NBER WORKING PAPER SERIES

ACCOUNTING FOR EXCHANGE RATE VARIABILITY IN PRESENT-VALUE MODELS WHEN THE DISCOUNT FACTOR IS NEAR ONE

Charles Engel
Kenneth D. West

Working Paper 10267
http://www.nber.org/papers/w10267

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 2004

This paper was prepared for "Understanding Exchange Rate Dynamics: A Session in Memory of Rudi Dornbusch," a session at the AEA meetings in San Diego, January 4, 2004. We thank Mark Watson for helpful discussion, and Camilo Tovar for excellent research assistance. Both authors thank the National Science Foundation for support for this research. The views expressed herein are those of the authors and not necessarily those of the National Bureau of Economic Research.

Accounting for Exchange Rate Variability in Present-Value Models When the Discount Factor is Near One
Charles Engel and Kenneth D. West
NBER Working Paper No. 10267
January 2004
JEL No. F31, G12

ABSTRACT

Nominal exchange rates in low-inflation advanced countries are nearly random walks. Engel and West (2003a) offer an explanation for this in the context of models in which the exchange rate is determined as the discounted sum of current and expected future fundamentals. Engel and West show that if the fundamentals are I(1), then as the discount factor approaches one, the exchange rate becomes indistinguishable from a random walk. An alternative explanation for the random-walk behavior of exchange rates is that there are some unobserved variables that drive exchange rates that follow near random walks. This paper takes the approach that both explanations are possible. We are able to measure how much of exchange-rate variation could be accounted for by the Engel-West explanation, despite the fact that we do not observe the information set of financial markets. We find that the observable fundamentals (money, income, prices, interest rates) may account for about 40 percent of the variance of changes in exchange rates under the assumption of discount factors near unity.

Charles Engel
Department of Economics
University of Wisconsin
1180 Observatory Drive
Madison, WI 53706-1393
and NBER
cengel@ssc.wisc.edu

Kenneth D. West
Department of Economics
University of Wisconsin
1180 Observatory Drive
Madison, WI 53706-1393
and NBER
kdwest@facstaff.wisc.edu

A well-known stylized fact about nominal exchange rates among low-inflation advanced countries – particularly U.S. exchange rates – is that their logs are approximately random walks. Mussa (1979) is most frequently cited for observing this regularity. In a famous paper, Meese and Rogoff (1983a, 1983b) found that the structural models of the 1970s could not "beat" a random walk in explaining exchange rate movements. Recently some authors (Mark (1995), Chinn and Meese (1995), Mark and Sul (2001)) have argued that the models can outforecast the random walk at long horizons. But a comprehensive recent study by Cheung, Chinn, and Pascual (2003) documents that "no model consistently outperforms a random walk."

Why? One obvious explanation is that the macroeconomic variables that determine the exchange rate themselves follow random walks. If the log of the nominal exchange rate is a linear function of forcing variables that are random walks, then it will inherit the random walk property. The problem with this explanation is that the economic "fundamentals" proposed in the most popular models of exchange rates do not, in fact, follow simple random walks.

One resolution to this problem is that there may be some other fundamentals – ones that have been proposed in some models but are not easily measurable, or ones that have not yet been proposed at all – that are important in determining exchange rates. If these "unobserved" fundamentals follow random walks, and dominate the variation in exchange rate changes, then exchange rates will nearly be random walks (even if the standard "observed" fundamentals are not.)

Engel and West (2003a) (hereinafter, EW) propose an alternative explanation. They consider linear models of the exchange rate that are in the "asset market approach" to exchange rates. These models emphasize the role of expectations of future economic fundamentals in determining the current exchange rate. The exchange rate (expressed as the home currency price of foreign currency in this paper) can be written as a discounted sum of the current and expected future fundamentals:

(1) $$s_t = x_{tI} \equiv (1-b)\sum_{j=0}^{\infty} b^j E(f_{t+j} + z_{t+j} \mid I_t), \quad 0 < b < 1$$

where f_t and z_t are economic fundamentals that ultimately drive the exchange rate, such as money supplies, money demand shocks, productivity shocks, etc. We differentiate between fundamentals observable to the econometrician, f_t, and those that are not observable, z_t. E is the expectations operator, and I_t is the information set of agents in the economy that determine the exchange rate.

EW show that if the fundamentals are I(1) (but not necessarily pure random walks), then as the discount factor approaches unity, the exchange rate will follow a process arbitrarily close to a random walk. Intuitively, we can decompose the I(1) fundamentals into the sum of a random walk and a stationary component. When the discount factor increases toward one, more weight is being placed on expectations of the fundamentals far into the future. Transitory components in the fundamentals become relatively less important in determining exchange rate behavior. When the discount factor is near unity, the variance of the change of discounted sum of the random walk component in fundamentals approaches infinity, but the variance of the change of the stationary component approaches a constant. So the variance of the change of the exchange rate is dominated by the change of the random walk component, and the exchange rate becomes indistinguishable from a random walk.

EW argue that the theorem is a possible explanation for the random-walk-like behavior of exchange rates. In the standard models, the fundamental typically is I(1), which is a condition of the theorem. They show that empirical estimates of the discount factor are sufficiently close to one so that, given the time-series behavior of observed fundamentals, the exchange rate will appear to be a random walk if it is indeed determined as a discounted sum of the current and expected future fundamentals.

But is the EW result the most appealing explanation for the random walk behavior of exchange rates? We can write

(2) $s_t = x_{tI}^f + U_t$,

where

(3) $x_{tI}^f \equiv (1-b)\sum_{j=0}^{\infty} b^j E(f_{t+j} \mid I_t)$.

x_{tI}^f is the discounted sum of current and expected future fundamentals that the econometrician observes (f_{t+j} .) In this paper, we take f_t to be the observable fundamental that emerges from one of two classes of asset-market exchange rate models: monetary models of exchange rates developed in the 1970s, and models based on Taylor-rules for monetary policy. x_{tI}^f is the part of the exchange rate that can be explained from observed fundamentals. U_t is the part of the exchange rate not determined by x_{tI}^f. We take an eclectic view on what U_t might be. It might be the case that exchange rates are determined as in equation (1), in which case U_t is the expected discounted sum of current and future values of z_t. Or, perhaps some other type of model relates exchange rates to fundamentals, and U_t measures those fundamentals. Or, perhaps the exchange rate is driven in part by noise, in which case U_t represents that noise. If U_t is important in driving the exchange rate, then given the random-walk nature of exchange rates, U_t must be a random walk.[1] This in turn would imply that s_t and x_{tI}^f are not cointegrated.

---

[1] U_t may be a random walk if the discounted sum of unobserved fundamentals, z_t, and z_t is I(1) and the discount factor is near one. In that case, the EW theorem applies to the discounted sum of expected current and future values of z_t. However, U_t could be a random walk for any reason, not just this one.

Our task in this paper is to get a measure of the contribution of x_{tI}^f and U_t in driving exchange rates. We cannot say much about the contribution of U_t, since it is not observed by us. But even measuring the contribution of x_{tI}^f may appear to be a quixotic goal. x_{tI}^f is also unobservable to the econometrician (even though f_t is observable.) That is because x_{tI}^f measures agents' expectations about future fundamentals, which are not perfectly observed by the econometrician who only sees a subset of the information that agents use in forming their expectations. For example, if the economic fundamentals involve monetary policy, the econometrician might observe the time-series behavior of monetary policy instruments, and might observe many of the macroeconomic variables that influence monetary policy. But agents, in forecasting future monetary policy, have access to a wide variety of information that is difficult to quantify – e.g., newspaper and newswire reports, speeches by policymakers, etc.

Nonetheless, this paper demonstrates that we can measure the variance of Δx_{tI}^f (the first-difference of x_{tI}^f) when the discount factor, *b*, approaches one. To be precise, define

(4) $$x_{tH}^f \equiv (1-b)\sum_{j=0}^{\infty} b^j E(f_{t+j} \mid H_t) .$$

Here, H_t is the information set used by the econometrician. An estimate $\hat{x}_{tH}^f$ can be constructed from VARs that include f_t and other observable macroeconomic variables that might help forecast f_t. This paper demonstrates that $\text{var}(\Delta x_{tH}^f)$ approaches $\text{var}(\Delta x_{tI}^f)$ when *b* approaches one. To be clear, this does not mean that $x_{tI}^f \approx x_{tH}^f$ as $b \to 1$, and for that reason we do not look to the correlation between Δs_t and Δx_{tH}^f to gauge the EW explanation. x_{tI}^f remains unobservable to the econometrician, but, remarkably, the variance of Δx_{tI}^f can be estimated consistently.

It follows from (2) that

$$\text{(5)} \qquad \operatorname{var}(\Delta s_t) = \operatorname{var}(\Delta x_{tI}^f) + \operatorname{var}(\Delta U_t) + 2\operatorname{cov}(\Delta x_{tI}^f, \Delta U_t).$$

If only observed fundamentals matter for the exchange rate, then $\operatorname{var}(\Delta s_t) = \operatorname{var}(\Delta x_{tI}^f)$. We will take $\operatorname{var}(\Delta x_{tI}^f)/\operatorname{var}(\Delta s_t)$ as a measure of the importance of observed fundamentals in driving the exchange rate, when the discount factor is near one. This satisfies our primary objective, which is to provide some insight into how effective the approach of EW is in accounting for the random-walk behavior of exchange rates.

The outline of the remainder of the paper is: Section 2 is a short recapitulation of standard asset market models of exchange rates. Some descriptive statistics for exchange rates and fundamentals are provided in Section 3. Section 4 demonstrates that $\operatorname{var}(\Delta x_{tH}^f)$ approaches $\operatorname{var}(\Delta x_{tI}^f)$ as b goes to one. Then in Section 5 we report measures of $\operatorname{var}(\Delta \hat{x}_{tH}^f)/\operatorname{var}(\Delta s_t)$ for some standard economic fundamentals, for the other G7 countries relative to the U.S.

The ability of the fundamentals to account for the variance of changes in the exchange rates differs somewhat across measures of fundamentals and across exchange rates. Roughly, we find $\operatorname{var}(\Delta \hat{x}_{tH}^f)/\operatorname{var}(\Delta s_t)$ to be around 0.4 when we draw the fundamentals from monetary models of exchange rates, and slightly lower when the fundamentals are derived from Taylor-rule models.

2. Asset Market Models of Exchange Rates

EW review the familiar models that fall under the label of "the asset market approach to exchange rates." The simplest summary comes directly from Frenkel's (1981, p. 674-675) paper on "news" and exchange rates, which in many ways is a precursor of our work. (Here we have changed only the notation to match ours.):

"This view of the foreign exchange market can be exposited in terms of the following simple model. Let the logarithm of the spot exchange rate on day *t* be determined by:

(6) $$s_t = f_t + z_t + \lambda\left[E\left(s_{t+1} \mid I_t\right) - s_t\right]$$

where $E\left(s_{t+1} \mid I_t\right) - s_t$ denotes the expected percentage change in the exchange rate between *t* and $t+1$, based on the information available at *t*, where $f_t + z_t$ represents the ordinary factors of supply and demand that affect the exchange rate on day *t*. These factors may include domestic and foreign money supplies, incomes, levels of output, etc. Equation (6) represents a sufficiently general relationship which may be viewed as a 'reduced form' that can be derived from a variety of models of exchange rate determination."

The two types of models we consider here fall into this general form. The first is the familiar monetary model. Following Mark (1995) and others, we take the observable fundamental, f_t, to be $m_t - y_t - (m_t^* - y_t^*)$, where m_t is the log of the domestic money supply, y_t is the log of domestic GDP, and m_t^* and y_t^* are the foreign counterparts. Following the derivation in EW, the unobserved fundamental, z_t, is a linear combination of variables such as home and foreign money demand errors, a foreign exchange risk premium (multiplied by λ), and real exchange rate shocks arising from sources such as home and foreign productivity changes. In the monetary model, the parameter λ represents the interest semi-elasticity of money demand (assumed to be identical in the home and foreign country.)

The second model is less familiar, and is based on Taylor-rules for monetary policy.[2] EW examine the implications of an interest rate rule that has as one target (in either the home or foreign country policy rule, or both) deviations of the exchange rate from its purchasing power parity level, $s_t - (p_t - p_t^*)$, where p_t is the log of the domestic price level and p_t^* is the foreign

[2] Engel and West (2003b) explore the implications of Taylor-rule models for real exchange rate behavior.

counterpart. They show that there are two different representations of the model that fall into the class of models given by (6). In the first, the $f_t = p_t - p_t^*$, and $\lambda = 1/\beta$, where β is the coefficient on deviations from (log) PPP in the Taylor rule. z_t in this model is a linear combination of other variables targeted by the Taylor rule as well as perhaps money demand errors and a risk premium. Intuitively, this model fits neatly into the framework of equation (6) because the log of the exchange rate is determined by its target, $f_t = p_t - p_t^*$, and the expected movement toward the target, $(1/\beta)\left[E\left(s_{t+1} \mid I_t\right) - s_t\right]$. Another representation of the same model adds the interest differential to the difference in the log of prices, so that the observed fundamental is given by $f_t = p_t - p_t^* + (i_t - i_t^*)$. In this case, $\lambda = (1-\beta)/\beta$. In this alternative representation, z_t is again a linear combination of other variables targeted by the Taylor rule, money demand errors, and a risk premium. The exchange rate contains information not only about the long-run target, but also about the interest differential. The deviation of the exchange rate from its target helps markets predict the path of interest rates set by monetary policymakers.

Solving equation (6) forward for the exchange rate yields equation (1), where $b = \lambda/(1+\lambda)$. Based on estimates of the interest semi-elasticity of money demand, EW note that in quarterly data, for the monetary model, $b \approx 0.97$ or 0.98.[3] The value of the discount factor is similar in the Taylor-rule model, based on estimates of the responsiveness of interest rates to exchange-rate targets in monetary policymaking rules.

[3] For example, the estimates of the semi-elasticity in Stock and Watson (1993) are around 0.11. Stock and Watson express interest rates in percentages and use annual rates. To get the units correct for equation (6), we want to express interest rates in decimal form, and we are considering a quarterly frequency. So we multiply their estimate by 400, which implies an interest semi-elasticity of 44, and *b* = 44/45, or approximately 0.978.

3. The Data and Summary Statistics

We use quarterly data, with most data spanning 1973:I-2003:I. The precise data span for the first-difference in each measure of f_t is given in Table 1. The U.S. is the home country, and we measure exchange rates and fundamentals relative to the other G7 countries: Canada, France, Germany, Italy, Japan and the U.K.

The exchange rates (end-of-quarter) and consumer prices (CPI) come from the *International Financial Statistics* CD-ROM for all seven countries. Seasonally adjusted money supplies come from the OECD's *Main Economic Indicators* available on Datastream, (M4 for the U.K., M1 for the other countries.) For real seasonally adjusted GDP, the data come from the OECD with the exception that for Germany the data combines IFS data (1974:I-2001:I) with data from the OECD after 2002:I. Interest rates are 3-month Euro rates from Datastream. We take logs of all data but interest rates, and multiply all data by 100.

In addition we use a separate measure of U.S. money supply (that we label *msw*) that adds “sweep account programs” to our measure of M1 from the OECD. “Sweeps” refer to balances that are moved by U.S. banks from checking accounts to various interest-earning accounts by automated computer programs as a way for banks to reduce their required reserve holdings. It has been argued that exclusion of sweeps from the M1 data will lead to an under-measurement of true transactions balances.[4] The data on sweeps is obtained from the website of the Federal Reserve Bank of St. Louis. For our monetary model, we consider measures of the fundamentals both correcting for sweeps $msw_t - y_t - (m_t^* - y_t^*)$, and also using the uncorrected U.S. M1 data, $m_t - y_t - (m_t^* - y_t^*)$.

[4] We thank J. Huston McCulloch for pointing out this issue to us.

We examine, then, the behavior of four observed fundamentals: $m_t - y_t - (m_t^* - y_t^*)$, $msw_t - y_t - (m_t^* - y_t^*)$, $p_t - p_t^*$, and $p_t - p_t^* + (i_t - i_t^*)$, for six countries relative to the U.S. We performed ADF tests (with 4 lags) with a constant and trend for all fundamentals and exchange rates, and failed to reject the null of a unit root in almost all cases.[5] We proceeded to test for no cointegration between the exchange rate and the corresponding four fundamentals. In almost every case, we were unable to reject the null of no cointegration using Johansen's $\lambda_{\max}$ and λ_{trace} tests.[6] This latter finding suggests that there may be a role for unobserved unit-root variables (the U_t from equation (2)) in driving exchange rates.

Table 1 presents some summary statistics for the changes in exchange rates and the various measures of fundamentals. We note that Δs_t has low serial correlation for all exchange rates – that is, the exchange rate looks approximately like a random walk. However, for many of the fundamentals, the serial correlation of Δf_t is quite high (in the range of 0.5). The random-walk like behavior of exchange rates cannot be explained by random-walk like behavior in the observed fundamentals. The alternative explanations we consider are that the unobserved forcing variables for exchange rates, U_t, are random walks; or, that the EW theorem is applicable. Indeed, both explanations may have merit, so we ask how much of the variance of Δs_t can be explained by the observed fundamentals under the conditions of the EW theorem.

5. Accounting for the Variance of Exchange Rate Changes

If only observed fundamentals determined exchange rates, then we would have $s_t = x_{tI}^f$, where x_{tI}^f is defined in equation (3). As we have noted, we cannot measure x_{tI}^f because we do not have access to all of the information that markets use in forming their expectations of future

[5] The exceptions were for the fundamentals involving prices, for Japan and Italy.
[6] The exceptions were for the U.K., for the fundamentals involving prices.

fundamentals. Here we show that we can, however, measure the variance of Δx_{tI}^f, when the discount factor, *b,* is close to one. We ask whether the variance of Δx_{tI}^f is a substantial fraction of the variance of Δs_t, so that observed fundamentals can account for much of the variance in the change of log exchange rates.

We can measure x_{tH}^f as defined in equation (4) – the discounted sum of current and expected future fundamentals based on the econometrician's information, H_t. Define the innovation in x_{tI}^f as:

$$e_{tI}^f \equiv x_{tI}^f - E(x_{tI}^f \mid I_{t-1}),$$

and the innovation in x_{tH}^f as

$$e_{tH}^f \equiv x_{tH}^f - E(x_{tH}^f \mid H_{t-1}).$$

Under the assumption that all the variables in I_t follow an ARIMA(*q,r,s*) process, $q, r, s \geq 0$, and that H_t is a subset of I_t that includes at least current and past values of f_t, equation (6) in West (1988) shows that

$$\text{var}(e_{tH}^f) = \frac{1-b^2}{b^2}\text{var}(x_{tH}^f - x_{tI}^f) + \text{var}(e_{tI}^f).$$

As $b \to 1$, $\text{var}(x_{tH}^f - x_{tI}^f)$ stays bounded, but $\frac{1-b^2}{b^2} \to 0$. It follows that for *b* near one, $\text{var}(e_{tH}^f) \approx \text{var}(e_{tI}^f)$.

The EW theorem gives us that when *b* is near one, $\Delta x_{tI}^f \approx e_{tI}^f$, and $\Delta x_{tH}^f \approx e_{tH}^f$. So, we can use an estimate of $\text{var}(\Delta x_{tH}^f)$ to measure $\text{var}(\Delta x_{tI}^f)$.

A simple example may help develop intuition. Suppose $f_t = f_{t-1} + e_{1t} + e_{2t-1}$, where e_{1t} and e_{2t} are mutually independent, i.i.d., mean-zero processes. Assuming agents observe e_{1t} and e_{2t} at time *t*, we can use (3) to solve and find $s_t (= x_{tI}^f) = f_t + be_{2t}$. Then, $\Delta s_t (= \Delta x_{tI}^f) = \Delta f_t + b\Delta e_{2t} = e_{1t} + be_{2t} + (1-b)e_{2t-1}$. As $b \to 1$, $\Delta s_t (= \Delta x_{tI}^f) \to e_{1t} + e_{2t}$. Note that, as in the EW theorem, when *b* approaches 1, s_t approaches a random walk.

Now, continuing with the example, suppose that H_t contains only current and lagged values of f_t. Then, solving using equation (4), we find $x_{tH}^f = f_t$, so $\Delta x_{tH}^f = \Delta f_t = e_{1t} + e_{2t-1}$. We see in this example that as *b* nears one, $\text{var}(\Delta x_{tI}^f) \to \text{var}(e_{1t} + e_{2t}) = \text{var}(e_{1t} + e_{2t-1}) = \text{var}(\Delta x_{tH}^f)$. This equality holds even though $\Delta x_{tI}^f \neq \Delta x_{tH}^f$ (even as $b \to 1$). In this example, the EW result completely explains the random walk in s_t as $b \to 1$, but that does not mean the exchange rate change can be completely explained by observable changes in f_t. The correlation between Δs_t and Δx_{tH}^f $(= corr(e_{1t} + e_{2t}, e_{1t} + e_{2t-1}))$ could be far less than one if the variance of e_{2t} is large.[7]

6. Results

In this section, we report estimates of $\text{var}(\Delta x_{tH}^f)/\text{var}(\Delta s_t)$ for our four measures of observed fundamentals: $m_t - y_t - (m_t^* - y_t^*)$, $msw_t - y_t - (m_t^* - y_t^*)$, $p_t - p_t^*$, and $p_t - p_t^* + (i_t - i_t^*)$. In calculating this statistic, we take the econometrician's information set to be only the current and lagged value of the fundamental in each case. For the $m_t - y_t - (m_t^* - y_t^*)$ and $msw_t - y_t - (m_t^* - y_t^*)$ measures of fundamentals, we also consider the case in which the

[7] Mark Watson has pointed out to us that if $U_t = 0$, then as the discount factor approaches one, the long-run correlation between the change in x_{tH}^f and the change in the exchange rate should approach one. We do not implement this useful observation here.

information set additionally includes current and lagged values of $p_t - p_t^*$. We do so as a robustness check, reminding the reader that, specification and sampling error aside, the two information sets will generate the same value for $\text{var}(\Delta x_{tH}^f)$ as b approaches 1.

To motivate our calculation of $\text{var}(\Delta x_{tH}^f)$, let W_t be a ($n \times 1$) vector of observable variables, with $f_t = a' W_t$. Assume ΔW_t follows a VAR of order d:

$$\Delta W_t = \Phi_1 \Delta W_{t-1} + \Phi_2 \Delta W_{t-2} + ... + \Phi_d \Delta W_{t-d} + \varepsilon_{Wt}.$$

Define $\zeta(b) \equiv \left[I - b\Phi_1 - ... - b^d \Phi_d \right]^{-1}$. Then using equation (4), we can write the innovation in x_{tH}^f as:

$$e_{tH}^f = a' \zeta(b) \varepsilon_{Wt}.$$

From the EW theorem, for $b \approx 1$, we have $\Delta x_{tH}^f \approx a' \zeta(b) \varepsilon_{Wt}$.

Mechanically, then, we estimate a VAR (with four lags in all cases) that includes the fundamentals and possibly other information (as noted above). We use estimates $\hat{\zeta}(b) \equiv \left[I - b\hat{\Phi}_1 - ... - b^4 \hat{\Phi}_4 \right]^{-1}$ and $\hat{\varepsilon}_{Wt}$ to construct $\Delta \hat{x}_{tH}^f = a' \hat{\zeta}(b) \hat{\varepsilon}_{Wt}$. Tables 2, 3, and 4 report our calculations of $\text{var}(\Delta \hat{x}_{tH}^f) / \text{var}(\Delta s_t)$.

Table 2 reports this ratio when the fundamentals are $m_t - y_t - (m_t^* - y_t^*)$ and $msw_t - y_t - (m_t^* - y_t^*)$ from the monetary model. For each fundamental, only current and lagged fundamentals are assumed to be observable by the econometrician. The notable result from Table 2 is that $\text{var}(\Delta \hat{x}_{tH}^f) / \text{var}(\Delta s_t)$ is fairly large. For the first fundamental, that ratio is above 0.5 for all countries except Italy, if we take a discount factor of $b = 0.95$. Not surprisingly, the ratio rises as b increases toward 1. For the second fundamental, the reported values of the ratio

$\text{var}(\Delta\hat{x}^f_{tH})/\text{var}(\Delta s_t)$ are slightly lower, but still quite large. For one country, Canada, the results are troubling for both sets of fundamentals, because the ratio exceeds one in all cases. From equation (5), that finding is sensible only when $\text{cov}(\Delta x^f_{tI}, \Delta U_t) < 0$. That is, there must be a negative correlation between the change in the discounted sum of current and expected future fundamentals with the unobserved ΔU_t.

Table 3 reports the ratio $\text{var}(\Delta\hat{x}^f_{tH})/\text{var}(\Delta s_t)$ for these same two fundamentals, but when we augment H_t with current and lagged values of $p_t - p^*_t$. The results are quite similar to those in Table 2. This is reassuring, since our demonstration that $\text{var}(\Delta x^f_{tH}) \approx \text{var}(\Delta x^f_{tI})$ when $b \approx 1$, does not depend on what is in the information set H_t (as long as it is a subset of I_t that includes at least current and past values of f_t.)

Table 4 looks at the fundamentals $p_t - p^*_t$, and $p_t - p^*_t + (i_t - i^*_t)$ from the Taylor-rule model. The econometrician is assumed only to observe current and lagged values of the fundamental. We find here that $\text{var}(\Delta\hat{x}^f_{tH})/\text{var}(\Delta s_t)$ is a bit lower than we found for the fundamentals from the monetary model. When $b = 0.95$ or 0.99, for most countries the ratio is around 0.20, though it is about half that size for Germany and Japan. In this case, all of the ratios are less than one, but only in the case of Italy, when $b = 1$ and the fundamental is $p_t - p^*_t$, does the ratio exceed 0.5.

There are few previous studies that permit comparison to these figures. The bounds on the variance of Δs_t and of $s_t - E_{t-1}(s_t)$ of Huang (1981, p. 37) and Diba (1987, p.106) use inequalities that are satisfied by construction for *b* arbitrarily near 1. Such inequalities unhelpfully guarantee values greater than 1 for the ratio that we consider. Using the monetary model, West (1987, p.70) finds a ratio of about .02 to .08 for the Deutschemark-dollar exchange rate. The present technique yields considerably higher figures, suggesting there is rather more in the monetary model than this previous volatility test would suggest.

We conclude that asset-market models in which the exchange rate is expressed as a discounted sum of the current and expected future values of these observed fundamentals can account for a sizable fraction of the variance of Δs_t when the discount factor is large. The EW explanation for a random walk provides a rationale for a substantial fraction of the movement in exchange rates. But there is still a role for left-out forcing variables: perhaps money demand errors, a risk premium, mismeasurement of the fundamentals we have examined here, some other variables implied by other theories, or noise.

References

Cheung, Yin-Wong; Menzie D. Chinn; and, Antonio Garcia Pascual, 2003, "Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?" manuscript, Department of Economics, University of California, Santa Cruz.

Chinn, Menzie D., and Richard A. Meese, 1995, "Banking on Currency Forecasts: How Predictable Is Change in Money?" *Journal of International Economics* 38, 161-178.

Diba, Behzad T., 1987, "A Critique of Variance Bounds Tests for Monetary Exchange Rate Models: Note," *Journal of Money, Credit and Banking* 19, 104-111.

Engel, Charles, and Kenneth D. West, 2003a, "Exchange Rates and Fundamentals," manuscript, Department of Economics, University of Wisconsin.

Engel, Charles, and Kenneth D. West, 2003b, "Taylor Rules and the Deutschmark-Dollar Exchange Rate," manuscript, Department of Economics, University of Wisconsin.

Frenkel, Jacob A., 1981, "Flexible Exchange Rates, Prices, and the Role of "News": Lessons from the 1970s, *Journal of Political Economy* 89, 665-705.

Huang, Roger D., 1981, "The Monetary Approach to Exchange Rate in an Efficient Foreign Exchange Market: Tests on Volatility," *Journal of Finance* 36, 31-41.

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

Mark, Nelson, and Donggyu Sul, 2001, "Nominal Exchange Rates and Monetary Fundamentals: Evidence from a Small post-Bretton Woods Sample," *Journal of International Economics* 53: 29-52.

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

Meese, Richard A., and Kenneth Rogoff, 1983b, "The Out of Sample Failure of Empirical Exchange Models," in J. Frenkel, ed., *Exchange Rates and International Macroeconomics* (University of Chicago Press, Chicago).

Mussa, Michael I., 1979, "Empirical Regularities in the Behavior of Exchange Rates and Theories of the Foreign Exchange Market," *Carnegie Rochester Conference Series on Public Policy* 11, 9-57.

Stock, James H., and Mark P. Watson, 1993, "A Simple Estimator of Cointegrating Vectors in Higher Order Autoregressive Systems," *Econometrica* 61, 783-820.

West, Kenneth D., 1987, "A Standard Monetary Model and the Variability of the Deutschemark-Dollar Exchange Rate," *Journal of International Economics* 23, 57-76.

West, Kenneth D., 1988, “Dividend Innovations and Stock Price Volatility,” *Econometrica* 56, 37-61.

Table 1

Summary Statistics

	$\Delta f =$ $\Delta(m-y-(m^*-y^*))$		$\Delta f =$ $\Delta(msw-y-(m^*-y^*))$		$\Delta f = \Delta(p-p^*)$		$\Delta f =$ $\Delta(p-p^*+i_t-i_t^*)$	
Canada	1974:II-2003:I		1974:II-2003:I		1974:II-2003:I		1975:II-2003:I	
	mean Δf (s.e.)	-0.620 (2.376)	mean Δf (s.e.)	-0.313 (2.412)	mean Δf (s.e.)	-0.052 (0.569)	mean Δf (s.e.)	-0.053 (0.639)
	corr-f	0.073	*corr-f*	-0.086	*corr-f*	0.479	*corr-f*	0.380
	corr-s	-0.051	*corr-s*	-0.051	*corr-s*	-0.051	*corr-s*	-0.053
France	1978:II-1998:IV		1978:II-1998:IV		1974:II-2003:I		1974:II-2003:I	
	mean Δf (s.e.)	-0.238 (2.573)	mean Δf (s.e.)	0.073 (2.417)	mean Δf (s.e.)	-0.123 (0.665)	mean Δf (s.e.)	-0.108 (0.944)
	corr-f	0.180	*corr-f*	0.075	*corr-f*	0.619	*corr-f*	0.098
	corr-s	0.133	*corr-s*	0.133	*corr-s*	0.096	*corr-s*	0.096
Germany	1974:II-1998:IV		1974:II-1998:IV		1974:II-2003:I		1974:II-2003:I	
	mean Δf (s.e.)	-0.610 (2.393)	mean Δf (s.e.)	-0.350 (2.172)	mean Δf (s.e.)	0.476 (0.742)	mean Δf (s.e.)	0.474 (0.862)
	corr-f	0.308	*corr-f*	0.159	*corr-f*	0.448	*corr-f*	0.296
	corr-s	0.084	*corr-s*	0.084	*corr-s*	0.058	*corr-s*	0.058
Italy	1975:II-1998:IV		1975:II-1998:IV		1974:II-2003:I		1978:III-2003:I	
	mean Δf (s.e.)	-1.422 (2.346)	mean Δf (s.e.)	-1.150 (2.316)	mean Δf (s.e.)	-0.881 (1.150)	mean Δf (s.e.)	-0.670 (1.168)
	corr-f	0.260	*corr-f*	0.232	*corr-f*	0.620	*corr-f*	0.345
	corr-s	0.176	*corr-s*	0.176	*corr-s*	0.136	*corr-s*	0.167
Japan	1974:II-2003:I		1974:II-2003:I		1974:II-2003:I		1978:IV-2003:I	
	mean Δf (s.e.)	-0.605 (2.800)	mean Δf (s.e.)	-0.298 (2.484)	mean Δf (s.e.)	0.514 (0.852)	mean Δf (s.e.)	0.651 (0.838)
	corr-f	0.437	*corr-f*	1.033	*corr-f*	0.129	*corr-f*	-0.114
	corr-s	0.114	*corr-s*	0.114	*corr-s*	0.114	*corr-s*	0.080
U.K.	1974:II-2003:I		1974:II-2003:I		1974:II-2003:I		1974:II-2003:I	
	mean Δf (s.e.)	-1.484 (2.124)	mean Δf (s.e.)	-1.177 (2.020)	mean Δf (s.e.)	-0.506 (1.263)	mean Δf (s.e.)	-0.493 (1.287)
	corr-f	0.378	*corr-f*	0.392	*corr-f*	0.276	*corr-f*	0.252
	corr-s	0.137	*corr-s*	0.137	*corr-s*	0.137	*corr-s*	0.137

Notes: The dates in each entry correspond to the data span for Δf.
mean Δf denotes sample mean, (s.e.) is standard error.
corr-f is the first autocorrelation of Δf.
corr-s is the first autocorrelation of Δs.

Table 2

Estimates of $\mathrm{var}(\Delta x_{tH}^{f}) / \mathrm{var}(\Delta s_t)$

Current and lagged fundamentals only in H_t

		Fundamental = $m - y - (m^* - y^*)$			Fundamental = $msw - y - (m^* - y^*)$		
Country	b	$Var(\Delta s_t)$	$Var(\Delta \hat{x}_{tH}^{f})$	Ratio	$Var(\Delta s_t)$	$Var(\Delta \hat{x}_{tH}^{f})$	Ratio
Canada	0.9	5.817	15.279	2.627	5.817	6.645	1.142
	0.95	5.817	17.544	3.016	5.817	6.867	1.181
	0.99	5.817	19.881	3.418	5.817	7.054	1.213
	1	5.817	20.559	3.534	5.817	7.102	1.221
France	0.9	38.807	16.517	0.426	38.807	10.443	0.269
	0.95	38.807	20.716	0.534	38.807	11.987	0.309
	0.99	38.807	25.925	0.668	38.807	13.668	0.352
	1	38.807	27.63	0.712	38.807	14.172	0.365
Germany	0.9	37.389	18.041	0.483	37.389	9.624	0.257
	0.95	37.389	23.894	0.639	37.389	11.243	0.301
	0.99	37.389	31.79	0.850	37.389	13.055	0.349
	1	37.389	34.526	0.923	37.389	13.609	0.364
Italy	0.9	31.513	10.926	0.347	31.513	9.944	0.316
	0.95	31.513	12.483	0.396	31.513	11.358	0.360
	0.99	31.513	14.099	0.447	31.513	12.835	0.407
	1	31.513	14.57	0.462	31.513	13.267	0.421
Japan	0.9	39.644	24.659	0.622	39.644	14.425	0.364
	0.95	39.644	29.731	0.750	39.644	16.083	0.406
	0.99	39.644	35.325	0.891	39.644	17.695	0.446
	1	39.644	37.02	0.934	39.644	18.146	0.458
U.K.	0.9	28.837	13.012	0.451	28.837	12.792	0.444
	0.95	28.837	15.22	0.528	28.837	15.562	0.540
	0.99	28.837	17.465	0.606	28.837	18.597	0.645
	1	28.837	18.11	0.628	28.837	19.51	0.677

Table 3

Estimates of $\text{var}(\Delta x_{tH}^{f})/\text{var}(\Delta s_t)$

Current and lagged fundamentals and $p_t - p_t^*$ in H_t

		Fundamental = $m - y - (m^* - y^*)$			Fundamental = $msw - y - (m^* - y^*)$		
Country	b	$Var(\Delta s_t)$	$Var(\Delta \hat{x}_{tH}^{f})$	Ratio	$Var(\Delta s_t)$	$Var(\Delta \hat{x}_{tH}^{f})$	Ratio
Canada	0.9	5.817	15.811	2.718	5.817	7.033	1.209
	0.95	5.817	19.13	3.289	5.817	7.617	1.309
	0.99	5.817	23.127	3.976	5.817	8.25	1.418
	1	5.817	24.413	4.197	5.817	8.44	1.451
France	0.9	38.807	15.247	0.393	38.807	9.176	0.236
	0.95	38.807	19.701	0.508	38.807	12.055	0.311
	0.99	38.807	27.81	0.717	38.807	19.245	0.496
	1	38.807	31.776	0.819	38.807	23.35	0.602
Germany	0.9	37.389	15.549	0.416	37.389	8.199	0.219
	0.95	37.389	19.727	0.528	37.389	9.087	0.243
	0.99	37.389	25.018	0.669	37.389	10.012	0.268
	1	37.389	26.809	0.717	37.389	10.306	0.276
Italy	0.9	31.513	9.799	0.311	31.513	8.612	0.273
	0.95	31.513	11.8	0.374	31.513	11.886	0.377
	0.99	31.513	15.994	0.508	31.513	20.457	0.649
	1	31.513	18.261	0.579	31.513	22.46	0.713
Japan	0.9	39.644	24.327	0.614	39.644	14.002	0.353
	0.95	39.644	29.326	0.740	39.644	15.639	0.394
	0.99	39.644	34.952	0.882	39.644	17.365	0.438
	1	39.644	36.701	0.926	39.644	17.895	0.451
U.K.	0.9	28.837	12.766	0.443	28.837	12.127	0.421
	0.95	28.837	15.184	0.527	28.837	15.251	0.529
	0.99	28.837	17.949	0.622	28.837	19.39	0.672
	1	28.837	18.834	0.653	28.837	20.856	0.723

Table 4

Estimates of $\mathrm{var}(\Delta x_{tH}^{f}) / \mathrm{var}(\Delta s_t)$

Current and lagged fundamentals only in H_t

		Fundamental = $p - p^*$			Fundamental = $p - p^* + i - i^*$		
Country	b	$Var(\Delta s_t)$	$Var(\Delta \hat{x}_{tH}^{f})$	Ratio	$Var(\Delta s_t)$	$Var(\Delta \hat{x}_{tH}^{f})$	Ratio
Canada	0.9	5.817	0.952	0.164	5.776	0.936	0.162
	0.95	5.817	1.092	0.188	5.776	1.045	0.181
	0.99	5.817	1.229	0.211	5.776	1.147	0.199
	1	5.817	1.267	0.218	5.776	1.176	0.204
France	0.9	34.633	1.876	0.054	34.633	2.441	0.070
	0.95	34.633	3.297	0.095	34.633	3.476	0.100
	0.99	34.633	6.468	0.187	34.633	5.044	0.146
	1	34.633	8.082	0.233	34.633	5.634	0.163
Germany	0.9	36.864	1.836	0.050	36.864	1.99	0.054
	0.95	36.864	2.846	0.077	36.864	2.631	0.071
	0.99	36.864	4.674	0.127	36.864	3.5	0.095
	1	36.864	5.46	0.148	36.864	3.803	0.103
Italy	0.9	34.811	5.092	0.146	35.794	5.132	0.143
	0.95	34.811	8.526	0.245	35.794	8.073	0.226
	0.99	34.811	15.557	0.447	35.794	13.454	0.376
	1	34.811	18.893	0.543	35.794	15.788	0.441
Japan	0.9	39.644	1.558	0.039	42.911	0.847	0.020
	0.95	39.644	2.313	0.058	42.911	0.968	0.023
	0.99	39.644	3.574	0.090	42.911	1.101	0.026
	1	39.644	4.085	0.103	42.911	1.142	0.027
U.K.	0.9	28.837	4.017	0.139	28.837	4.379	0.152
	0.95	28.837	5.782	0.201	28.837	5.948	0.206
	0.99	28.837	8.594	0.298	28.837	8.187	0.284
	1	28.837	9.692	0.336	28.837	8.995	0.312