Nonlinearities, Business Cycles and Exchange Rates

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Abstract: This paper conjoins the disparate empirical literatures on exchange rate models and monetary policy models, with special reference to the importance of output, inflation gaps and exchange rate targets. It focuses in on the dollar/euro exchange rate, and the differential results arising from using alternative measures of the output gap for the US and for the Euro area. A comparison of **in-sample** prediction against alternative models of exchange rates is also conducted. In addition to predictive power, I also assess the various models' plausibility as economic explanations for exchange rate movements, based on the conformity of coefficient estimates with priors. Taylor rule fundamentals appear to do as well, or better, than other models at the one year horizon.

Key words: exchange rates, Taylor rules, interest rate parity, monetary model, purchasing power parity, external imbalances, output gap, inflation.

JEL classification: F31, F47

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1. Introduction

Over the past few years, movements in the dollar/euro exchange rate have proven as inexplicable as ever. I investigate whether there are instances wherein the conjoining of exchange rate and monetary policy empirical literatures can add to our understanding of the behavior of the dollar/euro exchange rates.

I think it worthwhile to highlight several reasons to be interested in yet another paper on this subject. First, we are currently in the midst of the first major downturn in the dollar's value during a period when the euro is in existence; indeed, by some accounts we are nearing the completion of the first euro-dollar cycle.[1]

Second, models incorporating Taylor Rule fundamentals, as propounded by Engel and West (2006), Mark (2007), Molodtsova and Papell (2008), and Molodtsova, Nikolsko-Rzhevskyy and Papell (2008) have recently gained prominence as means of explaining movements in the exchange rate, with the last work focusing on the dollar/euro rate.

In this paper, I examine the ***in-sample*** fit of Taylor-rule based fundamentals, taking seriously the difficulty in modeling potential output. The next section presents a more complete motivation, in the context of the extant exchange rate literature. In Section 3, the model is outlined. Empirics are discussed in Section 4, while the subsequent section presents a comparison of in-sample results from competing models. Section 6 concludes.

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[1] The euro's initial depreciation and subsequent sharp appreciation provided the basis of previous studies as in Nautz and Offermans (2006), Mussa (2005), Schnatz at al. (2004), and Chinn and Alquist (2000).

2. Motivation

Consider for a moment how well the workhorse models of exchange rate determination do in fitting the data. For instance, the standard sticky-price monetary formulation, can be written thusly,

$$s_t = \beta_0 + \beta_1 \hat{m}_t + \beta_2 \hat{y}_t + \beta_3 \hat{i}_t + \beta_4 \hat{\pi}_t + u_t, \tag{1}$$

where m is log money, y is log real GDP, i and π are the interest and inflation rate, and u_t is an error term. The circumflexes denote inter-country differentials. The characteristics of the model are well known. The money stock and the inflation rate coefficients should be positive; and the income and interest rate coefficients negative. The negative coefficient associated with the interest rate coefficient holds as long as prices are sticky; if prices are perfectly flexible, either interest rates or inflation rates should enter in positively.

However, it has proven increasingly difficult to fit the data to this specification. Table 1 presents regression results for the dollar/euro rate over the 1999q1-08q1 period, and the 1993q1-08q1 period (where the dependent variable includes the synthetic euro and corresponding counterfactual determinants). The long run coefficients are estimated using dynamic OLS (Stock and Watson, 1993). In the extended sample, one finds the money aggregates pointing significantly in the wrong direction (indeed, money is about the only statistically significant coefficient). The income coefficient is not uniformly in the expected direction. Interest and inflation rates – key variables in the real interest differential model -- enter with the expected signs, but do not exhibit statistical significance.

Restricting attention to the period after EMU, one obtains even less satisfying

results, with a set of implausible coefficient estimates resulting.[2] It might be that

sometime in the future, with a longer sample of euro area data, one might be able to

obtain more plausible results, but for now, these results suggest an alternative path is

necessary.

A second reason to consider alternative models is that the relationships between

exchange rates and various fundamentals appear to often be nonlinear in nature. In terms

of the PPP relationship, Clarida and Taylor and Sarno and Taylor, among others, have

argued that real exchange rate reversion is nonlinear, specifically that the farther away the

exchange rate is from the conditional mean, the faster the rate of reversion. In terms of

the UIP relationship, several authors have argued that when interest rates exhibit large

differentials, then exchange rates are more likely to conform to the prediction of the

unbiasedness proposition (the combination of uncovered interest parity and rational

expectations).

The first stylized fact is fairly well documented: using threshold autoregressions,

Obstfeld and Taylor (1997); using smooth threshold autoregressions, see Kilian and

Taylor (2003), among others. This "threshold" nonlinearity is consistent with the

tendency for practitioners to focus on large deviations from some parity (e.g., the real

exchange rate from some conditional mean) as a trigger for reversion.

The second stylized fact is slightly less well known; Sarno et al. (2006) document

this particular finding. One particular type of nonlinearity is illustrated by Figure 1,

which shows the relationship between the ex post quarterly depreciation of the dollar

against the euro, and the corresponding 3 month interest differential, lagged a quarter. A

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[2] Alquist and Chinn (2008) obtain much more plausible coefficient estimates, but are forced to extend the
sample back to 1980.

nonlinear smoother (a "nearest-neighbor" fit) is shown in red. If the unbiasedness proposition held, then the fitted curve should approximate a line with slope of unity.

As the figure makes obvious, the fitted curve is not a straight line; rather it has upward slopes at the extremes. These apparent nonlinearities can be rationalized in the context of underlying factors that can be important to central bank reaction functions.

McCallum (1994) was an early case where the central bank's reaction function, responding to exchange rate depreciations, induced interest rate endogeneity. This interest rate endogeneity was what explained, in the McCallum model, the bias in the standard Fama regression.

Chinn and Meredith (2004) pursued a similar idea in their explanation of why interest rates predicted the wrong sign for exchange rate changes at short horizons, but the correct signs at long horizons. Essentially, their model relied upon a Taylor rule explanation.

In this paper, I pursue this particular idea, with the aim of integrating the idea of why interest rates point in the wrong direction at certain junctures with the idea that central banks react to output, inflation and exchange rate gaps.

3. The Model

In part, the Taylor rule approach is motivated by the difficulties attendant the previously discussed monetary approach. In particular, assumptions of stable money demand equations and uncovered interest parity appear to be too strong. Hence, following Engel and West (2006), I dispense with these assumptions. Instead, assume that policymakers follow Taylor rules, allowing for smoothing of interest rates:

$$i_t = \pi_t + \beta_y \tilde{y}_t + \beta_\pi \tilde{\pi}_t + \beta_q \tilde{q}_t + \bar{r}_t + \rho i_{t-1}$$
$$\beta_y > 0, \beta_\pi > 0, \beta_q > 0, \rho > 0$$

(2)

Where $\tilde{q}$ is the deviation of the real exchange rate from a target exchange rate, and the tilde's denote "gaps". The monetary authorities move the policy rate in response to the deviations of output from potential GDP, deviations of inflation from target inflation, after accounting for a natural level of interest rates (i.e., the sum of the natural real interest rate and the inflation rate), as well as a deviation of the real exchange rate from the target rate.

A lagged interest rate is included in order to account for the tendency of central banks to smooth interest rates. The inclusion of the real exchange rate is not uncontroversial; it presupposes that the monetary authority attempts to stabilize the exchange rate. However, it is not an uncommon approach, and has been employed by Clarida, Gali and Gertler (1998), as well as Chinn and Dooley (1998).

In order to introduce the exchange rate, I drop the uncovered interest parity assumption, and rely upon an ad hoc characterization of the exchange rate/interest differential relationship.

$$s_{t+k} - s_t = \kappa (i_t - i_t^*)$$
$$\kappa < 0$$

(3)

In words, a larger interest differential is associated with an appreciation of the currency over a four quarter horizon.

Combining (2) and (3), and assuming the foreign country is characterized by a similar Taylor rule, one obtains the following expression:

$$s_{t+k} - s_t = \kappa \beta_y \hat{\tilde{y}}_t + \kappa (\beta_y + 1) \hat{\tilde{\pi}}_t + \kappa \beta_q \hat{\tilde{q}}_t + \kappa \rho \hat{i}_{t-1} + c$$

(4)

Where the circumflexes indicate intercountry differentials.[3]

This specification accords well with practitioner intuition for how interest rates (and hence exchange rates) move in response to inflation and output gaps. Consider what happens if the inflation gap rises in the US relative to the foreign economy. Then the Fed will raise the policy rate, thereby appreciating the currency.

What about inflation? This framework implies that when inflation rises above the target level, then the currency will appreciate. Hence, the answer to Clarida and Waldmann's (2007) question "Is bad news about inflation good news for the dollar?" is yes.

Finally, if the real exchange rate rises (currency depreciates), then the central bank will "lean against the wind" and raise interest rates, thereby inducing a strengthening of the currency over the next four quarters.

Molodtsova and Papell (2008) and Engel, Mark and West (2007) document the fact that Taylor rule fundamentals have out-of-sample forecasting abilities, relative to a random walk. Molodtsova et al. (2008; forthcoming) focus on the euro exchange rate, and real-time data. They also rely upon a variety of proxy measures for output gaps and inflation gaps (including expected measures). They find that under certain circumstances, they are able to out-predict a random walk.[4]

Armed with these results, we consider the symmetric specification (i.e., the β's on output and inflation gaps are the same across countries) in (4).

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[3] Note that we are imposing the same coefficients for inflation and output gaps for both economies. Hence, this specification is a homogenous, asymmetric specification with smoothing, in Molodtsova and Papell's (2008) lexicon.
[4] Demonstrating the variety of approaches, Engel and West (2006) uses quadratic detrending, with a robustness check using the HP filter. Molodtsova and Papell (2008) use HP filters as well as judgmental estimates.

4. Empirics

4.1 Data

I rely upon quarterly data for the United States and the Euro Area over the 1970q1 to 2008q1 period.[5] The exchange rate, price, and income (real GDP) variables are drawn primarily from the IMF's *International Financial Statistics*. For the exchange rates (as dependent variable), I use the end-of-quarter values, and period average interest rates. The Euro Area data are drawn from the ECB, augmented by some data from Alquist and Chinn (2008). Greater detail is contained in the data appendix.

Inflation is calculated as the 4 quarter change in log CPI, and the real exchange rate gap is proxied by either the bilateral USD/EUR exchange rate, deflated by the CPI. It is often asserted that the Fed does not target the exchange rate; it then makes sense to include an exchange rate variable only for the ECB. I use the Euro Area real effective exchange rate.

The key challenge in using Taylor rule fundamentals is identification of the fundamentals. For instance, the simplest versions of the Taylor rule specify the policy rate as a function of the current output gap and the current inflation gap. However, some formulations incorporate the *expected* output gap. Other formulations rely upon the real time data based estimation of the output gap, as opposed to one based upon final revised data.[6]

In addition, it is not clear how to model the output gap itself. Calculation of this

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[5] Data series for the euro area begin around 1980 for GDP, much later (mid-1990's) for other financial series. See the Data Appendix.

[6] There are of course other challenges to implementing the Taylor rule. One that I have ignored relates to whether the monetary authorities target the current output and inflation gaps, or those that are expected sometime in the future (say 12 months). Another is the price variable that used as a target; often a core CPI is used for the Fed's reaction function.

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object requires some view on what potential GDP looks like. One can rely upon economics-based estimates of potential GDP (relying upon demographics, estimated capital stocks, etc.), or one can use statistical measures, such as linear time trends or the Hodrick-Prescott filter.

In the results reported here, I report results based upon the deterministic, Hodrick-Prescott filtered, and band pass filtered output gaps. The inflation gap is simply the deviation from a constant level of target inflation, which is subsumed in the estimation procedure into the constant.

Before proceeding, it might be useful to discuss some of the competing measures of the output gap.

4.2 Measures of the Output Gap

There are four key measures of output gaps used in the literature: (i) output deviations from judgmental calculations of potential GDP based upon trends in labor force, demographics, human and physical capital, and trend productivity growth; (ii) output deviations from either a deterministic linear trend, or a polynomial in linear trend; (iii) cyclical components identified by a statistical filter, such as the Hodrick-Prescott (in the time domain) or the band pass filter (in the frequency domain); (iv) structural econometric approaches that combine economics and econometrics, such as the Blanchard-Quah approach.[7]

All these measures are used in the literature. Figure 2 shows the four measures of output gaps for the United States: the log deviation from the CBO (2008) estimate of

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7 See e.g. Billmeier (2004) for a comparison of how well various of these approaches correlate with inflation, as suggested in the Phillips Curve framework.

potential, the log deviation from a quadratic in time trend, estimated over the 1970-08 period, the log deviation from the trend identified using the HP filter, and the cyclical component identified using the one-sided Christiano-Fitzgerald (2003) version of a band pass filter.[8]

4.3 Results

Table 2-4 presents the results from estimating the Taylor rule specifications, for the period pertaining to the post-EMU period, so as to focus on the behavior of the ECB, rather than the Bundesbank. In Table 2, the exchange rate gap variable is suppressed. In Table 3, the exchange rate is included.

The specification suppressing the exchange rate gap yields mixed results. As indicated in Table 2, the output gap measure comes in with the expected sign, regardless of the measure used. On the other hand, the inflation measure varies in importance depending upon the output gap used. This result suggests that the choice of output gap is not innocuous.

The lagged interest rate, surprisingly, does not come in with expected sign, except when the BP filter is used to determine the output gap; however, the coefficient on lagged interest rates is never statistically significant.

A final observation is that the adjusted R^2 is remarkably high in all the specifications. The proportion of variation explained is highest for the specifications using a deterministic trend for potential output; however, even for the other

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[8] There are some technical issues that arise in calculating these statistical filters. For the HP filter, the standard value (for quarterly data) of 1600 for the λ parameter is used, and the filter applied to the 1980-2011 period data on log real GDP. The extension of the time series is undertaken to mitigate the end-of-sample problem associated with the two-sided nature of the HP filter. The 2008Q2-11Q1 period is estimated using an ARIMA(1,1,1) estimated over the 1980-08 period. The band pass filter is the Christiano-Fitzgerald (2003) asymmetric filter assuming I(1) trend, applied to the 1980-2008 period.

specifications, the proportion of variation explained is remarkably high, ranging from 0.46 to 0.54.

Moving to a specification conforming to Equation 4, one finds that the results are not appreciably improved, in terms of goodness of fit. While the coefficients are not much changed relative to their corresponding entries in Table 2, the exchange rate coefficients are not statistically significant in any case. This is true regardless of whether the real exchange rate is a bilateral measure, or a trade weighted measure for the euro area.

The lack of significance for the exchange rate variable may come from the fact that the monetary authorities respond more strongly to large deviations than small. This could be modeled in a switching regime framework, but to keep the estimation simple for now, I merely include a cubic in the exchange rate. This leads to the set of results reported in Table 4.

The estimates contained here are much unchanged from those reported in Table 3. The output gap remains important, and the inflation gap has the correct sign but is only occasionally significant. The exchange rate variable is not significant again, but the cubic term is – at least when using the deterministic time trend measure of the output gap.

The preceding results relate to the period over which the euro has actually existed. If one is willing to take the additional jump to say that the relationships that existed prior to the creation of the euro also held in the post EMU period, then one might want to extend the sample backward in time. In the succeeding tables, I present results corresponding to the 1993-2008 period, where the synthetic dollar/euro exchange rate is used for the pre-1999 period, and aggregates built upon the component country

economies are used as determinants. This approach follows Alquist and Chinn (2000), among others.

These results, in Tables 5-7, can be summarized fairly easily. The output gap retains its significance, but the inflation gap increases in statistical significance. I conjecture that this outcome is due to the greater variability of inflation earlier in the sample.

Another interesting feature of the results is that the exchange rate target also exhibits greater significance in this extended sample (Table 6). This is true regardless of whether the bilateral or euro area effective exchange rate is used.

However, the really interesting finding is that the cubic term, representing the nonlinearity in reversion, shows up much more strongly, and is statistically significant in all specifications (Table 7).

On the other hand, the proportion of variation explained is substantially lower, with the exception of the specifications incorporating the deterministic output gap, than in the shorter sample.

5. How Do the In-Sample Results Differ from Standard Models?

How do these results compare, in terms of goodness of fit, against corresponding regressions associated with other approaches? This is a difficult question to answer, since there are so many different models to be considered. For instance, Cheung, et al. (2005b). investigated PPP, uncovered interest parity (UIP), the sticky price monetary approach, the productivity approach and the composite approach, sometimes called the behavioral equilibrium exchange rate (BEER) approach.

Here I will focus on the monetary, PPP, interest rate, and external imbalances approach, and compare against the Taylor rule approach discussed earlier.[9] The first two take an error correction specification. The third dispenses with UIP, and takes the interest rates at the appropriate maturity as the determinants. Finally, the external imbalances approach takes the Gourinchas-Rey (2007) log-linearization, and applies it to a bilateral exchange rate; this follows the procedure undertaken by Alquist and Chinn (2008).

These empirical specifications can be represented as follows:

$$s_t - s_{t-k} = b_0 + b_1 s_{t-k} + b_2 \hat{m}_{t-k} + b_3 \hat{y}_{t-k} + b_3 \hat{i}_{t-k} + b \hat{\pi}_{t-k} + u_t \tag{5}$$

Where m is log money, y is log real GDP, i and π are the interest and inflation rate, and u_t is an error term.

$$s_t - s_{t-k} = b_0 + b_1 (s_{t-k} - p_{t-k} + p^*_{t-k}) + u_t \tag{6}$$

Where p and p^* and the domestic and foreign price levels, measured as consumer price indices.

$$s_t - s_{t-k} = b_0 + b_1 \hat{i}^k_{t-k} + u_t \tag{7}$$

Where $\hat{i}^k_t$ is the interest differential measured using interest rates of maturity k. Under UIP, b_1 should equal unity.

$$s_t - s_{t-k} = b_0 + b_1 nxa_{t-k} + u_t \tag{8}$$

Where nxa_t is approximately the ratio of log exports/imports to log foreign assets to liabilities (see Gourinchas and Rey 2007 and Alquist and Chinn 2008).

$$s_t - s_{t-k} = b_0 + b_1 \hat{g}_{t-k} + b_2 \hat{\pi}_{t-k} + b_3 q_{t-k} + b_4 (q^3_{t-k}) + b_5 \hat{i}_{t-k-1} + u_t \tag{9}$$

Where g_t is the output gap measured using quadratic detrending, and q^3 is a cubic in the

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[9] I skip the productivity approach because productivity trends move opposite of that expected in the Balassa-Samuelson model over the 2003-07 period.

bilateral real exchange rate. In this experiment, comparisons of the in-sample fit are

evaluated at the 3 month, 1 year and 5 year horizons.

Estimating these equations over the 1999q1-2008q1 period yields some expected

– and some unexpected – results. First and foremost among the expected results, the

predictability of the dollar/euro rate at the short horizon is quite low. The adjusted R2 for

PPP regressions is negative at 3 months (using quarterly data), and below 0.15 for the

Gourinchas-Rey measure and interest differentials of 3 month maturity. The highest

adjusted R2 is for the monetary model error correction specification stripped of short run

dynamics, followed closely by the Taylor rule fundamentals.

The surprising results are to be found at the longer horizons, of one year and 5

years. At the one year horizon, there is generally more predictability of the dollar/euro

rate over this sample period, with the exception of the PPP specification.[10] Specifically,

the monetary and Taylor rule specification explain a large proportion of the variation at

the one year horizons – both roughly 80%. Moving to the 5 year horizon, all save the

interest differentials explain a large proportion of the variation.[11] These results are

presented in Figure 3. Since one would like a more direct measure of how well explained

the dependent variable is, irrespective of how many variables are used, I also present the

standard error of regression in Figure 4.

Figure 4 provides a slightly different insight into the comparative predictive

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[10] No doubt, a better fit could be obtained by allowing some sort of nonlinearity like a threshold
autoregression specification, as Taylor and Peel (2000) and Taylor, Peel and Sarno (2001), or an ad hoc
nonlinearity as in the Taylor rule specification. Here, I wanted to compare the Taylor rule against plain
vanilla specifications.

[11] Those who are familiar with the Chinn and Meredith (2004) results might be surprised by these findings.
However, it is of note that the interest rates being applied are a composite of rates of the legacy currencies –
i.e. for the 2001 rates, a weighted average of individual government bonds denominated in different
currencies in 1996 are used. Only beginning in 2005 would the truly euro denominated bond interest rates
be used to predict exchange rates.

powers of the models. In line with Figure 3, no model does particularly well at the 3 month horizon. However, it is clear at the one year horizon, the Taylor rule fundamentals do quite well relative to PPP, interest rates and the external imbalances fundamentals. They do about as well as the monetary fundamentals.

One thing that is obscured by comparison of these in-sample fit statistics is the fact that some of the coefficient estimates do not conform to priors. This is true, as mentioned before, of the interest differentials, where the composite hypothesis of UIP and rational expectation is dispensed with. But it is also true of the monetary model, where the long run coefficients on income, and most of the times money, point in the wrong direction. Interest rates are about the only variable that exhibit the right sign (at least in the sticky price monetary model formulation).

Hence, when thinking in broader terms of what economically better fits the data, Taylor rule fundamentals seem to be the best bet at horizons of about one year. At horizons of 5 years, PPP does about as well as all the other specifications.

More detail can be found in Figures 5 and 6, which depict the predictions from the various specifications. What is fairly clear is that Taylor rule fundamentals do a fairly good job of explaining movements in the dollar/euro rate. The monetary fundamentals perform similarly, but as we mentioned, the perverse signs in the estimated equations make it hard to take this outcome as a validation of the monetary model. PPP, interest differentials and external imbalances do not appear to do particularly well at the one year horizon.

6. Conclusions

At this juncture, it's necessary to take a detour into the philosophical aspects of these findings. The first point is that these results tell us little about which of these models would perform well in out-of-sample forecasting exercises. While it is straightforward to conduct out of sample forecasting exercises a la Meese and Rogoff (1983), Chinn and Meese (1995), Cheung et al. (2005a), the short span of actual dollar/euro data complicates obtaining a good fitting regression to use for forecasting.

Another reason to eschew out-of-sample forecasting comparison is the Engel and West (2006) argument that with a low discount factor, the exchange rate should exhibit low predictability, and indeed the exchange rate should look like it Granger causes exchange rate fundamentals.

The second caveat is that the regression analysis conducted in this study involved the latest vintage of GDP data for the US and the Euro area. That means that the exchange rate changes are being linked to variables that the market participants did not observe contemporaneously. Since in the theoretical derivation, the link from output and inflation gaps to exchange rates is mediated through a reaction function that is responding to observed data, the results are somewhat difficult to interpret.[12]

The third point is that the dollar/euro rate has exhibited substantial movement over the past nine years, and this sample period is not necessarily representative of other movements in other exchange rates in other periods. This is hinted at by the fact that *all* the models appear to explain an atypically high proportion of the variation in the

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[12] Molodtsova et al. (2008) explicitly conduct a real time out-of-sample forecasting exercise. However, due to the brevity of the post-EMU period, they are forced to use synthetic euro data for the pre-EMU period for initial estimation. See also Rogoff and Stavrakeva (2008).

exchange rate.[13]

       That being said, it is of interest that output gaps, inflation rates and exchange ratest are related to exchange rate movements in a systematic fashion, at least insofar as the dollar/euro exchange rate is concerned. Whether this stylized fact is durable remains to be seen.

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[13] Faust et al. (2003) provides the canonical cautionary tale.

References

Alquist, R. and M. Chinn. 2008. Conventional and Unconventional Approaches to Exchange Rate Modeling and Assessment. *International Journal of Finance and Economics* **13**: 2-13. Also *NBER Working Paper* No. 12481 (August 2006).

Billmeier, A. 2004. Ghostbusting: Which Output Gap Measure Really Matters? *IMF Working Paper* No. 04/146 (Washington, DC: IMF, August).

Cheung Y.-W., M. Chinn, and A. Garcia Pascual. 2005. Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive? *Journal of International Money and Finance* **24** (November): 1150-1175 (a).

Cheung Y.-W., M. Chinn, and A. Garcia Pascual. 2005. "Recent Exchange Rate Models: In-Sample Fit and Out-of-Sample Performance" in P. DeGrauwe (editor). *Exchange Rate Modelling: Where Do We Stand?* Cambridge: MIT Press (b).

Chinn M. and R. Alquist. 2000. Tracking the Euro's Progress. *International Finance* **3** (3): 357-374.

Chinn, M. and M. Dooley. 1998. "Monetary Policy in Japan, Germany and the United States: Does One Size Fit All?" in *Japanese Economic Policy Reconsidered*, edited by Craig Freedman (London: Edward Elgar, 1998): 179-217.

Chinn M. and R. Meese. 1995. Banking on Currency Forecasts: How Predictable Is Change in Money? *Journal of International Economics* **38**: 161-178.

Chinn M. and G. Meredith. 2004. Monetary Policy and Long Horizon Uncovered Interest Parity. *IMF Staff Papers* **51** (3): 409-430.

Christiano, L. J. and T. J. Fitzgerald. 2003. The Band Pass Filter. *International Economic Review* **44**(2): 435-465.

Clarida, R., J. Galí, and M. Gertler. 1998. Monetary policy rules in practise: some international evidence, *European Economic Review* **42**: 1033–67.

Clarida R. H., Sarno L., Taylor M.P., and G. Valente. 2003 The Out-of-Sample Success of Term Structure models as Exchange Rate Predictors: A Step Beyond. *Journal of International Economics* **60** (1): 61-83.

Clarida, R. H., and D. Waldman. 2007. Is Bad News About Inflation Good News for the Exchange Rate? *NBER Working Paper* No. 13010 (April).

Congressional Budget Office. 2008. *Update of CBO's Economic Forecast* (Washington, DC: Congressional Budget Office, February).

Dornbusch R. 1976. Expectations and Exchange Rate Dynamics. *Journal of Political Economy* **84**: 1161-76.

Engel, C., N. Mark, and K.D. West. Forthcoming. Exchange Rate Models are Not as Bad as You Think. *NBER Macroeconomics Annual 2007*.

Engel C. and K. D. West. 2005. Exchange Rates and Fundamentals. *Journal of Political Economy* **113** (2): 485-517.

Faust J., J. Rogers, and J. Wright. 2003. Exchange Rate Forecasting: The Errors We've Really Made. *Journal of International Economics* **60**: 35-60.

Frankel J. A. 1979. On the Mark: A Theory of Floating Exchange Rates Based on Real Interest Differentials. *American Economic Review* **69**: 610-622.

Gourinchas P.-O. and H. Rey. 2007. International Financial Adjustment. *Journal of Political Economy* **115**: 655-703

Kilian, L. and Taylor, M.P. 2003. Why is it So Difficult to Beat the Random Walk Forecast of Exchange Rates? *Journal of International Economics* **60**: 85-107.

McCallum, B.T. 1994. A Reconsideration of the Uncovered Interest Parity Relationship. *Journal of Monetary Economics*, Vol. 33, pp. 105-132.

Mark, N. 1995. Exchange Rates and Fundamentals: Evidence on Long Horizon Predictability. *American Economic Review* **85**: 201-218.

Mark, N. 2007. Changing Monetary Policy Rules, Learning and Real Exchange Rate Dynamics. Mimeo. (University of Notre Dame).

Meese R. and K. Rogoff. 1983. Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample? *Journal of International Economics* **14**: 3-24.

Molodtsova, T. and D. Papell. 2008. Out-of-Sample Exchange Rate Predictability with Taylor Rule Fundamentals. Mimeo (Houston: University of Houston, January).

Molodtsova, T., A. Nikolsko-Rzhevskyy, and D. Papell. Forthcoming. Taylor Rules with Real-Time Data: A Tale of Two Countries and One Exchange Rate. *Journal of Monetary Economics*.

Molodtsova, T., A. Nikolsko-Rzhevskyy, and D. Papell. 2008. Taylor Rules and the Euro. Mimeo (Houston: University of Houston, March).

Mussa M. 2005. The Euro, the Dollar, and the International Monetary System. *Journal of Policy Modeling* **27** (4): 445-454.

Nautz, D. and C. Offermanns. 2006. Does the Euro follow the German Mark? Evidence from the Monetary Model of the Exchange Rate. *European Economic Review* **50** (5): 1279-1295.

Obstfeld, M. and A. M. Taylor. 1997. Nonlinear Aspects of Goods-Market Arbitrage and Adjustment: Heckscher's Commodity Points Revisited. *Journal of the Japanese and International Economies* **11**(4): 441–79.

Rogoff, K. S., and V. Stavrakeva. 2008. The Continuing Puzzle of Short Horizon Exchange Rate Forecasting. NBER Working Paper No. 14071 (Cambridge, MA: NBER, June).

Rosenberg M. 2001. Investment Strategies based on Long-Dated Forward Rate/PPP Divergence. FX Weekly. New York: Deutsche Bank Global Markets Research.

Schnatz, B., F. Vijselaar, and C. Osbat. 2004. Productivity and the Euro-Dollar Exchange Rate. *Review of World Economics* **140** (1): 1-30.

Stock J. H. and M. W. Watson. 1993. A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems. *Econometrica* **61** (4): 783-820.

Taylor, M., and D. Peel .2000. Nonlinear Adjustment, Long-run Equilibrium and Exchange Rate Fundamentals. *Journal of International Money and Finance* **19**(1):33-53.

Taylor, M. P., D. A. Peel and L. Sarno. 2001. Nonlinear Mean-Reversion in Real Exchange Rates: Towards a Solution to the Purchasing Power Parity Puzzles. *International Economic Review* 42(4): 1015–042.

Data Appendix

1. Data Sources

Unless otherwise stated, we use seasonally-adjusted quarterly data from the *IMF International Financial Statistics* ranging from the first quarter of 1970 to the first quarter of 2008 (accessed June 2008). The exchange rate data are end of period exchange rates. The output data are measured in constant 2000 prices. The consumer price indexes also use 2000 as base year. Inflation rates are calculated as 4-quarter log differences of the CPI.

US M2 is drawn from *IFS*. The euro area M3 is drawn from the ECB. The overnight interest rates are daily averaged data from *IFS*. The three-month, annual and five-year interest rates are end-of-period constant maturity interest rates from the national central banks. See Chinn and Meredith (2004) for details. We use German interest rate data from the Bundesbank to extend the Euro Area interest rates backwards.

The annual foreign asset and liability data are from the 2007 international investment position release of June 26, 2008, and obtained from the BEA website (http://www.bea.gov/bea/di/home/iip.htm).To construct the measure of external imbalance, we backed out the weights implied by the point estimates from Gourinchas and Rey obtained using the estimates from the DOLS regressions. The procedure assumes that the weights are constant across subsamples. The problem reduces to solving 3 equations in 3 unknowns, where the unknowns were the weights normalized on μ_x. The weights are:

$\mu_x /(\mu_x +1) = 1.09639$; $\mu_l /(\mu_x +1)=.72308$; and $1/(\mu_x+1) = -0.09294$

Greater detail on the construction of this variable is contained in Alquist and Chinn (2008).

A.2. Measures of Output Gaps

Figure 2 shows the four measures of output gaps for the United States, where:

- The judgmental version is log deviation from the CBO (2008) estimate of potential;

- The second version is a log deviation from a quadratic in time trend, estimated over the 1970-08 period;

- The HP filter is applied with standard lambda parameter for quarterly data to the 1980-2011 period. The extension of the time series is undertaken to mitigate the end-of-sample problem associated with the two-sided nature of the HP filter. The 2008Q2-11Q1 period is estimated using an ARIMA(1,1,1) estimated over the 1980-08 period;

- The band pass filter is the Christiano-Fitzgerald (2003) asymmetric filter assuming I(1) trend, applied to the 1980-2008 period.

For the euro area, the trends are obtained from data starting from 1980.

Table 1: Monetary Model of Exchange Rates

coefficient	USD/EUR	USD/EUR	USD/EUR	USD/EUR
constant	-1.566	0.227	**-23.645**	**-28.806**
	1.116	2.693	**7.657**	**8.834**
money	**-3.566**	**-3.580**	4.704	1.489
	0.618	**0.699**	3.358	4.624
income	0.889	-0.404	**13.449**	**17.554**
	0.623	1.882	**4.375**	**5.179**
int rate	-2.769	-3.025	**20.718**	9.402
	3.156	3.320	**9.910**	13.792
infl rate	1.447	3.918	**-45.225**	-36.964
	8.559	9.661	**21.790**	24.845
time		0.004		**-0.**016
		0.005		0.009
adj.R^2	0.74	0.74	0.89	0.89
N	59	59	34	34
Sample	93Q1-07Q3	93Q1-07Q3	99Q1-07Q4	99Q1-07Q4

Notes: Point estimates from DOLS(2,2). For USD/EUR results over the 99Q1-07Q4 period, estimates from DOLS(1,1). HAC robust standard errors below point estimates. **Bold face** denotes significance at the 10% msl.

Table 2: Taylor Rule Model of Exchange Rate, 1999-2008
(Dependent variable: 4 quarter change in log exchange rate)

coefficient	deterministic	HP filter	BP filter
constant	**0.100**	**0.059**	**0.026**
	0.011	**0.014**	**0.008**
output gap	**-6.016**	**-5.957**	**-11.552**
	0.688	**1.826**	**2.767**
inflation gap	**-5.345**	-3.629	-0.462
	2.861	3.534	4.071
lag int rate	1.157	0.111	-0.967
	1.176	1.476	1.200
adj.R^2.	0.731	0.458	0.539
SER	0.057	0.081	0.074
N	37	37	37

Notes: OLS estimates with HAC robust standard errors below. **Bold face** denotes significance at 10% msl.

Table 3: Augmented Taylor Rule Model of Exchange Rate, 1999-2008
(Dependent variable: 4 quarter change in log exchange rate)

coefficient	Bilateral Real Exchange Rate			Trade Weighted Exchange Rate		
	deterministic	HP filter	BP filter	deterministic	HP filter	BP filter
constant	**0.102**	**0.038**	**0.024**	**0.106**	-0.001	**0.038**
	0.009	**0.019**	**0.009**	**0.014**	0.027	**0.021**
output gap	**-5.996**	**-8.820**	**-12.233**	**-5.994**	**-8.787**	**-12.147**
	0.634	**1.585**	**2.339**	**0.654**	**1.622**	**2.354**
inflation gap	**-4.889**	-4.556	-0.806	-5.018	-4.461	-0.772
	2.726	3.599	4.120	2.761	3.630	4.155
exch. rate	-0.053	**0.299**	0.084	-0.064	**0.478**	0.125
	0.073	**0.084**	0.081	0.109	**0.132**	0.131
lag int rate	1.029	1.374	-0.767	1.015	1.688	-0.699
	1.009	1.062	1.211	1.074	1.101	1.255
adj.R^2.	0.727	0.516	0.534	0.725	0.517	0.533
SER	0.057	0.076	0.075	0.057	0.076	0.075
N	37	37	37	37	37	37

Notes: OLS estimates with HAC robust stanard errors below. Bold face denotes significance at 10% msl.

Table 4: Augmented Taylor Rule Model of Exchange Rate, with Exchange Rate Nonlinearity, 1999-2008
(Dependent variable: 4 quarter change in log exchange rate)

coefficient	Bilateral Real Exchange Rate			Trade Weighted Exchange Rate		
	deterministic	HP filter	BP filter	deterministic	HP filter	BP filter
constant	**0.114**	**0.038**	**0.024**	**0.092**	-0.006	0.038
	0.010	**0.022**	**0.010**	**0.015**	0.032	0.025
output gap	**-7.072**	**-9.686**	**-12.648**	**-6.510**	**-8.936**	**-12.152**
	0.660	**1.913**	**2.469**	**0.707**	**1.708**	**2.345**
inflation gap	**-4.790**	-4.454	-0.654	**-4.534**	-4.335	-0.766
	2.340	3.756	4.267	**2.608**	3.820	4.261
exch. rate	**0.313**	**0.504**	0.169	**0.496**	0.631	0.132
	0.131	**0.263**	0.257	**0.291**	0.435	0.431
cubic xr	**-9.982**	-4.644	-2.179	**-13.327**	-3.423	-0.157
	3.039	5.366	6.173	**6.500**	8.957	9.320
lag int rate	**1.381**	1.605	-0.764	1.057	1.698	-0.700
	0.768	1.099	1.264	0.897	1.104	1.245
adj.R^2.	0.776	0.514	0.522	0.750	0.504	0.518
SER	0.052	0.076	0.076	0.055	0.077	0.076
N	37	37	37	37	37	37

Notes: OLS estimates with HAC robust standard errors below. Bold face denotes significance at 10% msl.

Table 5: Taylor Rule Model of Exchange Rate, 1993-2008
(Dependent variable: 4 quarter change in log exchange rate)

coefficient	deterministic	HP filter	BP filter
constant	**0.067**	**0.060**	**0.031**
	0.022	**0.020**	**0.011**
output gap	-2.293	-1.746	-0.019
	1.735	2.069	2.271
inflation gap	**-8.960**	**-8.483**	**-9.763**
	3.265	**3.397**	**3.505**
lag int rate	**1.473**	0.544	0.689
	0.761	0.681	1.085
adj.R^2.	0.318	0.261	0.233
SER	0.082	0.085	0.087
N	57	57	57

Notes: OLS estimates with HAC robust standard errors below. Bold face denotes significance at 10% msl.

Table 6: Augmented Taylor Rule Model of Exchange Rate, 1993-2008
(Dependent variable: 4 quarter change in log exchange rate)

coefficient	Bilateral Real Exchange Rate			Trade Weighted Exchange Rate		
	deterministic	HP filter	BP filter	deterministic	HP filter	BP filter
constant	**0.094**	**0.077**	**0.040**	**0.128**	**0.099**	**0.105**
	0.014	**0.019**	**0.009**	**0.024**	**0.028**	**0.024**
output gap	**-3.044**	-1.207	-0.390	**-3.031**	-1.332	-0.531
	1.359	1.961	1.913	**1.309**	1.862	1.924
inflation gap	**-6.520**	**-7.503**	**-7.946**	**-6.722**	**-7.527**	**-7.978**
	3.183	**3.304**	**3.404**	**3.176**	**3.294**	**3.397**
exch. rate	**-0.277**	-0.176	**-0.200**	**-0.447**	-0.285	-0.327
	0.107	0.131	**0.108**	**0.190**	0.218	0.190
lag int rate	1.020	0.141	0.063	0.888	0.046	-0.079
	0.825	0.845	1.164	0.849	0.875	1.214
adj.R^2.	0.425	0.296	0.284	0.421	0.296	0.282
SER	0.075	0.083	0.084	0.075	0.083	0.084
N	57	57	57	57	57	57

Notes: OLS estimates with HAC robust standard errors below. Bold face denotes significance at 10% msl.

Table 7: Augmented Taylor Rule Model of Exchange Rate, with Exchange Rate Nonlinearity, 1993-2008
(Dependent variable: 4 quarter change in log exchange rate)

coefficient	Bilateral Real Exchange Rate			Trade Weighted Exchange Rate		
	deterministic	HP filter	BP filter	deterministic	HP filter	BP filter
constant	**0.116**	**0.073**	**0.041**	**0.085**	0.043	**0.075**
	0.010	**0.019**	**0.010**	**0.016**	0.030	**0.025**
output gap	**-6.329**	**-4.173**	-1.669	**-5.894**	**-3.949**	-2.201
	0.914	**2.227**	1.939	**0.778**	**1.551**	1.689
inflation gap	**-7.146**	**-7.296**	**-7.892**	**-5.661**	**-6.192**	**-6.955**
	2.111	**3.167**	**3.464**	**2.268**	**3.191**	**3.468**
exch. rate	**0.341**	0.328	0.042	**0.835**	**0.739**	0.348
	0.109	0.246	0.198	**0.208**	**0.348**	0.335
cubic xr	**-11.939**	**-7.678**	**-4.329**	**-23.666**	**-16.274**	**-12.023**
	1.963	**2.622**	**2.253**	**3.634**	**4.156**	**3.957**
lag int rate	**2.484**	0.381	-0.155	**1.482**	-0.173	-0.738
	0.440	0.779	1.170	**0.277**	0.706	1.131
adj.R^2.	0.668	0.377	0.310	0.681	0.408	0.345
SER	0.057	0.078	0.082	0.056	0.076	0.080
N	57	57	57	57	57	57

Notes: OLS estimates with HAC robust standard errors below. Bold face denotes significance at 10% msl.
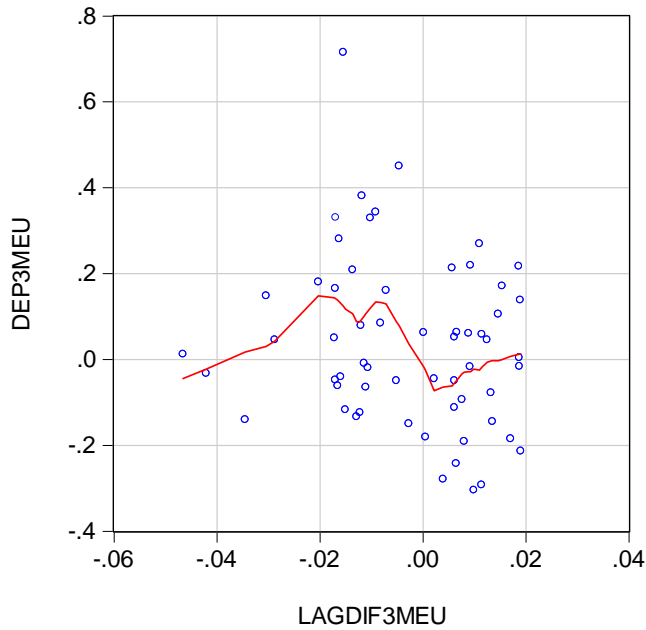
Figure 1: Annualized 3 month depreciation of dollar/euro rate versus 3 month interest differential, lagged one quarter, 1993q1-08q1. Nearest neighbor fit in red.
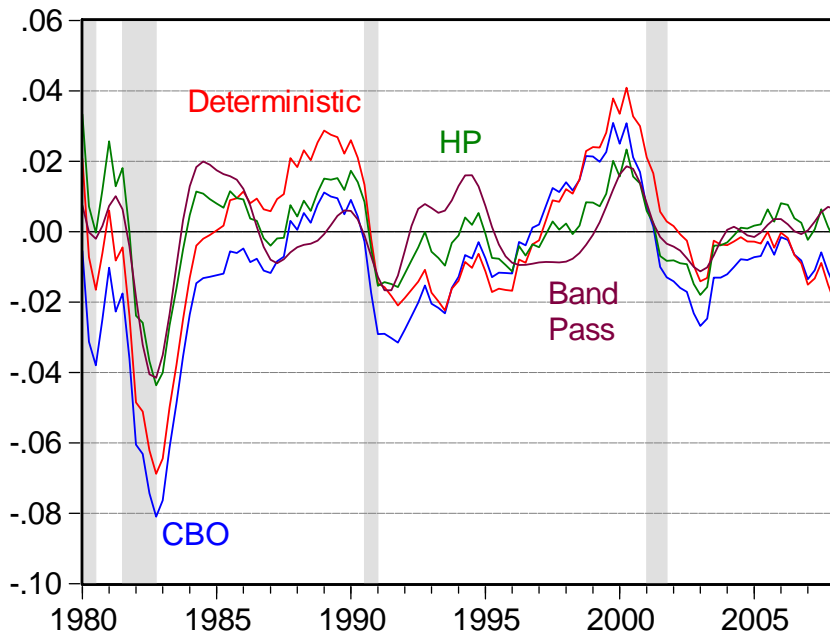

Figure 2: Output gaps, calculated as deviation from CBO potential (blue), from quadratic time trend (red), as cyclical component from HP filter (green), and as cyclical component from Band Pass filter (Christiano-Fitzgerald) (red). NBER defined recessions shaded gray. Source: CBO (2008), NBER, and author's calculations.
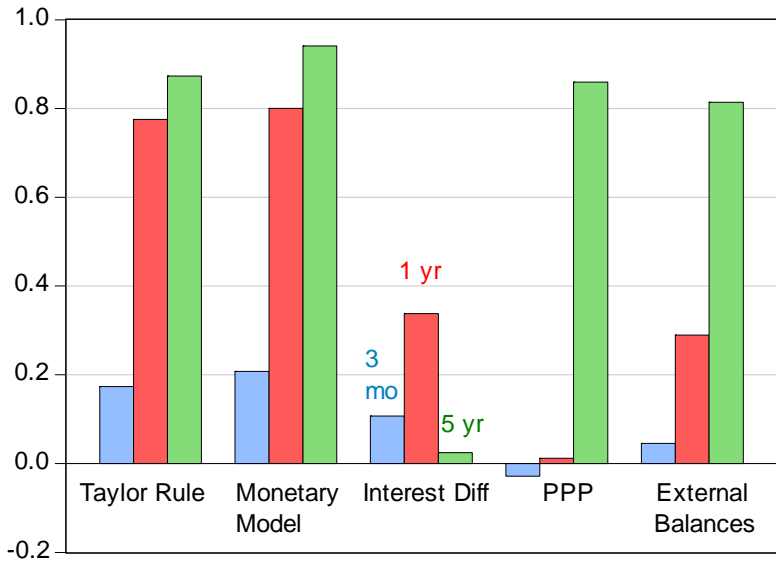
Figure 3: Adjusted R^2's from regressions in equations 5-9, at 3 month (blue), 1 year (red) and 5 years (green) horizons.
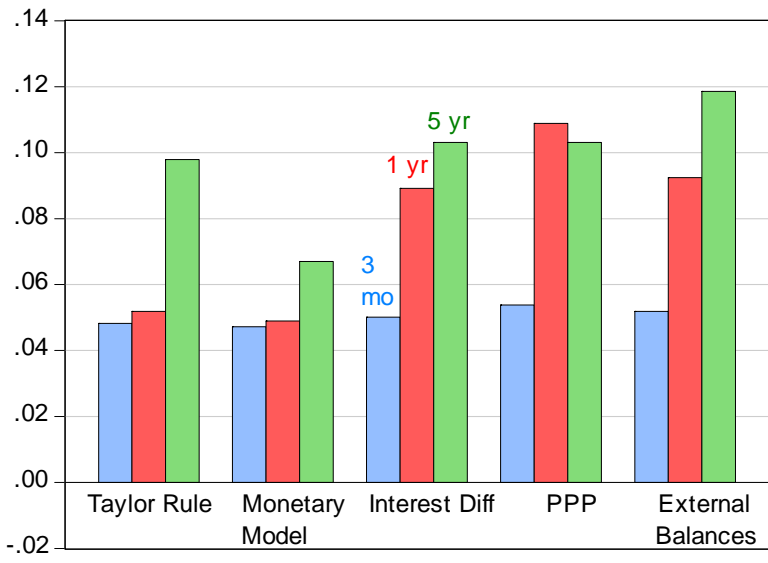

Figure 3: Standard error of regressions corresponding to estimates of equations 5-9, at 3 month (blue), 1 year (red) and 5 years (green) horizons.
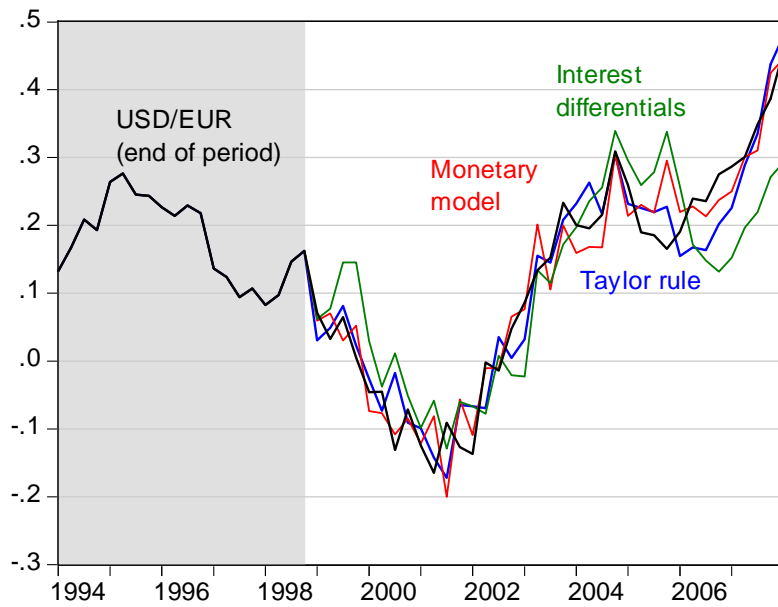
Figure 4: Actual USD/EUR exchange rate (end of period) and in-sample fit from Taylor rule (blue), monetary model (red) and interest differentials (green). Unshaded area is estimation period.
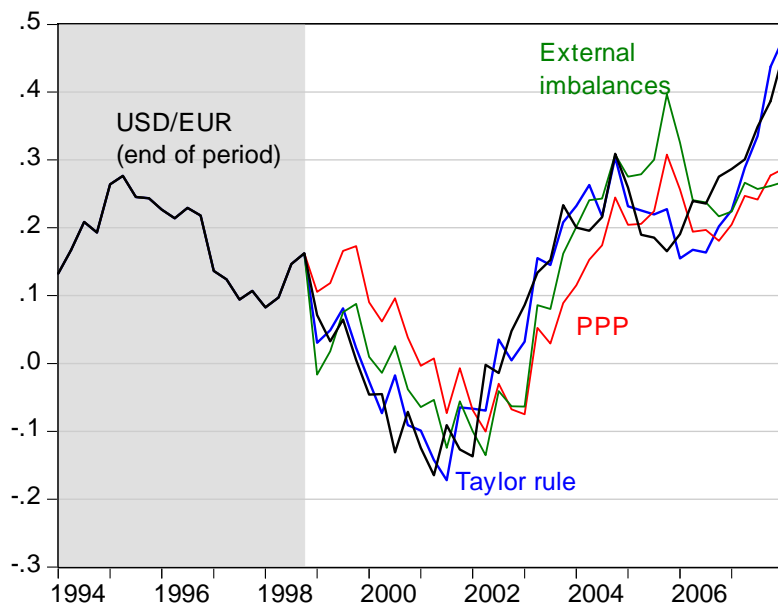

Figure 5: Actual USD/EUR exchange rate (end of period) and in-sample fit from Taylor rule (blue), PPP (red) and external imbalances fundamentals (green). Unshaded area is estimation period.