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Accounting for Forward Rates in Markets for Foreign Currency

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ABSTRACT

Forward and spot exchange rates between major currencies imply large standard deviations of both predictable returns from currency speculation and of the equilibrium price measure (the intertemporal marginal rate of substitution). Representative agent theory with time-additive preferences cannot account for either of these properties. We show that the theory does considerably better along these dimensions when the representative agent's preferences exhibit habit persistence, but that the theory fails to reproduce some of the other properties of the data—in particular, the strong autocorrelation of forward premiums.

SINCE THE ADVENT OF flexible exchange rates in the early 1970s, a large body of statistical work has established that forward rates for major currencies are not optimal predictors of future spot rates. Relevant evidence is reported in studies by Baillie, Lippens, and McMahon (1983), Bekaert (1991), Bilson (1981), Boothe and Longworth (1984), Cumby (1988), Cumby and Obstfeld (1984), Fama (1984), Gregory and McCurdy (1984), Hansen and Hodrick (1983), Hodrick and Srivastava (1984), and Korajczyk and Viallet (1990); a more complete list of references is provided by Hodrick (1987). These papers indicate that returns from speculation in forward and spot currency markets are predictable, and that the predictable components vary considerably over time.

A number of alternative explanations have been offered for the predictable variation in foreign currency market excess returns. Kaminsky (1988), Korajczyk (1985), and Krasker (1980) suggest that infrequent extreme events may make returns appear predictable in small samples—the so-called “peso problem.” Lewis (1989) argues that rational learning following infrequent changes in the process governing equilibrium prices can explain part of the *ex post* predictability of currency returns. Froot and Frankel (1989) and Froot and Thaler (1990) examine the hypothesis that market forecasts of future spot

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exchange rates are not informationally efficient. Our paper follows a branch of research that retains the assumption of market efficiency, but considers the possibility that forward rates contain, in addition to market forecasts of future spot rates, risk premiums that change through time. To date, this line of research has been unable to provide a convincing explanation of variation in expected returns. A useful way to characterize this inadequacy is to note that *ex post* expected returns from currency speculation vary substantially more than is predicted by intertemporal theories of asset pricing, in particular those based on a representative aggregate agent with time-separable preferences and modest degrees of risk aversion. This is implicit in econometric tests by Cumby (1988) and in numerical examples and simulations by Bekaert (1991), Canova and Marrinan (1990), Engel (1990), and Macklem (1991).

We approach the issue of predictable returns from currency speculation from the perspective of the representative agent theory of asset pricing. In this framework predictable returns, or risk premiums, arise if the conditional covariances of returns with the intertemporal marginal rate of substitution are nonzero. The question is whether this theory can replicate the quantitative properties of expected returns in the data. One weakness of this approach, particularly when combined, as it usually is, with time-additive preferences and modest degrees of risk aversion, is that it has not been able to reconcile the small amount of variability observed in aggregate consumption data with the relatively large average excess returns observed for many risky assets. The "equity premium puzzle" of Mehra and Prescott (1985) is probably the best known example, but papers by Bekaert and Hodrick (1992), Grossman, Melino, and Shiller (1987), Hansen and Jagannathan (1991), and Shiller (1984) are among those that illustrate similar phenomena for returns on a variety of assets. Generally speaking, the variability of intertemporal prices in these economies, measured by the standard deviation of the equilibrium price measure, or intertemporal marginal rate of substitution, is too small to account for mean excess returns on equity and long-term bonds.

One of the more successful modifications of this framework with respect to the equity premium puzzle is habit persistence; prominent applications include Abel (1990), Constantinides (1990), Nason (1988), and Sundaresan (1989). Constantinides, in particular, finds that this kind of intertemporal nonseparability greatly increases the theory's ability to generate mean excess returns on equity similar to those seen in the data. Ferson and Constantinides (1991) argue that this theory can also account for many of the properties of expected returns on equity and bonds. In this paper we examine the potential of such a theory to account for expected returns from speculation in foreign exchange markets. Unlike equity, average returns in currency markets are close to zero. The question, instead, is why expected returns are so variable.

We evaluate the theory of asset pricing with habits using two complementary methodologies: estimation and simulation. With respect to the former, we follow a common procedure in using first-order conditions to estimate the

parameters of a representative agent's preferences. With regard to the latter, we build what has come to be called an artificial economy—a numerical representation of the theory whose properties can be compared to those observed in the data. Given values for preference parameters and a stochastic process for consumption, the aggregate price level, and spot exchange rates, we compute equilibrium forward prices numerically. Statistical properties of these prices are then compared to those found in the data. We find that the two approaches together provide an informative assessment of the theory.

We begin by reviewing, in Section I, properties of monthly forward and spot exchange rates for five major currencies against the U.S. dollar over the post-Bretton Woods flexible exchange rate period. We verify earlier findings that excess returns on forward contracts are close to zero, on average, but vary in a predictable manner. We also compute estimates of the variability of expected returns and describe an investment strategy that exploits these predictable movements. Properties of returns from this strategy are used to compute estimates of the Hansen-Jagannathan (1991) lower bound on the standard deviation of the equilibrium price measure. This bound suggests a similarity with the equity premium: both the equity premium and predictable returns from currency speculation imply large standard deviations of the price measure. Moreover, the bound is tighter for currencies than for equity. Estimated standard deviations of predictable returns and the equilibrium price measure serve as benchmarks in our evaluation of the theory.

In Section II we describe a theoretical economy in which a representative agent's preferences exhibit habit persistence. The first-order conditions of the theory can be used either to estimate the representative agent's preference parameters or, given sufficient structure on the stochastic processes facing the agent, to derive equilibrium prices of forward contracts on foreign currencies. We do each, in turn. In Section III we estimate the preference parameters using Hansen's (1982) generalized method of moments estimator. Hansen's J -statistic provides us with an indication of the theory's ability to replicate observed relations between forward and spot rates. In Section IV we estimate a stochastic process for consumption growth rates, inflation, and currency depreciation, and use the first-order conditions of the theory to derive properties of forward rates and rates of return from currency speculation. These properties are then compared to those observed in the data. We conclude with a brief summary of our findings and some suggestions for future work.

I. Predictable Returns from Currency Speculation

A large number of studies have documented predictable returns from currency speculation: the return from issuing a forward contract at date t and converting the proceeds into dollars at the prevailing spot rate at $t + 1$, or the reverse. A comprehensive review is provided by Hodrick (1987, chapters 3, 4). We let s_t denote the spot price in U.S. dollars of one unit of foreign currency at date t and f_t the dollar price of a one-month forward contract

specifying delivery of one unit of foreign currency, with both payment and delivery taking place one month hence, at date $t + 1$. If we normalize the size of a contract by $1/s_t$, then the excess return from selling forward and buying spot is $(f_t - s_{t+1})/s_t$, which we call the return from currency speculation.

In Table I we report, in a format similar to Fama (1984), sample moments for several combinations of forward and spot rates for the U.S. dollar versus the Canadian dollar, the French franc, the German mark, the Japanese yen, and the British pound sterling. Data are monthly, July 1974 to April 1990, so we have almost twice as many observations as Fama (1984). We find, as other authors have, that mean returns from currency speculation are close to zero, both economically and statistically. The largest in absolute value, for the franc, is only half its standard error and amounts to just 0.15 percent per

Table I

Forward and Spot Exchange Rates: Summary Statistics

Forward and spot exchange rates, f and s , respectively, are expressed as dollars per unit of foreign currency. Data are last Friday of month, from the Harris Bank's *Weekly Review: International Money Markets and Foreign Exchange Rates*, compiled by Richard Levich at New York University. Dates t run from July 1974 to April 1990 (190 observations). Numbers in parentheses are Newey-West (1987) standard errors with six lags; they are robust to heteroskedasticity and autocorrelation of the residuals of the moment conditions.

Statistic	Country				
	Canada	France	Germany	Japan	United Kingdom
Panel A. Return from Currency Speculation, $(f_t - s_{t+1})/s_t$					
Mean	-0.0002 (0.0010)	-0.0015 (0.0029)	0.0001 (0.0028)	-0.0015 (0.0031)	-0.0008 (0.0028)
Standard deviation	0.0125 (0.0007)	0.0330 (0.0019)	0.0343 (0.0020)	0.0348 (0.0024)	0.0337 (0.0025)
Autocorrelation	0.089 (0.056)	-0.012 (0.089)	-0.034 (0.087)	0.105 (0.046)	0.076 (0.079)
Panel B. Depreciation Rate, $(s_{t+1} - s_t)/s_t$					
Mean	-0.0009 (0.0009)	-0.0005 (0.0028)	0.0028 (0.0027)	0.0042 (0.0029)	-0.0013 (0.0027)
Standard deviation	0.0122 (0.0008)	0.0325 (0.0019)	0.0339 (0.0020)	0.0342 (0.0024)	0.0330 (0.0025)
Autocorrelation	0.047 (0.058)	-0.042 (0.082)	-0.053 (0.086)	0.076 (0.046)	0.044 (0.078)
Panel C. Forward Premium, $(f_t - s_t)/s_t$					
Mean	-0.0012 (0.0002)	-0.0020 (0.0005)	0.0029 (0.0003)	0.0027 (0.0005)	-0.0021 (0.0005)
Standard Deviation	0.0014 (0.0001)	0.0033 (0.0004)	0.0018 (0.0002)	0.0030 (0.0003)	0.0028 (0.0004)
Autocorrelation	0.813 (0.049)	0.627 (0.099)	0.837 (0.046)	0.866 (0.031)	0.884 (0.034)

month or about 1.8 percent annually. The standard deviation of the return is substantially larger: more than one percent a month for the Canadian dollar, three percent for the remaining four currencies. The estimated first-order autocorrelations indicate that returns are not generally predictable from their own past. Panel C of the table indicates that the forward premium, $(f_t - s_t)/s_t$, is highly persistent, with autocorrelations ranging from 0.63 for the French franc to 0.88 for the pound sterling.

Although the return from currency speculation is small on average, other evidence suggests that it has a highly variable predictable component, which we label q :

$$q_t \equiv E_t(f_t - s_{t+1})/s_t, \quad (1)$$

where E_t denotes the expectation conditional on information available at date t . The most common evidence for predictability of the return comes from regressions of the form

$$(f_t - s_{t+1})/s_t = a_1 + b_1(f_t - s_t)/s_t + u_{t+1}. \quad (2)$$

Nonzero values of b_1 imply that the forward premium, which is an element of market participants' information sets, can be used to predict returns. We see in Table II, Panel A that this is the case for each of the five currencies we study, with estimated values of b_1 generally greater than two, and more than twice their standard errors in all cases.

Nonzero estimates of the coefficient b_1 in equation (2) have been a remarkably robust feature of the data, reported in studies for a variety of currencies over more than a decade. This feature appears, as we have seen, when we add eight years of data to Fama's (1984) nine-year sample period. It also appears when we divide the sample in the middle and look at subsamples, when we apply the same methods to other currencies (the Italian lira, the Belgian franc, the Dutch guilder, and the Swiss franc), or even when we examine nondollar cross rates (for which the rate between the French franc and the deutsche mark is the only example we have found for which the estimate of b_1 is not significantly different from zero). Evidence for all of these claims is available from the authors. Finally, these properties appear to be robust to measurement errors arising from nonsynchronous observations of forward and spot rates or from failing to incorporate bid/ask spreads or market rules governing delivery on foreign exchange contracts into return calculations. Although Cornell (1989) suggests that these issues may lead to spurious predictability of returns from currency speculation, subsequent studies by Bekaert and Hodrick (1993) and Bossaerts and Hillion (1991) have shown that inferences regarding both the sign and magnitude of estimates of b_1 are not sensitive to these types of measurement error.

The evidence in Table II thus indicates predictable variation in returns from currency speculation. We can estimate the variability of the predictable return with standard deviations of fitted values from estimates of (2), which we report in Panel B of Table II. Relative to the mean returns of Table I,

Table II

Properties of Monthly Returns from Currency Speculation

The data are described in the notes to Table I. Dates t run from July 1974 to April 1990. In Panel A, numbers in parentheses are Newey-West (1987) standard errors. "Standard error" is the estimated standard deviation of the residual, u . In Panel B, entries are standard deviations of fitted values from the regressions in Panel A. In Panel C, returns pertain to investment strategies derived from the regressions in Panel A; see text. The "Sharpe ratio" is the ratio of the mean to the standard deviation of the return from this strategy.

Statistic	Country				
	Canada	France	Germany	Japan	United Kingdom
Panel A. Estimated Regressions for Predicting Returns $(f_t - s_{t+1})/s_t = a_1 + b_1(f_t - s_t)/s_t + u_{t+1}$					
a_1	0.0027 (0.0009)	0.0021 (0.0032)	-0.0129 (0.0043)	-0.0088 (0.0033)	0.0062 (0.0028)
b_1	2.467 (0.580)	1.825 (0.910)	4.434 (1.353)	2.753 (0.723)	3.306 (0.865)
Standard error	0.0120	0.0325	0.0335	0.0339	0.0325
Panel B. Standard Deviations of Predicted Returns					
Standard deviation	0.0036	0.0061	0.0078	0.0082	0.0093
Panel C. Risk and Return from Currency Speculation					
Mean	0.0035	0.0055	0.0076	0.0077	0.0088
Standard deviation	0.0120	0.0325	0.0334	0.0339	0.0326
Sharpe ratio	0.293	0.169	0.226	0.227	0.270

these standard deviations are large, ranging from 0.36 percent per month for the Canadian dollar to 0.93 percent for the pound.

Our estimates of equation (2) can also be used to construct investment strategies that exploit the predictability of returns. One simple strategy is to sell in the forward market and convert in the spot market when the fitted value of regression (2) is positive, and the reverse when it is negative. Let I_t be an indicator variable taking the sign of the fitted value from the regression, with $I_t = +1$ when $a_1 + b_1(f_t - s_t)/s_t$ is positive, and $I_t = -1$ when it is negative. The return from this strategy is $r_{t+1} = I_t(f_t - s_{t+1})/s_t$. In Panel C of Table II we report the means and standard deviations of returns from applying this strategy (in-sample) to each of our five currencies. The Sharpe ratio of the mean return to the standard deviation provides a convenient summary measure of the risk involved in this investment strategy. Currency speculation has monthly Sharpe ratios in the range of 0.17 for the franc to 0.29 for the Canadian dollar. This compares with a monthly Sharpe ratio of about 0.14 for equity investments financed with short-term loans over a similar time period; see Breen, Glosten, and Jagannathan (1989, Table I, column 6). Bilson (1981) notes that currency speculation has a relatively favorable risk-return ratio even in out-of-sample experiments.

This representation of predictable returns from currency speculation has both practical and theoretical implications. As a practical matter, many financial institutions now offer their clients investment funds that follow sophisticated versions of the investment strategy just outlined, with reported Sharpe ratios at least as high as those reported here. See the contents of International Business Communications (1991) and Thomas (1990) for specific examples. The statistics of Table II, in other words, have passed the market test.

The Sharpe ratio also provides a useful benchmark for evaluating asset-pricing theories. For a broad class of theories, there exists a random variable n such that the return r on any zero net investment portfolio satisfies

$$E_t\{n_{t+1}r_{t+1}\} = 0; \quad (3)$$

see, for example, Hansen and Jagannathan (1991) and Shiller (1982). We refer to n as the equilibrium price measure. In representative agent theories n is the agent's intertemporal marginal rate of substitution. Hansen and Jagannathan (1991) show that the Sharpe ratio for any portfolio of this sort places a lower bound on the standard deviation of n :

$$\sigma_n/En \geq |Er|/\sigma_r,$$

where σ_z denotes the standard deviation of the random variable z . Since the mean of n is close to one (monthly interest rates are small), we estimate that the standard deviation of n is at least 0.29, the largest Sharpe ratio of Table II. We find it striking that predictable returns from currency speculation imply bounds that are more demanding of theoretical models than is the widely cited equity premium. Bekaert and Hodrick (1992) make the same point in a more dramatic fashion: they use information on both foreign currency market returns and international stock market returns to estimate lower bounds as high as 0.78 (see their Table XI).

To summarize briefly: the statistical properties of forward and spot exchange rates imply predictable returns from currency speculation. These predictable returns are highly variable, and imply a highly variable equilibrium price measure.

II. A Theoretical Framework

Our framework is a monetary extension of the representative agent theory of asset pricing developed by, among others, Cox, Ingersoll, and Ross (1985) and Lucas (1978). We examine, specifically, the restrictions implied by this theory on the joint stochastic process for consumption growth, inflation, and spot and forward exchange rates. These restrictions are first-order conditions for the representative agent. Although it is not necessary for our purpose, we might imagine building these relations into a dynamic general equilibrium model with multiple currencies. One such structure is an exchange economy with complete markets for state-contingent claims. Consumers, one for each

country, have homothetic preferences and money is introduced with cash-in-advance constraints, transaction technologies, or preferences for real money balances. Examples of such monetary economies are described by Bansal (1990), Lucas (1982), Macklem (1991), and Stulz (1987). Hodrick, Kocherlakota, and Lucas (1991, p. 380) suggest that for cash-in-advance models, it is sufficient simply to convert real prices to nominal units using the price level, which is what we do here.

Our theory follows Abel (1990), Constantinides (1990), Nason (1988), and Sundaresan (1989) in introducing a nonseparability into the representative agent's preferences. The agent's expected utility function takes the form

$$U_t = E_t \sum_{k=0}^{\infty} \beta^k u(d_{t+k}), \quad u(d) = [d^{1-\alpha} - 1]/(1 - \alpha), \quad (4)$$

$$d_t = c_t - \gamma c_{t-1},$$

where c_t is current expenditures on consumption goods and d_t is the associated service flow. The expectation operator E_t will be understood as conditional on complete knowledge of the state at date t . We refer to α as the curvature parameter, and require it to be nonnegative. We refer to γ as the habit parameter, since it governs the intertemporal nonseparability of preferences. The utility function is defined only for realizations of consumption and values of γ that guarantee positive d . For $\gamma > 0$ preferences exhibit habit formation, in the sense that higher current consumption requires higher future consumption to maintain the same level of future utility. We refer to negative values of γ as durability, since current expenditures raise future utility. With $\gamma = 0$ we have the additively separable power utility function used in most earlier studies.

In an equilibrium for such an economy, asset returns are related to consumption and inflation by the representative agent's first-order conditions. Consider a nominal asset for which one dollar invested at date t yields R_{t+1} dollars at date $t + 1$. The first-order condition is

$$E_t\{n_{t+1}R_{t+1}\} = 1, \quad (5)$$

where $n_{t+1} = m_{t+1}(p_t/p_{t+1})$ is the nominal marginal rate of substitution and p_t is the price level, the dollar price of the consumption good at date t . The real marginal rate of substitution is

$$m_{t+1} = \beta[\partial U_{t+1}/\partial c_{t+1}]/[\partial U_t/\partial c_t], \quad (6)$$

where

$$\partial U_t/\partial c_t = (c_t - \gamma c_{t-1})^{-\alpha} - \beta\gamma E_t(c_{t+1} - \gamma c_t)^{-\alpha} \quad (7)$$

is marginal utility. For $\gamma = 0$ this reduces to the familiar $m_{t+1} = \beta(c_{t+1}/c_t)^{-\alpha}$. The requirement that marginal utility be positive in all states places additional restrictions on the preference parameters and the process for consumption that we return to in Section IV.

For returns r_{t+1} on a zero net investment portfolio, the first-order condition is

$$E_t\{n_{t+1}r_{t+1}\} = 0. \quad (8)$$

It is clear from comparison with (3) that n is the equilibrium price measure for this economy. As a particular case, let $r_{t+1} = (f_t - s_{t+1})/s_t$, the return from currency speculation. Then expanding (8) gives us

$$q_t \equiv E_t[(f_t - s_{t+1})/s_t] = \text{Cov}_t[n_{t+1}, (s_{t+1}/s_t)]/E_t n_{t+1}, \quad (9)$$

where Cov_t denotes the covariance conditional on the date- t information set. This gives us a theoretical counterpart to the expected return q_t in equation (1). In principle q_t can vary through time and thus may account for the observed variability of expected returns.

Two special cases of (9) have received attention in the literature. One arose from the suggestion that the theory produces nonzero risk premiums even when the representative aggregate consumer is risk neutral ($\alpha = \gamma = 0$), in which case $n_{t+1} = \beta p_t/p_{t+1}$. Subsequent work has found the covariance of inflation and depreciation rates too small to account for the observed variability of expected returns; see, for example, Engel (1990). A second special case of additive separability ($\gamma = 0$) has received much closer attention. Cumby (1988) finds that this model also fails to account for predictable returns from currency speculation. We verify each of these conclusions for our economy in the following sections and proceed to examine nonzero values of the habit parameter γ .

III. Estimation

One way to evaluate the theory is to use the first-order condition (8) to estimate the preference parameters of the representative agent by the generalized method of moments (GMM). Hansen's (1982) J -statistic can then be used to provide an indication of how well the theory and data conform. This approach to model evaluation is widely used in statistical studies in finance, including Mark's (1985) study of foreign currencies.

We proceed as follows. As in related studies by Eichenbaum and Hansen (1990) and Ferson and Constantinides (1991), the moment condition is not (8) but an implication of it. Note that if (8) holds, then so does

$$0 = E_t\{n'_{t+1}r_{t+1}\}, \quad (10)$$

with

$$n'_{t+1} = (1 - \beta\gamma)^{-1} [\beta d_{t+1}^{-\alpha} - \beta^2 \gamma d_{t+2}^{-\alpha}] (p_t/p_{t+1})/d_t^{-\alpha}$$

where $d_t = (c_t - \gamma c_{t-1})$, as in (4). Implicit in our use of moment condition (10) is the assumption that, while the service flow d_t may not be stationary, its growth rate is. In addition, (10) is normalized by $(1 - \beta\gamma)$ in order to avoid the trivial solution, $\alpha = 0$ and $\gamma = 1/\beta$.

Condition (10) is a function of the data (consumption c , the price level p , and the return r) and of the parameters of the representative agent's preferences (α , β , and γ). For given parameter values, the product of $w_{t+1} = n'_{t+1}r_{t+1}$ and any instrumental variable v_t known at date t should have mean zero. The GMM estimator chooses values of the preference parameters that make the sample mean of $v_t w_{t+1}$ close to zero for each instrumental variable v . If there are more instruments than parameters, then not all of these orthogonality conditions can be exactly zero. We can evaluate the theory by calculating the J -statistic, which indicates whether the extra conditions (the overidentifying restrictions) have means that are close to zero relative to their sampling variability. The details of this procedure are described in Hansen (1982), Hodrick (1987), and many other places.

Our data are monthly, ranging from July 1974 to April 1990, as in Tables I and II. The series r are returns from currency speculation, $(f_t - s_{t+1})/s_t$, for the American dollar versus the five currencies studied earlier. We estimate the model jointly across these five foreign currency returns. The consumption series is U.S. nondurables and services, excluding clothing and medical care, and is measured on a per capita basis. The price level is the associated implicit price deflator. Blinder and Deaton (1985) argue that this measure of consumption is closer to the theoretical ideal of a flow of services, as opposed to expenditures, than measures that include consumer durables and the two excluded components. The implicit assumption with respect to durable goods is that their effect on utility is separable from that of nondurables and services.

Our set of instrumental variables consists of a constant, lagged consumption growth, c_t/c_{t-1} , the inverse of the lagged inflation rate, p_{t-1}/p_t , and four forward premiums, $(f_t - s_t)/s_t$, one for each currency save the pound, the inclusion of which resulted in a singular weighting matrix. Consequently, we have 35 orthogonality conditions (five moment conditions with seven instruments each) with which we can estimate the model's preference parameters. Since the parameter β is not identified from (10) (we can satisfy the condition exactly by setting $\beta = 0$), we set $\beta = 0.99$ and estimate the two remaining parameters, α and γ . The particular choice of β has little effect on our estimates. This procedure leaves us with 33 extra orthogonality conditions that can be used to evaluate the theory.

The outcome of this procedure is summarized in Table III, where we report estimates of the additively separable power utility model ($\gamma = 0$) and the habits model. For power utility our parameter estimates are similar to those of Mark (1985). The point estimate of the curvature parameter, α , is large relative to other studies (Hansen and Singleton (1982), for instance), but the corresponding standard error is also relatively large. Unlike Mark (1985), however, our J -statistic indicates sharp differences between the theory and the data. The marginal significance level associated with our minimized objective function is less than 0.01 percent. This difference may be attributed to our additional seven years of data, our use of five rather than four forward currency returns, and to our use of lagged forward premiums as instruments.

Table III
Generalized Method of Moments Estimates of Preference Parameters

Estimates of preference parameters using Hansen's (1982) two-step GMM estimator, implemented using the GAUSS code developed by Lars Hansen, John Heaton, and Masao Ogaki. The parameters are the discount factor, β , which we fix at 0.99; α , the curvature parameter (coefficient of relative risk aversion when $\gamma = 0$); and γ , the habit parameter. The moment conditions are

$$0 = E_t\{n'_{t+1}r^j_{t+1}\},$$

where r^j_{t+1} is the return from speculation in currency j and n'_{t+1} is related to the nominal marginal rate of substitution, as described in Section III of the text. Given values for the preference parameters, we compute n' with data on per capita consumption (nondurables and services net of clothing and medical care, divided by the resident population, from Citibank's *Citibase Economic Database*) and prices (the implicit price deflator of the consumption series). Our estimates use returns on all five currencies described in Table I. The instrument set consists of a constant, lagged consumption growth, c_t/c_{t-1} , the inverse of the lagged inflation rate, p_{t-1}/p_t , and four forward premiums, $(f_t - s_t)/s_t$, one for each currency save the pound, the inclusion of which resulted in a singular weighting matrix. The weighting matrix and standard errors use a quadratic spectral kernel as suggested by Andrews (1991). " J " is Hansen's J -statistic which, if the model generated the data, is asymptotically distributed as a chi-squared random variable with degrees of freedom equal to the number of overidentifying restrictions (33 in this case). Numbers in parentheses below the point estimates are standard errors, those below the J -statistics are prob-values.

Statistic	α	γ	J
Power utility	52.79 (29.70)		75.58 (5.40×10^{-5})
Habit persistence	107.39 (46.86)	-0.79 (0.88)	71.74 (1.09×10^{-4})

With respect to the latter, both Hodrick (1987, chapter 5) and Mark (1985) note that the evidence against the theory is stronger when forward premiums are used as instruments.

Estimates of the habit formation model also indicate a strong rejection of the overidentifying restrictions. The marginal significance level is less than 0.02 percent. In addition, our point estimate of the habit parameter, γ , is negative, suggesting durability rather than habits. Note, however that this parameter is estimated imprecisely: a plus-or-minus two standard error interval for the habit parameter includes the entire interval, $[-1, 1]$. The estimated value of the curvature parameter is again extremely high (107.39), but its standard error (46.86) is also quite large. Apparently, as the representative agent's preferences tend towards durability, even larger values for the curvature parameter are required by the GMM procedure. This should not be surprising: since durability tends to reduce variability of the intertemporal marginal rate of substitution (Hansen and Jagannathan, 1991), we need an increase in curvature to compensate.

Our parameter estimates are similar to those of Bansal (1990), who applies GMM to monthly data on industrial production (as a proxy for consumption) for a two-country model with temporally nonseparable preferences. Bansal (1990), too, rejects the model's overidentifying restrictions, but finds that his data are unable to distinguish, with any statistical precision, between habits and durability. Related work with returns on other assets includes Dunn and Singleton (1986) and Eichenbaum and Hansen (1990), who find that durability dominates at monthly frequencies, and Ferson and Constantinides (1991) who find weak evidence of habits at monthly frequencies and stronger evidence of habits at quarterly and annual frequencies. Our estimates provide little evidence to either support or oppose the hypothesis that monthly data are suggestive of habit formation. With this in mind we proceed to place additional structure on the model in order to draw a clearer picture of the types of temporal nonseparabilities that are helpful in accounting for returns from currency speculation.

IV. Simulation

In this section we follow a different, complementary methodology: we compute population moments for the theoretical economy and compare them to those of the data. We find that by placing more structure on the theory than we did in the previous section, we can strengthen its predictions. At issue are the conditional moments. As we saw in equations (5) to (7), the equilibrium price measure n for this economy depends on conditional moments of consumption growth, inflation, and currency depreciation. To compute the equilibrium price measure, and thus prices of assets, we need to know what these moments are.

With this in mind, we approximate the joint stochastic process for consumption growth, inflation, and currency depreciation by a finite state Markov chain, which we estimate with U.S. data. In the Markov chain states are indexed by i , for $i = 1, \dots, I$, for some finite number I . State i at date t determines the triple: $c_t/c_{t-1} = x_i$, $p_t/p_{t-1} = y_i$, and $s_t/s_{t-1} = z_i$. The evolution of the state is characterized by transition probabilities π_{ij} of moving from state i in one period to state j in the next. We combine these probabilities in the transition matrix $\Pi \equiv [\pi_{ij}]$. Thus the stochastic process for the three forcing variables, and conditional moments of these variables, are described completely by the values $\{x_i, y_i, z_i\}$ and the transition probabilities π_{ij} .

We estimate the transition matrix for the Markov chain from monthly time series for aggregate consumption, the price level, and spot exchange rates. The exchange rate is the Canadian dollar rate; the same conclusions follow from other currencies. We specify the state space so that each variable—consumption growth, inflation, and the rate of depreciation—assumes two values, high and low, with high and low defined as above and below the sample mean. The two-value specification for each variable implies eight states for the Markov chain describing the evolution of the three state variables. The

transition probabilities are estimated as relative frequencies, which is the maximum likelihood estimator. If g_{ij} is the number of times in the data that the economy passed from state i in one period to state j in the subsequent period, then our estimator of π_{ij} is $g_{ij}/\sum_k g_{ik}$. Given the estimated transition probabilities, we choose the two values assumed by each variable to equate the unconditional mean and standard deviation to their sample estimates.

In Table IV we report sample moments from the data and population moments of the estimated eight-state Markov chain used in our theoretical economy. By construction, the means and standard deviations are the same in the data and our Markov chain. The autocorrelations and correlations between variables are also quite similar, which suggests that the Markov chain provides a reasonable approximation to the actual multivariate process.

Given the estimated Markov chain, the properties of the theoretical economy are governed by the preference parameters $\{\alpha, \beta, \gamma\}$. In selecting values for these parameters we follow a strategy similar to that of Constantinides (1990), Heaton (1993), and Mehra and Prescott (1985). One way of evaluating the theory is to ask whether there exist plausible parameter values for which selected population moments for the theoretical economy are close to the sample moments reported earlier. Of particular interest are the standard deviations of the equilibrium price measure n and the expected return q

Table IV

Moments in the Data and in the Theoretical Economy

The first of each pair of numbers is the sample moment for the period July 1974 to April 1990, the second is the population moment for the Markov chain described in the text and used in our theoretical economies. The data are described in the notes to Tables I and III. The spot exchange rate series is the Canadian dollar.

	Consumption Growth c_{t+1}/c_t	Inflation Rate p_{t+1}/p_t	Depreciation Rate s_{t+1}/s_t
Panel A. Univariate Moments			
Mean	1.0011 1.0011	1.0050 1.0050	0.9991 0.9991
Standard deviation	0.0048 0.0048	0.0032 0.0032	0.0122 0.0122
Autocorrelation	-0.285 -0.204	0.455 0.374	0.047 0.021
Panel B. Cross Correlations			
Consumption growth	1.0	-0.454 -0.312	-0.028 -0.010
Inflation rate		1.0	-0.132 -0.082

from currency speculation. We define a set of plausible or permissible parameter values as follows:

1. The curvature parameter α is restricted to lie in the interval $[0, 10]$. Although there has been some debate on this point, we feel that larger values of α imply unreasonably strong aversion to risk. Moreover, this restriction is consistent with other applications of habit persistence to equilibrium asset pricing. Constantinides (1990, Table 1) uses $\alpha = 2.2$; Ferson and Constantinides (1991) estimate α to be less than ten, and generally less than five; and Heaton (1993) estimates α to be slightly smaller than one. Relative to these studies, our bound on the curvature parameter is fairly weak.
2. The preference parameters and the stochastic process for consumption guarantee that the service flow $d_t = c_t - \gamma c_{t-1}$ and marginal utility ($\partial U_t / \partial c_t$ in equation (7)) are positive in all states. The former implies that $\gamma < 0.9961$, the low value of the consumption growth rate in our Markov chain. The latter places more complex restrictions on preferences. As (7) shows, marginal utility is, for positive values of γ , the difference between two positive terms. We rule out parameter values that yield negative values of this difference in some states.
3. The unconditional mean of the price of a riskfree nominal bond, where the latter is given by the conditional mean of n , is restricted to lie within two standard deviations of the mean price of a one-month Eurodollar contract. If r is the riskfree rate, then the price in discount form is $b = 1/(1 + r)$. The mean price of such a contract, in our sample, is 0.9923, reflecting a monthly return of about 0.77 percent. The standard deviation is 0.0028, which yields a plus or minus two standard deviation interval of 0.9867 to 0.9978. This relatively narrow range is simply a consequence of small monthly rates of return.

The simulation methodology differs in several respects from the GMM estimation of Section III. First, the estimated Markov chain imposes some critical structure on the stochastic processes faced by the representative agent. As we see in equations (6) and (7), the agent's marginal rate of substitution depends not only on consumption growth, as it does with time-separable preferences, but on the conditional moments of consumption growth. The additional structure implied by our Markov chain results in stronger predictions of the theory. Second, the restrictions we place on the plausible, or permissible, parameter space limit the ability of the theory to mimic other features of the data. Foremost among these is Condition 2, that marginal utilities be positive in all states. This condition is not imposed by GMM. In our simulations, however, it plays an important role in ruling out what we feel are nonsensical combinations of parameter values.

In Table V we report properties of the equilibrium price measure, the expected return from currency speculation, and the forward premium, each for four choices of the preference parameters. The first row reports our sample estimates of the same moments for comparison. For the theoretical

Table V
Properties of Theoretical Economies

The price measure is the nominal marginal rate of substitution, which we denote by n in the text. The expected return is the predictable component of $(f_t - s_{t+1})/s_t$, denoted by q_t . The forward premium is $(f_t - s_t)/s_t$. "Std. Dev." is the standard deviation, "Mean" is the mean, and "Auto." is the first autocorrelation. Numbers in parentheses are standard deviations of sample estimators of the reported moments, computed from 2000 replications of length 190 as described in the text. For example, in constructing the standard deviation of the autocorrelation of the forward premium we computed a sample estimate of the autocorrelation in each replication. The standard deviation, in this case, is the standard deviation of this estimator across the 2000 samples. Properties of the United States refer to the Canadian dollar entries in Tables I and II. Other entries represent theoretical economies with different settings for the preference parameters, using the Markov chain described in the text and Table IV. The preference parameters are: β , the discount factor; α , the curvature parameter (coefficient of relative risk aversion when $\gamma = 0$); and γ , the habit parameter.

Economy (Parameters)	Price Measure Std. Dev.	Expected Return		Forward Premium		
		Mean	Std. Dev.	Mean	Std. Dev.	Auto.
United States (no parameters)	0.293	-0.0002	0.0036	-0.0012	0.0014	0.813
Risk neutral ($\alpha = 0, \beta = 0.99, \gamma = 0$)	0.003 (6×10^{-5})	3×10^{-6} (4×10^{-7})	1×10^{-5} (2×10^{-7})	-0.0008 (0.0002)	0.0028 (0.0002)	0.002 (0.080)
Power utility ($\alpha = 10, \beta = 0.99, \gamma = 0$)	0.04 (3×10^{-4})	2×10^{-5} (9×10^{-6})	0.0001 (5×10^{-6})	-0.0008 (0.0002)	0.0028 (0.0002)	-0.006 (0.081)
Moderate habits ($\alpha = 10, \beta = 0.99, \gamma = 0.5$)	0.215 (0.007)	0.0001 (3×10^{-5})	0.0005 (2×10^{-5})	-0.0007 (0.0002)	0.0029 (0.0002)	-0.022 (0.082)
Strong habits ($\alpha = 9, \beta = 0.6, \gamma = 0.86$)	0.933 (0.026)	0.0002 (0.0001)	0.0019 (0.0001)	-0.0006 (0.0002)	0.0035 (0.0003)	-0.109 (0.080)

economies we report, in parentheses, the standard deviations of estimators of the population moments to provide some measure of sampling variability. The standard deviations were computed from 2000 simulations of each theoretical economy, using samples of 190 periods, the same sample size as Tables I to III. For each simulation we compute a sample estimate of the moment in the table. The numbers in parentheses are the standard deviations of these estimates over the 2000 simulations.

The first two examples serve to orient our study with respect to earlier work; in each the representative agent's preferences are additively separable over time ($\gamma = 0$). In "Risk neutral" we further restrict preferences, setting the curvature parameter α equal to zero. This example quantifies the contribution of price level variability to the theoretical economy. We find that by almost any metric the contribution is small. The standard deviation of the equilibrium price measure is smaller than the estimated lower bound by a factor of one hundred, and the standard deviation of the predicted return

from currency speculation is smaller by a factor of close to four hundred. Sampling variability, as measured by the numbers in parentheses in the table, is small relative to the differences between the theory and the data. As Engel (1990) points out in a related context, price level variability is essentially irrelevant in this theoretical framework.

Our “Power utility” example introduces significant risk aversion to the analysis, with the curvature parameter α set equal to ten. This raises the standard deviation of the price measure by a factor of ten, but this property of the theory remains below our sample estimate by almost an order of magnitude. The standard deviation of the expected return remains more than two orders of magnitude smaller than we see in the data. These examples verify earlier findings that theory based on a representative agent with time-additive preferences cannot account for the salient properties of forward and spot exchange rates.

In “Moderate habits” we introduce an intertemporal nonseparability into preferences, setting $\gamma = 0.5$. This raises the variability of both the price measure and expected returns, bringing the former within 30 percent of our estimated lower bound. In Figure 1 we plot the standard deviation of the price measure against the habit parameter γ . We see that the standard deviation increases with γ , and for values of γ greater than 0.7 the standard deviation exceeds the Hansen-Jagannathan lower bound. In this sense habits extend the theory in a useful direction.

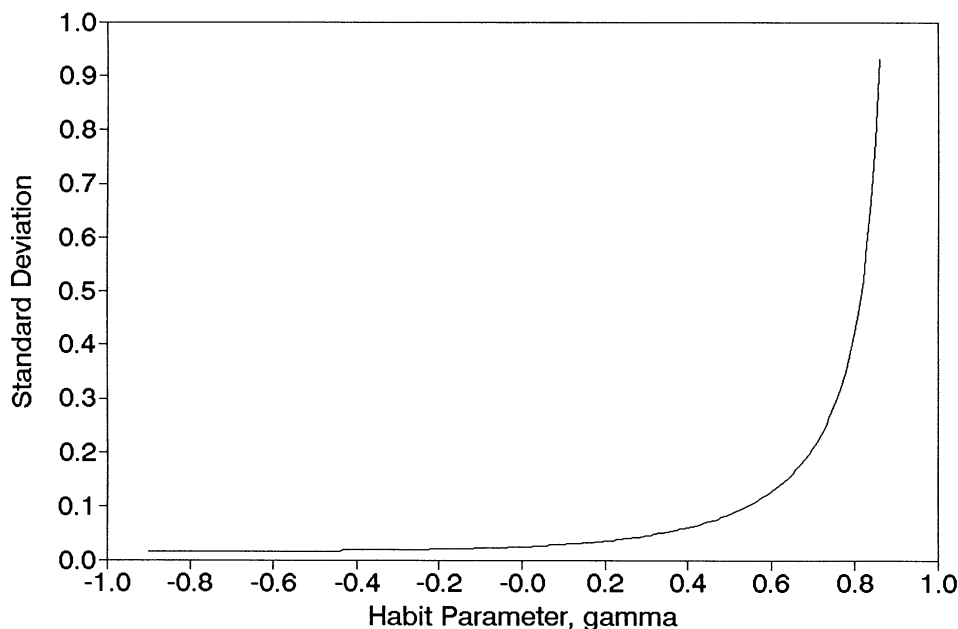


Figure 1. Variability of theoretical equilibrium price measure with different values of the habit parameter.

In “Strong habits” we choose parameters from our plausible set to maximize the standard deviation of the expected return from currency speculation. Here we find that although habits bring us much closer to our sample estimate, there remains substantially less variability in the theory than we estimate in the data; the standard deviation in our theoretical economy is only half our sample estimate. Figure 2 illustrates this feature for a broader range of values for γ : as we raise γ we increase the standard deviation of the expected return q . But there are no plausible values for which the standard deviation is as large as we estimate in the data. The restrictions on our parameter set are critical in this regard. If we eliminate Condition 2, requiring positive marginal utility in all states, then the theory can produce as much variability in expected returns as we see in the data. For example, with $\alpha = 9$, $\beta = 0.82$, and $\gamma = 0.86$, the standard deviation of the expected return is 0.0042, slightly above our sample estimate of 0.0036, but marginal utility is negative in some states. If, in addition, we relax Condition 3, that the mean price of a one-period riskfree bond lie within two standard deviations of its sample mean, we can raise this standard deviation to 0.32. We are unable, however, to replicate the variability of the expected return without violating one of our restrictions on the parameter space.

When we turn to other moments, we find additional discrepancies between theory and data. One of the more obvious concerns the standard deviation of the short-term riskfree rate of interest. In our data, as described earlier in

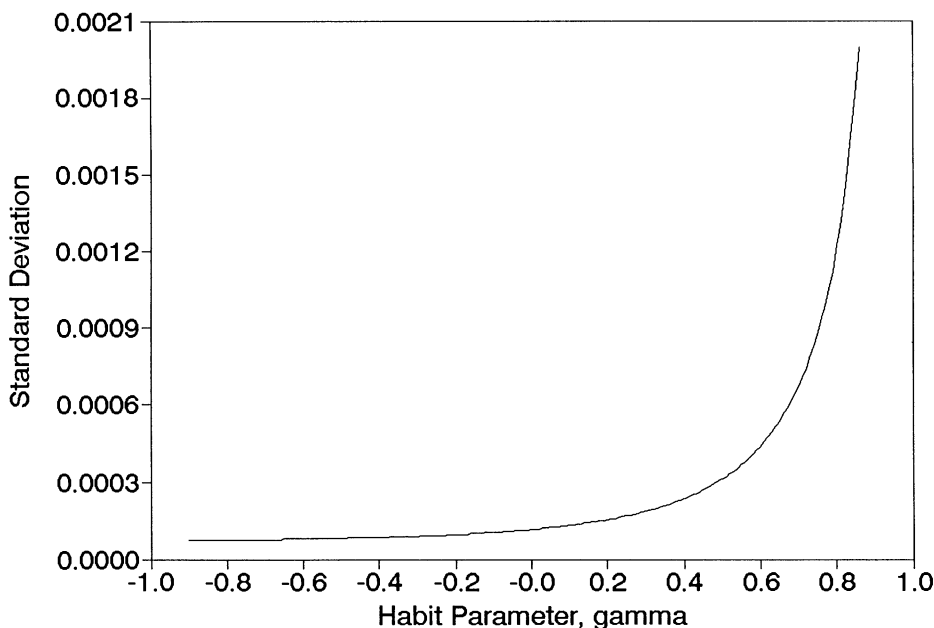


Figure 2. Variability of theoretical expected returns from currency speculation with different values of the habit parameter.

this section, the standard deviation of the price of a one-month Eurodollar contract is 0.0028. In our "Strong habits" example this standard deviation is 0.65, more than two hundred times larger than we see in the data.

A second discrepancy concerns the autocorrelation of the forward premium. In Table I we reported autocorrelations for five currencies between 0.63 and 0.88, with estimates for four currencies above 0.8. In the theory the forward premium exhibits small, and generally negative, autocorrelation. In Figure 3 we graph the autocorrelation of the forward premium versus γ and find that the autocorrelation is slightly negative whether preferences exhibit habits ($\gamma > 0$), durability ($\gamma < 0$), or time additivity ($\gamma = 0$). The anomaly, then, is not simply a consequence of habit formation. To understand this property, recall Fama's (1984) decomposition of the forward premium into the sum of the expected rate of depreciation and the expected return q :

$$(f_t - s_t)/s_t = E_t(s_{t+1} - s_t)/s_t + q_t.$$

Positive autocorrelation in the data could come from either component, or from a combination of the two. In our theory, however, most of the variability of the forward premium comes from the expected rate of depreciation, which in our Markov chain has a standard deviation of 0.0028 and an autocorrelation of 0.001. Since the standard deviation of q is, at most, 0.0019, the

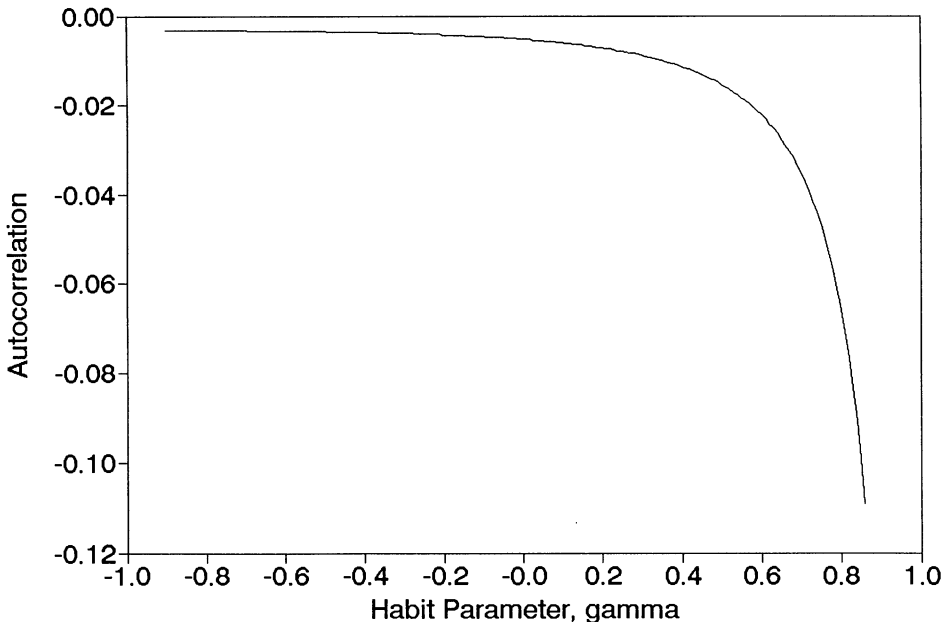


Figure 3. Autocorrelation of theoretical forward premium with different values of the habit parameter.

forward premium inherits, for the most part, the lack of autocorrelation of the expected rate of depreciation. As we raise γ the variability of the risk premium increases, and the forward premium begins to reflect the negative autocorrelation of q . For no parameter values, however, does the theory produce the strong positive autocorrelation observed in the data.

We conclude that a representative agent theory featuring habit persistence can account for a great deal more of the variability of the equilibrium price measure and expected returns from currency speculation than one based on time-additive preferences. In this sense nonseparable preferences are useful. Nevertheless, there are no plausible values of the preference parameters for which we account for more than half of the estimated standard deviation of expected returns, or for the strong autocorrelation of the forward premium.

VI. Final Thoughts

We have shown that habit persistence raises the standard deviation of the equilibrium price measure above its estimated lower bound, and the standard deviation of expected returns from currency speculation to about one-half its estimated value in the data. Without habits the theory accounts for less than one percent of either standard deviation, so habit formation is useful in both respects. At the same time, the theory has some features that differ sharply from those of the data. The most prominent of these are the standard deviation of the short rate, which is two orders of magnitude larger in the theory than the data, and the autocorrelation of the forward premium, which is strongly positive in the data, but slightly negative in our theoretical economies.

This limited success suggests that future work must take the theory in new directions. One direction is to allow more complex intertemporal preference relations. We have found little benefit from extending habits to two or three months. Studies by Bekaert (1991), Ferson and Constantinides (1991), and Heaton (1993), however, consider a combination of short-term durability and long-term habits that permits more complex dynamics. Perhaps a similar device would help to account for returns from currency speculation. Another direction, studied by Lewis (1989), is to introduce the possibility of infrequent unobservable changes in the economy's stochastic process. Lewis argues that the learning process that follows such regime changes accounts for about half the predicted returns from speculation in the dollar versus the deutsche mark and the pound in the early 1980s. The question is whether recurrent changes in regime can account for the fairly robust returns from currency speculation apparent in data for many currencies over the entire post-Bretton Woods period. Finally, it might be useful to consider alternatives to the representative agent framework of asset pricing. Two recent examples are Hakkio and Sibert (1991), who examine currency prices in an overlapping generations model, and Lucas (1990), Marcet and Singleton (1991), and Telmer (1993), who compute the standard deviation of the equilibrium price measure in

economies with incomplete markets and borrowing constraints. Perhaps future studies will tell us which of these directions is most useful in explaining returns from currency speculation.

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