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**ABSTRACT**

Standard models of exchange rates, based on macroeconomic variables such as prices, interest rates, output, etc., are thought by many researchers to have failed empirically. We present evidence to the contrary. First, we emphasize the point that "beating a random walk" in forecasting is too strong a criterion for accepting an exchange rate model. Typically models should have low forecasting power of this type. We then propose a number of alternative ways to evaluate models. We examine in-sample fit, but emphasize the importance of the monetary policy rule, and its effects on expectations, in determining exchange rates. Next we present evidence that exchange rates incorporate news about future macroeconomic fundamentals, as the models imply. We demonstrate that the models might well be able to account for observed exchange-rate volatility. We discuss studies that examine the response of exchange rates to announcements of economic data. Then we present estimates of exchange-rate models in which expected present values of fundamentals are calculated from survey forecasts. Finally, we show that out-of-sample forecasting power of models can be increased by focusing on panel estimation and long-horizon forecasts.

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There appears to be a consensus among researchers in exchange-rate economics that the standard models that relate exchange rates to monetary variables, prices, interest rates, etc., are off the mark. For example, Sarno and Taylor (2002, pp. 136-137) state, "Overall, the conclusion emerges that, although the theory of exchange rate determination has produced a number of plausible models, empirical work on exchange rates still has not produced models that are sufficiently statistically satisfactory to be considered reliable and robust...In particular, although empirical exchange rate models occasionally generate apparently satisfactory explanatory power in-sample, they generally fail badly in out-of-sample forecasting tests in the sense that they fail to outperform a random walk." Bacchetta and van Wincoop (2006, p. 552) observe, "The poor explanatory power of existing theories of the nominal exchange rate is most likely the major weakness of international macroeconomics. Richard A. Meese and Kenneth Rogoff (1983a) and the subsequent literature have found that a random walk predicts exchange rates better than macroeconomic models in the short run." Evans and Lyons (2002, pp. 170-171) assert, "Macroeconomic models of exchange rates perform poorly at frequencies higher than one year. Indeed, the explanatory power of these models is essentially zero (Meese and Rogoff 1983a, Meese 1990). In the words of Frankel and Rose (1995, p. 1704), this negative result has had a 'pessimistic effect on the field of empirical exchange rate modeling in particular and international finance in general.' The pessimistic effect has been with us 20 years."

We present evidence that exchange rate models are not so bad after all. We approach the problem from several angles, but all of the approaches are linked by the observation that short-run movements in exchange rates are primarily determined by changes in expectations – exactly as the standard models say. We begin in section 1 by demonstrating that standard models imply near random walk behavior in exchange rates, so that their power to "beat the random walk" in out-of-sample forecasts is low. We then offer various alternative means for evaluating exchange-rate models: (1) using in-sample fit of the models, but highlighting the role of endogeneity of monetary policy in explaining nominal and real exchange rate behavior (section 2); (2) examining whether exchange rates incorporate news that helps to predict the future macroeconomic fundamentals, as implied by the models (section 3); (3) re-examining the question of whether the models can account for the volatility of exchange rates (also section 3); (4) reviewing the recent literature that has examined the response of exchange rates to announcements of macroeconomic news (section 4); (5) presenting estimates of the model in which expectations of fundamentals are drawn from survey data (also section 4); and, (6) demonstrating that the predictive power

of the models can be greatly increased by using panel techniques and forecasting exchange rates at longer horizons (section 5). Conclusions are in section 6.

We begin by examining the theorem in Engel and West (2005) that demonstrates that under plausible assumptions, the models actually imply that the exchange rate should nearly follow a random walk. Therefore, it should not be surprising that the exchange rate models cannot provide better forecasts than the random walk model. As we will elucidate, the key insight behind the theorem is that current economic fundamentals have relatively little weight in determining the exchange rate in standard models. Much greater weight is put on expectations of future fundamentals, even fundamentals several years into the future.

We elaborate on the implications of the theorem. We show that in a standard parameterization of the famous Dornbusch “overshooting” model, the exchange rate nearly follows a random walk. We make this characterization in spite of the fact that the best-known feature of this model is that exchange-rate changes should be predictable – that the exchange rate overshoots its long-run value in response to monetary shocks. We also argue that Meese and Rogoff’s (1983a) exercise, in which the model forecasts use actual ex-post (rather than forecasted) values of the fundamentals, is potentially flawed, because the out-of-sample fit of the models can be made arbitrarily worse or better by algebraic transformations of the model. Indeed, the out-of-sample fit of the standard models can be made much better (under the Meese-Rogoff methodology) if the models are written in a way that emphasizes the importance of expectations in determining exchange rates.

If we do not use the criterion of outperforming the random walk model in out-of-sample forecasting power, how then should we evaluate exchange rate models? We offer a number of alternatives.

First, we can look at the in-sample fit of the models. Most empirical monetary models of the 1970s and 1980s paid little attention to the endogeneity of monetary policy. But if exchange rates are primarily driven by expectations, then correctly modeling monetary policy is critical. Changes in current economic fundamentals, for example, may have a greater impact on exchange rates indirectly through the induced changes in expectations of monetary policy than through any direct channel. Engel and West (2006), Mark (2007), Clarida and Waldman (2006) and Molodtsova and Papell (2007) have explored the empirical performance of models based on Taylor rules for monetary policy. In a traditional flexible price model, an increase in current inflation depreciates the currency. But it is important to understand the policy reaction to higher inflation. In the new Taylor-rule models, higher inflation leads to an appreciation in inflation-targeting countries, because higher inflation induces expectations of tighter future monetary policy.

We review these models, and also make note of the important result of Benigno (2004): the Taylor-rule models offer a potential solution to the “purchasing power parity” puzzle. In particular, the models offer the possibility that persistent real exchange rates do not require unrealistic assumptions about the stickiness of nominal price setting, and potentially de-link the two altogether.

Engel and West (2004, 2005) propose testing two implications of the present value models. They emphasize that because we acknowledge that there are “unobserved fundamentals” (e.g., money demand shocks, risk premiums), the exchange rate may not be exactly the expected present value of observed fundamentals. But if exchange rates react to news about future economic fundamentals, then perhaps exchange rates can help forecast the (observed) fundamentals. If the observed fundamentals are the primary drivers of exchange rates, then the exchange rates should incorporate some useful information about future fundamentals. We verify this proposition using Granger causality tests. Engel and West (2004) also develop a technique for measuring the contribution of the present discounted sum of current and expected future observed fundamentals to the variance of changes in the exchange rate, which is valid even when the econometrician does not have the full information set that agents use in making forecasts. Here we find that the observed fundamentals can account for a relatively large fraction of actual exchange-rate volatility, at least under some specifications of the models.

Standard tests of forward looking models under rational expectations make the assumption that the sample distribution of ex post realizations of economic variables provides a good approximation of the distribution used by agents in making forecasts. But (as Rossi (2005) has recently emphasized) when agents are trying to forecast levels of variables that are driven by persistent or permanent shocks, the econometrician might get a very poor measure of the agents’ probability distribution by using realized ex post values. The problem is enhanced when the data generating process is subject to long-lasting regime shifts (caused, for example, by changes in the monetary policy regime.) For an economic variable such as the exchange rate – which is primarily driven by expectations – it might be useful to find alternative ways of measuring the effect of expectation changes.

Several recent papers (Andersen, Bollerslev, Diebold, and Vega (2002), Faust, Rogers, Wang, and Wright (2007), Clarida and Waldman (2006)) have looked at the effects of news announcements on exchange rates, using high frequency data. We review these studies, and argue that the response of exchange rates to news is precisely in line with the predictions of the Taylor rule models.

We also provide new evidence of another sort. We directly measure expectations of inflation and output using surveys of professional forecasters. The particular survey we employ asks forecasters twice a

year to provide predictions for inflation and output growth in a dozen advanced countries for the current year, each of the next five years, and an average for years 6-10. From these surveys, we are able to construct a present value of current and expected future fundamentals implied by the Taylor rule model. We find strong confirmation of the model – higher output growth and higher inflation in the US relative to the other countries leads to an appreciation of the dollar relative to the other currencies.

While we argue that theoretically the models may have low power to produce forecasts of changes in the exchange rate that have a lower mean-squared-error than the random walk model, we also explore ways of increasing the forecasting power. Mark and Sul (2001) and Groen (2005) have used panel error-correction models to forecast exchange rates at long horizons (16 quarters, for example.) We find that with the increased efficiency from panel estimation, and with the focus on longer horizons, the macroeconomic models consistently provide forecasts of exchange rates that are superior to the “no change” forecast from the random walk model.

We find ourselves in the uncomfortable position of both pointing out that common formulations of monetary models imply that the models should have little power to produce better forecasts than a random walk, while at the same time finding more forecasting power for the models than many previous studies (though in line with the findings of the studies that employ panel techniques, cited above.) There are two possible resolutions to this conflict. First, in section 5, we demonstrate in an example that if the foreign exchange risk premium – whose behavior is not well understood, and which is not observable to the econometrician – is stationary with an innovation variance that is relatively small (compared to variances in innovations of standard “observed” fundamentals), then the models might have predictive power relative to the random walk at long horizons in the error-correction framework. So it may be that indeed, using panel techniques, we have confirmed the usefulness of the models in forecasting at horizons of 16 quarters. The other resolution to the conflict is that our prediction results might prove fleeting: History has shown that models that seem to fit well over some time periods end up not holding up as the sample extends. That might hold true for forecasting power as well. While it is encouraging that our forecasting results confirm the findings of Mark and Sul (2001) on an extended sample, these results may ultimately prove not to be robust. But the Engel and West (2005) theorem tells us that out-of-sample prediction power relative to a random walk is not a reliable gauge to judge exchange rate models.

## 1. Present-Value Models and Random Walks

Let  $s_t$  denote the log of the exchange rate, measured as the log of the domestic currency price of foreign currency. Thus, depreciation of the currency implies an increase in  $s_t$ . Consider models of the exchange rate that relate the value of the currency to economic fundamentals, and to the expected future exchange rate:

$$(1) \quad s_t = (1-b)a_1'x_t + ba_2'x_t + bE_t s_{t+1}, \quad 0 < b < 1.$$

$x_t$  is a vector of economic "fundamentals" that ultimately drive exchange-rate behavior. Many familiar exchange-rate models based on macroeconomic fundamentals take this general form, as subsequent examples will demonstrate.

Equation (1) is an expectational difference equation with a no-bubbles forward solution given by:

$$(2) \quad s_t = (1-b)E_t \left( \sum_{j=0}^{\infty} b^j a_1' x_{t+j} \right) + bE_t \left( \sum_{j=0}^{\infty} b^j a_2' x_{t+j} \right).$$

The log of the exchange rate is determined as the expected present discounted value of current and future fundamentals. As in many models of other asset prices, if the discount factor is large (close to one), expected future fundamentals matter a lot more than the current value of the fundamental. For example, if the fundamentals were expected to change between period  $t$  and  $t+1$  to new permanent values,  $\tilde{x}_{t+1}$ , the exchange rate would be a weighted average of the current and the future fundamental – but with much more weight placed on the future fundamental:

$$s_t = (1-b) \left[ a_1'x_t + \frac{b}{1-b} a_2'x_t \right] + b \left[ a_1'\tilde{x}_{t+1} + \frac{b}{1-b} a_2'\tilde{x}_{t+1} \right].$$

That is, in a model such as this, when fundamentals are very persistent we can say that the exchange rate is primarily determined by the expected future path of the fundamentals, with little weight given to the current fundamental.

The monetary exchange-rate models of the 1970s and 1980s take the form given by equation (1). They are based on a Cagan-style money demand model. For the home country we can write:

$$(3) \quad m_t - p_t = \alpha + \gamma y_t - \lambda i_t + v_t,$$

where  $m_t$  is the log of the money supply,  $p_t$  is the log of the home consumer price level,  $y_t$  is the log of output,  $i_t$  is the home interest rate (in levels), and  $v_t$  is a stochastic shift term. Defining the real exchange

rate as  $q_t = s_t + \rho_t^* - \rho_t$ , and assuming the foreign money demand equation has the same parameters as the home, we can write:

$$(4) \quad m_t - m_t^* - s_t + q_t = \gamma(y_t - y_t^*) - \lambda(i_t - i_t^*) + v_t - v_t^*.$$

Foreign variables are denoted with a  $*$ .

Now we will introduce the relationship:

$$(5) \quad i_t - i_t^* = E_t s_{t+1} - s_t + \rho_t.$$

This relationship defines  $\rho_t$ , the deviation from uncovered interest parity. As is well known, a vast empirical literature has rejected the hypothesis that  $\rho_t = 0$ . But so far there is no consensus on a model for  $\rho_t$ . Perhaps it is a risk premium, a short-run deviation from rational expectations, or some other market imperfection. It is possible that movements in  $\rho_t$  are important in explaining exchange rate movements (as Obstfeld and Rogoff (2003) have suggested), but we do not explore that avenue in this paper. We treat  $\rho_t$  as an “unobserved” fundamental – an economic variable that might drive the exchange rate, but a variable for which we do not have direct observations. The money demand shifts,  $v_t$  and  $v_t^*$  are also treated as unobserved fundamentals.

When we combine equations (4) and (5), we get an equation that takes the form of equation (1):

$$(6) \quad s_t = \frac{1}{1+\lambda} \left( m_t - m_t^* + q_t - \gamma(y_t - y_t^*) - (v_t - v_t^*) \right) + \frac{\lambda}{1+\lambda} \rho_t + \frac{\lambda}{1+\lambda} E_t s_{t+1}.$$

In this case, the discount factor,  $b$ , from equation (1) corresponds to  $\frac{\lambda}{1+\lambda}$  in equation (6). The linear combination of fundamentals  $\mathbf{a}_1' \mathbf{x}_t$  is given by  $m_t - m_t^* + q_t - \gamma(y_t - y_t^*) - (v_t - v_t^*)$ , while  $\rho_t$  corresponds to  $\mathbf{a}_2' \mathbf{x}_t$ . The no-bubbles forward solution to equation (6), then, is:

(7)

$$s_t = \frac{1}{1+\lambda} E_t \left( \sum_{j=0}^{\infty} \left( \frac{\lambda}{1+\lambda} \right)^j \left( m_{t+j} - m_{t+j}^* + q_{t+j} - \gamma(y_{t+j} - y_{t+j}^*) - (v_{t+j} - v_{t+j}^*) \right) \right) + \frac{\lambda}{1+\lambda} E_t \left( \sum_{j=0}^{\infty} \left( \frac{\lambda}{1+\lambda} \right)^j \rho_{t+j} \right)$$

Equation (7) is representative of the type of model that we contend is “better than you think”. That is, it is a rational-expectations model based on macroeconomic fundamentals. It is the traditional models that were explored in depth in the 1970s and 1980s. Moreover, a model such as this is derived in a



straightforward way by log-linearizing equations from modern optimizing macroeconomic models. In fact, the money demand equation (3) can be obtained directly from a dynamic model in which agents maximize utility of consumption and real balances. Obstfeld and Rogoff (2003) derive such an equation when consumption and real balances enter separably into utility as power functions:

$$\frac{1}{1-\sigma} C_t^{1-\sigma} + \frac{V_t}{1-\varpi} \left( \frac{M_t}{P_t} \right)^{1-\varpi},$$

where  $V_t$  is a random shift factor in preferences for real balances. The only difference between the money demand equation derived from the first-order condition in the money-in-the-utility function model and the ad hoc money demand equation is that the log of consumption,  $c_t$ , appears as the activity variable in money demand, rather than the log of income,  $y_t$ , as in equation (4). Using equation (5), Obstfeld and Rogoff (2003) derive an expression for the exchange rate analogous to equation (7).

Equation (7) is not entirely satisfactory as an “exchange rate equation” because the real exchange rate,  $q_t$ , appears as an explanatory variable on the right-hand-side of the equation. Equilibrium models with flexible goods prices would elaborate on this equation by relating the equilibrium real exchange rate to underlying economic variables such as productivity and current account balances. Or, the simplest such model, which assumes purchasing power parity, treats  $q_t$  as a constant. These models might also relate output differentials to other economic driving variables.

The sticky-nominal-price models of Dornbusch (1976) and subsequent authors treat the real exchange rate and perhaps the output differential as endogenous variables whose dynamics are in part determined by the stochastic process for money supplies.

We note also that monetary policy might be endogenous, so that the relative money supplies are set in response to the realizations of macroeconomic variables. We return to discussion of this in much greater detail later.

One might argue that equation (6) holds by definition. That is, equation (4) defines the money demand errors,  $v_t - \hat{v}_t$ , and equation (5) defines the deviation from interest parity,  $\rho_t$ . The exchange-rate equation (6) must hold if we allow a role for these suitably defined unobserved fundamentals. But while we need to acknowledge a role for unobserved fundamentals, this class of models is only interesting if the observed fundamentals do a good job of explaining exchange rates.

As the quotes that we begin this paper with suggest, a standard way of evaluating exchange-rate models is to compare their out-of-sample forecasting power to that of the random walk model. There are

many variants of the standard model, which might depend on the way the fundamentals are measured, or the set of fundamentals that are included in order to account for the behavior of  $q_t$ ,  $y_t - y_t^*$ ,  $v_t - v_t^*$ , and/or  $\rho_t$ . Because of the possibility of overfitting or data mining (by a single researcher, or by exchange-rate researchers collectively), in-sample fit is considered an unreliable benchmark. Good out-of-sample forecasting power is a higher hurdle, and has become the standard by which exchange-rate models are judged.

Engel and West (2005) (hereinafter referred to as EW05), however, demonstrate that under some plausible conditions, these models actually have the implication that the exchange rate is “nearly” a random walk. In typical samples, the models actually imply that the change in the exchange rate is not predictable.

The theorem states that as the discount factor,  $b$ , goes to one, the change in the log of the exchange rate between time  $t-1$  and  $t$  becomes uncorrelated with information in the time  $t-1$  information set. The conditions under which that holds are either (i)  $\mathbf{a}_1' \mathbf{x}_t$  is integrated of order 1, and  $\mathbf{a}_2' \mathbf{x}_t$  is zero, or (ii)  $\mathbf{a}_2' \mathbf{x}_t$  is  $I(1)$ .

Note first that this theorem does not require  $\mathbf{a}_1' \mathbf{x}_t$  or  $\mathbf{a}_2' \mathbf{x}_t$  to be pure random walks. If it did, the theorem would be trivial, since the weighted sum of random walk processes that would appear in the present-value formulas are also random walks.

Second, this theorem does not say that for discount factors less than one, the log of the exchange rate is exactly a random walk. It says, in essence, that for large values of the discount factor, the log of the exchange rate is approximately a random walk.

To illustrate the theorem, suppose  $\mathbf{a}_1' \mathbf{x}_t$  is a scalar  $x_t$ , and that  $\mathbf{a}_2' \mathbf{x}_t$  is identically zero. As shown below, this is a special case of the monetary model. Suppose further that  $x_t$  has a unit root, but is not a random walk. Assume

$$x_t - x_{t-1} = \phi(x_{t-1} - x_{t-2}) + \varepsilon_t, \quad \varepsilon_t \sim \text{i.i.d.}$$

Then the solution for the change in the exchange rate is given by:

$$s_t - s_{t-1} = \frac{\phi(1-b)}{1-b\phi}(x_{t-1} - x_{t-2}) + \frac{1}{1-b\phi}\varepsilon_t.$$

It is clear from this example that the change in the exchange rate is predictable from the lagged change in the fundamental  $x_t$ . But as  $b \rightarrow 1$ , the coefficient on the lagged money supply goes to zero, and the exchange rate approaches a random walk.

The theorem is proved in EW05. Intuitively, suppose first that  $\mathbf{a}_2' \mathbf{x}_t$  is identically zero. Consider the discounted sum,  $\sum_{j=0}^{\infty} b^j \mathbf{a}_1' \mathbf{x}_{t+j}$ . Using a Beveridge-Nelson decomposition, we can write  $\mathbf{a}_1' \mathbf{x}_t$  as the sum of two components, a pure random walk “permanent” component, and a transitory component,  $\tau_t$ . We have that  $\text{var}_t(\tau_{t+j})$  approaches a constant as  $j$  gets large, but the conditional variance of the random walk component grows in proportion to  $j$ . So from the perspective of time  $t$ , the permanent component becomes more and more important in accounting for the ex ante variation in  $\mathbf{a}_1' \mathbf{x}_{t+j}$  as  $j$  gets large. When the discount factor is close to one, the discounted sum puts a lot of weight on values of  $\mathbf{a}_1' \mathbf{x}_{t+j}$  in the future. As  $b \rightarrow 1$ , the discounted sum begins to look more and more like a sum of pure random walk variables.

Now allow non-zero values for both  $\mathbf{a}_1' \mathbf{x}_t$  and  $\mathbf{a}_2' \mathbf{x}_t$ . Because the present value of  $\mathbf{a}_1' \mathbf{x}_t$  is multiplied by  $(1-b)$ , movements in  $s_t$  are dominated by the present value of  $\mathbf{a}_2' \mathbf{x}_t$  as  $b \rightarrow 1$ . For reasons sketched in the previous paragraph,  $s_t$  will behave like a random walk for  $b$  near 1 if  $\mathbf{a}_2' \mathbf{x}_t$  has a unit root.

If this theorem is applicable to exchange rate models, it suggests that we should not evaluate the models by the criterion of beating a random walk in out-of-sample forecasting power. How close the exchange rate is to a random walk, if it is generated by a present-value model as in equation (2), depends in practice on how close the discount factor is to one, and how persistent is the transitory component of the economic fundamentals. EW05 calibrate these for some standard exchange-rate models, and show that apparently the models imply near-random-walk exchange-rate behavior.

For example, consider a simple monetary model in which uncovered interest parity holds ( $\rho_t = 0$ ), purchasing power parity holds ( $q_t = 0$ ), there are no money demand errors ( $v_t = v_t^* = 0$ ) and in which the income elasticity of money demand is unity ( $\gamma = 1$ ). In this case, the exchange rate model simplifies to

$$(8) \quad s_t = \frac{1}{1+\lambda} E_t \left( \sum_{j=0}^{\infty} \left( \frac{\lambda}{1+\lambda} \right)^j (m_{t+j} - m_{t+j}^* - (y_{t+j} - y_{t+j}^*)) \right).$$

A quite conservatively low estimate of  $\lambda$  for quarterly data, from studies of money demand and exchange rates, is  $\lambda = 10$ , which implies  $b \approx 0.90$ .<sup>1</sup> In the data for the U.S. relative to each of the other G7

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<sup>1</sup> It is important to recognize that the interest semi-elasticity of money demand depends on the units in which interest rates are expressed. For example, a value of  $\lambda$  of 0.025 estimated with quarterly data when interest rates are annualized and expressed in percent terms must be multiplied by 400 to get the relevant estimate when interest rates are in the same units as the change in the log of the exchange rate.

countries, the highest serial correlation for  $\Delta(m_t - m_t^* - (y_t - y_t^*))$  is 0.41. But the computations of EW05 show that for  $b = 0.90$  and a serial correlation of  $\Delta(m_t - m_t^* - (y_t - y_t^*))$  equal to 0.50, that the correlation of  $\Delta s_t$  and  $\Delta s_{t-1}$  is only 0.05, and the correlation of  $\Delta s_t$  with  $\Delta(m_{t-1} - m_{t-1}^* - (y_{t-1} - y_{t-1}^*))$  is 0.06. That is, if the exchange rate were generated from equation (8), it would exhibit near-random-walk behavior. The exchange rate is predictable, but (as EW05 discuss) we would not be likely to reject the random walk in sample sizes that are typically available to open-economy researchers.

We note that the technical conditions for the random walk rule out a stationary process for  $\mathbf{a}_2' \mathbf{x}_t$ . In the monetary model, this means that the risk premium,  $\rho_t$ , if it is present, must not be stationary. (See equation (7).) In practice, however, if this term has nearly a unit root, the random walk will nearly follow, as illustrated in the computations in EW05. Nevertheless, in practice, it is a critical question as to whether arguably stationary terms such as risk premia can be exploited to make predictions that beat the random walk. We discuss this further in section 5 below, when we present results from panel prediction exercises.

We observe that a discount factor close to one is helpful to reconcile the observation that the variance in innovations in exchange rates is large relative to the variance of innovations in interest differentials. Using equation (5), and if we associate  $\mathbf{a}_2' \mathbf{x}_t$  with the risk premium ( $\mathbf{a}_2' \mathbf{x}_t = \rho_t$ ), we can rewrite equation (1) as:

$$(9) \quad (1 - b)(s_t - \mathbf{a}_1' \mathbf{x}_t) = b(i_t - i_t^*).$$

Typically the volatility of innovations in the fundamentals  $\mathbf{a}_1' \mathbf{x}_t$  is small compared to that of exchange rates. But innovations in  $s_t - \mathbf{a}_1' \mathbf{x}_t$  have a much higher variance than innovations in the interest differential,  $i_t - i_t^*$ . In a model such as this, reconciliation of these facts could be accomplished by having the discount factor  $b$  close to one, or by appealing to the claim that there are unobserved components of the fundamentals that have a high variance. It is of course much more satisfying not to have to rely on the volatility of an unobserved variable to account for exchange rate volatility, so models with the discount factor near one are appealing on this score.

We turn now to two examples to help elucidate the EW05 theorem.

### Example 1

The Hong Kong dollar (HK\$) per U.S. dollar (US\$) nominal exchange rate is apparently a stationary random variable. It fluctuates between 7.75 and 7.85 HK\$ per US\$. That means that the US\$

per Japanese yen (¥) and HK\$ per ¥ exchange rates are cointegrated (with cointegrating vector (1,-1).) The Engle-Granger representation theorem tells us that if the US\$/¥ and HK\$/¥ exchange rates are cointegrated, then at least one of them is predictable.

We use this example to illustrate the EW05 theorem. Suppose, then that the US\$/¥ exchange rate,  $s_t^{JJ}$  is generated by a present value model,

$$s_t^{JJ} = (1-b) \sum_{j=0}^{\infty} b^j x_t^{JJ},$$

where  $x_t^{JJ}$  is an I(1) fundamental. The HK\$/¥ exchange rate,  $s_t^{HJ}$ , is determined by an analogous model, with  $x_t^{HJ}$  as the I(1) fundamental. If  $s_t^{JJ}$  and  $s_t^{HJ}$  are cointegrated, then  $x_t^{JJ}$  and  $x_t^{HJ}$  must also be cointegrated, say  $x_t^{HJ} = x_t^{JJ} + z_t$ , for some stationary  $z_t$ . For simplicity, assume  $z_t$  has a mean of zero. Then

$$(10) \quad s_t^{HJ} = (1-b) \sum_{j=0}^{\infty} b^j x_t^{HJ} = (1-b) \sum_{j=0}^{\infty} b^j x_t^{JJ} + (1-b) \sum_{j=0}^{\infty} b^j z_t = s_t^{JJ} + (1-b) \tilde{z}_t,$$

where  $\tilde{z}_t \equiv \sum_{j=0}^{\infty} b^j z_t$  is stationary and has finite variance even in the limit as  $b \rightarrow 1$ . Thus, we can write for the HK\$/US\$ exchange rate,  $s_t^{HU}$ .

$$(11) \quad s_t^{HU} = s_t^{HJ} - s_t^{JJ} = (1-b) \tilde{z}_t,$$

and as  $b \rightarrow 1$ ,  $s_t^{HU} \rightarrow 0$  (i.e., a constant, equal to zero here since  $z_t$  has a zero mean.) In other words, the EW05 theorem implies that while  $s_t^{JJ}$  and  $s_t^{HJ}$  each approach random walks as  $b \rightarrow 1$ ,  $s_t^{HU}$  approaches a constant.

To get a better sense of the behavior of these exchange rates for  $b < 1$ , consider the following simple example. Suppose  $\Delta x_t^{JJ} = e_t$ ,  $e_t \sim$  i.i.d. (that is,  $x_t^{JJ}$  is a random walk), and let  $z_t$  defined above also be i.i.d. Then  $\tilde{z}_t = z_t$ , and  $s_t^{HJ} = s_t^{JJ} + (1-b)z_t$ , implying

$$(12) \quad \Delta s_t^{HJ} = \Delta s_t^{JJ} + (1-b)\Delta z_t = e_t + (1-b)(z_t - z_{t-1}) = e_t + (1-b)z_t - (s_{t-1}^{HJ} - s_{t-1}^{JJ}).$$

So, upon defining the i.i.d. variable  $v_t = e_t + (1-b)z_t$ , we can write the VECM for  $s_t^{JJ}$  and  $s_t^{HJ}$  as:

$$(13a) \quad \Delta s_t^{JJ} = e_t$$

$$(13b) \quad \Delta s_t^{HJ} = v_t - (s_{t-1}^{HJ} - s_{t-1}^{JJ}).$$

According to equation (13b),  $\Delta s_t^{HU}$  is predictable using the lagged HK\$/US\$ exchange rate,  $s_{t-1}^{HU} = s_{t-1}^{HU} - s_{t-1}^{UU}$ . But as  $b \rightarrow 1$ ,  $s_{t-1}^{HU} - s_{t-1}^{UU} \rightarrow 0$ , and we get the EW05 result that  $s_t^{HU}$  follows a random walk.

## Example 2

Probably the best cited exchange rate model ever is Dornbusch's (1976) overshooting model. At first glance, it seems as though EW05's theorem could not apply to Dornbusch's model. The most celebrated aspect of the model – the fact that in response to a permanent money supply shock, the exchange rate overshoots, responding more in the short run than in the long run – implies that exchange rate changes are predictable. When the currency depreciates in response to a domestic monetary expansion, we can predict that it will appreciate toward its long-run equilibrium value.

The EW05 theorem actually is not designed to answer the question of whether the exchange rate in the Dornbusch model theoretically is nearly a random walk. Since equations (3), (4) and (5) hold in the Dornbusch model, then the present value relationship (6) also holds. The EW05 theorem takes the data generating processes for the fundamentals as given, and asks what the implied exchange rate behavior is for large values of the discount factor. That is subtly different than asking what happens in the model to the behavior of the exchange rate as the discount factor goes to one, because a change in the discount factor may change the implied data-generating process for the fundamentals. In other words, the EW05 theorem suggests that if the exchange rate is determined by the model (6), with the observed DGPs for the fundamentals, and the discount factor is close to one, then the exchange rate will be nearly a random walk.

Here we briefly examine the theoretical behavior of the exchange rate in the Dornbusch model when the discount factor is nearly unity, allowing for the fact that the data generating process for the fundamentals – particularly the real exchange rate – is affected by the discount factor.

We look at a version of the model very close in spirit to Dornbusch's original model. We use equations (3), (4), and (5), and, as in Dornbusch, assume that uncovered interest parity holds exactly,  $\rho_t = 0$ . As in the overshooting analysis of Dornbusch, we will take output as exogenous. Dornbusch examined the impact of a permanent change in the money supply in a non-stochastic model. In the stochastic setting, this is equivalent to looking at a random walk process for the money supply. Since output shocks and money demand shocks have identical effects on the exchange rate as money supply shocks (up to the sign of the effect), we will simply assume that the "fundamentals" follow a random walk:

$$(14) \quad \Delta(m_t - m_t^* - \gamma(y_t - y_t^*) - (v_t - v_t^*)) = u_t, \quad u_t \sim \text{i.i.d.}$$

We need to supplement the model with a price adjustment equation. The open-economy macro literature of the 1970s and 1980s assumed a backward looking element to price setting. The log of the domestic price level for time  $t$ ,  $p_{t-1}$ , is preset in time  $t-1$ , and adjusted to eliminate part of the deviation of  $p_{t-1}$  from its long-run equilibrium level. As in Dornbusch, we will assume purchasing power parity holds in the long run, so  $p_t - p_{t-1}$  eliminates part of the time  $t-1$  PPP deviation,  $s_{t-1} + \dot{p}_{t-1} - p_{t-1}$ . In addition, there is a forward looking trend term to price adjustment. Obstfeld and Rogoff (1984) emphasize that price-adjustment equations that do not include the forward looking element lead to counter-intuitive dynamics when considering expected future changes in policy, or non-stationary dynamics in the fundamentals. Here, we implement a version of what they call a Mussa rule – the trend term is the expected change in the market-clearing exchange rate. We have:

$$(15) \quad p_t - p_{t-1} = \theta(s_{t-1} + \dot{p}_{t-1} - p_{t-1}) + E_{t-1}s_t + \dot{p}_t - (s_{t-1} + \dot{p}_{t-1}).$$

This pricing rule is symmetric, in that the analogous pricing rule for the foreign country yields equation (15) as well. Equation (15) implies that the real exchange rate follows a first-order autoregressive process:

$$(16) \quad E_{t-1}q_t = (1 - \theta)q_{t-1}.$$

Note that the persistence of the real exchange rate is entirely determined by the speed of adjustment of nominal prices. We return to this point below when we discuss the “PPP puzzle”. However, the real exchange rate does depend on monetary shocks and on the discount factor, which work through their effect on innovations in the real exchange rate.

If we substitute equations (14) and (16) into the present value formula (7), we derive:

$$(17) \quad s_t - s_{t-1} = -\frac{\theta}{1 + \lambda\theta}q_{t-1} + \frac{1 + \lambda\theta}{\lambda\theta}u_t = -\frac{(1 - b)\theta}{1 - b + b\theta}q_{t-1} + \frac{1 - b + b\theta}{b\theta}u_t,$$

where, recall, the discount factor is  $b = \frac{\lambda}{1 + \lambda}$ . Equation (17) demonstrates the famous overshooting

result. In response to a shock,  $u_t$ , the exchange rate jumps more than one-for-one,  $\frac{1 + \lambda\theta}{\lambda\theta}$ . The volatility

is greater the stickier are prices (the smaller is  $\theta$ .) But the change in the exchange rate is predictable.

When  $s_t$  is above its PPP value in period  $t-1$  (so  $q_{t-1}$  is positive), then  $E_{t-1}(s_t - s_{t-1}) < 0$ . We can see, however, that the EW05 result holds in this model. As  $b \rightarrow 1$ ,  $s_t - s_{t-1} \approx u_t$ .

As noted above, the real exchange rate behavior does depend on the value of  $b$ :

$$(18) \quad q_t = (1-\theta)q_{t-1} + \frac{1+\lambda\theta}{\lambda\theta}u_t = (1-\theta)q_{t-1} + \frac{1-b+b\theta}{b\theta}u_t.$$

Assume that  $\lambda = 10$ , a conservatively low value if calibrated to quarterly data. Also, assume  $\theta = 0.25$ , which implies a half life of price adjustment of 2.4 quarters. This speed of price adjustment is in line with the typical calibration of modern sticky-price macroeconomic models. However, it would imply from equation (16) real exchange rate convergence that is much faster than what is typically observed among advanced countries. With these parameters, how well could we predict nominal exchange rate changes using the lagged real exchange rate? The implied R-squared from the regression in equation (17) is 0.012, or slightly greater than 1 per cent. While the exchange rate change is predictable in theory, in practice it would not be predictable in any reasonably sized sample.

One might expect that if price adjustment were slower (that is,  $\theta$  lower), that perhaps exchange rate changes would be more predictable. Since the overshooting is greater, the exchange rate has further to adjust to reach its long-run value, and perhaps we can predict that change. In fact, lower values of  $\theta$  reduce the predictability of exchange rate changes. After a shock to the fundamentals, it is true that the gap between the exchange rate and its long-run value is wider the smaller is  $\theta$ . The overshooting for a given monetary shock is proportional to  $1/\theta$ . But, the predictable percentage change in the exchange rate toward its long-run value is smaller in proportion to  $\theta$ . These two effects precisely offset each other. But the other effect of small values of  $\theta$  is to make the variance of innovations to the exchange rate larger – the overshooting is larger. So the variance of the unpredictable component of changes in the exchange rate grows relative to the variance of the predictable component as  $\theta$  gets smaller.

To further develop intuition, we can ask about longer-run changes in the exchange rate. We find:

$$(19) \quad s_{t+k} - s_t = -\frac{(1-(1-\theta)^k)}{1+\lambda\theta}q_t + \sum_{j=1}^k \left( \frac{(1-\theta)^{j-1} + \lambda\theta}{\lambda\theta} \right) u_{t+k+1-j}.$$

There are two effects as the horizon for forecasts gets longer. First, for higher  $k$ , the variance of the predictable part of the exchange rate change increases, since  $\frac{(1-(1-\theta)^k)}{1+\lambda\theta}$  is increasing in  $k$ . But, since the exchange rate has a unit root, the variance of the unpredictable part grows without bound as  $k$  grows. That can be seen from the second term on the right-hand-side of equation (19), which has a variance that is greater than  $k$  times the innovation variance. In practice, for the parameters considered above ( $\lambda = 10$  and  $\theta = 0.25$ ), the maximum R-squared in this regression comes at 6 quarters, and has a value of 0.027. At 16 quarters, the implied R-squared is 0.018.



## Using future values to 'forecast': Meese-Rogoff revisited

While recent literature has attempted to validate exchange rate models by comparing their out-of-sample forecasting power to that of the random walk, Meese and Rogoff (1983a) did something different. They apparently gave the exchange rate models an advantage relative to the random walk model. Forecasting from the exchange rate model requires forecasting the values of the fundamentals. But Meese and Rogoff evaluated the exchange rate models using the actual realized values of the fundamentals, rather than forecasting them.

The more recent literature has not used the Meese-Rogoff technique, and instead compared monetary exchange rate models to the random walk model using true out-of-sample forecasting power. By this standard, monetary models have not fared well in general. See, for example, Cheung, Chinn and Garcia-Pascual (2005), who find that the models generally do not have significantly better forecasting power than the random walk model. Below, we note that monetary model forecasts based on panel estimation techniques at long horizons (such as in Mark and Sul (2001)) do seem to have greater forecasting power than the random walk. We also examine the forecasting power of models in which monetary policy is endogenized (as in Molodtsova and Papell (2007).) But here we want to reconsider the Meese-Rogoff technique.

As an example (this is one model actually considered by Meese and Rogoff), use equation (4) to solve for the log of the exchange rate, under the assumption of PPP ( $q_t = 0$ ):

$$(20) \quad s_t = m_t - m_t^* - \gamma(y_t - y_t^*) + \lambda(i_t - i_t^*) + u_t,$$

where here the error term  $u_t$  is associated with the error terms in money demand,  $v_t - v_t^*$ .

Rossi (2005) emphasizes that Meese and Rogoff may not have fully accounted for the serial correlation in  $u_t$ . She notes that if the exchange rate is cointegrated with the economic fundamentals included in equation (20), then  $u_t$  is stationary, but it might be serially correlated. Suppose  $u_t = \rho u_{t-1} + \varepsilon_t$ ,  $\varepsilon_t \sim$  i.i.d. Then the model forecast for time  $t+1$  should be

$$m_{t+1} - m_{t+1}^* - \gamma(y_{t+1} - y_{t+1}^*) + \lambda(i_{t+1} - i_{t+1}^*) + \rho u_t.$$

Rossi argues that even with this addendum, the models still might be at a "disadvantage" relative to the random walk. This is because  $\rho$  is plausibly near one, in which case estimates of  $\rho$  tend to be biased downwards. Hence imposing a unit root (imposing  $\rho = 1$ ) might result in long-horizon forecasts superior to ones that rely on an estimate of  $\rho$  that is far below its true value. Moreover, when  $\rho$  is estimated,

distributions of test statistics tend to be nonstandard, a result captured by Rossi by modeling  $\rho$  as “local to unity”.

Suppose we impose  $\rho = 1$ , then our forecast of  $s_{t+1}$  is given by:

$$\begin{aligned} & m_{t+1} - m_{t+1}^* - \gamma(y_{t+1} - y_{t+1}^*) + \lambda(i_{t+1} - i_{t+1}^*) + u_t \\ & = \Delta \left[ m_{t+1} - m_{t+1}^* - \gamma(y_{t+1} - y_{t+1}^*) + \lambda(i_{t+1} - i_{t+1}^*) \right] + s_t \end{aligned}$$

In other words, taking into account the serial correlation of the residual, we should be using the change in the fundamentals to “forecast” the change in the exchange rate.

Note however that Meese and Rogoff (1983b) allow for a grid of possible values for  $\rho$ , including  $\rho = 1$ , and still find that the models do not improve the out-of-sample fit compared to the random walk.

We make a different observation about the Meese and Rogoff standard for evaluating the exchange rate models. There is a sense in which the out-of-sample fit of the model is arbitrary – the model can be rewritten to make the fit arbitrarily good or bad. That is, suppose that  $x_t$  is the model for some variable  $y_t$ , and we have:  $y_t = x_t + \omega_t$ . The variance of  $\omega_t$ ,  $\sigma_\omega^2$ , serves as a measure of the goodness of fit of the model under the Meese-Rogoff approach. Now, consider rewriting the model as:  $y_t = (x_t - (1-a)y_t)/a + \omega_t/a = z_t + \varpi_t$ , where  $a$  is an arbitrary constant,  $z_t \equiv (x_t - (1-a)y_t)/a$ , and  $\varpi_t = \omega_t/a$ . The model is not changed – the second equation is simply an algebraic manipulation of the first. But the variance of the error in the rewritten model – the variance of  $\varpi_t$  -- is  $(1/a)^2$  times the variance in the first model.

For example, using the log approximation to the pure arbitrage covered interest parity condition, we have  $f_t - s_t = i_t - i_t^*$ , where  $f_t$  is the log of the one-period ahead forward exchange rate. Substitute this expression into equation (20), and rearrange terms to get:

$$(21) \quad s_t = \frac{1}{1+\lambda}(m_t - m_t^* - \gamma(y_t - y_t^*)) + \frac{\lambda}{1+\lambda}f_t + \frac{1}{1+\lambda}u_t.$$

This representation of the model is very similar in spirit to equations (1) or (6): the exchange rate is a weighted average of the (observed) economic fundamentals, and the expected future exchange rate, here measured as  $f_t$ . This way of writing the exchange rate equation emphasizes the weight of expectations of the future relative to current fundamentals. But it also gives us an error term with a much lower variance.

The variance here is  $\left(\frac{1}{1+\lambda}\right)^2$  times the variance of the error term in equation (20). We have been using a

value of  $\lambda = 10$  for quarterly data in our examples so far, which would imply that the variance of the error term is lower by a factor of  $\frac{1}{121}$ .

Which is the correct way to write the model? Since they are algebraically equivalent, it is hard to argue for one in favor of the other, and indeed that is exactly the problem with the Meese and Rogoff methodology. Moreover, both ways of writing the model have natural economic interpretations. If the model is true with no error, then the right-hand-sides of equations (20) and (21) are equal:

$$(22) \quad m_t - m_t^* - \gamma(y_t - y_t^*) + \lambda(i_t - i_t^*) = \frac{1}{1+\lambda}(m_t - m_t^* - \gamma(y_t - y_t^*)) + \frac{\lambda}{1+\lambda}f_t.$$

When there is an error term, using the formulation in (20) magnifies the error because it includes  $-\lambda s_t$  as an “explanatory” variable.

To be clear, this critique does not apply to genuine out-of-sample forecast comparisons. At some level, it is obvious that we cannot simply rewrite the model and produce out-of-sample forecasts that have arbitrarily lower variance. If we could, we would not be writing or reading this paper, and instead would be out using this technique to get very rich. While we can rewrite the right-hand-side of the model to arbitrarily change the in-sample fit, it follows from equation (22) that our forecast of the right-hand-side is the same no matter which way it is written.

Finally, we note that it is often asserted that the “forecast” using the actual realized values of the explanatory variables must produce better forecasts of the exchange rate than when the right-hand-side variables must be forecast. However, this is not in general true if the explanatory fundamental variables are correlated with the “unobserved” variables. Unless we take this correlation into account, the fit could potentially be worse using the ex post fundamentals.

Our general point, then, is that the Meese-Rogoff procedure of using realized values of the explanatory variables is not invariant to the way the model is written. Plausible ways of rewriting the model can give much lower mean-squared-errors for the model.

Of course, we cannot conclude that if the model is not useful in forecasting exchange rate changes, we have support for the model. Any model can fail to forecast exchange rates. We turn now to alternative means of assessing exchange-rate models.

## 2. Taylor-rule models

### Overview

Meese and Rogoff originally suggested the out-of-sample fit criterion as a check on empirical studies that found good in-sample fit. Here, we return to examination of the in-sample fit, but with more attention paid to the market's expectations of future values of the macroeconomic fundamentals.

The monetary models that we have explored so far have been formulated in such a way that the endogeneity of monetary policy has been essentially completely ignored. We have used money supply to capture the monetary fundamental, and have focused on formulations in which nominal interest rates move to equilibrate money supply and money demand. We have not tried to relate movements of the money supply to the macroeconomic variables that policymakers might target.

But modern monetary macroeconomic models formulate the determination of interest rates and monetary equilibrium quite differently. First, they emphasize the endogeneity of monetary policy. Advanced countries have managed to stabilize inflation and apparently establish monetary policy credibility over the past twenty or twenty-five years. If our models of exchange rates are to capture expected future fundamentals, we need to recognize that market forecasts of the future incorporate their assumptions about monetary policy reactions to changes in the macro environment. Second, since the mid-1980s, central banks have used short-term interest rates as their policy instrument, rather than the money supply.

Engel and West (2006) and Mark (2007) (hereinafter, EW06 and M07) specify the monetary policy rules for the home and foreign country as interest-rate reaction functions for the central bank. Specifically, they assume the home country (in their empirical studies, the home country is Germany, prior to the adoption of the euro) sets the nominal interest rate to target the deviation of expected inflation from the central bank's target,  $E_t\pi_{t+1}$ ; the output gap,  $y_t$ ; and, possibly, the deviation of the nominal exchange rate from its purchasing power parity value – that is, the real exchange rate,  $q_t$ . The latter term is included to capture the notion that the monetary authorities in some countries tend to raise interest rates when their currency depreciates. For example, Clarida, Gali and Gertler (1998) find empirical support for this notion in Japan and some other countries. We summarize the monetary policy rule in equation (23):

$$(23) \quad i_t = \gamma_q q_t + \gamma_\pi E_t \pi_{t+1} + \gamma_y y_t + \delta i_{t-1} + u_{mt}.$$

We assume  $\gamma_q > 0$ ,  $\gamma_\pi > 1$ ,  $\gamma_y > 0$ , and  $0 \leq \delta < 1$ . Here,  $u_{mt}$  represents an error or shift in the monetary policy rule.

The foreign country (taken to be the U.S. in EW06 and M07) follows a similar policy rule:

$$(24) \quad \dot{i}_t = \gamma_\pi E_t \pi_{t+1}^* + \gamma_y y_t^* + \delta \dot{i}_{t-1} + \dot{u}_{mt}.$$

Here, we assume that the parameters on the inflation deviation and the output gap are the same in the home and foreign country, but assume that the foreign central bank is passive with respect to exchange rate fluctuations.

Using the uncovered interest parity relationship (including the u.i.p. deviation,  $\rho_t$ ),  $\dot{i}_t - \dot{i}_t^* = E_t s_{t+1} - s_t + \rho_t$ , we can manipulate these equations to get a forward-looking expression for the real exchange rate:

$$(25) \quad q_t = b \sum_{j=0}^{\infty} b^j E_t z_{t+j},$$

where

$$b \equiv \frac{1}{1 + \gamma_q},$$

$$z_t = -\left[ (\gamma_\pi - 1)(E_t \pi_{t+1} - E_t \pi_{t+1}^*) + \gamma_y (y_t - y_t^*) + \delta (\dot{i}_{t-1} - \dot{i}_{t-1}^*) + (u_{mt} - \dot{u}_{mt} - \rho_t) \right].$$

M07's formulation actually sets  $\gamma_q = 0$ , because his estimates of the Bundesbank's monetary policy reaction function yielded insignificant estimates for this parameter. With that change, we can still represent the real exchange rate with a present value expression, but the discount factor,  $b$ , is equal to one. We can do that if  $z_t$  has a zero (unconditional) mean – implying  $q_t$  has a zero mean, or long-run purchasing power parity holds – and satisfies a mild summability condition. Any ARMA process satisfies the condition, though we note that fractionally integrated processes do not. In this but not all contexts, there will be little difference in empirical results that impose  $\gamma_q = 0$  and empirical results that, consistent with the estimates in Clarida et al. (1998), impose small but positive values such as  $\gamma_q = 0.10$ . Through most of the empirical work below, we assume that in quarterly data,  $\gamma_q$  is a small positive number, less than 0.10 but strictly greater than zero.

The equation for the real exchange rate given by equation (25) does not solve a full general equilibrium model in terms of exogenous variables. The fundamentals – inflation and the output gap – are determined by underlying driving variables, such as productivity disturbances and cost-push shocks. We note, nonetheless, that equation (25) has an interesting implication – ceteris paribus, an increase in home relative to foreign inflation leads to a home real appreciation. This prediction stands in contrast to the usual interpretation of the effect of an increase in expected inflation in the monetary models we investigate

above. In those, an increase in expected inflation at home lowers home money demand, leading to a home depreciation. Here, when  $\gamma_\pi > 1$ , and increase in expected inflation leads the home central bank to raise the home real interest rate, leading to an appreciation.

EW06 and M07 estimate the model as summarized by equation (25). The present-value model requires a measure of expected inflation, output gap, and interest rates for all periods in the future. It also requires an estimate of future expected values of  $u_{mt} - u_{mt}^* - \rho_t$ . The empirical researcher faces a severe problem in estimating such a model, because the market forms expectations based on many sources of information that are not measurable by the econometrician.

EW06 and M07 handle estimation of the expected present value sum, (25), in similar ways. First, they ignore  $u_{mt} - u_{mt}^* - \rho_t$ , treating these as “unobservable” determinants of the real exchange rate. We now describe EW06’s methodology, then note the differences between EW06 and M07. First, EW06 do not include the lagged interest rate in the monetary policy rule, so they have set  $\delta = 0$ . EW06 then must measure  $E_t[(\gamma_\pi - 1)(\pi_{t+j+1} - \pi_{t+j+1}^*) + \gamma_y(y_{t+j} - y_{t+j}^*)]$  for all  $j$ . EW06 do not estimate the parameters  $\gamma_\pi$  and  $\gamma_y$  -- instead they base them on estimates of the Taylor rule on post-1979 data in Clarida, Gali, and Gertler (1998). EW06 also use Clarida et al.’s estimate of  $\gamma_q$ , from which the discount factor,  $b$ , is calculated. Then, EW06 estimate a VAR in  $\pi_{t+1} - \pi_{t+1}^*$ ,  $y_t - y_t^*$ , and  $i_t - i_t^*$ . From the VAR, expected values of  $\pi_{t+1} - \pi_{t+1}^*$ , and  $y_t - y_t^*$  for all periods can be constructed, and then the present value can be calculated.

EW06 then compare the “model” real exchange rate – the value of the right-hand-side of equation (25), where expectations are calculated as just described – to the behavior of the actual deutschemark/dollar real exchange rate. EW06 estimate the model on post-1979 data, using monthly data, 1979:10-1998:12. The correlation of the model real exchange rate and actual real exchange rate is 0.32. That is not extremely high, but it is not too bad, and represents a promising start in this literature. We note, however, that the model real exchange rate estimated by EW06 has a standard deviation about one-fifth of that of the actual real exchange rate.

The approach of M07 differs from EW06 in a number of ways. First, M07 estimates the parameters of the Taylor rule, for two periods 1960:II-1979:II, and 1979:III-2003:IV, using quarterly data. Second, as noted above, Mark does not include the real exchange rate in the interest-rate rule for Germany. Third,

M07 does include the lagged interest rate in the policy rule. Fourth, M07 compares the behavior of the model real exchange rate to the actual real exchange rate over a longer period, 1976:II-2003:IV.

The correlation of the model and actual real exchange rate in M07 is quite similar to that in EW06, equal to 0.304 (when the output gap is measured using deviations the HP-filter). However, the model volatility of the real exchange rate is much larger in M07, and more nearly matches that of the real exchange rate. The variance of 1-quarter changes in the real exchange rate from the model is 36.81 percent from the model, compared to 20.06 percent in the data.

### **Purchasing power parity puzzle**

In advanced economies, real and nominal exchange rate changes are highly correlated. A plausible model of real exchange rate behavior must account for this correlation. For an international macroeconomist, a model of nominal exchange rates that cannot be reconciled with real exchange rate behavior is not appealing, and vice-versa. Some existing literature (as exemplified by Rogoff (1996)) argues that both sticky and flexible price models fail to replicate some important exchange rate characteristics. As explained below, such authors argue that flexible price models have a hard time explaining volatility of real exchange rates, while sticky price models have difficulty explaining persistence of real exchange rates. But recent work by Benigno (2004) and others shows that with suitable modeling of price stickiness and monetary policy, real exchange rate persistence can be plausibly explained as coming from persistence in interest rates.

It is possible to understand the high correlation of real and nominal exchange rates in an environment in which nominal goods prices adjust quickly (no price stickiness), if we assume that monetary authorities stabilize nominal prices. In that case, we should think of nominal exchange rates as being driven by underlying real shocks that drive the real exchange rate. That is, since  $s_t = q_t + p_t - p_t^*$ , if nominal prices are flexible but  $p_t$  and  $p_t^*$  are stabilized by monetary policy, then movements in  $s_t$  will be highly correlated with those in  $q_t$ . However, as Rogoff (1996) emphasized, while flexible-price models can account for the extreme persistence of real exchange rates that we see among advanced countries, they are unable to explain the high volatility.

Alternatively, we might consider models in which  $p_t$  and  $p_t^*$  have low volatility (that is, low innovation variance) at least in part because of nominal price stickiness. In models with price stickiness, Rogoff notes, we have better explanations of real exchange rate volatility. Specifically, we can appeal to the Dornbusch overshooting model (that we have described in Section 1). Monetary shocks cause volatile

nominal exchange rate changes –see equation (17). But empirical studies have found the half-life of real exchange rates to be greater than two years. In sticky-price models of the Dornbusch vintage, the sluggishness of real exchange rates is directly tied to the speed of adjustment of nominal prices. Indeed, that can be seen directly from equation (16) – in this version of the model, if the response of real exchange rates to shocks has a half-life of two-plus years, so does the deviation of nominal prices from their flexible-price equilibrium level. Accounting for the slow adjustment of real exchange rates requires unrealistic assumptions about the sluggishness of price adjustment. Rogoff concludes that we cannot easily reconcile real exchange rate behavior with the monetary models of price stickiness either.

Benigno (2004), however, shows that models with two modifications to the Dornbusch-style model de-link real exchange rate persistence and the speed of nominal price adjustment. First, replace the ad hoc price adjustment equation (15) with a Calvo-style price adjustment equation. A fraction of firms each period reset their prices, recognizing that they will not be able to reset prices in every period. They set prices to maximize the value of the firm – the expected present value of current and future dividends. Thus prices are set in a purely forward-looking manner. Second, monetary policy is endogenous. Central banks set nominal interest rates by a Taylor rule, reacting to the inflation level and the output gap.

We demonstrate the point here in the model from Engel and West (2006), which is derived directly from the working paper version of Galí and Monacelli (2005). The home country is small relative to the foreign country. That is reflected in the behavior of consumer price inflation in each country. Home-country inflation is a weighted average of inflation of domestically-produced goods and home-currency inflation of foreign produced goods:

$$(26) \quad \pi_t = (1 - \alpha)\pi_{dt} + \alpha\pi_{ft}.$$

The law of one price holds for imported goods in the home country:

$$(27) \quad \pi_{ft} = \Delta S_t + \pi_t^*.$$

This equation embodies the assumption that the home country is small. The term  $\pi_t^*$  represents both the foreign-currency rate of inflation of foreign-produced goods, and the foreign consumer price inflation. The notion is that the home country is so small relative to the foreign country that, while the foreign country does import goods from the home country, the weight of home country prices is infinitesimally small in the overall foreign consumer price index.

Firms in each country set prices by a Calvo-price setting rule:

$$(28) \quad \pi_{dt} = \beta E_t \pi_{dt+1} + \kappa y_t + u_{ct}$$



$$(29) \quad \pi_t^* = \beta E_t \pi_{t+1}^* + \kappa y_t^* + u_{ct}^*$$

$y_t$  and  $y_t^*$  represent the output gaps in the home and foreign countries.  $u_{ct}$  and  $u_{ct}^*$  are cost-push shocks. The parameter  $\kappa$  captures the speed of price adjustment. In each period, the larger the proportion of firms that are able to adjust their prices, the larger is  $\kappa$ .

In each country, the monetary authority sets the nominal interest rate to react to expected consumer price inflation, and the local output gap. In addition, the home country puts some weight on the real exchange rate in its Taylor rule:

$$(30) \quad i_t = \gamma_q q_t + \gamma_\pi E_t \pi_{t+1} + \gamma_y y_t + u_{mt}$$

$$(31) \quad i_t^* = \gamma_\pi E_t \pi_{t+1}^* + \gamma_y y_t^* + u_{mt}^*$$

We assume parameter values that ensure a stationary solution. Sufficient assumptions are that all parameters are positive, that  $\gamma_\pi > 1$ , and that  $\alpha \gamma_\pi < 1$ .  $u_{mt}$  and  $u_{mt}^*$  are monetary policy errors.

Demand for output from each country depends on consumption levels and the terms of trade. But, in turn, the relative consumption levels are proportional to the real exchange rate through the familiar equilibrium condition that arises under complete markets. The terms of trade are proportional to the real exchange rate. Details are in Galí and Monacelli. We can then write:

$$(32) \quad y_t - y_t^* = \theta q_t + u_{yt} - u_{yt}^*$$

where  $u_{yt} - u_{yt}^*$  represents a relative productivity shock.

Here we briefly summarize how various shocks affect the economic variables in the system:

- A positive monetary policy shock (i.e., an exogenous monetary tightening) causes an appreciation. Inflation and output also decline.
- A positive Phillips curve shock that, given output and expected inflation, raises inflation transitorily and leads to a real appreciation.
- Suppose there is a positive real shock to the IS curve that, given the real exchange rate, raises output. Then in equilibrium, output rises, the real exchange rate falls, and the inflation rate of home produced goods rises relative to the foreign produced goods.

In order to highlight the comparison of real exchange rate behavior in this model to that of the Dornbusch model, we will set cost push shocks and productivity shocks to zero, leaving only monetary errors, which are assumed to follow an AR(1) process. We define the relative policy error as:

$$(33) \quad u_t = u_{mt} - u_{mt}^*$$

with

$$(34) \quad u_t = \phi u_{t-1} + \varepsilon_t, \quad 0 \leq \phi \leq 1.$$

Using equations (26) – (34), we get a solution for the real exchange rate:

$$(35) \quad q_t = c_m u_t,$$

where

$$c_m \equiv -(1 - \beta\phi) / d_m < 0$$

$$d_m \equiv (1 - \beta\phi)[\gamma + \eta(1 - \phi)] + \kappa\theta(\gamma_\pi - 1)\phi$$

$$\gamma \equiv \gamma_q + \gamma_y\theta$$

$$\eta \equiv (1 - \alpha\gamma_\pi) / (1 - \alpha).$$

The important thing to note about the solution for the real exchange rate is that it is proportional to the monetary policy error. Real exchange rates have no persistence, except to the extent that there is persistence in monetary policy errors. In the lingo of the new Keynesian literature, the real exchange rate exhibits no endogenous persistence. Greater price flexibility is represented by a larger value for  $\kappa$ . We see from the expressions for  $c_m$  and  $d_m$  that as  $\kappa$  grows, the impact effect of shocks falls ( $c_m$  falls). So while some price stickiness ( $\kappa < \infty$ ) is required to make the real exchange rate respond to monetary shocks, the degree of price stickiness does not affect the persistence of real exchange rates, but only affects the impact effect of monetary shocks.

In this model, the link between real exchange rate persistence and the speed of adjustment of nominal prices is broken. It might be possible in this simple framework to account for the persistence of real exchange rates, because in practice relative short term nominal interest rates among advanced countries are very persistent. It is usually not possible to reject a unit root in  $i_t - \hat{i}_t$  (at least not statistically). We note here that similar effects on the persistence of the real exchange rate would be generated in the model if shocks to the monetary rule were serially uncorrelated, but the lagged interest rate appeared in the rule with a positive coefficient near one.

Intuitively, even if there are a large proportion of firms that reset their prices each period, the firms that set their prices must take into account the effects of monetary policy. Suppose there is an expansionary monetary shock. The firms that adjust their price cannot raise prices fully to the level they would attain if all prices were set flexibly, because their prices might then be quite high relative to firms that have not adjusted prices this period. As argued for the closed economy model of West (1988), the

combination of persistence in monetary shocks and non-synchronized price setting can stretch out the price adjustment process, even if a large fraction of firms adjust prices at any given time.

The simple model presented here is not realistic enough to describe the most important moments in the macroeconomic data. For example, the output gap and inflation inherit the same persistence as the real exchange rate. Benigno (2004) shows how various types of asymmetries can contribute to even more sluggish real exchange rate adjustment – asymmetries in the price-setting rules, in monetary policy, etc.

The other aspect of the PPP puzzle is real exchange rate volatility. Again, we do not attempt to calibrate the simple model above to see if it is able to generate realistic volatility for plausible values of the parameters. However, Benigno (2004) and Benigno and Benigno (2006) do undertake such exercises in somewhat richer models, and find success in matching both the persistence and volatility of real exchange rates.

We do not mean to suggest that the PPP puzzle is solved. For example, estimated open-economy DSGE models frequently do not produce parameter estimates that will fully account for the persistence and volatility of real exchange rates (see Jung (2007), for example.) But we do believe that the Taylor-rule models provide a fruitful direction for future research. In the open-economy empirical literature, much effort has been put into reconciling the speed of adjustment of real exchange rates to the speed of adjustment of prices. Various authors have suggested that the half-life of real exchange rates might be overstated because of estimation bias. (See, for example, Murray and Papell, 2002, who emphasize the imprecision in estimates of the speed of reversion of real exchange rates. But Choi, Mark, and Sul (2006) find an unbiased point estimate of the half life of 3 years, with a 95% confidence interval between 2.3 to 4.2 years.) Others have suggested that aggregation bias can account for sluggish real exchange rate adjustment. That is, individual goods prices might adjust more quickly than the real exchange rate because the CPI-based real exchange rate aggregates individual prices, and aggregates adjust more slowly (Imbs, Mumtaz, Ravn, and Rey, 2005.) Others have attempted to reconcile the behavior of prices and real exchange rates by appealing to non-linearities (e.g., Taylor, Peel, and Sarno, 2001), or to some sort of slow adjustment of nominal exchange rates, perhaps due to transactions costs in foreign exchange markets (Cheung and Lai, 2004). What is intriguing about the open-economy models based on Taylor rules and Calvo price adjustment is that there may be no need to reconcile sluggish real exchange rate adjustment with the frequency of price setting.

### 3. Granger-causality tests and variance bounds

We have emphasized that in models encapsulated by equations (1) and (2), the market's expectations of future fundamentals are the key to understanding exchange-rate movements. But we then are faced with the dilemma of measuring expectations. We can follow the tack taken by Engel and West (2006) and Mark (2007), and use the forecasts from a statistical model for the fundamentals as measures of the market's expectations. But the market surely uses more information than is contained in a simple VAR forecast, so this method mismeasures expectations.

In this section, we examine two alternative approaches to evaluating present value models of exchange rates. First, we examine whether exchange rates can help forecast future (observed) fundamentals. Second, we ask whether the present value of observed fundamentals is sufficiently volatile to account for observed exchange-rate volatility. In section 4, we look at alternative methods of measuring expectations.

#### Forecasting fundamentals

If the exchange rate reacts to news about future fundamentals, then perhaps the exchange rate is useful in forecasting those fundamentals. Econometric evaluation of this observation was pioneered by Campbell and Shiller (1987). But the Campbell-Shiller analysis is not directly applicable to exchange rate models. This is because future fundamentals typically include some variables that are unobservable, even ex post. As explained in EW05, then, the present value models do not necessarily imply that the exchange rate will Granger cause fundamentals. But if the unobserved fundamentals are not the primary drivers of exchange rates, then perhaps movements in exchange rates are useful to forecast macroeconomic variables such as relative money supplies, outputs, prices or interest rates. That is, while the presence of unobserved fundamentals breaks the tight restriction tested by Campbell and Shiller, it is possible that the exchange rate might Granger cause the standard observed fundamentals. For this reason, we examine whether exchange rates Granger cause the fundamentals from the monetary and Taylor-rule models.

Following the example illustrated by EW05, set  $\mathbf{a}_2' \mathbf{x}_t$  from equation (1) equal to zero for simplicity, and write  $\mathbf{a}_1' \mathbf{x}_t = x_{ot} + x_{ut}$ , where  $x_{ot}$  stands for the fundamentals whose ex post values are observed by the econometrician, and  $x_{ut}$  signifies the unobserved fundamentals. We can rewrite equation (2) as:

$$(36) \quad s_t = (1-b)E_t \left( \sum_{j=0}^{\infty} b^j (x_{ot} + x_{ut}) \right).$$

In section 5 below, we present evidence from panel cointegration tests that  $s_t$  is cointegrated with the observed fundamentals from the monetary and Taylor-rule models. In other words, the unobserved fundamentals,  $x_{ut}$ , are found to be stationary. Equation (36) suggests that the exchange rate might contain news about future observed fundamentals,  $x_{ot}$ , though it also is affected by news about future unobserved fundamentals. We ask, then, whether the exchange rate can help forecast the observed fundamentals, in the sense that it Granger causes them.

We write the relationship between the observed fundamentals and the log of the exchange rate in error-correction form:

$$(37a) \quad s_t - s_{t-1} = \alpha_1 + \beta_1(x_{ot-1} - s_{ot-1}) + \sum_{i=1}^I \gamma_{1i}(s_{t-i} - s_{t-1-i}) + \sum_{j=1}^J \delta_{1j}(x_{ot-j} - x_{ot-1-j})$$

$$(37b) \quad x_{ot} - x_{ot-1} = \alpha_2 + \beta_2(x_{ot-1} - s_{ot-1}) + \sum_{i=1}^I \gamma_{2i}(s_{t-i} - s_{t-1-i}) + \sum_{j=1}^J \delta_{2j}(x_{ot-j} - x_{ot-1-j}).$$

The null that the exchange rate does not Granger cause the fundamentals is represented by the restriction  $\beta_2 = \gamma_{21} = \gamma_{22} = \dots = \gamma_{2J} = 0$ . If we reject this null, it means we "accept" the hypothesis that the exchange rate is helpful in forecasting future values of  $x_{ot}$ . Conversely, in order to accept the hypothesis that the observed fundamentals Granger cause the exchange rate, we must reject the null  $\beta_1 = \delta_{11} = \delta_{12} = \dots = \delta_{1J} = 0$ . We set the lag length  $J$  to 4.

In Table 1, we report results of these tests. We try three permutations of the observed fundamentals from the monetary model:  $\Delta(m_t - \hat{m}_t) - \Delta(y_t - \hat{y}_t)$ , which follows from the monetary model when the income elasticity of money demand is unity; and  $\Delta(m_t - \hat{m}_t)$  and  $\Delta(y_t - \hat{y}_t)$  separately.

We also examine whether the exchange rate can help forecast fundamental variables implied by the Taylor rule models. Rewrite the Taylor rule model as:

$$(38) \quad i_t - \hat{i}_t = \gamma(s_t - (p_t - \hat{p}_t)) + u_t.$$

Here, we have simply rolled into the disturbance term all the variables that might be targeted by the central bank other than the real exchange rate. Then using interest parity (and including the deviation from interest parity into the general disturbance term), we can rewrite equation (38) in one of two ways:

$$(39) \quad s_t = \frac{\gamma}{1+\gamma}(p_t - \hat{p}_t) - \frac{1}{1+\gamma}u_t + \frac{1}{1+\gamma}E_t s_{t+1}$$

$$(40) \quad s_t = \gamma(p_t - \hat{p}_t) + \gamma(i_t - \hat{i}_t) - u_t + (1-\gamma)E_t s_{t+1}.$$

These models suggest using  $\Delta(p_t - p_t^*)$  and  $\Delta(i_t - i_t^*)$  as measures of the fundamentals.

We perform the tests on quarterly data for the U.S. plus eighteen other OECD countries.<sup>2</sup> We use an update of the data Mark and Sul (2001), beginning in 1973:1, and have extended through the end of 2005. Nominal exchange rates are from the IFS CD-ROM (line code AE), end-of quarter observations. Exchange rates for the euro countries after 1998 were glued onto the euro-dollar rate with the appropriate normalization. We used quarterly industrial production indices for all countries as a proxy for national income because quarterly GDP is unavailable for several countries in the sample. The IMF's International Financial Statistics (IFS line code 66) provides our measure of industrial production. Our measure of money is from the IFS and is the sum of money (line code 34) plus quasi-money (line code 35) for all countries with the following exceptions for Great Britain, Norway, and Sweden due to availability. Money is M0 from the IFS for Great Britain, M2 from the OECD's Main Economic Indicators for Norway, and M3 also from the OECD for Sweden. The IFS continues to report currency, demand deposits and other deposits for euro-zone countries after the introduction of the euro. Price levels are measured using the CPI from the IFS (line code 64).

Mark and Sul (2001) did not use data on interest rates. We use line 60c (Treasury bill rate) from IFS as a source for short-term interest rate. However, for some countries, interest rate data was not available for much of our time span from this source. For these countries, we report NA in Table 1 for causality tests involving interest rates. However, for Japan, we were able to get the data on interest rate differential from Todd Clark, who has kindly provided the dataset used in Clark and West (2006).

Here, following Engel and West (2005), we estimate the tests country-by-country (rather than using panel estimation), using the Akaike criterion to determine lag length.

The tables show that the exchange rate does have modest power in forecasting future fundamentals. This finding is certainly not uniform across all fundamentals and across all countries. The forecasting power seems more uniformly good across countries for the fundamentals based on Taylor rules: relative prices and relative interest rates.

The second panel in each table shows results from the reverse causality test: can the fundamentals forecast the change in the exchange rate. Here we find a surprisingly large number of rejections of the null that the fundamentals do not Granger cause changes in exchange rates. This evidence is in conflict with much of the literature, which has found the models have little power to forecast

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<sup>2</sup> Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Great Britain, Greece, Italy, Japan, Korea, the Netherlands, Norway, Spain, Sweden, and Switzerland.

exchange-rate changes. In section 5 below, we discuss circumstances under which the models might be useful in forecasting exchange rate changes (that is, we discuss possible cases in which the conditions of the EW05 theorem do not hold.) We explore the models' ability to forecast exchange rates in that section using the more rigorous criterion of out-of-sample forecasting power.

### Volatility

Let us define:

$$h_{it} = (1-b) \sum_{j=0}^{\infty} b^j E(x_{t+j} | \Omega_{it}), \quad 0 < b < 1.$$

$h_{it}$  is the expected present discounted value of  $x_{t+j}$ . Expectations are taken with respect to the information set  $\Omega_{it}$ , which is the market's information at time  $t$ . We think of this present value as being a component of the determinants of the exchange rate. Specifically,  $h_{it}$  is associated with the present value of the macroeconomic fundamentals that drive exchange rates that can be observed by the econometrician.

As we have stated informally above, the econometrician may measure this present value with error, because the econometrician's information set at any time  $t$ ,  $\Omega_{jt}$ , is contained in the market's information set. The econometrician can calculate:

$$h_{jt} = (1-b) \sum_{j=0}^{\infty} b^j E(x_{t+j} | \Omega_{jt}).$$

Engel and West (2004) demonstrate that if  $x_t$  is an I(1) random variable, as the discount factor,  $b$ , gets close to one,  $\text{var}(h_{jt} - h_{j,t-1}) \approx \text{var}(h_{it} - h_{i,t-1})$ . This theorem does *not* say that the econometrician's measure,  $h_{jt}$ , gets close to  $h_{it}$  as  $b \rightarrow 1$ . But the result can be used in the following way: Suppose we observe only some subset of the fundamentals that drive the exchange rate, which we call  $x_t$ . By calculating  $h_{jt}$  (where we estimate  $E(x_{t+j} | \Omega_{jt})$  from a statistical model, in this case a 4<sup>th</sup>-order autoregression in  $\Delta x_t$ ), we can derive a measure of  $\text{var}(h_{jt} - h_{j,t-1}) \approx \text{var}(h_{it} - h_{i,t-1})$ . We can then ask how  $\text{var}(h_{it} - h_{i,t-1})$  compares to  $\text{var}(s_t - s_{t-1})$ ; i.e., how much of the variance of the change in the exchange rate can be accounted for by the variance of the change in  $h_{it}$ .

To be sure, this calculation cannot tell us whether the present value  $h_{it}$  is a good model of the exchange rate. It merely seeks to answer the question of whether the observed fundamentals are volatile

enough to account for the volatility in the exchange rate (as measured by the variance of the change in the exchange rate.) This question is of some interest because exchange rates are known to be very volatile, so it is natural to ask whether there is “excess” volatility. Here, we do not mean to ask whether the variance of changes in the log of the exchange rate have a greater variance than can be explained by the present value model, because we cannot observe all of the fundamentals that belong in the present value. Instead, in essence, we ask whether the observed fundamentals can account for enough of exchange-rate volatility that they are plausible candidates for explaining highly volatile nominal exchange rates.

We first consider the monetary fundamentals:  $x_t = m_t - m_t^* - (y_t - y_t^*)$ . Table 2 reports  $\text{var}(h_{jt} - h_{jt-1}) / \text{var}(s_t - s_{t-1})$ . We report results for values of the discount factor  $b$  equal to 0.90, 0.95, and 0.99.

The table shows that the monetary fundamental can generally account for a fairly high fraction of exchange rate variance. The case of Canada is unusual because the measure of the variance ratio is greater than one, so that if the model is correct, the unobserved fundamentals would have to be negatively correlated with the monetary fundamentals. Excluding the case of Canada, the variance ratio is on average equal to 0.48 when  $b = 0.95$ .

We can write the Taylor-rule model of equation (25) as a model for nominal exchange rates:

$$(41) \quad s_t = \Phi_t + \Gamma_t,$$

where

$$(42) \quad \Phi_t = (1 - b) \sum_{j=0}^{\infty} b^j E_t(p_{t+j} - p_{t+j}^*),$$

$$\Gamma_t = \sum_{j=0}^{\infty} b^j E_t(z_{t+j} - \pi_{t+j+1} + \pi_{t+j+1}^*),$$

and  $b$  and  $z_t$  are defined as in equation (25). (Equation (41) expresses  $s_t$  in the form of equation (2), with  $\Phi_t$  and  $\Gamma_t$  corresponding to equation (2)'s present values in  $\mathbf{a}_1' \mathbf{x}_t$  and  $\mathbf{a}_2' \mathbf{x}_t$  respectively.)

In the second column of Table 2, we treat  $\Gamma_t$  as an unobserved fundamental, and assume that  $z_t$  contains a unit root. We are then relying only on  $\Phi_t$  to account for the volatility of the exchange rate, and not  $\Gamma_t$ .  $\Phi_t$  accounts for less of the variance than we found with the monetary model. Again, take for example the case of  $b = 0.95$ . The present value of the fundamentals can account for only the fraction 0.19 (averaged across all countries) of the exchange rate variance.



We leave to future work the examination of the model when  $\Gamma_t$  is included. We note that it is unlikely that the condition that  $z_t$  have a unit root is satisfied in our data for OECD countries, but if  $z_t$  is highly persistent – so that its largest root is near unity – our method of calculating the implied volatility should work in practice.

#### 4. Using Surveys to Measure Expectations

##### Announcement studies

Present-value models as characterized by equation (2) have the implication that news about current and future fundamentals influence exchange rates. We could examine the plausibility of models by testing whether exchange rates react to news about future fundamentals in the way predicted by the models.

When government agencies announce data measurements – GDP growth, unemployment rates, inflation, etc. – economic agents learn about the current value of fundamentals, and also revise their expectations of future fundamentals. “News” is the information contained in the announcement – the difference between the announced level of the economic variable and the market’s expectation. The problem confronting researchers, as we have noted, is measuring expectations. We can proceed (as in, for example, the studies of the Taylor-rule model by Engel and West (2006) and Mark (2007) discussed above) by inferring expectations from the estimates of a VAR or other statistical model. However, it is likely that the market uses many other sources of information to form expectations that are contained in typical statistical analyses, so the researcher may mismeasure expectations.

An alternative means of measuring expectations is from survey data. In particular, several recent studies have examined the response of exchange rates to announcements of economic news, and use a measure of the market’s expectation of that announcement culled from surveys of market participants. In particular these studies have typically used the surveys conducted by Money Market Services. Since 1977, MMS has conducted a survey each Friday of some 40 money managers at commercial and investment banks, recording forecasts of all indicators to be released (in the U.S.) in the subsequent week. The news contained in the release is measured as the difference between the announced value and the median forecast of that value by the MMS survey.

At least four recent papers have made use of high frequency data (Faust et al. 2003, 2007; Andersen, et al. 2003, and Clarida and Waldman 2007). These studies examine the response of the exchange rate from shortly before to shortly after the announcement (for example, in a 10-minute window.)

Many earlier studies performed similar studies (such as Engel and Frankel, 1984, and Hardouvelis, 1988), but using exchange rate changes measured at less high frequencies (for example, from open of the New York market to close of the New York market on the day of the announcement.)

The recent studies uniformly find responses of dollar exchange rates in line with the predictions of the Taylor rule model. Specifically, news of activity variables that suggest an expanding economy in the U.S., or announcements of higher inflation (greater than expected), lead to an appreciation of the dollar at the time of the announcement. To see this, write out equation (25), omitting the lagged interest rates and “unobserved” variables for convenience:

$$(44) \quad q_t = -\sum_{j=0}^{\infty} \left( \frac{1}{1+\gamma_q} \right)^{j+1} E_t \left[ (\gamma_\pi - 1)(\pi_{t+j+1} - \pi_{t+j+1}^*) + \gamma_y(y_{t+j} - y_{t+j}^*) \right].$$

Recall the restrictions on the coefficients:  $\gamma_q > 0$ ,  $\gamma_\pi > 1$ ,  $\gamma_y > 0$ .

Denote the exchange rate immediately before the announcement as  $q_{t-}$ , and immediately after,  $q_{t+}$ , and use a similar notation to capture the change in expectations. Then we have:

$$(45) \quad q_{t+} - q_{t-} = -\sum_{j=0}^{\infty} \left( \frac{1}{1+\gamma_q} \right)^{j+1} (E_{t+} - E_{t-}) \left[ (\gamma_\pi - 1)(\pi_{t+j+1} - \pi_{t+j+1}^*) + \gamma_y(y_{t+j} - y_{t+j}^*) \right].$$

From this expression, we see that the dollar should appreciate ( $q_t$  falls) if U.S. inflation is announced to be greater than expected, or if news revises upward expectations about the future U.S. output gap.

Andersen et. al. (2003) examine the response of the value of the dollar in terms of Swiss francs, (synthetic) euros, British pounds, Japanese yen, and German marks from January 3, 1992 through December 30, 1998. They look at the reaction to a wide range of macroeconomic announcements. The findings strongly go in the direction predicted by the Taylor-rule model. For example, for all five exchange rates, the dollar appreciates (on average) to positive news about U.S. GDP, non-farm payrolls, retail sales, industrial production, durable goods orders, construction spending, factory orders, and several other indicators of economic activity. If we interpret this news as meaning that agents revise their opinion about the current and future output gaps in the U.S. upward, the Taylor rule model indeed posits an appreciation of the dollar. The mechanism is that the Fed is expected to increase interest rates, which makes U.S. assets more attractive, inducing a dollar appreciation to equilibrate the asset market. Strikingly, it is also the case that the dollar appreciates against all five currencies with news about PPI or CPI inflation: when inflation in the U.S. is greater than expected, the dollar appreciates.

Faust et. al. (2007) look at the response of the German mark/euro and the British pound to macroeconomic announcements between January 9, 1987 and December 18, 2002, again for several macro variables. Their findings are very similar to those of Andersen et. al.: For both currencies, the dollar appreciates in response to positive news about U.S. economic activity. When there is a positive surprise to GDP, housing starts, nonfarm payrolls, retail sales, or a negative surprise to initial unemployment claims or unemployment, the dollar appreciates. Moreover, the dollar appreciates to positive inflation surprises to the PPI for both currencies, and to the CPI for the dollar/pound rate.

Clarida and Waldman (2007) examine the reaction of the dollar value of the Japanese yen, Canadian dollar, Norwegian krone, Swedish krona, Swiss franc, euro, British pound, Australian dollar, and New Zealand dollar from July 2001 to December 2005. This study differs from the previous two in that it uses data on macroeconomic announcements from non-U.S. countries. In particular, it looks at the reaction to news about inflation from each of these countries, as measured by the surprise component of the announcement of consumer price inflation. Expectations are measured from surveys conducted by Blomberg News Service.

The specification examines how the local currency responds to news about local inflation. In a regression that pools across all currencies, Clarida and Waldman find that an announcement of higher inflation (greater than expected) leads to a stronger currency. The findings carry over to country-by-country regressions, though they are a bit weaker in the two countries (the U.S. and Japan) that do not explicitly target inflation. Indeed, in England and Norway, there is evidence that the effect changed as the countries changed monetary policy to inflation targeting.

Faust et al. (2003) examine a slightly different situation: They look at the effects of surprise changes in the Fed's target for its policy instrument, the Fed funds rate, using high frequency data. They look at the response of the dollar value of the mark/euro and the pound to 62 announcements from March 1994 to October 2001. The expected Fed funds rate is measured from Fed funds futures data. As the models would predict, there is a strong and significant effect on the currencies, where a surprise increase in the Fed funds rate appreciates the dollar.

Engel and Frankel (1984) looked at the effects of announcements of the money supply in the US in the early 1980s on the value of the dollar. That study related the change in the exchange rate to the difference between the announced value of the money supply, and the expected value of the announced money supply as calculated from the MMS survey of forecasters. The flavor of the finding is similar to the recent studies –an unexpectedly high U.S. money supply led to an appreciation of the dollar. Why? The

markets apparently believed that the central bank was likely to react to this announcement by contracting the money supply. Indeed, Engel and Frankel also found that short term interest rates reacted positively to the money surprise. In the early 1980s, the Fed (supposedly) had a money supply target, so the reaction of the real exchange rate reflected the credibility of Fed policy. Likewise the exchange rate reaction to news about inflation in the Clarida and Waldman paper reflects credibility of inflation targeting central banks.

Hardouvelis (1988) looks at the reaction of interest rates and exchange rates to announcements of a number of economic variables in the October 1979 – August 1984 period. His findings are consistent both with Engel-Frankel and Clarida-Waldman. That is, he finds that the dollar consistently and significantly appreciates in response to positive surprises in the money supply, as in Engel-Frankel, and as we would expect if the Fed were credibly targeting the money stock. But the reaction of the dollar to announcements of CPI and PPI inflation is mixed. Across seven exchange rates, the sign of the response varies and is never statistically significant. This finding contrasts with the more recent literature which finds that positive home inflation surprises almost uniformly lead to a stronger home currency. But we note that the period of Hardouvelis's study is one in which the Fed probably had not yet established the credibility it had in the 1990s and later for fighting inflation.

### **Long-run expectations based on surveys**

In order to evaluate directly the model of the real exchange rate given by equation (44), we need a measure of expected inflation and output gap for all periods into the future. Rather than measuring expectations of macroeconomic fundamentals far into the future by using VARs, we consider survey measures of expectations. Consensus Forecasts publishes a monthly volume that surveys economic forecasters, and constructs an average forecast for a large number of economic and financial variables. Twice a year, in April and October, for some of these variables, they canvass forecasters for their forecast of that the variable will take in the current year, in each of the next five years, and then for an average for years 6 through 10 from the current year.

We use these surveys to construct the present value relationship in equation (44). We use the surveys from April 1997 to October 2006, for the U.S., Japan, Germany, France, the U.K., Canada, Italy, the Netherlands, Norway, Spain, Sweden, and Switzerland.<sup>3</sup> We use forecasts of inflation and output.

There are three important limitations to this data:

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<sup>3</sup> We note that there are missing values for Japan and Norway for October 2001, and for Norway and Switzerland for April 1997 to October 1998.

- 1) The survey asks for expectations of output, but the model requires expectations of the output gap. The expected relative output gap,  $E_t(y_{t+j} - y_{t+j}^*)$  corresponds to expected relative output for all  $j$  when the full employment level of output in the home and foreign country remain in constant proportion.
- 2) The surveys record expectations only 10 years into the future, while the sum in equation (44) requires expectations infinitely far into the future. To handle the truncation, for inflation we assume that the expectations recorded for years 6-10 for each country will hold into the indefinite future. However, it is unrealistic to assume that expected output growth differentials will continue forever. The survey provides output growth expectations for years 6-10 for each country. We assume (at each survey date) that the market expects the output growth for years 11 onward for each country to equal the average output growth expected for all countries.
- 3) There is not much data. We have observations only twice a year, for 10 years. We estimate the model in first-differences, which removes country fixed effects. So, we have at most 19 observations for each country. For a few countries, there are some missing data points and we have fewer observations.

For each date, we construct a present value of forecasts of current and future inflation, and current and future output, using a semi-annual discount factor of 0.9. We choose this value based on estimates of  $\gamma_q$  in the monetary policy rule in Germany by Clarida, Gali, and Gertler (1998). We construct the present values for output and inflation for the U.S. relative to each of the other countries.

We estimate the regression for real exchange rates in first differences:

$$(46) \quad q_t - q_{t-1} = a + b_1(PDV_{y_t} - PDV_{y_{t-1}}) + b_2(PDV_{\pi_t} - PDV_{\pi_{t-1}}) + b_3(q_{t-1} - q_{t-2}) + u_t.$$

Here,  $PDV_{y_t}$  refers to the present discounted values of relative output expectations, and  $PDV_{\pi_t}$  to the present discounted value of relative inflation expectations. We began with a specification implied by the model, with  $b_3 = 0$ , but found serial correlation in the residuals. We re-estimated including the lagged dependent variable, and we report results from both regressions below.<sup>4</sup>

We estimate the above equation by OLS, but acknowledge two potential problems: First, it is likely that there still is serial correlation in  $u_t$ . Suppose  $u_t$  is the first difference in the expected discounted sum of the errors in the monetary policy rule above,  $\frac{u_{mt} - \dot{u}_{mt} - \rho_t}{1 + \gamma_q}$ . With the real exchange rate sampled every

six months, expected changes in the monetary rule for one year or more in the future will result in serially

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<sup>4</sup> The source for consumer price data used to construct the real exchange rates is the same as in the rest of the paper (IFS, line 64.) We use the annual average exchange rate (IFS, line rf) for the nominal exchange rate.

correlated values for  $u_t$ . This problem is partly attenuated by the inclusion of the lagged change in the real exchange rate in the regression. We also have ignored the possibility of correlation between the error term and the explanatory variables in the regression, leading to coefficient estimates that might be inconsistent.

We estimate equation (44) for each of the 11 U.S. real exchange rates. The coefficients in the regressions are only occasionally significant and so we do not report them. However, this is not surprising given the paucity of data. We note that in the country-by-country regressions, the coefficient on the relative output present values have the correct sign in 10 of 11 cases, and the coefficient on the relative inflation present value is correctly signed in 9 of 11 cases.

To increase efficiency, we estimated the model as a panel. We note that estimating in differences eliminates country-specific fixed effects to levels of the real exchange rate. We estimated the panel model in three versions: with no intercept, with a common intercept, and with country-specific intercepts. In the two specifications with intercept terms, the estimated intercepts were small and statistically insignificant in all cases. The estimated coefficients on the discounted sums were essentially unaffected by the inclusion of these intercept terms, and the standard errors of the estimates increased a very small amount when intercepts were included. The results are presented below for the no-intercept case:

Regression results,  $b_3 = 0$

	Coefficients	Standard Error
Y discounted	-0.6106	0.2052
$\pi$ discounted	-3.8850	2.3606

Regression results,  $b_3 \neq 0$

	Coefficients	Standard Error
Y discounted	-0.8802	0.2115
$\pi$ discounted	-4.3405	2.2901
q lagged	0.2522	0.0678

Note especially the coefficient on the discounted sum of current and future expected inflation – it is negative. As we have emphasized, when central bank policy to target inflation is credible, an increase in home relative to foreign inflation leads to a home real appreciation.

There are obvious limitations to this empirical exercise. Aside from the data limitations described above, researchers must use survey data on expectations with a modicum of caution. We really do not have any idea whether the forecasts from the surveys do correspond to the forecasts of market

participants, and there is also the possibility that the professional forecasters are not reporting their true expectations accurately. (For example, they may “talk their book”.) But, on the other hand, the limitations of using forecasts from VARs are also well-recognized: the markets use more information than is contained in the VAR, there may be shifts in the data-generating process not captured by the VAR, etc. It is interesting and reassuring that the model fits well using this data on long-run expectations.

## 5. Out-of-Sample Forecasts based on Panel Estimates

### Motivation

Mark and Sul (2001), Rapach and Wohar (2002) and Groen (2005) have in fact found that panel error-correction models (ECM) based on the simple monetary model using the “fundamental”  $m_t - \hat{m}_t - (y_t - \hat{y}_t)$ , or the closely related purchasing power parity model, in which the fundamental is given by  $p_t - \hat{p}_t$  do have power to forecast exchange rates out of sample. The forecasting power is particularly strong at long horizons.

In this section, we replicate Mark and Sul (2001) with a longer sample, confirming the finding that the random walk can be beaten in a panel study. We do not have a precise economic or econometric story as to why panel estimates do so much better than country-by-country estimates. We conjecture that the efficiency of panel estimation is key.

In any event, we know from the argument in section 1 that beating the random walk requires a stationary unobserved component to the fundamentals. Consistent with the monetary model in equation (7), we label this component  $\rho_t$ , and our discussion interprets this as a risk premium. On the one hand, the EW05 result shows that acceptable formulations of the monetary model imply that the exchange rate should look very much like a random walk. The calculations in EW05 find that the exchange rate would be nearly unforecastable if it is entirely determined by the observable fundamentals, given the observed data-generating processes for these fundamentals. But it is also possible that, in an ECM framework, the monetary model could be used to forecast changes in exchange rates, especially at longer horizons, when the unobserved  $\rho_t$  is present.

Consider this example, which is very similar to the type of model that Campbell (2001) uses to account for long-horizon predictability in stock prices:<sup>5</sup>

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<sup>5</sup> See also Mark and Sul (2002) for a related discussion of the asymptotic power of long-horizon regression tests in error-correction models.

Suppose the exchange rate is determined by:

$$s_t = (1-b)x_t + b\rho_t + bE_t s_{t+1}.$$

Assume the fundamental  $x_t$ , is observed, and for simplicity assume it follows a random walk process:

$$x_t - x_{t-1} = \varepsilon_t, \quad \varepsilon_t \sim \text{i.i.d.}, \quad \sigma_\varepsilon^2 \equiv \text{var}(\varepsilon_t).$$

We could assume that the first difference is serially correlated, as in Example 1 in section 1 above. When  $b$  is close to one, the observed fundamental imparts near-random-walk behavior to the exchange rate. Our point here is made more transparent by simply assuming the observed fundamental is a random walk.

Now assume the deviation from uncovered interest parity,  $\rho_t$ , which is the unobserved fundamental, follows a stationary first-order autoregressive process:

$$\rho_t = \alpha\rho_{t-1} + u_t, \quad u_t \sim \text{i.i.d.}, \quad \sigma_u^2 \equiv \text{var}(u_t).$$

The forward-looking no-bubbles solution for the exchange rate is:

$$(47) \quad s_t = x_t + \frac{b}{1-b\alpha} \rho_t.$$

Assume that the econometrician does not have an independent observation of the risk premium. However, if the model is correct, then the econometrician can observe the "error",  $z_t \equiv x_t - s_t$ , which is an indirect observation on  $\rho_t$ , since

$$(48) \quad z_t = x_t - s_t = \frac{-b}{1-b\alpha} \rho_t.$$

Now, suppose we are interested in forecasting the  $k$ -period change in the log of the exchange rate, using an error-correction model. We have:

$$(49) \quad \begin{aligned} s_{t+k} - s_t &= x_{t+k} - x_t + \frac{b}{1-b\alpha} (\rho_{t+k} - \rho_t) \\ &= \sum_{j=1}^k \varepsilon_{t+j} + \frac{b}{1-b\alpha} (\alpha^k - 1) \rho_t + \frac{b}{1-b\alpha} \sum_{j=1}^k \alpha^{k-j} u_{t+j} \\ &= \sum_{j=1}^k \varepsilon_{t+j} + (1 - \alpha^k) z_t + \frac{b}{1-b\alpha} \sum_{j=1}^k \alpha^{k-j} u_{t+j} \end{aligned}$$

How good are forecasts of the change in the exchange rate at the  $k$ -horizon? We can use the theoretical R-squared from the above error-correction model, assuming the parameters are known, to gauge this. We calculate this R-squared for the  $k$ -period ECM as:

$$(50) \quad R_k^2 = \frac{(\alpha^k - 1)^2 \text{var}(x_t)}{\text{var}(s_{t+k} - s_t)} = \frac{(1 - \alpha^k)^2 \sigma_u^2}{(1 - \alpha^k)^2 \sigma_u^2 + (1 - \alpha^{2k}) \sigma_u^2 + (k(1 - \alpha^2)(1 - b\alpha)^2 \sigma_\varepsilon^2 / b^2)}.$$



This R-squared may take on a humped-shape pattern in  $k$ . For the shortest horizons, it may be small, but may initially increase as  $k$  increases. However, as  $k$  goes to infinity, the R-squared goes to zero.

Calibrating this model is difficult because we do not have a good measure of the variance of innovations to  $\rho_t$ , or a measure of its serial correlation. Suppose that the ratio of standard deviations of the innovations of the observed fundamental to  $\rho_t$  is 3: that is,  $\sigma_\varepsilon / \sigma_u = 3$ . Suppose further that the serial correlation of  $\rho_t$  in quarterly data is 0.95., and set the discount factor as  $b = 0.90$ . Then we find that  $R_1^2 = .02$ , meaning little short-run predictability. But initially, as the horizon increases, the predictability from the ECM rises. At 16 quarters, we have  $R_{16}^2 = 0.21$ , and the maximum R-squared occurs at 44 quarters, with a value of  $R_{44}^2 = 0.28$ . It seems possible that we would not detect any short-run forecasting power for the model in this case, but that at longer horizons the forecasting power would become more apparent. As we shall see, this intuition is not well borne out when we estimate forecasting equations country by country; by and large, there is not much more predictability at long ( $k = 16$  quarters) than at short ( $k = 1$  quarter) horizons. But when we estimate a panel, and forecasts rely in part on mean reversion in panel estimates of time effects, we find distinctly more predictability at 16 than at 1 quarter horizons. Perhaps this occurs because all of the exchange rates are dollar exchange rates, and there is a common element to the risk premium. That is,  $\rho_{it} = \bar{\rho}_t + \zeta_{it}$  for exchange rate  $i$ , so that the panel estimation is picking up the common component of the risk premium,  $\bar{\rho}_t$ .

### Forecasting methodology

Here we update the previous studies. It has been claimed that the forecasting power of models is sensitive to the sample (for example, see Faust, Rogers, and Wright (2003)), so it is useful to re-examine previous studies using more current data.

Our econometric analysis centers on panel estimation of the short-horizon predictive regression,

$$(51) \quad s_{it+k} - s_{it} = \beta_k z_{it} + \varepsilon_{it+k},$$

where

$$z_{it} \equiv x_{it} - s_{it}, \text{ and } \varepsilon_{it} \equiv \zeta_i + \theta_t + u_{it}.$$

Here,  $i$  indexes the country and  $t$  is the time period. We give the regression error  $\varepsilon$  an unobserved components interpretation where  $\zeta_i$  is an individual-specific effect,  $\theta_t$  is a time-specific effect that allow us to account for a limited amount of  $t$  cross-sectional dependence, and  $u_{it}$  is the residual idiosyncratic error.

$z_{it} \equiv x_{it} - s_{it}$  is the error-correction term representing the deviation of the exchange rate from the fundamentals for country  $i$ . Monetary fundamentals are defined as in Example 1,

$$(53) \quad x_{it} \equiv m_{0t} - m_{it} - \gamma(y_{0t} - y_{it})$$

with  $\gamma = 1$  and where the U.S. serves as the base country (denoted by '0'). Alternatively, PPP fundamentals are defined as:

$$(54) \quad x_{it} = p_{0t} - p_{it}.$$

We also consider fundamentals based on the Taylor rule. As in Molodtsova and Papell (2007), we develop an error correction formulation for the Taylor rule model by noting that under uncovered interest parity,  $E_t s_{it+1} = i_{0t} - i_{it} + s_{it}$ . We then replace  $i_{0t} - i_{it}$  with the components of the (relative) Taylor rules. So here we use  $i_{0t} - i_{it} = 1.5(\pi_{0t} - \pi_{it}) + 0.1(y_{0t}^g - y_{it}^g) + 0.1(s_{it} + p_{it} - p_{0t})$ , a Taylor rule that we posit (rather than estimating the coefficients.) Here,  $y^g$  is the output gap, computed with an HP filter. The parameter on the inflation gap is fairly standard (and coincides with the estimated Taylor rules in M07). We have used a slightly smaller coefficient on output gap than is typically used, on the grounds that many of the countries in our sample have announced pure inflation targeting regimes. We have used a parameter of 0.10 on the real exchange rate as in our Taylor-rule models discussed above. Thus we have:

$$(55) \quad x_{it} = 1.5(\pi_{0t} - \pi_{it}) + 0.1(y_{0t}^g - y_{it}^g) + 0.1(s_{it} + p_{it} - p_{0t}) + s_{it}.$$

The Taylor rule model then gives us  $E_t s_{it+1} - s_{it} = x_{it} - s_{it}$ . Following Molodtsova and Papell (2007), we use the forecasting model  $E_t s_{it+k} - s_{it} = \beta_k (x_{it} - s_{it})$ . Molodtsova and Papell find that the Taylor rule model is able to forecast well at short-horizons using univariate methods, while finding little support for the monetary or PPP models at any horizon.

The predictive regression is most appealing when  $z$  is  $I(0)$ , or equivalently when  $x$  and  $s$  are cointegrated. Since we are not estimating the cointegration vector, we can test for cointegration with standard unit-root tests. We use Sul's (2006) RMA test, in which the null hypothesis being tested is that  $z_{it}$  is  $I(1)$  for all  $i$ . Details are in the notes to Table 3. The results reported in that Table indicate that we reject the null of no cointegration for PPP and Taylor rule fundamentals but not monetary fundamentals. In the interest of simplicity, however, and in light of the possible low power of unit root tests, we forecast using  $z$  as defined above for monetary as well as PPP and Taylor rule fundamentals.

We generate out-of-sample forecasts both at a short-horizon ( $k=1$ ) and at a long-horizon ( $k=16$ ). We begin by estimating the predictive regression by LSDV on observations available through 1982.4. The

$k=1$  regression is then used to forecast the 1-quarter ahead exchange rate return in 1983.1 and the  $k=16$  regression to forecast the 16 quarter ahead exchange rate return through 1986.4. We then update the estimation sample by one period by adding the observation for 1983.1 and repeat the procedure. This recursive updating scheme gives us 92  $k=1$  forecasts and 77 overlapping  $k=16$  forecasts. We compare the panel regression forecasts against those implied by the random walk model. We do this for both for the monetary, PPP and Taylor rule fundamentals. In the Taylor rule forecasts, we compute the output gap with an HP filter, using only the data in the estimation sample.

Because the time effect enters contemporaneously in the predictive regression, the  $k$ -period ahead forecast requires a forecast of the time effect. We use the recursive mean of the time effect as this forecast and form the exchange rate prediction according to

$$(56) \quad s_{it+k} - s_{it} = \hat{\zeta}_i + \left( \frac{1}{t} \sum_{j=1}^t \hat{\theta}_i \right) + \hat{\beta} z_{it}.$$

We measure relative forecast accuracy with Theil's  $U$ -statistic – the ratio of the root-mean-square prediction error (RMSPE) from two competing models.  $U < 1$  if forecasts from the predictive regression are more accurate than the random walk. We report  $t$ -statistics from the Clark and West (2006, 2007) procedure for testing for equal predictive ability of two nested models.

The data are the same as used in section 3, except that we control for seasonality by filtering the money and output series by applying a one-sided moving average of the current observation and 3-lagged values.

## Results

The prediction results for the US are displayed in Table 4. We compare the predictive power of the models against two versions of the random walk: with drift and without drift. Engel and Hamilton (1990) and Diebold et. al. (1994) make the case for using the random-walk-with-drift null. Engel and Hamilton present evidence that one can reject the null that the drift in the exchange rate of the dollar (against the yen, mark, and pound) is constant in their sample. They then note “The driftless random walk is just a special case of this hypothesis. Imposing a particular value for the drift (in this case, zero) may of course improve the fit over selected subsamples...” (p. 701). That is, using a zero drift random walk as the null imposes a restriction that does not come from theory, but instead from peeking at the data. However, a and Meese and Rogoff (1983a) did use the driftless random walk as the null, and indeed in our sample the driftless random walk outperforms the random walk with drift in forecasting exercises. So we report the performance of the model against both null hypotheses.

At the 1-quarter horizon, the monetary fundamentals (Table 4a) produce a lower RMPSE than the random walk with drift for 13 of the 18 currencies, but they outforecast the random walk with no drift for 6 of the 18 exchange rates. In only 4 cases does the monetary model significantly (at the 10% level, using the 1-sided t-test based on the Clark-West statistic) outforecast the random walk with no drift at the short horizon, but the model performs significantly better than the random walk with drift for 9 exchange rates.

The PPP fundamentals (Table 4b) also generally produce lower RMPSEs than the random walk with drift (in 15 out of 18 cases), but not so for the driftless random walk (a lower RMPSE in only 7 of 18 cases), at the 1-quarter horizon. In general, the performance of the PPP model and the random walk are very similar at the 1-quarter horizon, with U statistics very near unity. The PPP model produces significantly lower RMPSEs than the random walk with drift for six exchange rates, but it outperforms the driftless random walk significantly in only three cases at the 1-quarter horizon.

The Taylor rule model's performance (Table 4c) at the 1-quarter horizon is similar to that of the PPP model. The RMPSE of forecasts from the Taylor rule model are very close to those from the random walk, both with and without drift. The Taylor rule model actually produces a lower RMPSE than the random walk with drift for 14 of the 18 currencies, but does so for only 2 currencies for the driftless random walk. Of the 14 cases in which the Taylor-rule model yields lower RMPSEs than the random walk with drift, only three are significantly lower.

The forecasting performance of the models relative to the random walk at the 1-quarter horizon is not very good, which is exactly what the EW05 theorem predicts. However, the picture changes when we look at the 16-quarter ahead forecasts.

The monetary model (Table 4a) produces lower RMPSEs than the random walk with drift for all but two currencies (Greece and Australia) at the 16-quarter horizon, though for only 11 of the 18 currencies when the null is the random walk without drift. The average U-statistic across all of the 18 currencies is quite low, 0.769. The monetary model does very well in forecasting some currencies. The monetary models' forecast is significantly better than the random walk with drift for 15 currencies, and significantly better than the random walk without drift for eleven currencies. In the latter case, the average U statistic is 0.951.

It is interesting to examine the models in which the random walk with no drift performs better than the random walk with drift. The British pound is a case in point – the ratio of the RMPSE for the random walk with no drift to the random walk with drift is 1.541 (= .9405/.6102.) The monetary model outforecasts the random walk with drift, but not the driftless random walk. It would have taken a courageous forecaster

to choose the random walk with no drift as the forecasting model in 1983. The pound depreciated from a price of \$2.58 in June 1973 (and \$2.42 in October 1980) to \$1.09 in February 1985. It surely must have seemed like there was downward drift in the dollar/pound rate at that point, but indeed the pound eventually appreciated to \$1.87 in May 1988 then fluctuated and reached a value of \$1.96 in December of 2006. It is clear why the random walk model with no drift does better than the random walk with drift if the drift were estimated over the 1973-1985 period, but that clarity comes perhaps only with hindsight. We have performed recursive t-tests currency-by-currency for the null of no drift in the random walk using 16 quarter changes.<sup>6</sup> Roughly speaking, at any given date between 1982 and 2005, we would reject the null of no drift for about half the exchange rates.

The PPP model (Table 4b) produces a lower RMPSE than the random walk with drift for all currencies except the Greek drachma. In this case, the improvement is significant in 15 of the cases, and the average U statistic is 0.702. Compared to the random walk with no drift, the PPP model produces a lower RMPSE in 14 of the 18 cases, and it is significantly better for 13 of the currencies. The average U statistic is 0.876, and 0.770 across the 14 currencies for which the RMPSE was lower than the random walk. The PPP model is able to deliver large improvements in forecast accuracy relative to the random walk at longer horizons.

The results are mixed at the 16-quarter horizon for the Taylor rule model (Table 4c). The model produces RMPSEs that are lower than the random walk with drift for 14 currencies, but only 2 are significantly lower. The random walk with no drift outperforms the Taylor rule model in terms of RMPSE for 11 of the 18 currencies.

Table 5 produces the analogous statistics to Table 4, but when the models are estimated country by country, rather than by panel. It is clear from the table that the panel estimates improve the forecasts relative to the single-equation estimation for the monetary and PPP models, in terms of RMPSE. However, the Taylor rule model performs about as well with single-equation estimation as with the panel. Perhaps this occurs because the restrictions imposed by the panel – that the model is identical across all countries – are far too strong in this case, because monetary rules differ too much across the set of 18 countries.

There is one interesting aspect of Table 5 that requires comment. There are several cases (for example, see the 16-quarter ahead forecast for Sweden for the PPP model, reported in Table 5b) in which the Clark-West t-statistic indicates that the model significantly outperforms the random walk (both with drift and without drift), even though the Theil U statistic is greater than one, indicating that the RMPSE for the

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<sup>6</sup> The results are not reported, but are available upon request.

model was greater than for the random walk. We can understand this, taking the particular example of the PPP model for Sweden: In this case, there is a very high positive correlation between the 16-quarter change in the exchange rate and the 16 quarter ahead forecast from the structural model (around 0.67). The structural forecast, however, overshoots by a long margin - that is, the forecast points in the right direction (tends to be positive when subsequent 16 quarter change is positive, negative when 16 quarter change is negative), but is much too large in absolute value. Because the forecasted change is too large, the model has a large MSPE and the U statistic is greater than one. But because it is highly correlated with the actual change in the exchange rate, there is strong evidence against the random walk.

Table 6 summarizes the results presented in detail in Tables 4 and 5. Overall, our conclusion is that the models estimated using panel techniques and producing forecasts at long horizons have some power to beat the random walk. The results are not uniformly strong across the models, in keeping with the EW05 theorem, but it does appear that this approach increases the forecasting power of the models.

## 6. Conclusions

For many years, the standard for evaluating exchange rate models has been out of sample fit. In particular, exchange rate models have been deemed successful or unsuccessful based on their ability to produce better forecasts than the random walk model.

However, many of the models actually imply that the exchange rate should nearly follow a random walk. We should not expect the models to have much power to forecast changes in exchange rates. This might be disappointing news for forecasters working on Wall Street, but may be good news for open-economy macroeconomists. The usual finding that the models cannot beat a random walk – especially at short horizons – does not mean that open-economy models have been using the “wrong” exchange rate model, or models that have been refuted by the data.

In fact, and in contrast to many previous studies, we have found evidence that the monetary models do help to forecast changes in exchange rates. That is, with panel techniques, our findings are that the model generally produces better forecast than the random walk – lower mean-squared prediction errors. We find these results encouraging, because they confirm the positive findings of previous studies that have used monetary exchange-rate models estimated by panel techniques to forecast exchange rates. But we do not intend to rely on these positive results as our sole piece of evidence in favor of the models. As we have explained, out-of-sample forecasting power relative to the random walk is an unreliable gauge for measuring the models.

At the same time, failure to predict changes in the exchange rate is not a badge of honor for a model. We must develop other means for evaluating and comparing models. This task is made especially difficult because of the fact that plausible models capture the fact that exchange rates are asset prices, and are therefore primarily driven by expectations. Because we do not have a direct measure of the market's expectation, we cannot test the models directly.

The array of evidence presented in this paper – including out-of-sample forecasting comparisons – lends weight to monetary models of exchange rates. That is, to a large extent, the evidence is consistent with the view that nominal exchange rate movements are monetary phenomena. It is, however, especially important to pay attention to how monetary policy is formulated, because expectations of future monetary conditions play an important role in determining current exchange rates.

We do not intend to claim that the evidence in this paper is conclusive in favor of macroeconomic models of the exchange rate. There may well be room for models with private information (such as Bacchetta and van Wincoop (2006)), or models based on the microstructure of foreign exchange markets (e.g., Evans and Lyons (2003)) to improve our understanding of currencies. Moreover, our empirical verification of the models here is by no means the final word. We hope, instead, that this paper sparks a renewed interest in the empirical examination and comparison of exchange rate models, but using tests that can fairly support or reject one model in favor of another.

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**Table 1**  
Granger-Causality Tests

	Austria	Australia	Belgium	Canada	Denmark	Finland	France	Germany	Greece
	H0: $\Delta s$ fails to cause $\Delta x_o$								
<i>i-i*</i>	NA		**		NA	N/A	**	**	
<i>m-m*</i>		*	**						
<i>m-m*-(y-y*)</i>		***	***			*			
<i>p-p*</i>		*	***		**			*	*
<i>(y-y)</i>		**	*		**				
	Austria	Australia	Belgium	Canada	Denmark	Finland	France	Germany	Greece
	H0: $\Delta x_o$ fails to cause $\Delta s$								
<i>i-i*</i>	N/A		**	**	N/A	N/A		**	**
<i>m-m*</i>	*		***				**	**	**
<i>m-m*-(y-y*)</i>									
<i>p-p*</i>	*		**			*	*	**	*
<i>(y-y)</i>		**				*			

**Table 1**  
**(continued)**  
**Granger-Causality Tests**

	Gt.Britain	Italy	Japan	Korea	Netherlands	Norway	Spain	Sweden	Switzerland
H0: $\Delta s$ fails to cause $\Delta x_o$									
$i-i^*$	**		***	N/A	NA	N/A			**
$m-m^*$				**					
$m-m^* - (y-y^*)$		***	*	***					
$p-p^*$				***	*			***	
$(y-y)$									
H0: $\Delta x_o$ fails to cause $\Delta s$									
$i-i^*$	***	*	*	N/A	N/A	N/A	**	**	*
$m-m^*$	**				***		**	**	***
$m-m^* - (y-y^*)$	**	***		**	**			**	**
$p-p^*$	*	**		***				*	**
$(y-y)$	**	***			**	**			**

Notes:

1. The data are quarterly, 1973:1-2005:4. In variables  $i^*$ ,  $m^*$ ,  $y^*$ , and  $p^*$ , the “\*” denotes data from one of the eighteen countries listed in the headers to the columns, while variables with no star refer to the U.S. Variable definitions:  $i$  and  $i^*$  are Treasury bill rates;  $m$  and  $m^*$  are the sum of money plus quasi-money, with exceptions noted in the text;  $y$  and  $y^*$  are industrial production;  $p$  and  $p^*$  are the CPI;  $s$  is the end of quarter nominal exchange rate versus the U.S. dollar. All variables except  $i$  and  $i^*$  are measured in logarithms. In Euro area countries, post-1998 data on exchange rates were glued to the earlier data, with suitable normalization. For further details see section 3.

2. We estimated bivariate error-correction models in  $(\Delta S_t, \Delta x_{ot})'$ , where  $\Delta S_t$  is the change in the (log) of the nominal exchange rate and  $x_{ot}$  is one of the five variables listed in the rows of each of the two panels. Each equation in the bivariate model included a constant, a lag of  $x_{ot} - S_t$  and four lags of  $\Delta S_t$  and  $\Delta x_{ot}$ .

3. The table reports the results of F-tests of the null of no Granger causality. The top panel reports tests of the null that the coefficients on all four lags of  $\Delta S_t$  are zero in the equation for  $\Delta x_{ot}$ ; the bottom panel reports parallel tests for lags of  $\Delta x_{ot}$  in the  $\Delta S_t$  equation. Rejections are indicated at the 10% (\*), 5% (\*\*) and 1% (\*\*\*) levels.

Table 2  
Variance Ratios

	b	fundamental			b	fundamental			b	fundamental	
		m-y-(m*-y*)	p-p*			m-y-(m*-y*)	p-p*			m-y-(m*-y*)	p-p*
Australia	0.9	0.349	0.152	France	0.9	0.326	0.063	Korea	0.9	0.549	0.151
	0.95	0.364	0.228		0.95	0.353	0.111		0.95	0.611	0.205
	0.99	0.378	0.356		0.99	0.381	0.219		0.99	0.678	0.28
Austria	0.9	0.327	0.079	Germany	0.9	0.412	0.053	Netherlands	0.9	0.252	0.154
	0.95	0.347	0.079		0.95	0.481	0.087		0.95	0.272	0.156
	0.99	0.363	0.157		0.99	0.561	0.156		0.99	0.293	0.158
Belgium	0.9	0.449	0.065	Greece	0.9	0.605	0.306	Norway	0.9	0.302	0.112
	0.95	0.515	0.108		0.95	0.62	0.543		0.95	0.283	0.165
	0.99	0.589	0.194		0.99	0.637	1.12		0.99	0.268	0.251
Canada	0.9	6.981	0.147	Gt.Britain	0.9	0.458	0.185	Spain	0.9	0.559	0.206
	0.95	6.832	0.169		0.95	0.54	0.283		0.95	0.627	0.366
	0.99	6.705	0.191		0.99	0.642	0.456		0.99	0.701	0.737
Denmark	0.9	0.528	0.045	Italy	0.9	0.527	0.196	Sweden	0.9	0.433	0.098
	0.95	0.554	0.053		0.95	0.597	0.343		0.95	0.44	0.134
	0.99	0.58	0.063		0.99	0.682	0.667		0.99	0.45	0.186
Finland	0.9	0.538	0.139	Japan	0.9	0.481	0.034	Switzerland	0.9	0.431	0.047
	0.95	0.594	0.24		0.95	0.551	0.044		0.95	0.442	0.078
	0.99	0.651	0.458		0.99	0.627	0.059		0.99	0.453	0.14

Notes:

1. Data are described in notes to Table 1.

2. Let  $x_t = m_t - m_t^* - (y_t - y_t^*)$  or  $x_t = p_t - p_t^*$ , let  $b$  be one of the three discount factors listed in the Table, and let  $h_{jt} = (1 - b) \sum_{j=0}^{\infty} b^j E(x_{t+j} | \Omega_{jt})$ , where the expectation is computed using a fourth order autoregression in  $\Delta x_t$ . The table reports estimates of  $\text{var}(h_{jt} - h_{j,t-1}) / \text{var}(s_t - s_t)$ . See the "Volatility" subsection in section 3 of the paper for more details.

Table 3  
Panel Unit Root Tests

	Monetary		PPP		Taylor rule	
	t-stat	p-value	t-stat	p-value	t-stat	p-value
H0: unit root in common factor	-1.155	>0.10	-1.897	<.05	-2.141	<.05
H0: unit roots in error correction terms in all 18 countries	n.a		-4.713	<.001	-6.356	<.001

Notes:

1. Data are described in notes to Table 1.

2. Let an  $i$  subscript denoting country, with the U.S. defined to be country 0 ( $i = 0$ ). In country  $i$  ( $i \neq 0$ ) let  $x_{it}$  be one of three measures of fundamentals:  $x_{it} = m_{0t} - m_{it} - (y_{0t} - y_{it})$  (monetary fundamentals);  $x_{it} = p_{0t} - p_{it}$  (PPP fundamentals);

$$x_{it} = 1.5(\pi_{0t} - \pi_{it}) + 0.1(y_{0t}^g - y_{it}^g) + 0.1(s_{it} + p_{it} - p_{0t}) + s_{it} \text{ (Taylor rule fundamentals, where } y^g \text{ is the HP filtered output gap)}.$$

3. For any one of the measures of fundamentals defined in the previous note, let  $z_{it} = x_{it} - s_{it}$  denote the corresponding error correction term.

4. The table report's Sul's (2006) panel unit root test. The procedure first tests whether one can reject a unit root in a common factor. If that null is rejected, one performs a panel unit root test of the null that  $z_{it}$  is I(1) for all eighteen countries. The regressions include a time trend and individual country fixed effects.

## Table 4a

Panel data error-correction forecast evaluation using monetary fundamentals

	No Drift				Drift			
	u(1)	cw	u(16)	cw	U(1)	cw	u(16)	cw
Australia	1.027	0.695	1.306	0.675	1.018	0.226	1.028	0.906
Austria	1.000	0.618	<b>0.860</b>	<b>1.437</b>	<b>0.994</b>	1.170	<b>0.802</b>	<b>3.118</b>
Belgium	1.007	0.675	<b>0.786</b>	<b>1.912</b>	1.000	1.271	<b>0.669</b>	<b>3.168</b>
Canada	1.174	-0.952	1.092	<b>1.604</b>	1.156	-1.355	<b>0.900</b>	<b>1.665</b>
Denmark	1.011	0.093	1.043	0.796	<b>0.999</b>	0.995	<b>0.823</b>	<b>2.012</b>
Finland	1.003	0.684	<b>0.975</b>	0.883	<b>0.991</b>	<b>1.292</b>	<b>0.784</b>	<b>1.462</b>
France	1.005	0.229	<b>0.826</b>	<b>1.603</b>	<b>0.991</b>	<b>1.285</b>	<b>0.610</b>	<b>4.311</b>
Germany	<b>0.988</b>	<b>1.515</b>	<b>0.622</b>	<b>2.450</b>	<b>0.983</b>	<b>1.768</b>	<b>0.576</b>	<b>3.585</b>
Greece	1.010	<b>2.343</b>	1.359	<b>1.578</b>	1.031	-0.983	1.262	-0.137
Gt.Britain	1.004	0.326	1.010	0.747	<b>0.990</b>	<b>1.328</b>	<b>0.676</b>	<b>2.731</b>
Italy	1.013	0.671	1.175	0.620	<b>0.986</b>	<b>1.523</b>	<b>0.740</b>	<b>1.439</b>
Japan	<b>0.998</b>	0.754	<b>0.854</b>	<b>1.430</b>	<b>0.999</b>	1.186	<b>0.849</b>	<b>3.256</b>
Korea	<b>0.996</b>	0.878	<b>0.864</b>	0.596	<b>0.987</b>	<b>1.441</b>	<b>0.717</b>	0.764
Netherlands	<b>0.991</b>	<b>1.289</b>	<b>0.751</b>	<b>2.144</b>	<b>0.985</b>	<b>1.532</b>	<b>0.683</b>	<b>3.772</b>
Norway	1.005	0.255	<b>0.898</b>	<b>1.604</b>	<b>0.996</b>	1.164	<b>0.735</b>	<b>3.630</b>
Spain	1.037	0.461	1.356	0.761	1.009	0.942	<b>0.825</b>	<b>1.726</b>
Sweden	<b>0.992</b>	1.109	<b>0.660</b>	<b>2.217</b>	<b>0.979</b>	<b>2.319</b>	<b>0.511</b>	<b>5.537</b>
Switzerland	<b>0.985</b>	<b>1.935</b>	<b>0.674</b>	<b>2.768</b>	<b>0.978</b>	<b>2.023</b>	<b>0.657</b>	<b>4.636</b>
<b>Average</b>	1.014		0.951		1.004		0.769	

Notes:

1. Data are described in notes to Table 1.

2. For quarterly horizons  $k=1$  and  $k=16$ , the panel regression  $S_{i,t+k} - S_{i,t} = \beta_k Z_{i,t} + \varepsilon_{i,t+k}$  was estimated. See notes to Table 3 for definition of the error correction term  $z_{i,t}$  for monetary (Tables 4a and 5a), PPP (Tables 4b and 5b) and Taylor rule (Tables 4c and 5c) fundamentals. The regressions include a time effect and fixed effects.

3. The sample period for the dependent variable in the initial regression sample is 1973:2-1982:4 ( $k=1$ ) or 1976:1-1982:4 ( $k=16$ ). The regression estimates (including estimates of time and fixed effects) were used as described in the text to predict the one quarter exchange rate change through 1983:1 or the 16 quarter change through 1986:4. An observation is then added to the end of the sample, and the procedure is repeated. This recursive updating scheme yields 92  $k=1$  predictions and prediction errors and 77 overlapping  $k=16$  predictions and prediction errors.

4. The “u(1)” and “u(16)” columns report Theil U-statistics, presenting the ratio of the root mean squared prediction error (RMSPE) from the procedure described in the previous note relative to the RMSPE from a random walk or random walk with drift. Values less than one are in **bold**, and indicate that the panel error correction model had a lower RMSPE than did the random walk. The drift parameter in the random walk with drift was computed recursively, using the samples described in the previous note.

4. The “cw” columns present Clark and West (2006, 2007) statistics for the null of equal predictive accuracy. Values greater than 1.282 are in **bold**, and indicate rejection at the 10% level using a one sided test.

## Table 4b

Panel data error-correction forecast evaluation using PPP fundamentals

	No Drift				Drift			
	u(1)	cw(1)	u(16)	cw	u(1)	cw	u(16)	cw
Australia	<b>0.996</b>	1.025	<b>0.870</b>	<b>1.653</b>	<b>0.987</b>	<b>1.509</b>	<b>0.684</b>	<b>5.579</b>
Austria	<b>0.998</b>	0.814	<b>0.617</b>	<b>2.746</b>	<b>0.991</b>	1.170	<b>0.575</b>	<b>3.590</b>
Belgium	1.004	0.358	<b>0.708</b>	<b>2.582</b>	<b>0.997</b>	1.006	<b>0.602</b>	<b>4.028</b>
Canada	1.011	0.430	<b>0.863</b>	<b>1.811</b>	<b>0.995</b>	<b>1.433</b>	<b>0.711</b>	<b>4.258</b>
Denmark	1.006	-0.052	<b>0.887</b>	<b>1.409</b>	<b>0.995</b>	1.044	<b>0.700</b>	<b>3.120</b>
Finland	1.001	0.464	<b>0.775</b>	<b>1.395</b>	<b>0.990</b>	<b>1.383</b>	<b>0.623</b>	<b>2.635</b>
France	1.010	-0.261	<b>0.896</b>	<b>1.443</b>	<b>0.996</b>	0.948	<b>0.661</b>	<b>3.703</b>
Germany	<b>0.999</b>	0.921	<b>0.652</b>	<b>2.486</b>	<b>0.994</b>	1.103	<b>0.604</b>	<b>2.797</b>
Greece	<b>0.998</b>	<b>2.318</b>	1.221	<b>1.533</b>	1.019	-0.395	1.134	0.372
Gt.Britain	1.006	0.420	1.063	0.580	<b>0.992</b>	1.050	<b>0.711</b>	<b>1.574</b>
Italy	1.025	0.449	1.313	0.578	<b>0.998</b>	0.746	<b>0.826</b>	1.103
Japan	<b>0.992</b>	<b>1.380</b>	<b>0.736</b>	<b>2.880</b>	<b>0.992</b>	1.136	<b>0.732</b>	<b>4.557</b>
Korea	<b>0.985</b>	<b>1.948</b>	<b>0.808</b>	0.794	<b>0.975</b>	<b>2.632</b>	<b>0.671</b>	1.148
Netherlands	1.015	0.529	<b>0.754</b>	<b>2.502</b>	1.010	0.642	<b>0.686</b>	<b>2.949</b>
Norway	1.000	0.468	<b>0.898</b>	1.075	<b>0.991</b>	1.211	<b>0.735</b>	<b>2.050</b>
Spain	1.036	0.069	1.401	0.486	1.007	0.455	<b>0.853</b>	<b>1.354</b>
Sweden	1.002	0.422	<b>0.737</b>	<b>1.539</b>	<b>0.989</b>	<b>1.657</b>	<b>0.571</b>	<b>3.127</b>
Switzerland	<b>0.995</b>	1.214	<b>0.576</b>	<b>2.271</b>	<b>0.987</b>	<b>1.387</b>	<b>0.562</b>	<b>2.158</b>
	1.004		0.876		0.995		0.702	

Notes: See notes to Table 4a.



**Table 4c**  
Panel data forecast evaluation using Taylor-rule fundamentals

<b>Taylor</b>	<b>No Drift</b>				<b>Drift</b>			
	<b>u(1)</b>	<b>cw</b>	<b>u(16)</b>	<b>cw</b>	<b>u(1)</b>	<b>cw</b>	<b>u(16)</b>	<b>cw</b>
Australia	1.005	0.627	1.047	0.541	<b>0.996</b>	<b>1.463</b>	<b>0.824</b>	1.061
Austria	1.004	0.039	<b>0.911</b>	1.064	<b>0.998</b>	0.982	<b>0.850</b>	<b>1.460</b>
Belgium	1.006	-0.881	1.051	-0.189	<b>0.999</b>	0.513	<b>0.894</b>	<b>1.958</b>
Canada	1.010	0.111	1.120	0.187	<b>0.994</b>	<b>1.295</b>	<b>0.922</b>	0.741
Denmark	1.010	-0.967	1.235	-0.726	<b>0.999</b>	0.740	<b>0.974</b>	0.435
Finland	1.009	-0.644	1.137	-0.253	<b>0.997</b>	1.243	<b>0.914</b>	0.846
France	1.012	-0.606	1.290	-0.599	<b>0.999</b>	0.665	<b>0.952</b>	0.509
Germany	1.004	0.084	<b>0.937</b>	0.907	<b>0.999</b>	0.729	<b>0.868</b>	1.225
Greece	<b>0.990</b>	<b>2.445</b>	1.175	<b>1.631</b>	1.010	-1.819	1.091	-0.073
Gt.Britain	1.013	-0.217	1.345	-0.308	<b>0.999</b>	0.615	<b>0.900</b>	0.529
Italy	1.027	0.313	1.549	-0.068	1.000	0.129	<b>0.975</b>	0.204
Japan	<b>0.997</b>	0.837	<b>0.856</b>	1.161	<b>0.998</b>	0.721	<b>0.850</b>	0.733
Korea	1.005	0.608	1.176	0.308	<b>0.995</b>	<b>1.491</b>	<b>0.976</b>	0.146
Netherlands	1.008	-0.239	<b>0.976</b>	0.988	1.002	-0.056	<b>0.888</b>	<b>2.013</b>
Norway	1.007	-0.667	1.103	-0.026	<b>0.998</b>	0.778	<b>0.903</b>	0.677
Spain	1.030	0.029	1.682	-0.402	1.001	-0.246	1.024	0.043
Sweden	1.009	-0.127	1.159	0.085	<b>0.996</b>	<b>1.440</b>	<b>0.898</b>	0.662
Switzerland	1.006	0.388	<b>0.832</b>	1.112	<b>0.999</b>	0.906	<b>0.811</b>	0.679
<b>Average</b>	1.008		1.143		0.999		0.917	

Notes: See notes to Table 4a.

## Table 5a

Single-equation error-correction forecast evaluation using monetary fundamentals

	no drift				drift			
	u(1)	cw(1)	u(16)	cw(16)	u(1)	cw(1)	u(16)	cw(16)
Australia	1.042	-0.307	1.777	0.657	1.032	-1.395	1.398	<b>1.383</b>
Austria	1.010	-0.090	1.290	0.654	1.004	0.773	1.203	<b>1.823</b>
Belgium	1.006	0.347	1.895	<b>1.931</b>	<b>0.999</b>	0.916	1.612	<b>2.764</b>
Canada	1.030	1.017	1.509	0.455	1.014	0.882	1.243	-0.082
Denmark	1.011	-0.301	1.431	<b>1.328</b>	<b>0.999</b>	0.524	1.129	<b>2.368</b>
Finland	1.014	-0.571	1.548	0.869	1.003	0.106	1.244	1.161
France	1.003	0.785	1.083	<b>2.326</b>	<b>0.989</b>	<b>1.785</b>	<b>0.799</b>	<b>4.107</b>
Germany	1.000	0.804	1.136	<b>2.071</b>	<b>0.995</b>	<b>1.295</b>	1.052	<b>2.989</b>
Greece	<b>0.990</b>	<b>2.533</b>	1.669	<b>1.482</b>	1.010	-0.973	1.549	0.091
Gt.Britain	1.010	0.131	2.029	0.748	<b>0.995</b>	0.960	1.358	<b>2.064</b>
Italy	1.016	0.906	1.287	1.054	<b>0.990</b>	<b>1.402</b>	<b>0.810</b>	<b>1.526</b>
Japan	1.008	-0.344	1.282	0.305	1.008	0.120	1.274	<b>1.771</b>
Korea	1.017	1.057	1.187	0.489	1.007	<b>1.377</b>	<b>0.986</b>	0.335
Netherlands	1.000	0.773	<b>0.949</b>	<b>1.530</b>	<b>0.995</b>	<b>1.293</b>	<b>0.864</b>	<b>2.605</b>
Norway	1.006	0.427	1.536	<b>1.604</b>	<b>0.997</b>	0.856	1.257	<b>3.085</b>
Spain	1.040	0.387	1.974	<b>1.373</b>	1.011	0.065	1.202	<b>2.170</b>
Sweden	<b>0.998</b>	0.819	1.641	<b>1.876</b>	<b>0.985</b>	<b>1.806</b>	1.272	<b>4.005</b>
Switzerland	<b>0.994</b>	1.206	1.056	1.202	<b>0.987</b>	<b>1.675</b>	1.030	<b>2.760</b>
<b>Average</b>	1.011		1.460		1.001		1.182	

Notes: See notes to Table 4a.

Table 5b

Single-equation error-correction forecast evaluation using PPP fundamentals

	no drift				drift			
	u(1)	cw(1)	u(16)	cw(16)	u(1)	cw(1)	u(16)	cw(16)
Australia	1.021	-0.376	1.270	0.487	1.011	-0.018	<b>0.999</b>	<b>2.391</b>
Austria	1.002	0.293	<b>0.968</b>	<b>2.512</b>	<b>0.996</b>	0.874	<b>0.903</b>	<b>3.163</b>
Belgium	1.006	0.307	1.565	<b>2.431</b>	<b>0.999</b>	0.630	1.331	<b>3.424</b>
Canada	1.011	-0.439	1.162	0.623	<b>0.996</b>	1.007	<b>0.957</b>	<b>2.183</b>
Denmark	1.009	-0.110	1.251	<b>1.857</b>	<b>0.997</b>	0.748	<b>0.987</b>	<b>3.267</b>
Finland	1.009	-0.306	<b>0.923</b>	1.278	<b>0.998</b>	0.702	<b>0.742</b>	<b>2.042</b>
France	1.013	0.122	1.496	<b>2.099</b>	<b>0.999</b>	0.595	1.104	<b>3.973</b>
Germany	1.002	0.561	1.361	<b>2.634</b>	<b>0.997</b>	0.843	1.261	<b>2.861</b>
Greece	<b>0.992</b>	<b>2.787</b>	1.824	1.036	1.013	0.041	1.693	0.641
Gt.Britain	1.013	0.213	1.361	0.693	<b>0.999</b>	0.568	<b>0.911</b>	1.267
Italy	1.036	-0.137	1.708	0.782	1.009	-0.745	1.075	1.078
Japan	1.003	0.396	1.044	0.964	1.003	-0.100	1.037	<b>2.401</b>
Korea	<b>0.979</b>	<b>2.462</b>	<b>0.883</b>	1.006	<b>0.970</b>	<b>2.942</b>	<b>0.733</b>	<b>1.427</b>
Netherlands	1.012	-0.038	1.194	<b>2.660</b>	1.006	0.058	1.087	<b>3.004</b>
Norway	1.007	0.183	1.389	<b>1.424</b>	<b>0.998</b>	0.672	1.137	<b>2.510</b>
Spain	1.037	0.011	1.735	0.798	1.008	-1.139	1.056	<b>1.393</b>
Sweden	1.020	0.539	1.987	<b>2.158</b>	1.007	0.669	1.540	<b>4.047</b>
Switzerland	1.000	1.095	<b>0.782</b>	<b>2.356</b>	<b>0.992</b>	1.154	<b>0.762</b>	<b>2.376</b>
<b>Average</b>	1.010		1.328		1.000		1.073	

Notes: See notes to Table 4a.

Table 5c

Single-equation error-correction forecast evaluation using Taylor-rule fundamentals

	no drift				drift			
	u(1)	cw(1)	u(16)	cw(16)	u(1)	cw(1)	u(16)	cw(16)
Australia	1.010	0.700	1.004	0.742	1.001	0.328	0.790	1.269
Austria	1.007	0.119	<b>0.679</b>	<b>2.671</b>	1.001	0.412	<b>0.633</b>	<b>3.320</b>
Belgium	1.013	-0.147	<b>0.845</b>	<b>2.578</b>	1.005	-0.117	<b>0.719</b>	<b>3.992</b>
Canada	1.015	-0.035	1.145	0.275	1.000	0.278	<b>0.944</b>	0.729
Denmark	1.011	-0.738	1.200	0.223	1.000	0.235	<b>0.947</b>	1.119
Finland	1.025	-0.694	1.032	0.594	1.014	-0.555	<b>0.829</b>	1.274
France	1.024	-0.033	1.268	1.004	1.011	-0.160	<b>0.936</b>	<b>2.291</b>
Germany	1.013	-0.037	<b>0.779</b>	<b>2.398</b>	1.008	-0.034	<b>0.721</b>	<b>2.517</b>
Greece	<b>0.984</b>	<b>2.633</b>	1.187	<b>1.658</b>	1.004	0.681	1.103	-0.138
Gt.Britain	1.029	-1.313	1.502	-0.107	1.015	-1.375	1.005	0.318
Italy	1.036	-0.353	1.688	0.195	1.009	-0.165	1.063	0.201
Japan	1.003	0.499	<b>0.790</b>	<b>2.773</b>	1.004	-0.980	<b>0.785</b>	<b>3.833</b>
Korea	<b>0.998</b>	1.220	1.200	0.165	<b>0.989</b>	1.460	<b>0.996</b>	0.042
Netherlands	1.022	-0.358	1.416	<b>3.684</b>	1.016	-0.283	1.289	<b>4.366</b>
Norway	1.027	-0.555	1.004	0.471	1.018	-0.858	<b>0.822</b>	1.165
Spain	1.036	-0.389	1.889	0.111	1.007	-1.393	1.150	0.189
Sweden	1.024	0.019	<b>0.874</b>	1.110	1.011	-0.377	<b>0.677</b>	<b>2.143</b>
Switzerland	1.003	0.633	<b>0.619</b>	<b>2.002</b>	<b>0.996</b>	0.926	<b>0.604</b>	<b>1.589</b>
<b>Average</b>	1.016		1.118		1.006		0.889	

Notes: See notes to Table 4a.

**Table 6**  
Summary of forecasting results

	----- Panel -----				----- Single equation -----			
	vs. random walk		vs. random walk w/drift		vs. random walk		vs. random walk w/drift	
	u(1)	u(16)	u(1)	u(16)	u(1)	u(16)	u(1)	u(16)
<b>Monetary</b>								
No. of countries in which $u() < 1$	6	11	13	16	3	1	10	4
Mean value of $u()$	1.014	0.951	1.004	0.769	1.011	1.460	1.001	1.182
<b>PPP</b>								
No. of countries in which $u() < 1$	7	14	15	17	2	4	11	8
Mean value of $u()$	1.004	0.876	0.995	0.702	1.010	1.328	1.000	1.073
<b>Taylor rule</b>								
No. of countries in which $u() < 1$	2	5	14	16	2	6	2	12
Mean value of $u()$	1.004	1.143	0.999	0.917	1.016	1.118	1.006	0.889

Notes:

1. This table summarizes results presented for each of the 18 currencies in Tables 4a-4c (in columns headed "Panel") and 5a-5c (in columns headed "Single equation"). See notes to Table 4a for details.

2. The "u(1)" columns present results for one quarter ahead forecasts. The "u(16)" columns present results for 16 quarter ahead forecasts. When  $u(1) < 1$  or  $u(16) < 1$ , the panel or single equation forecast had lower root mean squared prediction error than did the random walk or random walk with drift model.