# Phoenix Taylor Rule Exchange Rate Forecasting During the Financial Crisis

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**Abstract**

This paper evaluates out-of-sample exchange rate predictability 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:Q1, but the evidence weakens in 2008:Q2, falls precipitously at the peak of the crisis in 2008:Q3, and continues to fall in 2008:Q4 and 2009:Q1. Taylor rule predictability, however, rises from the dead in 2009 and 2010. When indicators of financial stress are added to the Taylor rule, the model performs better from 2007:Q1 to 2008:Q2, worse during the peak period of the financial crisis, and better in 2009 and 2010. The performance of the Taylor rule models is superior to the interest rate differentials, monetary, and purchasing power parity models.

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## 1. Introduction

The past few years have seen a resurgence of academic interest in out-of-sample exchange rate predictability. Gourinchas and Rey (2007), using an external balance model, Engel, Mark, and West (2008), using monetary, Purchasing Power Parity (PPP), and Taylor rule models, and Molodtsova and Papell (2009), using a variety of Taylor rule models, 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. 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. Molodtsova, Nikolsko-Rzhevskyy, and Papell (2011), henceforth MNP (2011), 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.

Molodtsova and Papell (2009) conduct out-of-sample exchange rate forecasting with Taylor rule fundamentals, using the variables, including inflation rates and output gaps, which normally comprise Taylor rules. 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 version of their model, which we call the Taylor rule differentials model.[2] Since there is no evidence that either the Fed or the ECB targets the exchange rate, we do not include the real exchange rate in the forecasting regression for either model.[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

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[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.

[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.

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]

It is important to be clear about the distinction between forecasting and predictability. Since the seminal paper of Meese and Rogoff (1983), the standard benchmark for evaluating out-of-sample exchange rate forecasting is the naïve random walk (no change) forecast and the standard metric is the mean squared prediction error (MSPE). It is by now well-known that, under the random walk null hypothesis, the MSPE of the alternative (linear) model is larger than the MSPE of the random walk model, making tests, such as Theil's U test and the DMW test of Diebold and Mariano (1995) and West (1996) that depend on MSPE comparisons, seriously undersized. While correctly sized tests can be constructed by bootstrapping the DMW statistic as in Mark (1995) or adjusting the critical values of the DMW test as in McCracken (2007), they are not necessarily minimum mean squared prediction error tests. They test for out-of-sample exchange rate predictability, can the null hypothesis that the exchange rate follows a random walk be rejected in favor of the alternative hypothesis of a linear model, not for out-of-sample forecasting, can the null hypothesis that the MSPEs of the two models are equal be rejected in favor of the alternative hypothesis that the MSPE of the linear model is smaller than the MSPE of the random walk model.

[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.johnbtaylorsblog.blogspot.com/.

The purpose of this paper is to evaluate Taylor rule out-of-sample exchange rate predictability for the euro/dollar exchange rate with real-time data during and following the financial crisis of 2008 – 2009. On August 9, 2007, the spread between the dollar London interbank offer rate (Libor) and the overnight index swap (OIS), an indicator of financial stress in the interbank loan market, jumped from 13 to 40 basis points on concerns that problems in the subprime mortgage market were spreading to the broader mortgage market. The spreads mostly fluctuated between 50 and 90 basis points until September 17, 2008, when they spiked following the announcement that Lehman Brothers had filed for bankruptcy, peaking on October 10 at over 350 basis points. Following the end of the panic phase of the financial crisis in October, 2008, the spread gradually returned to near pre-crisis levels in September 2009. The spread increased again, although not nearly as sharply, during the mid-2010 financial crisis in Europe, but has subsequently returned to late 2009 levels. Taylor and Williams (2009) analyze this episode, calling it a "black swan" in the money market.[7]

Taylor (2008) has proposed adjusting the systematic component of monetary policy by subtracting a smoothed version of the spread from the interest rate target that would otherwise be determined by deviations of inflation and real GDP from their targets according to the Taylor rule. He argues that such an adjustment, which would have been about 50 basis points in early 2008, would be a more transparent and predictable response to financial market stress than a purely discretionary adjustment.

The spread between the euro interbank offer rate (Euribor) and the euro OIS also jumped in August 2007 and spiked in September and October 2008, although not by as much as the U.S. spread. While the Euribor-OIS spread came down in September 2009, it did not return to its pre-crisis levels. During August and December 2010, the spread jumped to as high as 40 basis points. The smoothed Libor-OIS, Euribor-OIS, and the difference between the Libor-OIS and Euribor-OIS spreads are depicted in Figure 1. While both spreads returned to lower levels in September 2009, the gap between the two spreads had narrowed by 2009:Q1.

This paper investigates out-of-sample exchange rate forecasting during the financial crisis with Taylor rule-based models that incorporate indicators of financial stress. We use core inflation and estimate models with both the output gap and the unemployment gap for the Taylor rule fundamentals and Taylor rule differentials models. When the Libor-OIS/Euribor-OIS differential is included in the forecasting regression, we call the models spread-adjusted Taylor rule fundamentals and differentials models. According to these models, when the Libor-OIS spread increases, the Fed would be expected to either lower the interest rate or, if it had already attained the zero lower bound, engage in quantitative expansion, depreciating the dollar. When the Euribor-OIS spread increases, the ECB would be expected

[7] Thornton (2009) discusses the Libor-OIS spread.

to react similarly, depreciating the Euro. We therefore use the difference between the Libor-OIS and Euribor-OIS spreads in addition to the difference between the U.S. and Euro Area inflation rates and output gaps for out-of-sample forecasting of the Dollar/Euro exchange rate. For the purpose of comparison, we also evaluate the performance of conventional monetary, Purchasing Power Parity (PPP), and interest rate differential models.

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 2011:Q1, with 46 forecasts. We report the ratio of the mean squared prediction errors (MSPE) of the linear and random walk models and the CW test of Clark and West (2006).

The Taylor rule fundamentals model with the output gap displays a strikingly clear pattern. 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 test at the 5 percent level for the initial set of forecasts ending in 2007:Q1. As the number of forecasts increases, the MSPE ratios decrease and the strength of the rejections increases, peaking at the 1 percent level in 2008:Q1. In the following quarter, 2008:Q2, the MSPE ratios start to fall and, in 2008:Q3, at the peak of the financial crisis, the MSPE ratio rises precipitously and continues to increase through 2009:Q1 (although the rejections continue at the 5 percent level). If the trends of the previous three 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 beginning of 2009, 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, the MSPE ratios stabilized, and the random walk can be rejected in favor of the Taylor rule models at the 5 percent significance level for all specifications between 2009:Q2 and 2011:Q1.

We proceed to delve more deeply into the reasons for this pattern. In 2008:Q3, the dollar appreciated by nearly 12 percent against the euro. This occurred during the "panic" period of the financial crisis that included the Lehman Brothers bankruptcy, 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. Between 2009:Q2 and

2011:Q1, the dollar-euro rate experienced high volatility, with changes of 5 percent or more in 5 of the 8 quarters, and the Taylor rule fundamentals model forecasts about as well as the random walk model.

The results for the Taylor rule differentials model with the output gap display a similar pattern to those of the Taylor rule fundamentals model. The MSPE ratios start below one and the random walk null can be rejected in favor of the Taylor rule model using the CW test at the 5 percent level for the initial set of forecasts ending in 2007:Q1. The MSPE ratios fall through 2008:Q1, rise sharply in 2008:Q3 at the height of the financial crisis, and continue rising through 2009:Q1 (although the rejections continue at the 5 percent level). The random walk null can be rejected in favor of the Taylor rule differentials model at the 10 percent level or higher throughout the entire sample. Between 2009:Q2 and 2011:Q1, the Taylor rule differentials model forecasts about as well as the random walk model.

The performance of both Taylor rule models deteriorates when the output gap is replaced by the unemployment gap. For the Taylor rule fundamentals model, the MSPE ratios are greater than one for the entire sample and the null hypothesis can (with one exception) only be rejected at the 5 percent level through 2009:Q1.For the Taylor rule differentials model, the MSPE ratios are less than one and the null hypothesis can only be rejected at the 5 percent level through 2008:Q2. As with the output gap, the MSPE ratios fall through 2008:Q1 and rise during the financial crisis.

An innovation in this paper is to incorporate indicators of financial stress, measured by the difference between the Libor-OIS and Euribor-OIS spreads, for out-of-sample exchange rate forecasting with Taylor rule models. Incorporating the interest rate spread differential improves the performance of the Taylor rule fundamentals and differentials models with both the output and unemployment gap between 2007:Q1 and 2008:Q2. During the peak of the financial crisis from 2008:Q3 to 2009:Q1, however, the performance of the spread-adjusted models is much worse than the original models. Following the peak of the crisis, the performance of the spread-adjusted models is somewhat worse than the original models.

An active policy debate during 2009 – 2011 centered on the question of whether prescribed Taylor rule interest rates should be calculated using Taylor’s original specification or with a larger output gap coefficient, the unemployment gap instead of the output gap, or the unemployment gap with a larger coefficient. We investigate the implications of this issue on out-of-sample exchange rate forecasting by specifying an alternative Taylor rule differentials model with larger output and unemployment gap coefficients. The performance of the Taylor rule differentials models deteriorates with the larger coefficients. Among the Taylor rule differentials models, the most successful is the one using Taylor’s original rule.

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 and the random walk can be rejected with the CW tests from 2007:Q1 to 2008:Q2. Starting with the panic period of the financial crisis in 2008:Q3, the MSPE ratios rise above one and the random walk null cannot be rejected through 2011:Q1. 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

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

where $i_t$ is the target for the short-term nominal interest rate, $\pi_t$ is the inflation rate, $\overline{\pi}$ 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.[8]

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. The unemployment gap, the difference between the unemployment rate and the natural rate of unemployment, can replace the output

[8] 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.

gap in Equation (1) 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. 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,

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

where $\lambda = 1 + \phi$. Because $\lambda > 1$, the real interest rate is increased when inflation rises, and so the Taylor principle is satisfied. Following Taylor (2008), the original Taylor rule can be modified by subtracting the spread between the dollar Libor rate and the OIS swap rate,

$$i_t = \mu + \lambda\pi_t + \gamma y_t - s_t \qquad (3)$$

where $s_t$ is the spread.

We do not incorporate several modifications of the Taylor rule that, following Clarida, Gali, and Gertler (1998), are typically used for estimation. 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. 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. Finally, while inflation forecasts are often used on the grounds that Federal Reserve policy is forward looking, there is no publicly available data on Euro Area core inflation forecasts.

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.:

$$i_t - i_t^* = \alpha + \alpha_\pi(\pi_t - \pi_t^*) + \alpha_y(y_t - y_t^*) - (s_t - s_t^*) + \eta_t \qquad (4)$$

where asterisks denote Euro Area variables, subscripts $\pi$ and $y$ denote coefficients for inflation and output gap differentials, and $\alpha$ 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).[9]

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:[10]

$$\Delta e_{t+1} = \omega - \omega_{\pi}(\pi_t - \pi_t^*) - \omega_y(y_t - y_t^*) + \omega_s(s_t - s_t^*) + \eta_t \qquad (5)$$

where asterisks denote Euro Area variables, subscripts $\pi$, $y$, and s denote coefficients for inflation, output gap, and spread differentials, and $\omega$ is a constant. Alternatively, the unemployment gap differential can substitute for the output gap differential in Equation (4).

The variable $e_t$ is the log of the U.S. dollar nominal exchange rate determined as the domestic price of foreign currency, so that an increase in $e_t$ is a depreciation of the dollar. The reversal of the signs of the coefficients between (4) and (5) 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 $e_t$ ). 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 (4) and (5).

### *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,

$$\Delta e_{t+1} = \alpha + \omega(i_t - i_t^*) \qquad (6)$$

Since we do not restrict $\omega$ to be equal to 1, or even its sign, (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.

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[9] 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.

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

### *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,

$$i_t - i_t^* = 1.5(\pi_t - \pi_t^*) + 0.5(y_t - y_t^*) \tag{7}$$

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 (6), where the implied Taylor rule interest rate differentials replace the actual interest rate differentials.[11] The Taylor rule differentials model can be modified by subtracting the spreads from the U.S. and Euro Area Taylor rules,

$$i_t - i_t^* = 1.5(\pi_t - \pi_t^*) + 0.5(y_t - y_t^*) - (s_t - s_t^*) \tag{8}$$

where $s_t$ is the Libor-OIS spread and $s_t^*$ is the Euribor-OIS spread.

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 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.

During 2009 and 2010, a number of commentators, most notably Rudebusch (2010), argued that the appropriate output or unemployment gap coefficient in the Taylor rule for the U.S. should be double the coefficient in Taylor's original rule. We implement this by estimating an "alternate" Taylor rule differentials model with a coefficient of 1.0 on the output gap or -2.0 on the unemployment gap.

### *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.

$$\Delta e_{t+1} = \alpha + \omega z_t + \nu_t, \tag{9}$$

where $$z_t = f_t - e_t$$

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

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:

$$m_t = p_t + ky_t - hi_t \tag{10}$$

$$m_t^* = p_t^* + k^* y_t^* - hi_t^* \tag{11}$$

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.

$$f_t = (m_t - m_t^*) - k(y_t - y_t^*) \tag{12}$$

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 (12) into (9), 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.[12] 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 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,

$$f_t = (p_t - p_t^*) \tag{13}$$

where $p_t$ is the log of the national price level. We substitute the PPP fundamentals (13) into (9), 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.

[12] See Papell (2006) for a recent example.

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.[13] 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 exchange rate can be described by a linear model. An alternative is to use the DMW statistic with bootstrapped critical values. 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 $\beta$ is zero rather than whether the sample MSPE from the model-based forecast is smaller than the sample MSPE from the random walk forecast.

[13] 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.

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 bootstrapping or adjusting the DMW statistic, 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 $\beta$ 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 two test statistics: the ratio of the MSPE of the linear model to that of the random walk model and the CW statistic. While rejecting the random walk null in favor of the linear model alternative with the CW 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.[14] The dataset has a triangular format with the vintage date on the horizontal axis and calendar dates on the vertical. The term vintage denotes the date in which a time series of data becomes known to the public.[15] 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 1999:Q4 to 2007:Q2, etc., up to 46 exchange rate changes from 1999:Q4 to 2011:Q1. Since

[14] 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.

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

we use vintage data, the estimated coefficients are based on revised data, but the forecasts are conducted using real-time data.[16]

We use the core Personal Consumption Expenditure (PCE) index to measure inflation for the U.S. and the core HICP to measure inflation for Euro Area. 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. Since inflation is released monthly, we use the price indices released in the second month of each quarter to measure quarterly inflation rates.[17]

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, nowcasts, and future forecasts of annual values of the output gap for OECD countries including the Euro Area. The OECD Economic Outlook is published in June and December of each year. In order to construct quarterly vintages from semiannually released real-time output gap data, we use the nowcast of the output gap for the second and fourth quarter of each year and the forecast of the output gap for the first and third quarter of each year. 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.

The unemployment rates are from the OECD Original Release and Revisions Database. As with the inflation rates, the unemployment rates are released monthly and we use the unemployment rate released in the second month of each quarter to measure quarterly unemployment rates. We use the Non-Accelerating Inflation Rate of Unemployment (NAIRU) from semi-annual OECD Economic 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

[16] 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.

[17] We do not consider headline inflation because, as the oil price spike raised headline inflation in 2008, the implied Taylor rule interest rate rose sharply above the actual rate for both the U.S. and the Euro area. Bernanke (2010) has emphasized this for the U.S.

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 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. We use the end of the third month of each quarter as our exchange rate.

The short-term nominal interest rates, defined as the interest rate in the third month of each quarter, are taken from 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 Libor-OIS and Euribor-OIS spreads are from Rosenberg (2011). 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 2, we depict the actual U.S. and Euro Area interest rate and the counterfactual interest rate prescribed 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 core PCE real-time inflation for the U.S., core HICP real-time inflation for the Euro Area, and OECD estimates of the output gap.

The overall impression from Figure 2 is that the Taylor rule provides a reasonable benchmark for interest rate setting for both the Fed and the ECB. The pattern of deviations is similar for the two central banks, with the actual interest rate above the prescribed interest rate in 2000 and 2006 – 2007 and below the prescribed interest rate in 2002 – 2005 and in 2008 - 2009. The deviations for the U.S. for 2002 – 2005 are smaller than reported by Taylor (2007) and Poole (2007) because, as in Kohn (2007), we use the core PCE deflator rather than the headline CPI to calculate the prescribed interest rates.[18] The prescribed Taylor rule interest rates for the U.S. in 2009 and 2010 are positive because, in order to have comparable

[18] Nikolsko-Rzhevskyy and Papell (2011) show that, if the real-time GDP deflator is used to measure inflation, the deviations are smaller than with the CPI but larger than with the core PCE deflator.

data between the U.S. and the Euro Area, we use OECD real-time output gaps. If, as in Nikolsko-Rzhevskyy and Papell (2011), we had used CBO output gaps, the prescribed rates would have been slightly negative.[19]

Panel B of Figure 2 depicts the actual and prescribed interest rates with an output gap coefficient of 1.0 instead of 0.5. The fit between the actual and prescribed rates is closer for both the U.S. and the Euro Area during 203 – 2005, the period for which the Fed has been criticized, most notably by Taylor (2007), for keeping interest rates too low and fueling the housing bubble. The prescribed interest rates for both the U.S. and the Euro Area with the alternate Taylor rule are considerably below the zero lower bound starting in 2009:2, a result that has been used by Bernanke to justify quantitative easing.[20]

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 and scant justification for using Taylor rule fundamentals rather than interest rate differentials. 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 2002 – 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 previous quarter. For example, the forecast for 2008:Q3 predicts the exchange rate change from the end of June to the end of September, using the data on inflation, output gaps, and unemployment gaps that was available to market participants at the time that the forecasts would have been made. This forecast spans what Taylor (2010a) calls the panic period of the crisis in late September of 2008. The forecast for

[19] Taylor (2011) argues that the prescribed federal funds rate is positive using the average output gap in Weidner and Williams (2011)

[20] Bernanke's argument and Taylor's response are contained in Taylor (2011). Nikolsko-Rzhevskyy and Papell (2011) discuss these issues in a historical context.

2008:Q4 predicts the exchange rate change from the end of September to the end of December, 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 core 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 and the second column reports the CW 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 2011:Q1 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 the specification with the output gap start under one with forecasts through 2007:Q1, so the forecast errors of the linear model are smaller than those of the random walk model, and remain under one throughout the sample except for two quarters in late 2010. 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.[21] The evidence strengthens through 2007 and early 2008, with the lowest MSPE ratios coming from samples that end in 2008:Q1, before the onset of the panic phase of the financial crisis. The no predictability null can be rejected using the CW test at the 5 percent level in 2007:Q1 and 2007:Q2 and at the 1 percent level starting in 2007:Q3. The evidence is not as strong for the specification with the unemployment gap. While the no predictability null can be rejected at the 5 percent level from 2007:Q1 to 2008:Q1, the MSPE ratios never fall below one.

When real economic activity is measured by the output gap, the MSPE ratios rise from 2008:Q1 to 2009:Q1, with the sharpest increase in 2008:Q3, and the no predictability null can only be rejected at the 5 percent level by 2009:Q1. The MSPE ratios also rise for the specification with the unemployment gap, although the sharpest increase occurs in 2009:Q2, and the no predictability null can only be rejected at the 10 percent level by 2009:Q2. From the perspective of early 2009, exchange rate forecasting with Taylor rule fundamentals seemed finished. The federal funds rate for the U.S. was at the

[21] 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.

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 three quarters, the MSPE ratio for the specification with the output gap would have been projected to rise above one by 2009:Q2, accompanied by less significant CW statistics. But these trends did not continue. The MSPE ratios stabilize below one for most of the periods, and the no predictability null can be rejected at the 5 percent level from 2009:1 to 2011:1. Although the MSPE ratios also stabilize for the specification with the unemployment gap, they stabilize around values consistently above one, and the no predictability null is generally either not rejected or rejected at the 10 percent level. As discussed above, since, under the null, the MSPE of the linear model will be greater than the MSPE of the random walk model, the stable MSPE ratios since early 2009 can be interpreted as a partial success of the Taylor rule models.

Some intuition for these results can be found in Panel A of Figure 3, which depicts actual and forecasted exchange rate changes with the output and unemployment gaps. 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 steadily depreciated against the euro from 2006:Q1 to 2008:Q1. In 2008:Q2, the depreciation turned to appreciation and, in 2008:Q3, the dollar sharply appreciated at the peak of the financial crisis. The dollar/euro rate has remained very volatile, with the largest appreciation in 2010:Q2 and the largest depreciation in 2010:Q3.

The success, failure, and partial rehabilitation of Taylor rule forecasting can be seen in Figure 3. The forecasts with the output gap 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:Q3, when the dollar appreciated by more than 10 percent. As shown in Figure 2, the Taylor rule specifications predicted continued dollar depreciation while, by definition, the random walk model predicted neither depreciation nor appreciation. Starting in 2009, the Taylor rule model continued to predict dollar depreciation, while the actual exchange rate seesawed between appreciation and depreciation. For the specification with the unemployment gap, the forecasts were less successful through 2008 and the model generally predicted dollar appreciation during 2009 and 2010. In 2011:1, both models correctly predicted the dollar depreciation.

Panel B of Table 1 presents results for the spread-adjusted Taylor rules fundamentals model. Because the interest rate spread data does not begin until 1999:Q1, we cannot forecast with spreads starting in 1999:Q3 as we did without spreads. In order to maintain comparability with our previous results, we perform the forecasts without the spreads through 2007:Q1, so that the first row of Panels A and B in Table 1 are constrained to be identical, and incorporate the spreads thereafter. We again use 26 quarters to represent the historical relationship between the Taylor rule fundamentals and the exchange rate changes.

Between 2007:Q1 and 2008:Q2, the out-of-sample forecasting performance of the spread-adjusted Taylor rule differentials model is superior to that of the original model for both the output and the unemployment gap. By 2008:Q2, the no predictability null can be rejected at the 1 percent level for the output gap and the 5 percent level for the unemployment gap. Between 2008:Q3 and 2009:Q1, however, the forecasting performance of the spread-adjusted model deteriorates compared to that of the original model. During 2008:3 and 2008:4, when both the Libor-OIS and Euibor-OIS spreads rose to record levels, The U.S. spread increased more than the E.U. spread, causing the spread differential to rise. According to the model, this should have decreased the implied Taylor rule interest rate for the U.S. more than for the Euro Area, causing the dollar to depreciate against the Euro. Instead, the dollar appreciated sharply against the Euro.

As discussed above and shown in Figure 1, while the Libor-OIS spread did not decrease until September 2009, the differential between the Libor-OIS and Euibor-OIS spreads narrowed earlier and, in 2009:Q1 and 2009:Q2, was back to its historical norms. Once the spreads narrowed, it would not make sense to continue to use the abnormally high spreads in 2008:3 and 2008:4 to forecast, and so we replace the spreads in 2008:3 and 2008:4 with spreads interpolated between 2008:2 and 2009:1. Between 2009:Q2 and 2011:Q1, the forecasting performance of the spread-adjusted model is somewhat inferior to that of the original model.

### *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 table, the MSPEs and the CW statistic are reported for each model. The results for the Taylor rule differentials model, while favorable, are not as strong as those for the Taylor rule fundamentals model. Panel A of Table 2 presents one-quarter-ahead out-of-sample forecasts of the euro/dollar exchange rate with core inflation and both measures of economic activity. The MSPE ratio is below one and the random walk null can be rejected at the 5 percent level in favor of the Taylor rule differentials model for the initial sample ending in 2007:Q1 when real economic activity is measured by either the output gap or the unemployment gap. The MSPE ratios fall during the early part of the sample through 2008:Q1, rise during the financial crisis through 2009:Q1, and stabilize after the crisis. The evidence of predictability is stronger with the output gap than with the unemployment gap. With the output gap, the no predictability null can be rejected at the 10 percent level or higher for the entire sample and at the 5 percent level or higher through 2010:Q2. With the unemployment gap, the null can only be rejected at the 5 percent level through 2008:Q2. The actual and predicted exchange rate changes are illustrated in Figure 4.

Panel B of Table 1 presents results for the spread-adjusted Taylor rules differentials model. The out-of-sample forecasting performance of the spread-adjusted Taylor rule differentials model is superior to that of the original model between 2007:Q1 and 2008:Q3 for both the output and the unemployment gap and, by 2008:Q3, the no predictability null can be rejected at the 1 percent level for the output gap and the 5 percent level for the unemployment gap. In 2008:Q4 and 2009:Q1, however, the forecasting performance is much worse with the spread-adjusted model than with the original model. Between 2009:Q2 and 2001:Q1, neither model does well when compared with the random walk model.

Table 3 presents the results for an alternate Taylor rule differentials model with a coefficient of 1.0 on the output gap or -2.0 on the unemployment gap. While the same pattern is observed as for the Taylor rule fundamentals or Taylor rule differentials models, the evidence against the random walk model is weaker. The MSPE ratios start in 2007:Q1 below one for the output gap and equal to one for the unemployment gap, decrease until 2008:Q1, increase until 2009:Q1, and stabilize thereafter. The largest increase in the MSPE ratios occurs in 2008:Q3, when they rise above one for the remainder of the forecasts. The null hypothesis of equal predictability can only be rejected at the 5 percent significance level from 2007:Q1 to 2008:Q2 for the output gap and from 2008:Q1 to 2008:Q2 for the unemployment gap. The spread-adjusted model again does better than the original model from 2007:Q1 to 2008:Q3, much worse in 2008:Q4 and 2008:Q4, and somewhat worse thereafter.

### *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 4. The MSPE ratio is below one for the forecast intervals ending between 2007:Q1 and 2008:Q2, attaining its lowest point in 2008:Q1. The ratio rises between 2008:Q1 and 2008:Q4 and is greater than one for all but one of the intervals ending between 2008:Q3 and 2011:Q1. Using the CW test, the null hypotheses of equal predictability can be rejected at the 5 percent significance level for all forecast intervals ending between 2007:Q1 and 2008:Q2. For all of the forecast intervals ending between 2008:Q3 and 2011:Q1, however, the equal predictability null cannot be rejected at even the 10 percent significance level. Figure 5 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 2006, the interest rate differentials model is slower to pick up the subsequent appreciation of the euro and performs worse than the others thereafter.

Prior to the panic phase of the financial crisis, the interest rate differentials model perform about as well as either the Taylor rule fundamentals or the Taylor rule differentials models. This should not be surprising, as this period was the heyday of the carry trade. Once the financial crisis hit and the Fed and ECB lowered interest rates to unprecedented levels for an extended period, both Taylor rule models clearly outperform the interest rate model.

### *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 4 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 and the null hypothesis of equal predictability cannot be rejected with the CW test at even the 10 percent significance level. Neither the monetary nor the PPP models provide any evidence whatsoever against the random walk.

Figure 5 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.

## 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 for the forecast intervals ending in 2009 and 2010.

The Taylor rule fundamentals model with the output gap and both Taylor rule differentials models display strikingly similar patterns. For the forecast intervals ending in 2007:Q1, the MSPE ratios are below one and the null hypothesis of equal predictability can be rejected at the 5 percent level for all three specifications. The MSPE ratios fall through 2008:Q1, rise through 2009:Q1 with the sharpest increasing occurring during the panic phase of the financial crisis in 2008:Q3, and stabilize thereafter. The strongest evidence against the null hypothesis of equal predictability of the random walk and Taylor rule models comes from the Taylor rule fundamentals model with the output gap, followed by the Taylor rule differentials model with the output gap, the Taylor rule fundamentals model with the unemployment gap and the Taylor rule differentials model with the unemployment gap.

We augmented the Taylor rule fundamentals and differentials models with the difference between the Libor-OIS and Euribor-OIS spreads, which we call the spread-adjusted Taylor rule models. The out-of-sample exchange reta forecasting performance of the spread-adjusted models is better than the original models from 2007:Q1 to 2008:Q3, much worse than the original models in 2008:Q4 and 2009:Q1, and somewhat worse than the original models thereafter.

Both of the Taylor rule models are more successful than other specifications. The alternate Taylor rule model with higher output and unemployment gap coefficients provides some evidence of predictability, but the evidence is weaker than with the Taylor rule fundamentals or differentials models. While the interest rate differentials model provides some evidence of predictability through 2008:Q2, the evidence disappears during the crisis, and 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 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.

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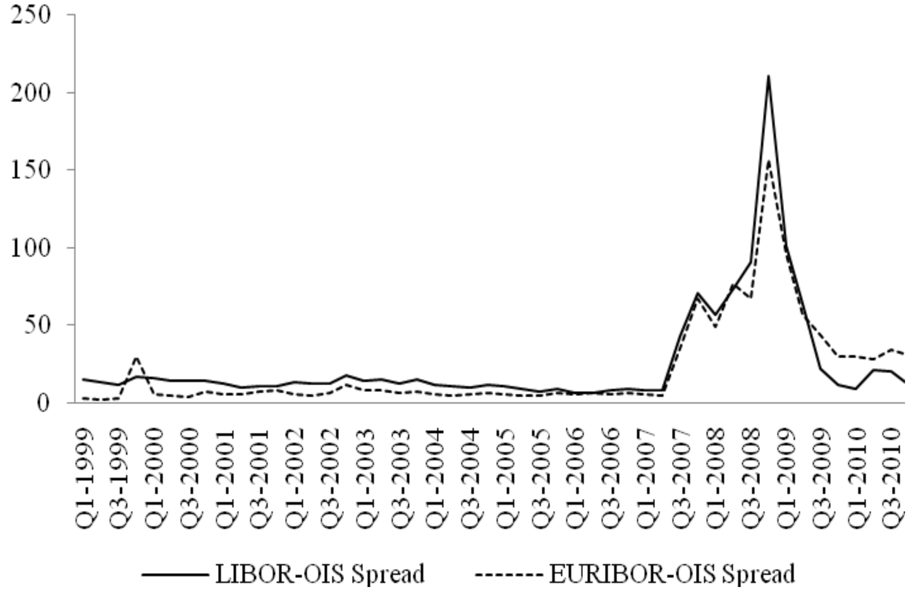
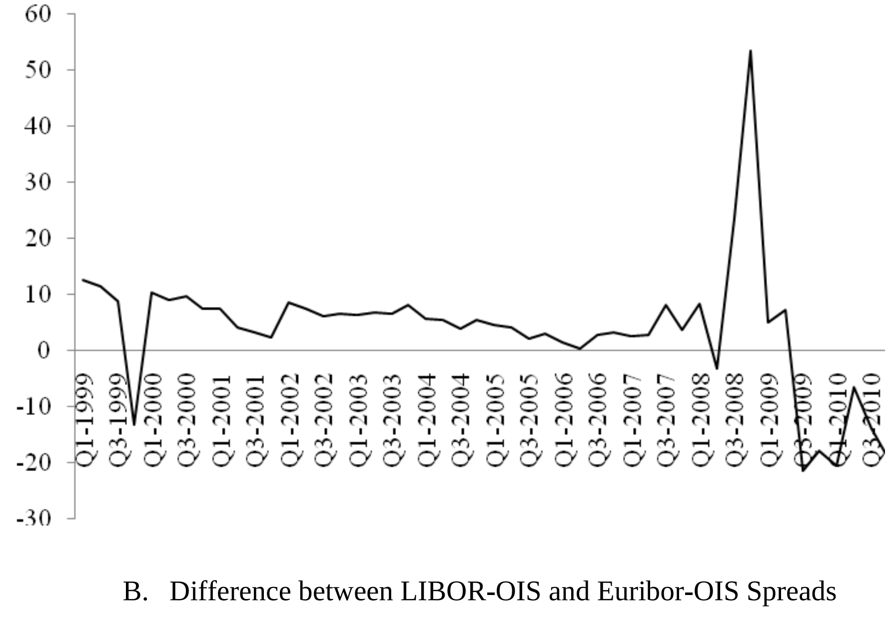
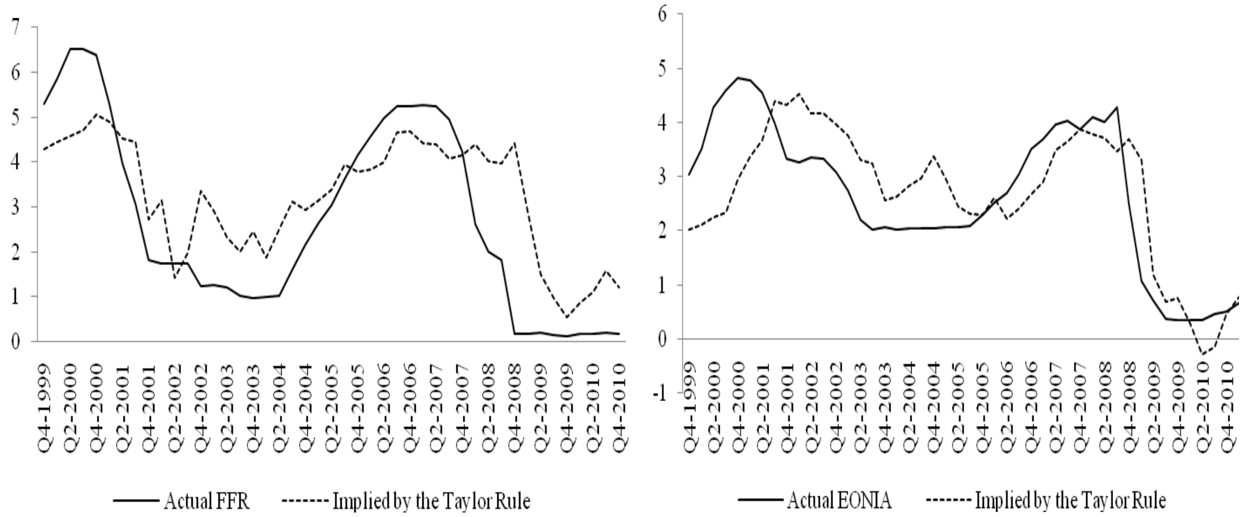



A. Libor-OIS and Euribor-OIS Spreads

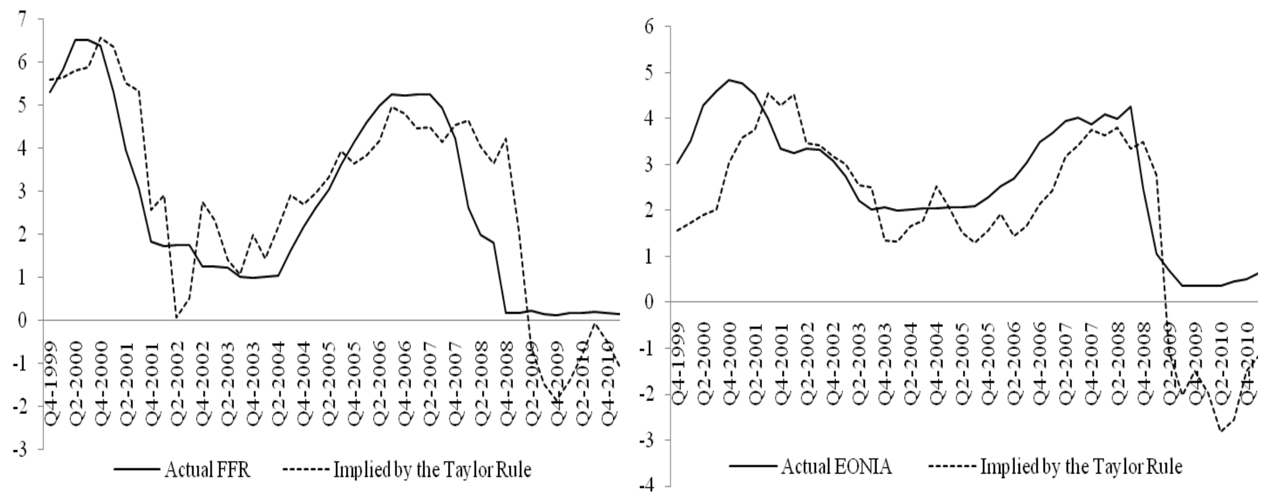



B. Difference between LIBOR-OIS and Euribor-OIS Spreads

Figure 1. Libor-OIS and Euribor-OIS Spreads for the US and Euro Area

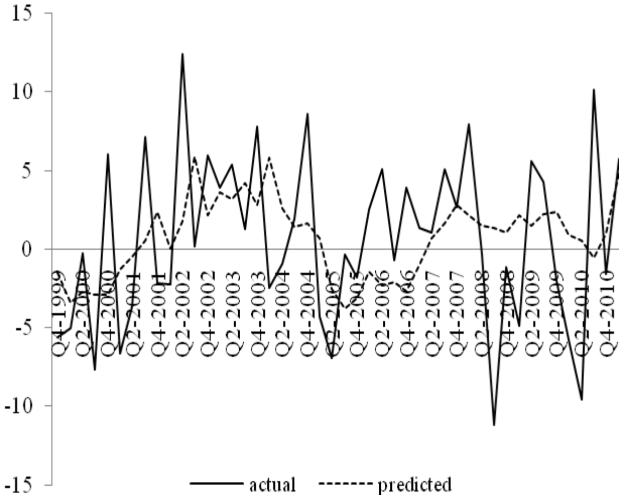



A. Taylor Rule

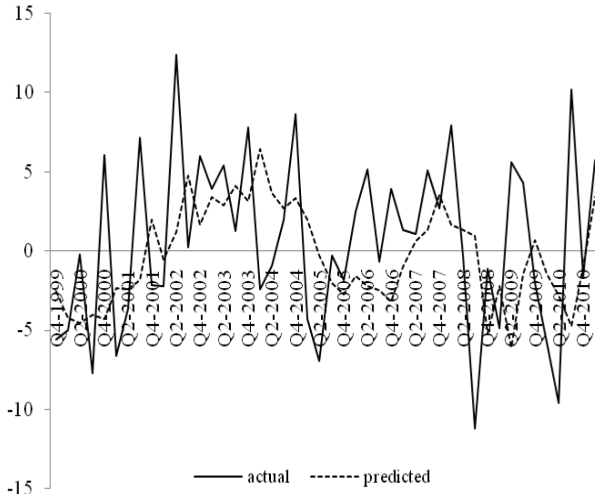



B. Alternate Taylor Rule

Figure 2. Actual and Implied by the Taylor Rule Interest Rates for the US and Euro Area

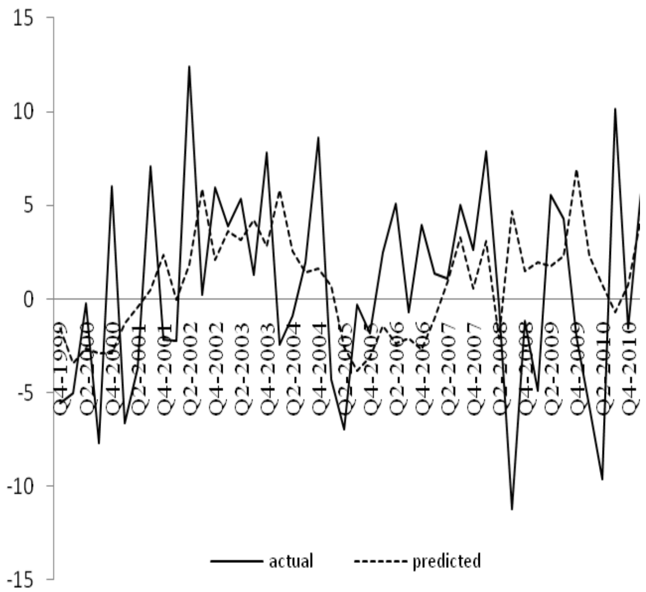



OECD Output Gap

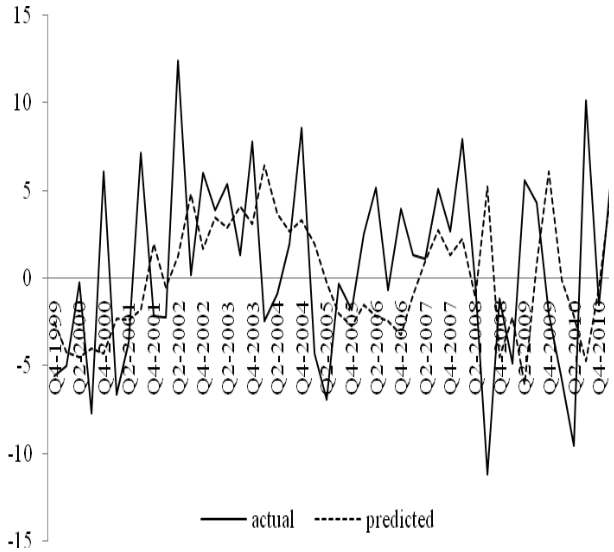



Unemployment Gap

A. Taylor Rule Fundamentals Model



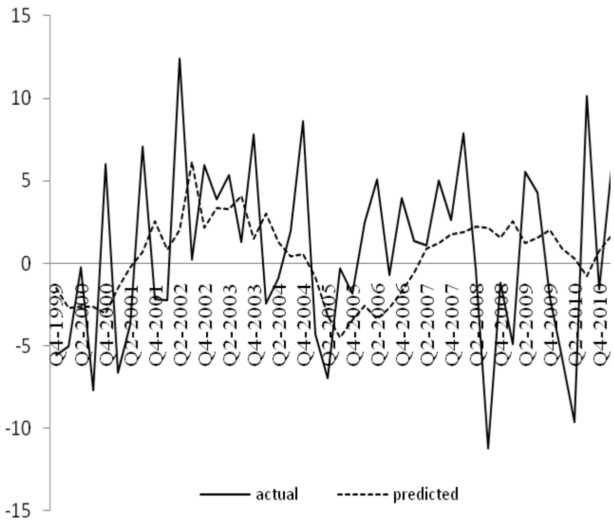

OECD Output Gap

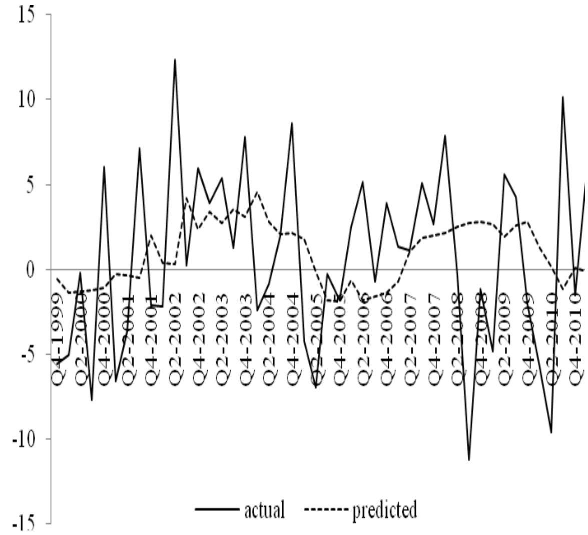



Unemployment Gap

B. Spread-Adjusted Taylor Rule Fundamentals Model

Figure 3. Actual and Predicted Changes in the Dollar/Euro Exchange Rate

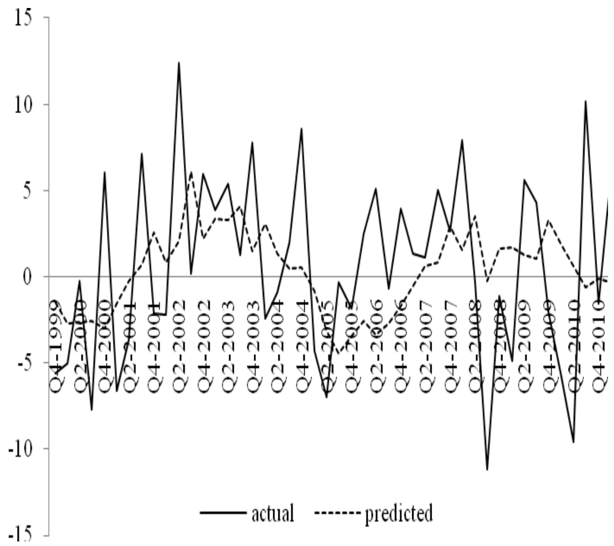


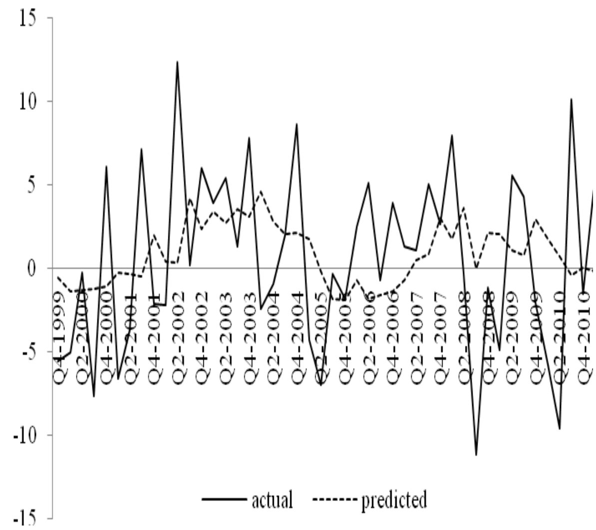




OECD Output Gap

Unemployment Gap

C. Taylor Rule Differentials Model



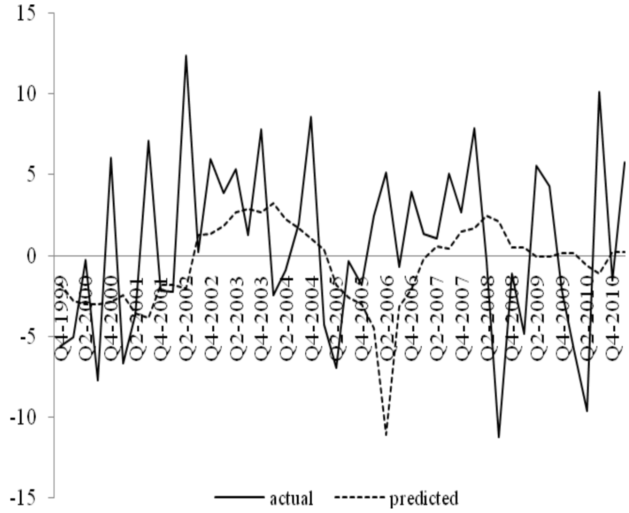




OECD Output Gap

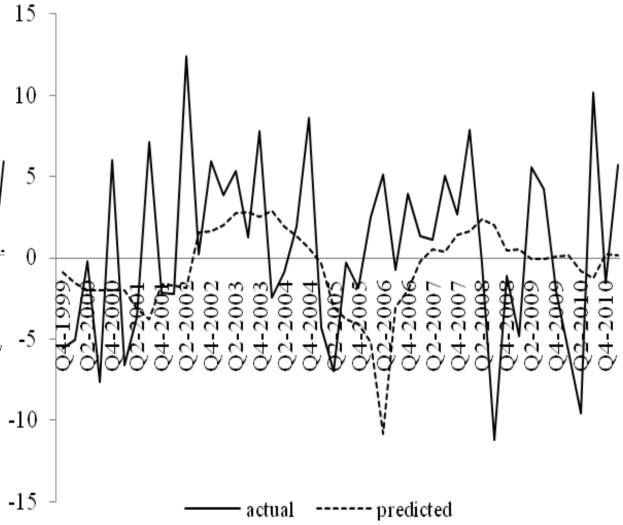
Unemployment Gap

D. Spread-Adjusted Taylor Rule Differentials Model

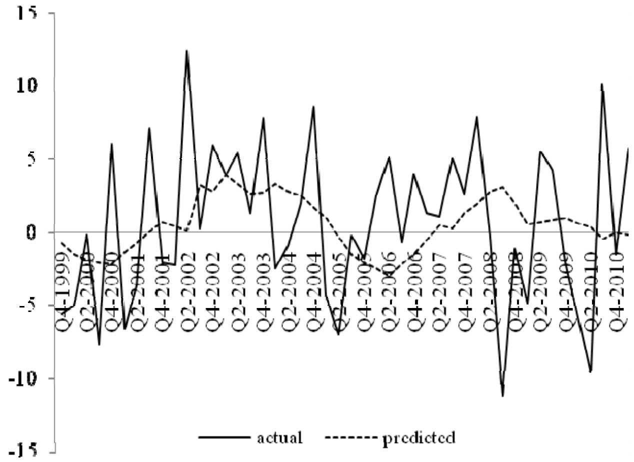
Figure 4. Actual and Predicted Changes in the Dollar/Euro Exchange Rate



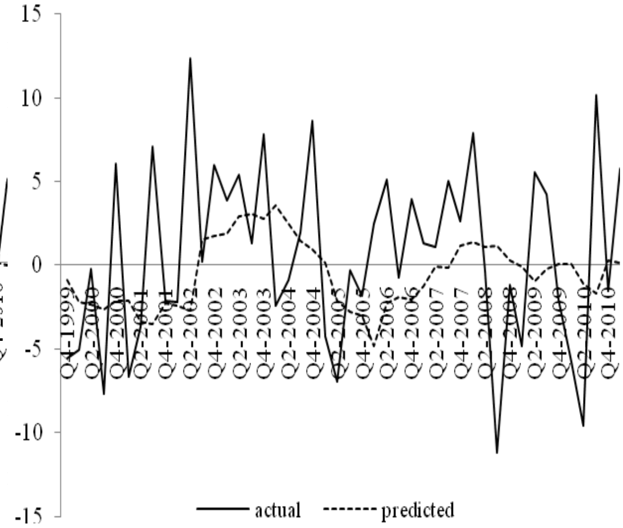

A. Monetary Model: k=0




B. Monetary Model: k=1




C. Interest Rate Model




D. PPP Model

Figure 5. Actual and Predicted Changes in the Dollar/Euro Exchange Rate
Interest Rate, Monetary, and PPP Models

Table 1. Taylor Rule Fundamentals Model

| Forecast Date | MSPE Ratio | CW | MSPE Ratio | CW |
|---|---|---|---|---|
| | Output Gap | | Unemployment Gap | |
| A. Taylor Rule Fundamentals Model | | | | |
| 2007:Q1 | 0.962 | 2.243** | 1.055 | 1.680** |
| 2007:Q2 | 0.961 | 2.252** | 1.054 | 1.687** |
| 2007:Q3 | 0.945 | 2.388*** | 1.037 | 1.780** |
| 2007:Q4 | 0.937 | 2.514*** | 1.029 | 1.905** |
| 2008:Q1 | 0.908 | 2.741*** | 1.000 | 2.072** |
| 2008:Q2 | 0.912 | 2.722*** | 1.003 | 2.061** |
| 2008:Q3 | 0.955 | 2.353*** | 1.024 | 1.885** |
| 2008:Q4 | 0.959 | 2.326*** | 1.039 | 1.964** |
| 2009:Q1 | 0.985 | 2.106** | 1.022 | 2.101** |
| 2009:Q2 | 0.972 | 2.229** | 1.121 | 1.471* |
| 2009:Q3 | 0.959 | 2.366*** | 1.133 | 1.387* |
| 2009:Q4 | 0.974 | 2.271** | 1.136 | 1.369* |
| 2010:Q1 | 0.985 | 2.168** | 1.118 | 1.465* |
| 2010:Q2 | 0.995 | 2.071** | 1.071 | 1.717** |
| 2010:Q3 | 1.004 | 1.976** | 1.157 | 1.011 |
| 2010:Q4 | 1.007 | 1.950** | 1.155 | 1.026 |
| 2011:Q1 | 0.983 | 2.219** | 1.130 | 1.201 |
| B. Spread-Adjusted Taylor Rule Fundamentals Model | | | | |
| 2007:Q1 | 0.962 | 2.243** | 1.055 | 1.680** |
| 2007:Q2 | 0.961 | 2.256** | 1.053 | 1.692** |
| 2007:Q3 | 0.934 | 2.487*** | 1.027 | 1.866** |
| 2007:Q4 | 0.931 | 2.509*** | 1.020 | 1.913** |
| 2008:Q1 | 0.891 | 2.772*** | 0.984 | 2.119** |
| 2008:Q2 | 0.895 | 2.777*** | 0.984 | 2.121** |
| 2008:Q3 | 1.037 | 1.438* | 1.131 | 1.023 |
| 2008:Q4 | 1.140 | 1.301* | 1.130 | 1.030 |
| 2009:Q1 | 1.146 | 1.246 | 1.210 | 0.717 |
| 2009:Q2 | 1.047 | 1.400* | 1.218 | 0.781 |
| 2009:Q3 | 1.032 | 1.510* | 1.208 | 0.814 |
| 2009:Q4 | 1.104 | 1.320* | 1.265 | 0.687 |
| 2010:Q1 | 1.129 | 1.150 | 1.256 | 0.691 |
| 2010:Q2 | 1.132 | 1.066 | 1.206 | 0.875 |
| 2010:Q3 | 1.133 | 0.980 | 1.281 | 0.383 |
| 2010:Q4 | 1.135 | 0.967 | 1.279 | 0.390 |
| 2011:Q1 | 1.108 | 1.204 | 1.248 | 0.617 |

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 statistic for the test of equal predictability between the two models. 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. 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 2011:Q1 reports statistics for 46 forecasts, but the rolling regressions still use 26-quarter window.

Table 2. Taylor Rule Differentials Model

| Forecast Date | MSPE Ratio | CW | MSPE Ratio | CW |
|---|---|---|---|---|
| | Output Gap | | Unemployment Gap | |
| A. Taylor Rule Differentials Model | | | | |
| 2007:Q1 | 0.960 | 2.174** | 0.982 | 1.660** |
| 2007:Q2 | 0.959 | 2.189** | 0.980 | 1.684** |
| 2007:Q3 | 0.947 | 2.298** | 0.962 | 1.876** |
| 2007:Q4 | 0.939 | 2.382*** | 0.954 | 1.991** |
| 2008:Q1 | 0.914 | 2.600*** | 0.923 | 2.262** |
| 2008:Q2 | 0.921 | 2.576*** | 0.932 | 2.236** |
| 2008:Q3 | 0.985 | 1.933** | 1.009 | 1.307* |
| 2008:Q4 | 0.991 | 1.898** | 1.023 | 1.247 |
| 2009:Q1 | 1.022 | 1.659** | 1.055 | 0.992 |
| 2009:Q2 | 1.009 | 1.758** | 1.036 | 1.159 |
| 2009:Q3 | 0.999 | 1.856** | 1.021 | 1.327* |
| 2009:Q4 | 1.011 | 1.782** | 1.039 | 1.223 |
| 2010:Q1 | 1.020 | 1.693** | 1.052 | 1.095 |
| 2010:Q2 | 1.024 | 1.646** | 1.051 | 1.066 |
| 2010:Q3 | 1.034 | 1.508* | 1.067 | 0.855 |
| 2010:Q4 | 1.037 | 1.489* | 1.067 | 0.853 |
| 2011:Q1 | 1.023 | 1.624* | 1.066 | 0.842 |
| B. Spread-Adjusted Taylor Rule Differentials Model | | | | |
| 2007:Q1 | 0.960 | 2.174** | 0.982 | 1.660** |
| 2007:Q2 | 0.959 | 2.181** | 0.981 | 1.670** |
| 2007:Q3 | 0.951 | 2.258*** | 0.971 | 1.769** |
| 2007:Q4 | 0.942 | 2.393*** | 0.963 | 1.935** |
| 2008:Q1 | 0.921 | 2.588*** | 0.938 | 2.178** |
| 2008:Q2 | 0.938 | 2.554*** | 0.955 | 2.142** |
| 2008:Q3 | 0.939 | 2.608*** | 0.960 | 2.148** |
| 2008:Q4 | 1.128 | 2.242** | 1.136 | 1.740** |
| 2009:Q1 | 1.244 | 1.405* | 1.222 | 0.992 |
| 2009:Q2 | 0.955 | 2.480*** | 0.984 | 1.921** |
| 2009:Q3 | 0.949 | 2.558*** | 0.978 | 1.993** |
| 2009:Q4 | 0.971 | 2.406*** | 0.998 | 1.840** |
| 2010:Q1 | 0.994 | 2.170** | 1.018 | 1.590* |
| 2010:Q2 | 1.005 | 2.057** | 1.029 | 1.432* |
| 2010:Q3 | 1.014 | 1.933** | 1.033 | 1.343* |
| 2010:Q4 | 1.014 | 1.934** | 1.033 | 1.341* |
| 2011:Q1 | 1.017 | 1.898** | 1.034 | 1.318* |

Notes: The table reports the ratio of the out-of-sample MSPEs of the linear model to that of the random walk model and the CW statistics for the test of equal predictability 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. We use real-time quarterly data from 1999:Q4 to 2011:Q1 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 2011:Q1 reports statistics for 46 forecasts, but the rolling regressions still use 26-quarter window.

Table 3. Alternate Taylor Rule Differentials Model

| Forecast Date | MSPE Ratio | CW | MSPE Ratio | CW |
|---|---|---|---|---|
| | Output Gap | | Unemployment Gap | |
| A. Alternate Taylor Rule Differentials Model | | | | |
| 2007:Q1 | 0.984 | 1.879** | 1.000 | 1.127 |
| 2007:Q2 | 0.983 | 1.899** | 0.999 | 1.158 |
| 2007:Q3 | 0.970 | 2.010** | 0.978 | 1.388* |
| 2007:Q4 | 0.963 | 2.089** | 0.970 | 1.504* |
| 2008:Q1 | 0.936 | 2.311** | 0.938 | 1.805** |
| 2008:Q2 | 0.944 | 2.288** | 0.949 | 1.779** |
| 2008:Q3 | 1.015 | 1.539* | 1.040 | 0.710 |
| 2008:Q4 | 1.024 | 1.498* | 1.059 | 0.643 |
| 2009:Q1 | 1.054 | 1.268 | 1.085 | 0.444 |
| 2009:Q2 | 1.042 | 1.357* | 1.073 | 0.530 |
| 2009:Q3 | 1.034 | 1.433* | 1.061 | 0.648 |
| 2009:Q4 | 1.042 | 1.377* | 1.074 | 0.568 |
| 2010:Q1 | 1.051 | 1.293* | 1.082 | 0.480 |
| 2010:Q2 | 1.054 | 1.227 | 1.072 | 0.520 |
| 2010:Q3 | 1.060 | 1.119 | 1.097 | 0.210 |
| 2010:Q4 | 1.061 | 1.104 | 1.096 | 0.218 |
| 2011:Q1 | 1.052 | 1.184 | 1.099 | 0.168 |
| B. Spread-Adjusted Alternate Taylor Rule Differentials Model | | | | |
| 2007:Q1 | 0.984 | 1.879** | 1.000 | 1.127 |
| 2007:Q2 | 0.983 | 1.890** | 0.999 | 1.140 |
| 2007:Q3 | 0.973 | 1.974** | 0.988 | 1.259* |
| 2007:Q4 | 0.965 | 2.103** | 0.979 | 1.431* |
| 2008:Q1 | 0.941 | 2.303** | 0.952 | 1.704** |
| 2008:Q2 | 0.958 | 2.272*** | 0.970 | 1.670** |
| 2008:Q3 | 0.962 | 2.278** | 0.982 | 1.563* |
| 2008:Q4 | 1.138 | 1.934** | 1.139 | 1.192 |
| 2009:Q1 | 1.260 | 1.087 | 1.208 | 0.574 |
| 2009:Q2 | 0.981 | 2.128** | 1.014 | 1.267 |
| 2009:Q3 | 0.974 | 2.209** | 1.009 | 1.323* |
| 2009:Q4 | 0.995 | 2.066** | 1.025 | 1.196 |
| 2010:Q1 | 1.017 | 1.837** | 1.043 | 0.973 |
| 2010:Q2 | 1.026 | 1.721** | 1.054 | 0.791 |
| 2010:Q3 | 1.034 | 1.596* | 1.053 | 0.736 |
| 2010:Q4 | 1.034 | 1.597* | 1.054 | 0.731 |
| 2011:Q1 | 1.036 | 1.563* | 1.053 | 0.728 |

Notes: The table reports the ratio of the out-of-sample MSPEs of the linear model to that of the random walk model and the CW statistics for the test of equal predictability 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. We use real-time quarterly data from 1999:Q4 to 2011:Q1 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 2011:Q1 reports statistics for 46 forecasts, but the rolling regressions still use 26-quarter window.

Table 4. Interest Rate, Monetary, and PPP Models

| Forecast Date | MSPE Ratio | CW | MSPE Ratio | CW |
|---|---|---|---|---|
| | A. Monetary Model: k=0 | | B. Monetary Model: k=1 | |
| 2007:Q1 | 1.146 | -0.298 | 1.180 | -0.766 |
| 2007:Q2 | 1.145 | -0.267 | 1.178 | -0.733 |
| 2007:Q3 | 1.123 | -0.104 | 1.156 | -0.559 |
| 2007:Q4 | 1.114 | 0.001 | 1.147 | -0.449 |
| 2008:Q1 | 1.077 | 0.272 | 1.109 | -0.155 |
| 2008:Q2 | 1.091 | 0.251 | 1.121 | -0.176 |
| 2008:Q3 | 1.137 | -0.225 | 1.161 | -0.620 |
| 2008:Q4 | 1.139 | -0.238 | 1.163 | -0.634 |
| 2009:Q1 | 1.100 | 0.160 | 1.130 | -0.271 |
| 2009:Q2 | 1.137 | -0.277 | 1.159 | -0.672 |
| 2009:Q3 | 1.134 | -0.266 | 1.156 | -0.664 |
| 2009:Q4 | 1.134 | -0.277 | 1.156 | -0.672 |
| 2010:Q1 | 1.137 | -0.339 | 1.158 | -0.731 |
| 2010:Q2 | 1.141 | -0.472 | 1.157 | -0.851 |
| 2010:Q3 | 1.131 | -0.493 | 1.146 | -0.869 |
| 2010:Q4 | 1.249 | 0.007 | 1.246 | -0.046 |
| 2011:Q1 | 1.241 | 0.022 | 1.239 | -0.037 |
| | C. Interest Rate Model | | D. PPP Model | |
| 2007:Q1 | 0.954 | 1.773** | 1.181 | -0.511 |
| 2007:Q2 | 0.953 | 1.781** | 1.179 | -0.484 |
| 2007:Q3 | 0.952 | 1.803** | 1.158 | -0.339 |
| 2007:Q4 | 0.946 | 1.875** | 1.150 | -0.266 |
| 2008:Q1 | 0.919 | 2.123** | 1.120 | -0.098 |
| 2008:Q2 | 0.931 | 2.096** | 1.127 | -0.112 |
| 2008:Q3 | 1.018 | 1.125 | 1.143 | -0.386 |
| 2008:Q4 | 1.027 | 1.087 | 1.152 | -0.428 |
| 2009:Q1 | 0.948 | 1.981 | 1.147 | -0.259 |
| 2009:Q2 | 1.023 | 1.106 | 1.152 | -0.489 |
| 2009:Q3 | 1.017 | 1.161 | 1.148 | -0.477 |
| 2009:Q4 | 1.022 | 1.128 | 1.149 | -0.493 |
| 2010:Q1 | 1.027 | 1.072 | 1.153 | -0.568 |
| 2010:Q2 | 1.030 | 1.026 | 1.159 | -0.743 |
| 2010:Q3 | 1.035 | 0.945 | 1.152 | -0.805 |
| 2010:Q4 | 1.034 | 0.947 | 1.095 | 0.495 |
| 2011:Q1 | 1.035 | 0.925 | 1.092 | 0.507 |

Notes: The table reports the ratio of the out-of-sample MSPEs of the linear model to that of the random walk model and the CW statistics for the test of equal predictability 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.