exchange Rate
Taylor Rule Differentials Model



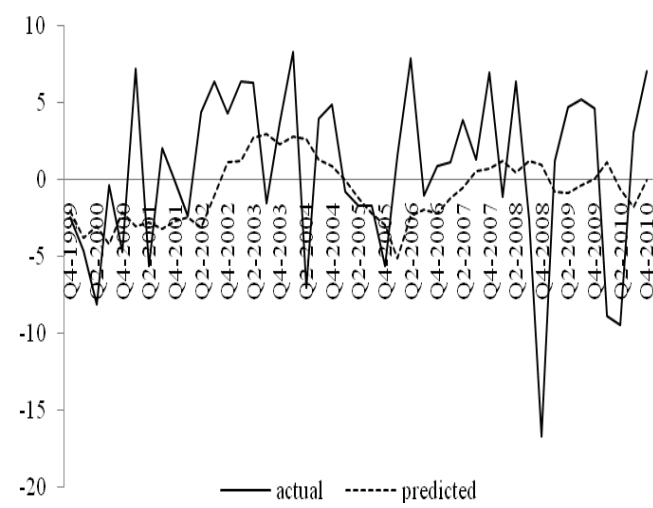
A. Monetary Model: $k=0$



B. Monetary Model: $k=1$

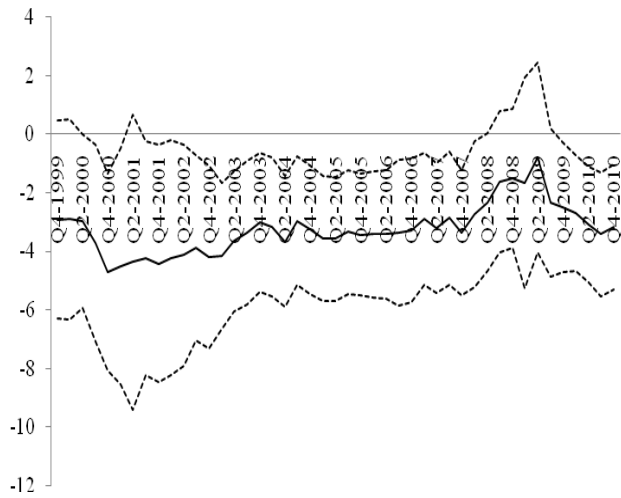


C. Interest Rate Model

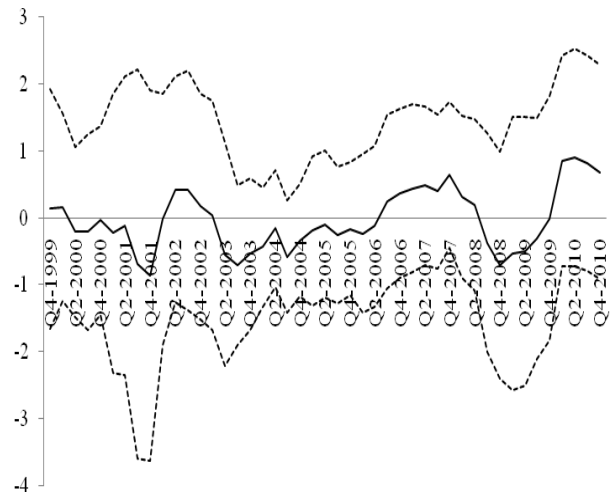


D. PPP Model

Figure 4. Actual and Predicted Changes in the Dollar/Euro Exchange Rate
Interest Rate, Monetary, and PPP Models

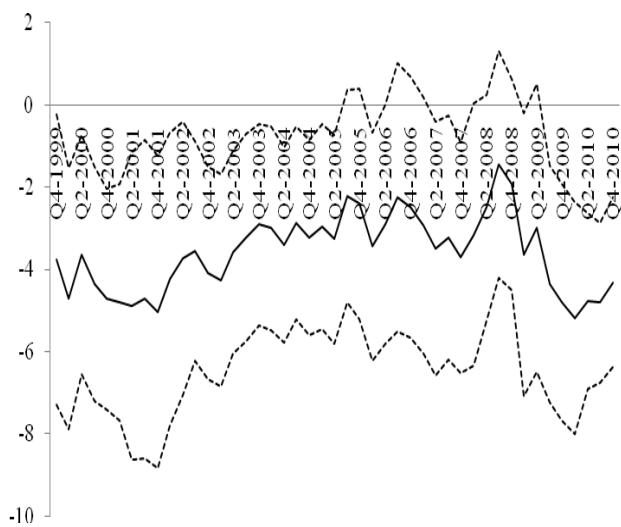


Inflation Differential Coefficient

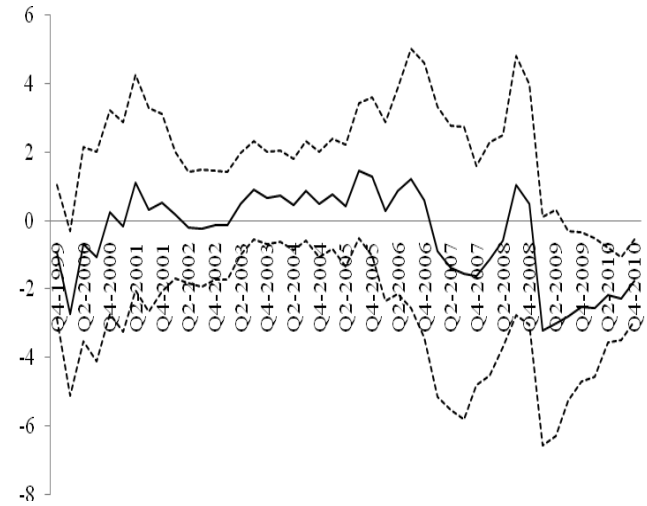


Output Gap Differential Coefficient

A. Contemporaneous Specification with OECD Output Gap



Inflation Differential Coefficient

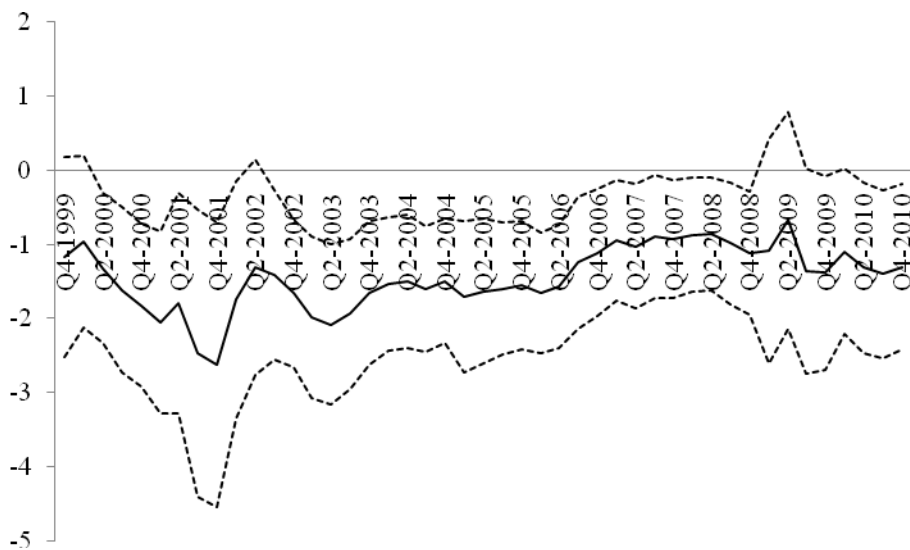


Unemployment Gap Differential Coefficient

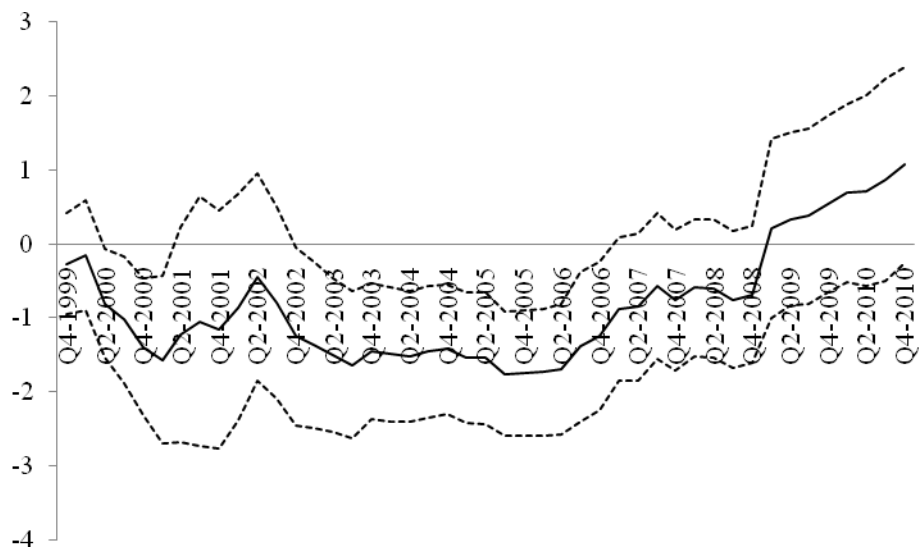
B. Contemporaneous Specification with Unemployment Gap

Figure 5. Dynamics of Forecasting Equation Coefficients

Taylor Rule Fundamentals Model



A. Implied Interest Rate Differential



B. Interest Rate Differential

Figure 6. Dynamics of Forecasting Equation Coefficients
Taylor Rule and Interest Rate Differential Models

Table 1. Taylor Rule Fundamentals Model with Headline Inflation

Forecast Date	MSPE Ratio	CW	DMW	MSPE Ratio	CW	DMW
A. Contemporaneous Taylor Rule Model						
	OECD Output Gap			Unemployment Gap		
2007:Q1	0.856	2.431 ^{***}	0.890 ^{**}	0.833	2.497 ^{***}	0.986 ^{**}
2007:Q2	0.845	2.552 ^{***}	0.988 ^{**}	0.824	2.587 ^{***}	1.067 ^{***}
2007:Q3	0.843	2.563 ^{***}	1.001 ^{***}	0.825	2.578 ^{***}	1.067 ^{***}
2007:Q4	0.814	2.802 ^{***}	1.237 ^{***}	0.798	2.806 ^{***}	1.289 ^{***}
2008:Q1	0.814	2.797 ^{***}	1.241 ^{***}	0.796	2.813 ^{***}	1.300 ^{***}
2008:Q2	0.803	2.947 ^{***}	1.383 ^{***}	0.789	2.940 ^{***}	1.423 ^{***}
2008:Q3	0.830	2.779 ^{***}	1.174 ^{***}	0.824	2.743 ^{***}	1.148 ^{***}
2008:Q4	0.937	1.586 ^{**}	0.558 ^{**}	0.921	1.843 ^{**}	0.715 ^{**}
2009:Q1	0.934	2.190 ^{**}	0.549 ^{**}	0.920	1.845 ^{**}	0.719 ^{**}
2009:Q2	0.918	2.381 ^{***}	0.697 ^{**}	0.908	2.363 ^{***}	0.811 ^{**}
2009:Q3	0.889	2.640 ^{***}	0.358 ^{**}	0.909	2.372 ^{***}	0.823 ^{**}
2009:Q4	0.879	2.886 ^{***}	1.020 ^{***}	0.896	2.528 ^{***}	0.952 ^{***}
2010:Q1	0.867	3.050 ^{***}	1.192 ^{***}	0.844	2.271 ^{***}	1.280 ^{***}
2010:Q2	0.856	3.219 ^{***}	1.367 ^{***}	0.785	2.502 ^{***}	1.604 ^{***}
2010:Q3	0.852	3.272 ^{***}	1.415 ^{***}	0.830	2.363 ^{***}	1.193 ^{***}
2010:Q4	0.829	3.496 ^{***}	1.645 ^{***}	0.837	2.359 ^{***}	1.193 ^{***}
B. Forward-Looking Taylor Rule Model						
	OECD Output Gap			Unemployment Gap		
2007:Q1	1.160	-0.235	-0.906	0.907	1.799 ^{**}	0.956 ^{**}
2007:Q2	1.143	-0.114	-0.821	0.888	2.049 ^{**}	1.150 ^{***}
2007:Q3	1.141	-0.060	-0.813	0.939	2.264 ^{**}	0.536 ^{**}
2007:Q4	1.101	0.199	-0.612	0.881	2.424 ^{***}	0.965 ^{**}
2008:Q1	1.117	0.144	-0.703	0.958	2.220 ^{**}	0.279 [*]
2008:Q2	1.079	0.429	-0.488	0.916	2.501 ^{***}	0.568 ^{**}
2008:Q3	1.125	0.223	-0.750	1.006	2.064 ^{**}	-0.033
2008:Q4	1.206	-0.576	-1.252	1.189	0.310	-0.848
2009:Q1	1.241	-0.459	-1.435	1.217	0.385	-0.965
2009:Q2	1.221	-0.314	-1.331	1.203	0.441	-0.921
2009:Q3	1.207	-0.248	-1.275	1.217	0.351	-1.008
2009:Q4	1.204	-0.255	-1.281	1.222	0.307	-1.051
2010:Q1	1.111	-0.514	-1.127	1.186	-0.056	-1.110
2010:Q2	1.317	-0.797	-1.077	1.261	-0.358	-0.982
2010:Q3	1.193	-0.382	-1.400	1.196	0.287	-1.074
2010:Q4	1.197	-0.474	-1.485	1.192	0.269	-1.091

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 the tests of equal predictability and forecasting ability, respectively, between the two models. Panels A and B contain the results for the Taylor rule fundamentals models with contemporaneous and forecasted headline inflation and two measures of economic activity, respectively. The left column reports results where economic activity is measured by OECD output gap estimates for the U.S. and the Euro Area and the right column depicts results where economic activity is measured by the unemployment gap. The table reports the statistics for the Taylor rule models that restrict coefficients on inflation and measure of economic activity in the two countries to be the same. *, **, 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 2010:Q4 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. The first row in each panel reports test statistics for 30 forecasts from 1999:Q4 to 2007:Q1 with rolling regressions, using a 26-quarter window. For each subsequent row, an additional forecast is included, so that the last row for 2010:Q4 reports statistics for 45 forecasts, but the rolling regressions still use 26-quarter window.

Table 2. Taylor Rule Fundamentals Model with Core Inflation

Forecast Date	MSPE Ratio	CW	DMW	MSPE Ratio	CW	DMW
OECD Output Gap			Unemployment Gap			
2007:Q1	0.837	2.029**	0.782**	0.896	1.895**	0.450**
2007:Q2	0.832	2.075**	0.824**	0.897	1.896**	0.456**
2007:Q3	0.831	2.108**	0.832**	0.895	1.914**	0.466**
2007:Q4	0.803	2.321***	1.021***	0.864	2.106**	0.638**
2008:Q1	0.816	2.276**	0.952**	0.874	2.073**	0.594**
2008:Q2	0.803	2.408***	1.070***	0.870	2.131**	0.648**
2008:Q3	0.821	2.321***	0.974***	0.896	2.023**	0.514**
2008:Q4	0.961	1.110	0.293*	0.962	1.317*	0.311**
2009:Q1	0.961	1.149	0.293*	1.007	1.201	-0.055
2009:Q2	0.943	1.662**	0.500**	1.101	1.131	-0.551
2009:Q3	0.923	1.770**	0.510**	1.128	0.968	-0.709
2009:Q4	0.909	1.903**	0.609**	1.122	0.987	-0.692
2010:Q1	0.933	1.758**	0.475**	1.117	0.970	-0.708
2010:Q2	0.945	1.694**	0.417**	1.069	1.248	-0.436
2010:Q3	0.948	1.673**	0.397**	1.117	1.052	-0.711
2010:Q4	0.936	1.791**	0.507**	1.125	0.967	-0.786

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 the tests of equal predictability and forecasting ability, respectively, between the two models. The table reports the statistics for the Taylor rule fundamentals models that restrict coefficients on the contemporaneous core inflation and measure of economic activity in the two countries to be the same. The left column reports results where economic activity is measured by OECD output gap estimates for the U.S. and the Euro Area and the right column depicts results where economic activity is measured by the unemployment gap. *, **, 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 2010:Q4 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. The first row in each panel reports test statistics for 30 forecasts from 1999:Q4 to 2007:Q1 with rolling regressions, using a 26-quarter window. For each subsequent row, an additional forecast is included, so that the last row for 2010:Q4 reports statistics for 45 forecasts, but the rolling regressions still use 26-quarter window.

Table 3. Taylor Rule Differentials Model with Headline Inflation

Forecast Date	MSPE Ratio	CW	DMW	MSPE Ratio	CW	DMW
A. Contemporaneous Taylor Rule Model						
OECD Output Gap			Unemployment Gap			
2007:Q1	0.896	2.281**	0.625**	0.837	2.401***	1.078***
2007:Q2	0.889	2.341***	0.681**	0.828	2.502***	1.161***
2007:Q3	0.887	2.362***	0.695**	0.827	2.538***	1.176***
2007:Q4	0.863	2.566***	0.889**	0.805	2.769***	1.390***
2008:Q1	0.866	2.541***	0.869**	0.809	2.733***	1.357***
2008:Q2	0.849	2.709***	1.023**	0.793	2.934***	1.536***
2008:Q3	0.877	2.541***	0.821**	0.828	2.697***	1.233***
2008:Q4	0.946	2.067**	0.453*	0.936	1.763**	0.531**
2009:Q1	0.957	2.149**	0.368*	0.937	1.810**	0.525**
2009:Q2	0.940	2.349***	0.522**	0.929	1.903**	0.605**
2009:Q3	0.917	2.600***	0.719**	0.907	2.156**	0.794**
2009:Q4	0.899	2.835***	0.871**	0.889	2.395***	0.945**
2010:Q1	0.898	2.906***	0.943**	0.929	2.026**	0.611**
2010:Q2	0.891	3.040***	1.078***	0.957	1.786**	0.393*
2010:Q3	0.893	3.017***	1.064***	0.953	1.833**	0.431**
2010:Q4	0.886	3.130***	1.173***	0.942	1.954**	0.548**
B. Forward-Looking Taylor Rule Model						
OECD Output Gap			Unemployment Gap			
2007:Q1	1.101	-0.742	-1.534	0.970	1.109	0.226
2007:Q2	1.086	-0.446	-1.284	0.953	1.280*	0.354*
2007:Q3	1.083	-0.345	-1.249	0.951	1.339*	0.364*
2007:Q4	1.048	0.217	-0.683	0.904	1.697**	0.721**
2008:Q1	1.061	0.117	-0.855	0.927	1.613*	0.538*
2008:Q2	1.029	0.578	-0.391	0.899	1.859**	0.764**
2008:Q3	1.056	0.312	-0.718	0.929	1.680**	0.527**
2008:Q4	1.138	-0.703	-1.248	1.062	0.404	-0.412
2009:Q1	1.138	-0.657	-1.243	1.064	0.449	-0.424
2009:Q2	1.126	-0.546	-1.147	1.051	0.541	-0.347
2009:Q3	1.112	-0.424	-1.041	1.037	0.654	-0.253
2009:Q4	1.301	-0.962	-1.907	1.025	0.748	-0.176
2010:Q1	1.111	-0.514	-1.127	1.054	0.517	-0.395
2010:Q2	1.285	-1.015	-1.239	1.187	-0.234	-0.765
2010:Q3	1.109	-0.580	-1.195	1.062	0.416	-0.492
2010:Q4	1.112	-0.658	-1.272	1.058	0.437	-0.472

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 the tests of equal predictability and forecasting ability, respectively, between the two models. Panel A contains the results for the Taylor rule differentials model with contemporaneous real-time headline inflation and OECD estimates of the output gap and unemployment gap, and Panel B contains the results for the Taylor rule differential with forward-looking headline inflation and OECD estimates of the output gap and unemployment gap. *, **, 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 2010:Q4 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. The first row in each panel reports test statistics for 30 forecasts from 1999:Q4 to 2007:Q1 with rolling regressions, using a 26-quarter window. For each subsequent row, an additional forecast is included, so that the last row for 2010:Q4 reports statistics for 45 forecasts, but the rolling regressions still use 26-quarter window.

Table 4. Taylor Rule Differentials Model with Core Inflation

Forecast Date	MSPE Ratio	CW	DMW	MSPE Ratio	CW	DMW
OECD Output Gap			Unemployment Gap			
2007:Q1	0.872	2.143**	0.725**	0.848	1.903**	0.984**
2007:Q2	0.870	2.175**	0.756**	0.844	1.960**	1.038**
2007:Q3	0.868	2.208**	0.769**	0.843	2.009**	1.044**
2007:Q4	0.848	2.397***	0.940***	0.822	2.223**	1.247***
2008:Q1	0.858	2.348***	0.874**	0.835	2.167**	1.151**
2008:Q2	0.840	2.523***	1.029**	0.815	2.369***	1.336***
2008:Q3	0.861	2.396***	0.887**	0.844	2.201**	1.110**
2008:Q4	0.976	1.435*	0.173	0.989	0.939	0.074
2009:Q1	0.978	1.480*	0.162	0.990	0.977	0.071
2009:Q2	0.977	1.595*	0.169	0.977	1.091	0.163*
2009:Q3	0.950	1.738**	0.372*	0.958	1.266*	0.299**
2009:Q4	0.940	1.836**	0.453*	0.942	1.424*	0.413**
2010:Q1	0.961	1.683**	0.316*	0.991	1.065	0.066
2010:Q2	0.970	1.621*	0.261*	1.007	0.942	-0.052
2010:Q3	0.975	1.578*	0.216*	1.008	0.934	-0.060
2010:Q4	0.978	1.556*	0.196*	1.011	0.905	-0.088

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 the tests of equal predictability and forecasting ability, respectively, between the two models. The Table contains the results for the Taylor rule differentials model with contemporaneous real-time core inflation and OECD estimates of the output gap and unemployment gap. *, **, 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 2010:Q4 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. The first row in each panel reports test statistics for 30 forecasts from 1999:Q4 to 2007:Q1 with rolling regressions, using a 26-quarter window. For each subsequent row, an additional forecast is included, so that the last row for 2010:Q4 reports statistics for 45 forecasts, but the rolling regressions still use 26-quarter window.

Table 5. Interest Rate, Monetary, and PPP Models

Forecast Date	MSPE Ratio	CW	DMW	MSPE Ratio	CW	DMW
A. Monetary Model: k=0			B. Monetary Model: k=1			
2007:Q1	1.191	-0.943	-1.410	1.243	-1.787	-2.080
2007:Q2	1.179	-0.871	-1.349	1.230	-1.696	-2.003
2007:Q3	1.176	-0.837	-1.330	1.228	-1.653	-1.977
2007:Q4	1.142	-0.590	-1.121	1.190	-1.342	-1.716
2008:Q1	1.153	-0.644	-1.208	1.201	-1.401	-1.810
2008:Q2	1.124	-0.405	-1.008	1.169	-1.108	-1.565
2008:Q3	1.142	-0.532	-1.158	1.186	-1.241	-1.723
2008:Q4	1.140	-0.896	-1.466	1.170	-1.572	-2.016
2009:Q1	1.127	-0.789	-1.334	1.159	-1.458	-1.876
2009:Q2	1.139	-0.916	-1.484	1.168	-1.587	-2.029
2009:Q3	1.140	-0.971	-1.537	1.169	-1.655	-2.095
2009:Q4	1.145	-1.059	-1.625	1.176	-1.769	-2.210
2010:Q1	1.128	-0.940	-1.514	1.154	-1.590	-2.044
2010:Q2	1.119	-0.938	-1.512	1.137	-1.471	-1.932
2010:Q3	1.136	0.768	-1.036	1.151	0.613	-1.160
2010:Q4	1.266	-0.112	-1.081	1.251	-0.181	-1.083
C. Interest Rate Model			D. PPP Model			
2007:Q1	0.922	1.490*	0.445*	1.212	-1.884	-2.272
2007:Q2	0.923	1.494*	0.451*	1.200	-1.772	-2.172
2007:Q3	0.962	1.209	0.635**	1.198	-1.740	-2.146
2007:Q4	0.911	1.614*	0.556**	1.171	-1.508	-1.938
2008:Q1	0.921	1.574*	0.491*	1.173	-1.534	-1.967
2008:Q2	0.889	1.826**	0.714**	1.158	-1.432	-1.873
2008:Q3	0.933	1.623*	0.417*	1.142	-1.618	-2.120
2008:Q4	1.025	0.511	-0.162	1.131	-1.812	-2.221
2009:Q1	1.055	0.497	-0.306	1.100	-1.112	-1.579
2009:Q2	1.077	0.426	-0.439	1.094	-1.036	-1.514
2009:Q3	1.067	0.481	-0.392	1.097	-1.128	-1.602
2009:Q4	1.059	0.529	-0.350	1.110	-1.333	-1.808
2010:Q1	1.067	0.449	-0.426	1.075	-0.616	-1.175
2010:Q2	1.070	0.395	-0.477	1.068	-0.582	-1.141
2010:Q3	1.070	0.393	-0.479	1.102	1.286*	-0.677
2010:Q4	1.072	0.356	-0.515	1.094	0.631	-0.882

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 the tests of equal predictability and forecasting ability, respectively, between the two models. Panels A and B contain the results for the monetary model with income elasticity $k=0$ and 1 , respectively, Panel C contains the results for the Interest Rate Model, and Panel D contains the results for the PPP Model. *, **, 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 2010:Q4 for the United States and the Euro Area. The data for the first vintage starts in 1993:Q1. The first row in each panel reports test statistics for 30 forecasts from 1999:Q4 to 2007:Q1 with rolling regressions, using a 26-quarter window. For each subsequent row, an additional forecast is included, so that the last row for 2010:Q4 reports statistics for 45 forecasts, but the rolling regressions still use a 26-quarter window.