Cointegration Modeling of Expected Exchange Rates

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Abstract

If foreign exchange market participants form rational forecasts of future exchange rates, we should expect that these forecasts should be closely matched to subsequent realizations. Specifically, rational forecasts of a time series and the observed series itself should be cointegrated. In this paper, we apply this insight to multiple exchange rate series and a corresponding set of market expectations of future values of the exchange rate series. We build a cointegration (and associated error-correction) model of actual and expected exchange rates for five exchange rates against the U.S. Dollar, using weekly expectations data from Money Market Services, International for the 1986 – 1997 period.

Our empirical work produces very strong evidence of cointegration between the exchange rate series and the expected rates series. We find strong evidence that existing work that ignores the impact of error-correction is significantly misspecified. At the shortest forecast horizon, the error-correction term dominates all other determinants of changes in expected exchange rates in our sample and indicates a sensible response by market participants to past mistakes in forecasting future rates. At longer forecast horizons, error-correction remains very important, but lagged changes in actual and expected rates also play a role. We find limited evidence of threshold effects in our error-correction models.

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I. Introduction

An enduring issue in international finance is the forward premium bias problem.[1] Simply stated, forward rates for the U.S. Dollar against other G-7 currencies appear to be consistently biased estimates of future exchange rate movements. While this result might be traced to different causes, the process by which market participants form expectations about future exchange rates is potentially very important.[2] Among them, Froot and Frankel (1989) provide evidence that the forward premium may reflect irrational expectations of market participants. In their work, they decomposed the forward premium into several pieces, and showed that irrational market expectations appeared to be the dominant factor in explaining the forward premium bias.[3]

Separately, a number of papers have investigated directly the characteristics of exchange rate expectations. Dominguez (1986) began this work studying whether the expectations data gathered by Money Market Services (MMS), Inc. were consistent with rational expectations. Froot and Frankel (1987a, b, c) extended these tests and incorporated additional data sets. Takagi (1991) surveys this early work. In a series of papers, Ito (1994) and Elliott and Ito (1999) have studied an unique set of exchange rate expectations data collected regularly from Tokyo market participants.

Evidence from these investigations suggests interesting differences in the expectations formation and adjustment process depending on the horizon. Short horizon expectations (one-week to one-month) display persistence, or bandwagon characteristics. That is, exchange rate movements are generally expected to continue. Longer horizon expectations, by contrast, seem to be mean reverting: market participants expect rate movements to be reversed. For example, Cheung and Chinn (1999b) survey participants in the U.S. interbank foreign exchange markets. They report that market participants believe short-run exchange rate dynamics depend principally on non-fundamental forces such as bandwagon effects, overreaction to news, technical trading, and excessive speculation. Fundamentals are believed to exert a more significant impact at longer horizons (greater than six months), but the identification of fundamentals remains problematic.

In this paper, we take some steps toward addressing both parts of the international finance literature on exchange rate expectations. We re-address the early work on exchange rate expectation formation and the

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1. See Froot and Thaler (1990), Lewis (1995), and Engel (1996) for surveys of the issue.
2. Bansal and Dahlquist (1998) provide interesting evidence that the bias problem exists only for the developed countries where domestic interest rates are less than U.S. interest rates. Roll and Yan (1998) advance another explanation of the forward bias anomaly.
3. Exchange rate expectations also have a central role in theoretical international finance and in practical currency market affairs, too. See Obstfeld and Rogoff (1996) for a textbook treatment of exchange rate expectations and theoretical international finance models. On the practical side, Ito (pg. 120, 1994) notes that "a majority of the foreign (*exchange*) transactions are for capital transactions reflecting exchange rate expectations, rather than current account transactions *(word added for clarity)*."

irrationality evidence in Froot and Frankel. More specifically, our paper studies the process by which market participants adjust their exchange rate expectations. The insight that lies at the heart of our approach is drawn from the cointegration econometrics literature: if foreign exchange market participants are rational, exchange rate forecasts of those agents should differ only randomly from the subsequent realization of the exchange rates. In technical terms, rational forecasts of a time series and the observed series itself should be cointegrated.[4] This means that forecast errors should display specific time series behavior, i.e., while an exchange rate series (whether actual or expected) should be an integrated (or nearly integrated) process, the forecast errors should appear to be a random process.

Roll and Yan (1998) also exploit this same property of rational forecasts, too. Aggarwal, Mohanty, and Song (1995) and Cheung and Chinn (1999) apply the cointegration insight to expectations of macroeconomic aggregates. In this paper, we extend their work to expected exchange rates for each of five exchange rates, using weekly data on exchange rate expectations for the January 1986 – April 1997 period.[5]

Our empirical investigation is centered on answering three related questions.

Question 1: Is there cointegration between the actual and forecasted exchange rate series?

Our principal empirical task is to assess whether foreign exchange rate expectations (as measured by the MMS data) display the cointegration property of rational forecasts. The related questions are whether the Frankel-Froot irrationality results hold in the longer data sample considered here when rationality is assessed using empirical methods specifically designed for regressions with nonstationary regressors.[6]

Question 2: Presuming that actual and expected exchange rates display cointegration, how important are cointegration errors vs. lagged changes in actual rate or lagged changes in expected rates in explaining the dynamics of adjustments in expected exchange rates?

There is a gap in existing empirical work on expected exchange rate adjustment. Because expected rates were studied long before cointegration was discovered, the literature cited earlier exists largely divorced from cointegration. Instead, these empirical models focus on how changes in expected exchange rates vary with lagged changes in actual or expected exchange rates. By contrast, papers adopting the cointegration framework generally only report results of tests for cointegration (rationality). We have not found any work studying error-correction-based models of expected exchange rate revisions.

4. Campbell and Shiller make this point (1988a,b) in their work on cointegration of stock prices and dividends: an I(1) series and a rational forecast of future values of that I(1) series should be cointegrated.
5. In addition to these cointegration-oriented papers, there are many other investigations of the rationality of expectations. Among them are Frankel and Chinn (1993), Frankel and Froot (1986, 1987), and MacDonald (1990, 1990).
6. A number of papers have addressed the issues surrounding use of integrated series in the context of the forward bias problem. A sampling includes Liu and Maddala (1992), Hai, Mark, and Wu (1996), and Zivot (1997).

In our view, these two empirical approaches can be readily reconciled in the error-correction framework. The question we pose can be answered directly by applying standard hypothesis testing methods to an error-correction model (ECM). The change in expected exchange rates is the dependent variables and the lagged cointegration error (the error-correction term) and lagged changes in actual and expected exchange rates are the principal regressors.

Question 3: Are there asymmetries in the ECM models of expected exchange rate adjustment and are they economically important?

The empirical approach we take here encompasses the possibility that expectation adjustment may not be a smooth, continuous process. In fact, we think it is just as reasonable for market participants to adjust expectations infrequently, perhaps as new information arrives or perhaps because expectation formation reflects other psychological imperatives than rationality. While it is common in equity market analysis to view information arrival as a very high frequency activity, our supposition is that the arrival process for the most important information for exchange rate forecasting may be quite different. Specifically, this information may be impounded in noisy signals, and separating signal from noise with confidence may be possible only when other information is received (e.g., announcement of Federal Open Market Committee policy changes). These information events and their analogue in other countries also occur fairly infrequently.

Even in settings where monetary policy is completely transparent or set by rule, information about macroeconomic aggregates that can affect real interest rates (to name but one candidate) may arrive only infrequently. Consequently, there may be significant inertia in expectations because it may not be economical for market participants to revise their expectations.[7] Of course, it is also possible that with frequent, transparent reporting of underlying data, expectations might display significant persistence if the underlying data is highly persistent.[8]

Gruen and Gizycki (1993) develop a model of exchange rates in which traders form expectations that are anchored (in the sense of Tversky and Kahneman (1974)) to the forward exchange rate. Anchoring occurs when agents form expectations of future values by adjusting from a given starting point. Gruen and Gizycki show that their model can account for the forward discount bias and is consistent with the results of existing econometric work on exchange rate expectations.[9]

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7. If the marginal cost of exchange rate revision is positive, it is not obvious how the marginal benefit could exceed the marginal cost if the information set of market participants is unchanged.
8. Much ink has been spilled in the past twenty years on the issue of unit roots in the major macroeconomic aggregates. Whatever your position on this issue, most would agree that there is significant persistence in many of the macroeconomic aggregates, particularly interest rates which, given covered interest rate parity, are likely to be especially important in forming forecasts of future exchange rates.
9. Shiller (1999) surveys aspects of psychology especially relevant for understanding performance of financial markets. His survey includes a helpful discussion of anchoring.

From our perspective, the implication of each view (transaction/adjustment costs and/or psychological inertia/anchoring) of exchange rate expectation revision is that there may not be smooth, continuous adjustment of expected exchange rates. Rather, there may be a region of exchange rate forecasting errors in which there is a diminished incentive for adjustments by market participants. Errors outside this region may instead bring swift adjustments. Accordingly, the econometric analysis needs to accommodate this potential nonlinearity.[10]

Indeed, this is perhaps the most distinctive element of our econometric work. Unlike much of the existing work, we do not require that market participants smoothly and continuously adjust their expectations of future exchange rates. In our cointegration framework, we make this operational by replacing the (implicit) assumption of symmetric adjustment of cointegration errors with a model based on threshold cointegration.[11]

The idea behind threshold cointegration may be readily seen in a couple of examples. When cointegration errors are positive, adjustment in the error-correction model may be different than when cointegration errors are negative. In this case, there is a threshold (zero in this example) which splits the sample into two parts. Intuition suggests that market imperfections or transaction costs may lead two series to give the appearance of wandering randomly within a band around zero, but display compelling evidence of cointegration outside the band. For example, financial market arbitrage only works when the profit opportunities (i.e., the deviations from a parity condition) are larger than the (transaction) costs of undertaking the arbitrage. The presence of transaction or adjustment costs produces a region around zero arbitrage pricing in which normal market forces do not operate. Outside the band, we can expect the swift, purposeful action of market participants will change prices in predictable ways as arbitrage profits are taken.

Alternatively, a large realized cointegration error might signal an underlying structural shift. In this case, strong adjustment may not be sensible because the basic model structure may be changing. This implies we might see larger adjustment inside the band (because market participants believe the structure is stable) and smaller adjustment outside the band (because market participants attach non-zero probability to structural shift). We develop versions of threshold models in Section III and connect the models more directly to the existing literature on expectation formation and adjustment.

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10. We are not the first to propose this approach. Dumas (1992) shows that proportional transactions costs in spatially separated markets imply that deviations from PPP follow a nonlinear, mean-reverting process in which the speed of adjustment depends positively on the size of the PPP deviation. Michael, Nobay, and Peel (1997) study the implications of Dumas' analysis for real exchange rates using a (nonlinear) exponential autoregressive model. They show that PPP deviations are display random walk-like behavior when PPP deviations are small but their estimates imply swift adjustment toward equilibrium for large deviations from PPP. In the end, deviations from PPP look to be highly persistent, but mean-reverting. For other work in this area, see Baum, Caglayan, and Barkoulas (1998) and Enders and Falk (1998).

11. See Balke and Fomby (1997) and Enders and Siklos (1999) and references therein for recent analysis of threshold cointegration.

One of the important insights of the cointegration modeling approach is that adjustment dynamics are more complicated than is usually captured in, for example, VAR or univariate autoregressive modeling. The direct implication of threshold-style nonlinearities in cointegration is that the linear adjustment to cointegration errors featured in the usual error-correction model (ECM) is too simple. In turn, this implies that adjustment dynamics are likely to be misspecified, and potentially interesting characteristics of the expectations formation and adjustment process may be overlooked.

Our results can be summarized briefly. We find compelling evidence of cointegration between the exchange rate series and the expected exchange rate series. When we use unit-root tests that encompass potential asymmetric adjustments, we find evidence of this form of non-linearity in several cases. We also document an interesting variety of threshold-related behavior in tests for cointegration and in error-correction modeling. In the end, we believe that the foreign exchange rate expectations formation and adjustment process seems to display many important properties of rationality.

In the next section, we summarize some of the salient points from the relatively large literature on exchange rate expectations. Section III presents standard and threshold cointegration modeling methods.[12] We also describe how we make operational the ideas discussed in Section II. We focus on data-related issues in Section IV, and we discuss our empirical findings in Section V. We present a summary and a few concluding remarks in a final section.

II. Expected vs. Actual Exchange Rates

A. Forward Bias and Expected Exchange Rates

In rational expectations, forward-looking pricing models, formation and adjustment of price expectations is important to the dynamic properties and welfare implications of market prices. As an example, financial models of exchange rates have shifted toward emphasizing pricing of foreign currency in domestic currency terms as a function of expected, future period exchange rate values (in lieu of emphasizing the exchange rate as one of a few prices in an aggregate model). One potential role for fundamental variables (like money supply or income growth) in these models is that they help to make operational a model of the formation and revision of exchange rate expectations.[13]

Froot and Frankel (1989) study the connection between the forward premium puzzle and the process by which exchange rate expectations are formed and revised. More specifically, with the spot rate at time t given by s_t

12. In Appendix C, we also consider the connections between our results and Hansen's (1996, 1998, and 1999) work on threshold models.
13. Meese (1989) provides an accessible introduction to this approach in his review article.

and the forward rate at time t maturing at time t+k given by $f_{t,t+k}$ (both are in logs), they decompose the probability limit of the slope coefficient in

$$s_{t+k} - s_t = \alpha + \beta(f_{t,t+k} - s_t) + \varepsilon_{t+k} \quad (1)$$

into a portion attributable to failure of rational expectations and another portion arising from the risk premium. They show that

$$\beta = 1 - b_{re} - b_{rp} \quad (2)$$

where $rp_{t,t+k} = (f_{t,t+k} - s_t) - [E_t(s_{t+k}) - s_t]$ is the risk premium, $b_{re} = -cov(\varepsilon_{t+k}, f_{t,t+k} - s_t)/var(f_{t,t+k} - s_t)$, and $b_{rp} = [var(rp_{t,t+k}) + cov(E_t(s_{t+k}) - s_t, rp_{t,t+k})]/var(f_{t,t+k} - s_t)$.

If expectations data reflect rational formation and adjustment of expected exchange rates, $b_{re} = 0$. If the risk premium is uncorrelated with the forward discount, $b_{rp} = 0$. Using several data sets from the 1981- 1987 period and exchange rate expectations defined over periods of one to 12 months, Froot and Frankel find $b_{re} > 0$, often by economically significant amounts. On the basis of this and other test results, they conclude that they "cannot reject the hypothesis that all of the (forward premium) bias is attributable to these systematic expectational errors, and none to a time-varying risk premium (pg. 159, words added for clarity)."

Their results have not been replicated widely. Using a sample from the ***Currency Forecasters Digest*** for February 1988 – February 1991, Chinn and Frankel (1994) confirm the Froot and Frankel results, but discover smaller biases involving high-inflation countries. Cavaglia, Verschoor, and Wolff (1994) extend the analysis to currency cross rates with a different data set for the January 1986 – December 1990 period. Unlike Froot and Frankel, they find evidence that the bias in the forward discount is due both to expectations errors and to a time-varying risk premia.[14]

B. Expected Exchange Rate Models

Frankel and Froot (1987) provide a useful introduction to many of the major ideas in the literature studying exchange rate expectation formation and adjustment. The following expression for the expected spot rate captures some of the basic ideas:

$$E_t(s_{t+k}) = \gamma \cdot X_t + (1 - \gamma) \cdot s_t \quad (3)$$

where X_t represents other factors that might affect expectations beyond the current exchange rate, s_t. If $\gamma = 0$, expectations are said to be static in the sense that the expected rate is the current rate.[15] With extrapolative

14. To be sure, there are at least two other explanations for the results just cited. First, Lewis (1989) shows that learning about shifts in the money supply function in the U.S. could explain about 50 per cent of the error in the DM/US$ foreign exchange market in the early 1980's. More broadly, learning may be part of the explanation, but presumably, learning cannot explain persistent mistakes. Second, as Krasker (1980) suggests, a 'peso' problem may be part of the forward bias explanation. Flood and Rose (1996) provide some evidence suggesting this 'peso' explanation is not of practical importance.
15. This is also the prediction of the random walk model.

expectations, $X_t = s_{t-1}$. The adaptive expectations model sets $X_t = E_{t-1}(S_{t+k-1})$, and regressive expectations hold when $X_t = \hat{s}_t$, where $\hat{s}_t$ is the long-run equilibrium level of the spot rate. Researchers have investigated each of these models using a variety of different data sets on exchange rate expectations.

Revisions of exchange rate expectations may also be studied in a somewhat analogous way. Expressions for the revision of exchange rate expectations for each assumed model are:

Static: $$E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = (s_t - s_{t-1}) \tag{4}$$

Extrapolative: $$E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \gamma \cdot (s_{t-1} - s_{t-2}) + (1-\gamma) \cdot (s_t - s_{t-1}) \tag{5}$$

Adaptive: $$E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \gamma \cdot [E_{t-1}(S_{t+k-1}) - E_{t-2}(S_{t+k-2})] + (1-\gamma) \cdot (s_t - s_{t-1}) \tag{6}$$

Regressive: $$E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \begin{cases} \gamma \cdot (\hat{s}_t - \hat{s}_{t-1}) + (1-\gamma) \cdot (s_t - s_{t-1}) & (\text{if } \Delta\hat{s}_t \neq 0) \quad (7a) \\ (1-\gamma) \cdot (s_t - s_{t-1}) & (\text{if } \Delta\hat{s}_t = 0)\ . \quad (7b) \end{cases}$$

A few comments are in order about the variety of expectations models. First, bandwagon effects may be viewed as a special case of static expectations

$$E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = -\delta \cdot (s_t - s_{t-1}) \tag{8}$$

when we assume that $\delta < 0$. With this assumption, (8) implies that expectations of depreciation (or appreciation) are self-reinforcing. One characteristic of bandwagon expectations is that expected spot rates have an elasticity with respect to actual rates greater than one. Static expectations (see (4) above) have an elasticity of one. If expectation adjustment is inelastic with respect to spot rate changes, the expectation revision process is stabilizing. Here, the idea is that currency depreciation generates the expectation of future currency appreciation (in terms of (8), $\delta > 0$). Similar to (3), this may be represented as

$$E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = (1-\delta) \cdot s_t + \delta \cdot s_{t-1} \quad . \tag{9}$$

where the right-hand side of (5) is a special case of distributed lag expectations where the weights on the current and lagged spot rate are $(1-\delta)$ and δ.[16]

Second, modeling regressive expectations (7a and 7b) may be somewhat involved. If the data analyst is not prepared to assume the equilibrium value is constant throughout the sample period, the model has some similarities with a switching regression. Additional structure will be required to identify and estimate the model, not the least of which is a model of the equilibrium exchange rate. The real issue, of course, seems to be what market participants (not the data analyst) believe the equilibrium exchange rate is, and how and when it changes. It remains uncertain

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16. Adaptive expectations may also be seen using the distributed lag idea where the expected future spot rate is a weighted average of the lagged expected rate and the spot rate. That is, $E_t(S_{t+k}) = (1-\delta) \cdot s_t + \delta \cdot E_{t-1}(S_{t+k-1})$ where δ is again the weight.

what market participants believe 'the model' is and whether using (say) PPP-based equilibrium rates will produce meaningful results.[17]

In the next section, we lay out a cointegration – error-correction approach to modeling revisions of expected exchange rates. We show how the models of exchange rate expectations 4 – 7b can be viewed as special cases of an encompassing error-correction model.

III. Econometric Modeling of Expected Exchange Rate Dynamics

A. Cointegration Testing

In this section, we describe the modeling strategy that we use to study the dynamics of expected exchange rates. We begin by describing how to test for cointegration and how to approach linear error-correction modeling of changes in expected exchange rates. In the next few subsections, we generalize the discussion to accommodate nonlinear settings.

Before running cointegration tests and estimating ECM models, we have to establish that the actual exchange rate and the forecasts display unit roots (i.e., they are I(1) series). One commonly-used test for unit roots is the Dickey-Fuller test in which the analyst runs the regression

$$\Delta y_t = \rho \cdot y_{t-1} + \varepsilon_t \tag{10}$$

and compares the estimated value of $T(1 - \rho)$ (where T is the sample size) against the tabulated critical values.[18]

The basic cointegration model may be written as

$$E_t(s_{t+k}) = \varphi_0 + \varphi_1 \cdot s_{t+k} + z_{t+k} \tag{11}$$

where z_{t+k} is the cointegrating regression error. The z_{t+k} series should be stationary if actual and expected exchange rates are cointegrated. This means that the same unit root tests as we used in the first step can be applied again to the issue of testing for cointegration, including (as we discuss later in this section) testing for threshold cointegration. A standard cointegration test might be conducted by testing whether the realized error term series from the cointegrating regression is I(0). That is, a Dickey-Fuller or Phillips-Perron test might be applied to the slope coefficient, ρ, in the regression

$$\Delta z_{t+k} = \alpha + \rho \cdot z_{t-1} + e_t \ . \tag{12}$$

17. Cheung and Chinn's (1999b) survey results indicate that the relative importance of macroeconomic fundamentals appears to be time-varying, consistent with the relative superiority of time-varying parameter models of exchange rates over fixed coefficient models at longer horizons. If this is an accurate portrayal of the views of market participants, it suggests that the appropriate 'equilibrium' model might be quite different for short-horizon and long-horizon expectations modeling. In turn, this implies that regressive expectations may not be a particularly fruitful approach to understanding the dynamics of one- and four-week ahead expected exchange rates data we study in this paper.

18. The heteroscedasticity-robust Phillips-Perron test may be used instead in situations where the constant variance assumption of the ordinary least squares estimator is not believed to hold.

Following earlier work in Cheung and Chinn (1999), we also test the unitary elasticity of expectations hypothesis. Rejecting the null $\varphi_1 = 1$, implies that expectations and actual rates can diverge from each other in the long run. To test this hypothesis, we use a modification of (11) that includes both leads and lags of changes in actual exchange rates. We adjust the usual t-test for $\varphi_1 = 1$ with a procedure outlined in Hamilton (1996, pgs. 610-611).

B. Threshold Models

Before discussing threshold cointegration models, it is useful to consider the characteristics of threshold models.[19] There are three separate choices that need to be made to define a threshold model: the type of threshold, the threshold variable, and the lag length on the threshold variable. While threshold models come in different varieties depending on the choices made, we limit our attention to a few that we believe have particular appeal for threshold cointegration tests. Applied to evaluating the stationarity of cointegration errors, the equilibrium threshold autoregressive model is given by:

$$z_t = \begin{cases} z_{t-1} + e_t & z_{t-1} \leq \theta \quad \text{(13a)} \\ \rho z_{t-1} + e_t & z_{t-1} > \theta. \quad \text{(13b)} \end{cases}$$

Here, the choice of threshold type creates two regimes based on the value of the cointegration regression error value (θ) last period. In one regime, the autoregressive coefficient is one (indicating nonstationary). In the other regime, the autoregressive coefficient is potentially different from (and implicitly less than) one (indicating stationary). Put more simply, below θ, the error term follows a random walk, but above θ, the error term follows autoregressive process with $\rho < 1$.

Band threshold autoregressive (Band-TAR) models capture the idea that the adjustment may be different in a band of values. Applied again to evaluating the stationarity of cointegration errors, a simple version of a Band-TAR model is given by:

$$z_t = \begin{cases} \rho_1 \cdot z_{t-1} + e_t & |z_{t-1}| \leq \theta \quad \text{(14a)} \\ \rho_2 \cdot z_{t-1} + e_t & |z_{t-1}| > \theta. \quad \text{(14b)} \end{cases}$$

In this formulation, the band is defined by the absolute value of the lagged value of the cointegration regression error. The autoregressive coefficient is ρ_1 when the absolute value of the cointegrating regression error is less than or equal to the threshold value, θ. The autoregressive coefficient is ρ_2 when the absolute value of the cointegrating regression error is greater than the threshold value. There are two potential interpretations of (14a) – (14b). First, adjustment or transaction costs may rationally limit error correction for small errors, but not for large

19. There is a large literature on threshold models. Among the important contributions are Granger and Teräsvirta (1993), Teräsvirta, Tjøstheim, and Granger (1994), Tong (1990), and Tsay (1988, 1989). In addition to the PPP-oriented work mentioned earlier (fn. 10), other applications of threshold methods include Hirayama and Tsutsui (1998), Martens, Kofman, and Vorst (1998), Pfann, Schotman, and Tschernig (1996), and Prakash and Taylor (1997).

errors. Second, large errors may imply structural instability so we might expect $\rho_2 < \rho_1$. This reflects an assumption that with stable structure, market participants may adjust more completely than when there is structural instability.

C. Threshold Unit Root Tests

Enders and Granger (1998) suggest an asymmetric alternative to standard unit root tests based on a specific version of a threshold autoregressive (TAR) model. Specifically, they consider the following process

$$\Delta y_t = \begin{cases} \rho_1 \cdot y_{t-1} + \varepsilon_t & \text{if } y_{t-1} \geq \theta \quad (15a) \\ \rho_2 \cdot y_{t-1} + \varepsilon_t & \text{if } y_{t-1} < \theta\,. \quad (15b) \end{cases}$$

Their alternative to the Dickey-Fuller test may be implemented by running the regression

$$\Delta y_t = I_t \cdot \rho_1 \cdot y_{t-1} + (1 - I_t) \cdot \rho_2 \cdot y_{t-1} + \varepsilon_t \tag{16}$$

where the Heaviside indicator function, I_t, equals one if $y_{t-1} \geq \theta$, $I_t = 0$ if $y_{t-1} < \theta$, and θ is a threshold value that may be unknown (but can be consistently estimated).[20] With a convergent system, $y_t = 0$ is the equilibrium value in the long run, so $\rho_1 \cdot y_{t-1}$ ($\rho_2 \cdot y_{t-1}$) gives the adjustment when y_t is above (below) the long-run equilibrium value.

Enders and Granger develop an F-test of the null hypothesis $\rho_1 = \rho_2 = 0$ (i.e., a random walk model), denoted φ_μ. If the calculated F-value is large enough to reject this null hypothesis, the analyst can test the null hypothesis of symmetric adjustment ($\rho_1 = \rho_2$) against the alternative of asymmetric adjustment, $\rho_1 \neq \rho_2$. They report critical values for both tests and a Monte Carlo analysis of their properties in their paper.

Another version of the model, called the momentum threshold model (MTAR), uses the idea that under the alternative hypothesis, the series y_t has more 'momentum' in one direction than another. In this case the Heaviside function is specified in terms of the lagged change in the threshold variable, not the lagged level of the threshold variable.[21] The MTAR model is written:

$$I_t = \begin{cases} 1 & \text{if } \Delta y_{t-1} \geq \theta \quad (17a) \\ 0 & \text{if } \Delta y_{t-1} < \theta. \quad (17b) \end{cases}$$

Extending these results to accommodate potential threshold effects in cointegration tests is straightforward. The test for cointegration (i.e., φ_μ, the Enders-Granger F-test for $\rho_1 = \rho_2 = 0$) is now undertaken with the following model used to provide estimates of the autoregressive coefficients:

$$\Delta z_{t+k} = I_t \cdot \rho_1 \cdot z_{t-1} + (1 - I_t) \cdot \rho_2 \cdot z_{t-1} + e_t\,. \tag{18}$$

I_t is the Heaviside indicator function introduced in the last subsection. A variety of tests might be run conditional on the choice of the indicator function, I_t.

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20. As in standard Dickey-Fuller tests, lagged values of Δy_t may be added to the model (12) and the sensitivity of inferences to different lag structures established.
21. This may be particularly useful in capturing threshold effects due to policy reaction functions where the central bank intervenes based on large movements in exchange rates, for example.

D. Threshold Error-Correction Models

One feature of this paper that distinguishes it from others applying cointegration methods is the focus on error-correction dynamics, not the cointegrating regression.[22] We approach the rationality question by studying how expectations are revised. The value of studying error-correction models is fairly simple: if expectations are formed and revised rationally, we should expect that mistakes made last period in forecasting exchange rates should help to explain changes in expected exchange rates. Following on the usual cointegration analysis, the error-correction term should have a negative sign. A positive (negative) error should lead to a lower (higher) expected exchange rate in the subsequent period.

The next step is to model the process by which expected exchange rates are revised. Empirically, there are several options to us. First, we can build the ECM from our cointegration structure and ignore the possibility that there are threshold effects. This yields a fairly standard ECM representation of the change in expected exchange rates:

$$\Delta E_t(s_{t+k}) = \nu_0 + \sum_{i=1}^{M} \nu_i z_{t+k-i} + \sum_{j=1}^{N} \lambda_j \Delta E_t(s_{t+k-j}) + \sum_{l=1}^{P} \kappa_k \Delta s_{t+k-l} + \varepsilon_t \qquad (19)$$

where the z_{t+k} ($= E_t(s_{t+k}) - \varphi_0 + \varphi_1 \cdot s_{t+k}$) are the errors from the cointegrating regression.

Second, to accommodate potential threshold effects, we can incorporate threshold effects from the cointegrating regression into the error-correction modeling process. Specifically, the equations capturing the dynamics of expected and actual exchange rates are adjusted as follows:

$$\Delta E_t(s_{t+k}) = \nu_0 + I_t \cdot \rho_1 \cdot z_{t+k-1} + (1 - I_t) \cdot \rho_2 \cdot z_{t+k-1} + \sum_{i=1}^{m} \lambda_i \Delta E_t(s_{t+k-i}) + \sum_{j=1}^{n} \kappa_j \Delta s_{t+k-j} + \varepsilon_t \qquad (20a)$$

$$\Delta s_{t+k} = \nu_0^{'} + I_t \cdot \rho_1^{'} \cdot z_{t+k-1} + (1 - I_t) \cdot \rho_2^{'} \cdot z_{t+k-1} + \sum_{i=1}^{m^{'}} \lambda_i^{'} \cdot \Delta E_t(s_{t+k-i}) + \sum_{j=1}^{n^{'}} \kappa_j^{'} \cdot \Delta s_{t+k-j} + \varepsilon_t^{'} . \qquad (20b)$$

Based on the analysis reported in Enders and Siklos (1999), we develop a multivariate approach to estimating (20a) and (20b) conditional on a consistent estimate of the threshold value embedded in the Heaviside indicator function, I_t. Essentially, we minimize a multivariate AIC criteria by searching over lag lengths (m and n in 20a) and values of the model parameters (e.g., ν_0, ρ_1, ρ_2, λ_i and κ_j) simultaneously. Further details on the algorithm, programmed in GAUSS, are available on request.

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22. For example, in Cheung and Chinn (1999), they test whether the cointegrating regression coefficients (φ_0 and φ_1 in (11) above) are zero and one, respectively. These are the restrictions implied by rationality.

Third, we can compare inferences from our ECM-based estimates to results from applying existing univariate models of exchange rate expectation dynamics (i.e., extrapolative, regressive, adaptive, etc.). As noted earlier, specific expectations adjustment models are nested within the general, encompassing specification (20a). The (reduced) regression models are reproduced here except for the regressive expectations approach which we do not analyze in this version of our work:

Static: $E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \nu_0 + \kappa_1 \cdot (s_t - s_{t-1}) + \varepsilon_t$ (4')

Extrapolative: $E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \nu_0 + \gamma \cdot (s_{t-1} - s_{t-2}) + (1 - \gamma) \cdot (s_t - s_{t-1}) + \varepsilon_t$ (5')

Adaptive $E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \nu_0 + \lambda_1 \cdot [E_{t-1}(S_{t+k-1}) - E_{t-2}(S_{t+k-2})] + \kappa_1 \cdot (s_t - s_{t-1}) + \varepsilon_t$ (6')

Using standard F-tests, it is straightforward to evaluate the evidence favoring each of these specific models as a restricted version of (20a). A common feature of the models given by 4' – 6' is that they provide no linkage between past mistakes in forecasting rates and changes in expected exchange rates. This, of course, is a strength of error-correction models.

IV. Data Issues

Money Market Services, Inc. collects a wide range of forecasts from financial market participants through weekly surveys.[23] It makes available the median forecast for each data item, but does not provide any other measures of central tendency or other moments of the distribution such as measures of cross-sectional variation. For our work, we purchased weekly observations on one- and four-week ahead forecasted values for the Canadian Dollar, Deutschemark, Japanese Yen, and Swiss Franc against the U.S. Dollar, and the forecasted values for the U.S. Dollar against the British Pound. The sample period covers January 1986 through April 1997, about 486 observations for each sample.

While others have used the MMS data, there is considerable variety in data used among the published papers in this area of research. Chinn and Frankel collected data from the Financial Times ***Currency Forecaster*** to support their empirical work. MacDonald and Torrance (1988a, 1988b) used data on exchange rate forecasts collected from traders and other market participants in the U.K. Ito (1994) and his collaborators have studied exchange rate expectation formation using an unique set of exchange rate expectations data gathered from Tokyo foreign exchange market participants.

Perhaps the most important limitation of this data set is that the forecast horizon is relatively short: either one week or four weeks. This limitation is important because it means we are not able to contribute directly to the

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23. This data source has been used in other work. Dominguez' first paper in this area was based on a small sample of MMS data. Frankel and Froot's original empirical work was based on several sources of exchange rate expectations data, including the MMS survey.

research aimed at distinguishing between long-horizon vs. short-horizon expectations effects. Nonetheless, the methods used in this paper might be applied to that data.

The sample period we investigate, January 1986 through April 1997, witnessed some significant shifts in institutional exchange rate arrangements (e.g., Great Britain's entry and exit from the Exchange Rate Mechanism). Structural shifts are potentially very important to the economics and econometrics of our investigation. For example, Lewis (1989) shows that up to half of the U.S. Dollar-Deutschemark forward premium bias in the early 1980's might be attributed to shifts in U.S. money market structure. It is also well known that unstable model structure can create the illusion of nonstationarity when none exists. Because structural shifts can also compromise standard cointegration tests, we check our inferences by applying the cointegration test methods developed by Gregory and Hansen (1996).[24]

Table 1 reports summary statistics for our data series. By currency, the means and standard errors for the actual and expected exchange rate series are quite similar. We note two common features across exchange rate series: the first-order autocorrelations are very nearly one (> .98) and the autocorrelations decline fairly slowly.

V. Empirical Results

A. Is There Cointegration?

Cointegration implies we can find a stationary linear combination of two nonstationary series. Before we proceed to test for cointegration, it is important to establish whether the basic data series are I(1).

Table 2, Panel A reports results from applying Dickey-Fuller and Phillips-Perron tests. Results from both test generally indicate our one- and four-week ahead exchange rate series are nonstationary in the levels. Treatment of the trend does not change the inferences we draw from this exercise. There is some evidence that the $/£ rate may be stationary, since some of the test statistics constitute evidence against the null hypothesis of a unit root at the five per cent level (but not at the one per cent level). Accounting for a trend term leads to much larger test statistics for the $/£ rate, indicating support for the null hypothesis of a unit root.

Table 2, Panel B reports results from Dickey-Fuller and Phillips-Perron tests applied to the residuals of the cointegrating regression (11). The clear finding is that the residuals from the cointegration equation are stationary, not unit root processes. This holds for both forecast horizons and all currencies.

As we noted earlier, the sample period includes some significant changes in the structure of exchange rate arrangements and periods of unusual turbulence. Since structural shifts can invalidate inferences from standard unit root and cointegration tests, we also apply the Gregory-Hansen cointegration test. Their test accounts for the impact

24. It has become standard knowledge in time series econometrics that structural instability can give the appearance of nonstationarity in unit root tests.

of one shift in model structure on Dickey-Fuller and Phillips-Perron tests. In every case, we replicate the inferences from applying the standard tests. [25]

Aside from these cointegration test results, direct estimates of the cointegration model (11) also indicate the MMS survey data appear to display some statistical departures from the unitary elasticity of expectations standard studied recently by Cheung and Chinn (1999). We report estimates of our cointegration model in Table 2, Panel C. For the one-week ahead sample, the slope estimates are .99 in four cases and .98 in the other case. Despite this, the test statistics reject the null in four of five cases. The slope estimates from the four-week ahead sample range from .95 to 1.03, and the test statistics reject the null in every case. In these finite samples, then, we find statistical evidence against this characteristic of 'rational' expectations: the data do not display the unitary elasticity of expectations that we might expect. Economically, however, the point estimates of the slope coefficient are very close to one.

We also investigated whether the linearity assumptions embedded in the Table 2 are appropriate. Specifically, we studied whether the cointegration results are affected by potential threshold effects. We estimate (18) using the equilibrium threshold model given by (15a) and (15b) and using the momentum threshold model given by (17a) and (17b). In each case, the threshold variable is based on the lagged residual of the cointegration regression (11). Since we do not know the critical value of the threshold variable (θ), we use a method proposed by Chan (1993) to estimate the optimal threshold. Finally, the lag length choice is made on the basis of AIC and BIC values. Optimal lag lengths are reflected in the estimates reported in Table 3. For both one-week and four-week ahead data, we again find clear evidence of stationarity (i.e., cointegration). The test statistic, φ_μ, indicates that there is no evidence that asymmetries are consequential in assessing the cointegration evidence. The F-test for equality of the adjustment coefficients never rejects the null hypothesis of equal rates of adjustment above and below the threshold. [26]

B. Are There Error-Correction Effects?

The second question we address is the role of error-correction vs. autoregressive and other influences on changes in expected exchange rates. We use the ECM (20a) presented in the section III.D. In Table 4, we report

25. The test statistics are reported in Appendix A, Table 1. Because of the potential for moving average errors with weekly observations on four-week ahead forecasts, we also computed the tests by sampling the four-week ahead data every four weeks. The table indicates each of the four samples created by sampling every fourth observation, beginning alternatively in the first through fourth week of the month.

26. Beyond this important result, we find some interesting regularities in the estimates reported in Table 3. First, we find relatively small differences in adjustment coefficients for the expected and actual exchange rate series. Second, for the one-week ahead data, we find that $\rho_1 > \rho_2$ except for the \$/£ exchange rate. Using the four-week ahead data, we find the opposite except for the estimates of the momentum model applied to the \$/£ and ¥/\$ exchange rates. Third, we find the AIC values for the M-TAR models are smaller than the AIC values for the equilibrium models, except for the C\$/US\$. Based on extensive analysis of alternative lag lengths, we found strong evidence that the data favor M-TAR models in virtually every setting.

estimates of four different error-correction models using both one-week ahead and four-week ahead forecast data. The first model (denoted Model 1 in the table) is the standard ECM ((19) above). The other three models (Model 2 – Model 4) admit the possibility of threshold behavior using three different threshold variables. For Model 2, we use the lagged cointegration error. Model 3 is a momentum-type model: we use the lagged change in the cointegration error in this model. Finally, Model 4 is a simple band threshold model that uses the absolute value of the lagged cointegration error as the threshold variable. For Model 1, we report OLS-based estimates of the model parameters. The estimates for Models 2 – 4 are from a multivariate approach in which we estimate jointly the error-correction model for both the expected rate and the actual rate simultaneously.

We focus first on the simple error-correction models. For all currencies and both forecast horizons, the lagged cointegration term has the expected negative sign and is significantly different from zero. The coefficient on this term (z_{t-1}) may be interpreted as the percentage of forecast error reflected in the current change in the forecasted currency rate. For the one-week ahead forecast data, the smallest error-correction coefficient is -.82 and the largest is -.95. At the four-week forecast horizon, the error-correction coefficients are smaller, ranging from -.35 for the DM to -.70 for the C$. The modal value of these coefficients for the four-week forecast horizon is about -.45.

An interesting difference between the one- and four-week forecast horizon results centers on the role of lagged changes in actual and forecasted rates. At the four-week forecast horizon, F-tests reject the null hypothesis that excludes lagged changes in actual and forecasted rates from the model. For the one-week horizon data, the same tests reject the null only for lagged expected rate changes of the Swiss Franc rate. This implies that error-correction is the dominant explanation of changes in forecast rates at the one-week horizon, but only part of the story at the longer horizon. Focusing only on these simple error-correction models, we conclude that expectations of future exchange rates are adjusted in an economically sensible way. Past forecasting mistakes are 'corrected' at both horizons studied here, and at relatively longer horizons, other predetermined variables also are important in explaining changes in forecast rates.

C. Are There Threshold Effects in Error-Correction?

Table 4 also includes some evidence of nonlinearities in the error-correction models. For the DM and SFr. series, the AIC criterion always chooses the simple, linear error-correction model for both forecast horizons. For the $/£ rate, the AIC criterion chooses the momentum threshold (MTAR) formulation of the error-correction model (see (17a) and (17b) in Section III.C) for both forecast horizons. Despite this, the differences in the error-correction coefficients above and below the threshold are reasonably small.[27] At the one-week horizon, the adjustment is 90 per cent for large changes in the cointegration error and 97 per cent for changes in the cointegration error below the

27. The momentum threshold error-correction coefficients are also fairly similar to the error-correction coefficient in the simple, linear error-correction model.

threshold. That is, the adjustment of expectations to forecasting errors is relatively less aggressive when the cointegration error grows larger, but relatively more aggressive when the cointegration error grows smaller. We see the same pattern at the four-week horizon: the adjustment is 45 per cent for large changes in the cointegration error and 48 per cent for changes in the cointegration error below the threshold.

At the one-week forecast horizon, the AIC criterion also chooses a nonlinear model for changes in the expected C$/$ and ¥/$ rate. At the four-week horizon, the AIC is minimized for the simple, linear error-correction model for both currencies. For the ¥/$ rate, the AIC criterion chooses for the momentum threshold model where we find the error-correction coefficients are –1.0 above the threshold and -.92 below the threshold. The data reject the null hypothesis that these coefficients are identical (t = 9.2, p-value < .01). See Test 5 in Table 4. That is, the adjustment of expected exchange rates is more aggressive when the cointegration error grows larger. This is the opposite of what we find for the $/£ rate.

For the C$/$ series, a Band-TAR specification minimizes the AIC criterion. The error-correction coefficients, -.77 outside the band vs. -.86 within the band, suggest a learning interpretation of the band, not the costly arbitrage motivation discussed in Section I. The data reject the null hypothesis that these error-correction coefficients are equal (t-statistic = 6.0, p-value < .01). The threshold value indicates that about 72 percent of the sample falls inside the band with the remainder outside the band. This suggests that the band threshold estimate is not being driven by a small set of outliers in the data. For the other three cases where asymmetric error-correction minimizes the AIC criterion, the percentages of the sample below the threshold are 52 ($/£, 1-week), 84 (¥/$, 1-week), and 15 ($/£, 4-week).

To summarize, estimates of the error-correction models for expected exchange rates show that deviations from the fundamental cointegration relationship are reflected in changes in expected rates. The adjustment is larger at the one-week horizon than at the four-week horizon. In addition, we find that the adjustment at the shortest horizon is explained completely by error-correction. At the relatively longer horizon, lagged changes in actual and expected rates also help to explain the adjustments. These findings suggest that the oft-used univariate approach in the literature may be inadequate for characterizing the characteristics of expected exchange rate dynamics, especially at high frequencies.

D. Evidence from the Frankel-Froot Data

The original Frankel and Froot papers on expected exchange rates and forward bias were published before the consequences of cointegration for modeling revisions of exchange rate expectations were appreciated. To link our work with theirs more directly, we also estimated the same models for the same expectations data they used in their empirical studies.[28] Our principal findings on error-correction and expected exchange rate dynamics are confirmed in their data. Further details on this aspect of our work are available in Appendix B.

VI. Summary and Concluding Remarks

In this paper, we have exploited a property of rational forecasts, cointegration with actual rates, to investigate the dynamics of one- and four-week ahead forecasts for the January 1986 – April 1997 period. We posed three basic questions.

Question 1: Is there cointegration between the actual and forecasted exchange rate series? Based on our unit root tests, it certainly appears that way. Using the standard tests for cointegration (and some nonstandard tests, too), we find evidence of cointegration. This means that the exchange rate forecast data display this important characteristic of rationality. Our tests for the unitary elasticity of expectations, referred to by Cheung and Chinn (1999) as the most restrictive property of rational expectations, reject the unitary elasticity hypothesis in nine of ten cases. Despite this, the point estimates from the cointegrating regressions are very close to unity, particularly at the one-week forecast horizon.

Question 2: Presuming that actual and expected exchange rates display cointegration, how important are cointegration errors vs. lagged changes in actual rate or lagged changes in expected rates in explaining the dynamics of adjustments in expected exchange rates? At the one-week forecast horizon, we find that error correction is the dominant explanation of changes in expected exchange rates. At the four-week horizon, lagged changes in actual and expected rates are also important. Interestingly, we also find the error-correction coefficients are smaller (often by 50 per cent) at the four-week horizon. This appears to hold for linear and nonlinear error-correction models. We confirmed these same results for the Frankel and Froot data, too.

Question 3: Are there asymmetries in the ECM models of expected exchange rate adjustment and are they economically important? For the long time series of expected exchange rates that we study here, nonlinearities appear to be important in error-correction for the C$/$, $/£, and ¥/$ series. The AIC criterion selects M-TAR models for the $/£ rates at both forecast horizons, an M-TAR model the ¥/$ expected rate series at the one-week horizon, and a Band-TAR model for the C$/$ expected exchange rate series at the one-week horizon. Of the four nonlinear error-correction models estimated here, we do find statistically significant differences in the error-correction effects for all currencies at the one-week horizon, but not at the four-week forecast horizon. There is little evidence of nonlinearities in the Frankel and Froot data. It is unclear whether this reflects an inadequate sample size or the consequences of a different sample period.

28. We are grateful to Ken Froot for providing the data.

In the end, we believe that the expected exchange rate data studied here display some very important 'rationality' properties. Specifically, market participants appear to adjust their expectations in a sensible way in response to past mistakes. Our reading of the results suggests that evidence in earlier studies for "bandwagon" effects or autoregressive expectations may have reflected neglect of error-correction effects. The strong error-correction effects at short horizons also seem to suggest that expectations are unlikely to be destabilizing. In addition to error-correction, we find that at longer forecast horizons market participants also appear to make some use of lagged changes in actual and expected rates when adjusting their forecasts of future rates.

We find an interesting diversity in the nonlinear models, and this suggests some questions for additional study. The M-TAR models for the $/£ and ¥/$ series point to different views of the adjustment process. In one case, the response to increasing errors is more aggressive adjustment (¥/$), but in the other case, the response is less aggressive adjustment. We have suggested there are two potential interpretations of this difference in response, but further work is needed to understand the economic foundations of this result. Likewise, the Band-TAR estimates seem to be more consistent with a structural change-learning view, rather than the costly arbitrage explanation often associated with the Band-TAR model. Again, further study of the connections between structural change, learning, and expectation formation (see Gourinchas and Tornell (1996) for a recent effort) may be quite helpful in understanding more deeply our empirical results.

Finally, while the expectations data clearly appear to satisfy many important characteristics of rationality, it is unclear how to reconcile the dynamics we estimate with the stylized facts of the forward bias problem. This issue remains under active study. We are also studying whether there are other variables that might identify more economically significant threshold effects in the expected exchange rate revision series. Specifically, we have some preliminary evidence that volatility in spot rates and interest differentials may play a role in understanding dynamics of expected exchange rates. We expect to report further results on these questions, and we look forward to seeing the work of other researchers.

Table 1

Summary Statistics for One- and Four-Week Ahead Exchange Rate Forecasts and Actual Values

Currency/Series	No. Obs.	Mean	Std. Error	Min.	Max.	Autocorrelations 1	2	3	4	5	6	7	8
1-Week Ahead													
DM/$													
Survey	486	1.632	.140	1.370	2.010	.974	.956	.939	.919	.895	.874	.854	.834
Actual	486	1.633	.142	1.368	2.003	.985	.970	.954	.935	.917	.896	.876	.857
$/£													
Survey	487	1.654	.137	1.410	1.995	.980	.959	.937	.913	.891	.868	.843	.817
Actual	487	1.655	.136	1.423	1.996	.981	.962	.941	.918	.896	.874	.849	.822
¥/$													
Survey	487	120.84	17.08	83.00	159.38	.994	.988	.982	.975	.968	.960	.953	.946
Actual	487	120.97	17.17	82.63	158.90	.995	.989	.983	.977	.970	.962	.955	.948
SFr/$													
Survey	487	1.400	.142	1.123	1.760	.986	.972	.958	.941	.923	.903	.885	.866
Actual	487	1.401	.142	1.127	1.758	.986	.974	.960	.944	.927	.909	.891	.873
C$/US$													
Survey	487	1.262	.089	1.120	1.420	.993	.987	.980	.975	.967	.964	.960	.955
Actual	487	1.263	.090	1.120	1.423	.994	.988	.981	.975	.970	.965	.960	.955
4-Week Ahead													
DM/$													
Survey	483	1.636	.137	1.379	2.010	.983	.964	.944	.921	.898	.873	.849	.825
Actual	483	1.633	.142	1.368	2.003	.985	.970	.954	.935	.917	.896	.877	.857
$/£													
Survey	483	1.649	.141	1.413	1.996	.980	.958	.936	.910	.886	.861	.834	.806
Actual	483	1.655	.136	1.423	1.996	.982	.962	.942	.919	.898	.874	.847	.820
¥/$													
Survey	483	120.82	16.64	81.00	157.00	.993	.987	.979	.971	.963	.953	.945	.936
Actual	483	120.90	17.23	82.63	158.90	.995	.989	.983	.976	.970	.962	.955	.948
SFr/$													
Survey	483	1.403	.140	1.130	1.752	.984	.968	.952	.933	.912	.890	.868	.846
Actual	483	1.401	.143	1.127	1.758	.986	.974	.961	.944	.928	.909	.891	.873
C$/US$													
Survey	483	1.261	.088	1.120	1.420	.993	.987	.981	.975	.970	.965	.960	.955
Actual	483	1.262	.090	1.120	1.423	.993	.987	.981	.975	.970	.965	.960	.955

Table 2

Empirical Results from Unit Root Tests Applied to Actual and Expected Exchange Rate Series

Panel A

Currency	Actual FX Rate Values				Survey FX Rate Values			
1-wk. ahead	DF-No Trend	DF-Trend	PP-No Trend	PP-Trend	DF-No Trend	DF-Trend	PP-No Trend	PP-Trend
C$/US$	-1.28	-9.99	-1.07	-9.36	-0.78	-9.21	-0.75	-9.04
DM/$	-7.00	-10.36	-7.84	-12.05	-12.21	-18.92	-10.46**	-16.59
SFr/$	-6.46	-10.30	-7.01	-11.40	-6.83	-11.15	-7.60	-12.60
$/£	-8.84**	-11.69	-10.22**	-13.80	-9.18**	-11.81	-10.86**	-14.34
¥/$	-2.54	-3.12	-2.92	-3.97	-2.78	-4.10	-3.05	-4.74
4-wk. ahead								
C$/US$	-0.93	-9.43	-0.71	-8.77	-1.56	-9.98	-1.43	-9.59
DM/$	-7.03	-10.24	-7.86	-11.93	-7.77	-12.29	-9.85**	-15.97
SFr/$	-6.37	-10.19	-6.92	-11.33	-7.68	-12.35	-8.58**	-13.97
$/£	-8.68**	-11.60	-10.07**	-13.71	-9.21**	-11.86	-11.31**	-15.03
¥/$	-2.47	-3.30	-2.85	-4.19	-3.44	-6.09	-3.57	-6.48

Panel B

Currency	Cointegrating Regression Residual: Actual on Survey				Cointegrating Regression Residual: Survey on Actual			
1-wk. ahead	DF-No Trend	DF-Trend	PP-No Trend	PP-Trend	DF-No Trend	DF-Trend	PP-No Trend	PP-Trend
C$/US$	-417.36*	-417.36*	-405.26*	-405.24*	-417.32*	-419.70*	-405.49*	-405.74*
DM/$	-432.82*	-433.16*	-441.42*	-441.43*	-427.63*	-433.09*	-441.82*	-442.74*
SFr/$	-455.60*	-455.59*	-485.17*	-485.16*	-455.25*	-460.79*	-485.95*	-486.79*
$/£	-410.95*	-412.41*	-417.62*	-418.17*	-410.61*	-412.41*	-418.52*	-418.17*
¥/$	-461.54*	-462.00*	-489.85*	-489.97*	-461.32*	-462.26*	-490.12*	-490.12*
4-wk. ahead								
C$/US$	-114.61*	-114.63*	-130.37*	-130.40*	-114.15*	-117.42*	-129.92*	-133.80*
DM/$	-100.67*	-100.81*	-114.41*	-114.53*	-99.99*	-104.19*	-112.54*	-118.01*
SFr/$	-107.67*	-107.65*	-115.98*	-115.95*	-106.37*	-112.05*	-114.04*	-121.15*
$/£	-100.84*	-102.74*	-112.75*	-115.15*	-100.32*	-101.10*	-111.76*	-112.67*
¥/$	-114.36*	-114.64*	-124.00*	-124.30*	-113.40*	-114.93*	-122.81*	-124.75*

Table 2 (cont.)

Empirical Results from Unit Root Tests Applied to Actual and Expected Exchange Rate Series

Panel C: Cointegration Model Estimates

Currency	1-Week Ahead Sample		t-test	4-Week Ahead Sample		t-test
C$/US$	$E_t(S_{t+k}) = .001 + .993 \cdot S_{t+k}$ (.001) (.004)	$R^2 = .99$	-.53	$E_t(S_{t+k}) = .008 + .962 \cdot S_{t+k}$ (.002) (.008)	$R^2 = .99$	-4.56
DM/$	$E_t(S_{t+k}) = .014 + .969 \cdot S_{t+k}$ (.005) (.010)	$R^2 = .99$	-15.2	$E_t(S_{t+k}) = .051 + .900 \cdot S_{t+k}$ (.008) (.016)	$R^2 = .99$	-9.13
SFr./$	$E_t(S_{t+k}) = .006 + .980 \cdot S_{t+k}$ (.003) (.008)	$R^2 = .99$	-5.39	$E_t(S_{t+k}) = .029 + .916 \cdot S_{t+k}$ (.005) (.015)	$R^2 = .99$	-23.1
US$/£	$E_t(S_{t+k}) = .022 + .961 \cdot S_{t+k}$ (.023) (.044)	$R^2 = .98$	-5.25	$E_t(S_{t+k}) = .018 + .957 \cdot S_{t+k}$ (.009) (.019)	$R^2 = .99$	7.25
¥/$	$E_t(S_{t+k}) = .044 + .991 \cdot S_{t+k}$ (.022) (.005)	$R^2 = .99$	-6.47	$E_t(S_{t+k}) = .269 + .944 \cdot S_{t+k}$ (.046) (.010)	$R^2 = .99$	-14.6

Note: DF-No Trend refers to a Dickey-Fuller test without a trend term included. DF-Trend refers to a Dickey-Fuller test with a trend term included. PP-No Trend indicates a Phillips-Perron test without a trend term included. PP-Trend refers to a Phillips-Perron test with a trend term included. Significance at the one- and five-percent level is indicated by a * or **. Critical values for all the tests without the trend term are –13.6 (1 %) and –8.0 (5 %). Critical values for all the tests with the trend term included are –28.7 (1 %) and –21.4 (5 %).

In Panel A of the table, we report results from applying the Dickey-Fuller or Phillips-Perron tests to the exchange rate series directly. In Panel B of the table, we are applying the tests to the residuals from the cointegrating regression given by $E_t(s_{t+k}) = \varphi_0 + \varphi_1 \cdot s_{t+k} + z_{t+k}$.

In Panel C, we report the intercept and slope coefficient from the cointegrating regression given by (11) in the text, augmented by leads and lags of the change in actual rates. For the one-week (four-week) ahead regressions, we used four (eight) leads and four (eight) lags. We have suppressed the coefficient estimates for the leads and lags. We compute the t-test for the null hypothesis $\varphi_1 = 1$using the methods described in Hamilton (1996, pgs. 610 – 611). Asymptotic standard errors are reported in parentheses beneath the parameter estimates.

Table 3

Results from Cointegration Tests Using Enders-Granger Unit Root Tests with Asymmetric Adjustments

Panel A: 1-Week ahead Forecasts

Currency:	DM/$		$/£		¥/$		SFr/$		C$/US$	
Model:	Equilib.	Moment.	Equilib.	Moment.	Equilib.	Moment.	Equilib.	Moment.	Equilib.	Moment.
Parameter	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$
ρ_1	-.850*	-.837*	-.904*	-.986*	-.914*	-.902*	-.846*	-.900*	-.840*	-.831*
	(-15.0)	(-14.7)	(-13.6)	(-15.1)	(-13.7)	(-13.1)	(-13.0)	(-13.5)	(-13.6)	(-13.1)
ρ_2	-.946*	-0.962*	-0.791*	-.727*	-.970*	-.989	-1.02*	-.971*	-.893*	-.890*
	(-12.8)	(-13.0)	(-13.1)	(-10.9)	(-15.9)	(-16.4)*	(-16.3)	(-15.8)	(-13.9)	(-13.8)
AIC	-399.5	-400.0	-513.1	-520.1	3570.7	3561.4	-578.1	-575.2	-1589.9	-1587.2
BIC	-391.2	-391.6	-504.7	-511.7	3579.1	3569.8	-569.7	-566.8	-1581.5	-1578.8
φ_μ	193.4*	192.5*	178.2*	184.9*	220.2*	220.7*	217.0*	214.8*	188.6*	180.9*
$\rho_1 = \rho_2$	1.05	1.80	1.58	8.43	0.39	0.90	3.74	0.61	0.36	0.42

Panel B: Four-Week Ahead Forecasts

Currency:	DM/$		$/£		¥/$		SFr/$		C$/US$	
Model:	Equilib.	Moment.	Equilib.	Moment.	Equilib.	Moment.	Equilib.	Moment.	Equilib.	Moment.
Parameter	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$	$E_t(s_{t+1})$
ρ_1	-.197*	-.181*	-.212*	-.238*	-.226*	-.255*	-.210*	-.213*	-.225*	-.226*
	(-5.28)	(-4.71)	(-5.19)	(-6.38)	(-5.43)	(-6.20)	(-5.35)	(-5.20)	(-5.61)	(-5.51)
ρ_2	-.219*	-.237*	-.205*	-.171*	-.246*	-.215*	-.231*	-.229*	-.251*	-.250*
	(-5.34)	(-5.91)	(-5.44)	(-4.11)	(-5.90)	(-5.11)	(-5.57)	(-5.76)	(-5.72)	(-5.81)
AIC	-350.5	-350.7	-309.2	-309.9	3856.6	3846.2	-367.3	-368.2	-1386.8	-1383.9
BIC	-342.2	-342.4	-300.8	-301.6	3865.0	3854.5	-358.9	-359.8	-1378.4	-1375.6
φ_μ	28.2*	28.6*	28.3*	28.8*	32.2*	32.3*	29.8*	30.1*	32.1*	32.1*
$\rho_1 = \rho_2$	0.15	1.02	0.02	1.41	0.12	0.46	0.15	0.07	0.20	0.16

Table 3 (cont.)

Results from Cointegration Tests Using Enders-Granger Unit Root Tests with Asymmetric Adjustments

Notes to table: T-statistics are reported in parentheses beneath parameter estimates. AIC (BIC) refers to the Akaike (Bayesian) Information Criteria value for the indicated model. The null hypothesis of the test statistic, φ_{μ}, is a random walk. Critical values for this test applied to the equilibrium model at the one per cent (five per cent) level are 6.44 (4.56) and are reported in Panel C, pg. 306 in Enders and Granger (1998). Critical values for this test applied to the momentum model at the one per cent (five per cent) level are 6.94 (4.95) and are reported in Panel D, pg. 306 in Enders and Granger (1998). The test for $\rho_1 = \rho_2$ is an F-test and the critical values at the one per cent (five per cent) level are 6.69 (3.86).

Table 4

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision

Panel A: 1-week ahead forecasts

Currency:	**C$/US$**				**DM/US$**			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.819*				-.951*			
	(.08)				(.09)			
$\mathbf{I_t \cdot z_{t-1}}$		-.848*	-.811*	-.772*		-.944*	-.933*	-.972*
		(.08)	(.08)	(.08)		(.10)	(.11)	(.10)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.806*	-.827*	-.860*		-.951*	-.951*	-.948*
		(.08)	(.08)	(.08)		(.09)	(.09)	(.09)
Test 1	.74	.79	.70	1.15	1.89	1.88	1.75	1.76
Test 2	. 00	.01	.00	.07	.79	.72	.58	.90
Test 3		1.89***	2.4**	2.97*		.54	.64	.28
Test 4		2.52**	2.2**	1.79***		.57	.57	.60
Test 5		1.037	.180	6.0**		.02	.08	.18
AIC	-10619.1	-10612.4	-10616.5	-10619.3	-8569.0	-8555.3	-8563.5	-8555.6
Thresh. Value		.0052	.0029	.0067		.0098	.0183	.0177
Percentile		80.7%	63.9%	72.1%		74.5%	81.5%	74.3%

Currency:	**SFr/$**				**$/£**			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	.871*				-.936*			
	(.07)				(.08)			
$\mathbf{I_t \cdot z_{t-1}}$		-.920*	-.887*	-.915*		-.951*	-.898*	-.965*
		(.08)	(.08)	(.08)		(.08)	(.08)	(.08)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.867*	-.863*	-.867*		-.901*	-.966	-.921*
		(.07)	(.07)	(.07)		(.08)	(.08)	(.08)
Test 1	8.67*	9.24*	9.09*	8.77*	2.21	1.64	2.13	1.70
Test 2	.33	.19	.33	.21	.71	.80	.50	.67
Test 3		.97	1.4	1.02		.64	1.30	.44
Test 4		1.83***	1.9***	1.83**		1.25	.44	1.02
Test 5		1.60	.440	1.31		2.71	4.8**	2.26
AIC	-8902.4	-8896.3	-8899.2	-8900.0	-9254.3	-9249.9	-9265.8	-9248.5
Thresh. Value		.0175	.0247	.0250		-0.0078	.0003	.0218
Percentile		84.8%	85.2%	83.6%		29.0%	52.0%	84.6%

Table 4 (cont.)

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision

Panel A: 1-week ahead forecasts

Currency:	¥/$			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.939*			
	(.08)			
$\mathbf{I_t \cdot z_{t-1}}$		-.944*	-1.03*	-.997*
		(.09)	(.09)	(.09)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.937*	-.917*	-.911*
		(.08)	(.08)	(.08)
Test 1	.502	.512	2.28	.866
Test 2	.391	.397	.030	.484
Test 3		.656	-.293	.040
Test 4		.752	1.01	1.07
Test 5		.034	9.2*	6.5**
AIC	-9241.9	-9234.1	-9246.9	-9240.5
Thresh. Value		.0113	.0178	.0174
Percentile		79.1%	83.8%	77.2%

Panel B: 4-week ahead forecasts

Currency:	C$/US$				DM/US$			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.703*				-.348*			
	(.04)				(.03)			
$\mathbf{I_t \cdot z_{t-1}}$		-.681*	-.690*	-.706*		-.344*	-.365*	-.348*
		(.05)	(.05)	(.04)		(.03)	(.04)	(.03)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.712*	-.708*	-.699*		-.357*	-.336*	-.347*
		(.04)	(.04)	(.05)		(.04)	(.04)	(.06)
Test 1	4.25*	4.40*	4.04*	4.02*	8.25*	8.04*	8.32*	7.98*
Test 2	183.0*	182.2*	182.5*	178.6*	233.0*	230.6*	232.7*	230.5*
Test 3		6.6*	6.7*	6.7*		18.8*	17.4*	19.2*
Test 4		6.7*	6.8*	6.7*		16.6*	18.9*	11.7*
Test 5		.671	.299	.044		.259	1.5	.000
AIC	-10032.2	-10025.5	-10027.1	-10025.6	-8625.2	-8617.6	-8618.8	-8617.3
Thresh. Value		.0121	.0035	.0171		-.0276	.0009	.0062
Percentile		83.9%	66.9%	84.1%		18.4%	53%	20.5%

Table 4 (cont.)

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision

Panel B: 4-week ahead forecasts

Currency:	**SFr/$**				**$/£**			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.445*				-.457*			
	(.04)				(.04)			
$\mathbf{I_t \cdot z_{t-1}}$		-.449*	-.457*	-.468*		-.452*	-.454*	-.459*
		(.04)	(.05)	(.04)		(.04)	(.04)	(.04)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.432*	-.442*	-.432*		-.462*	-.479*	-.455*
		(.05)	(.04)	(.04)		(.04)	(.05)	(.04)
Test 1	4.49*	4.55*	4.52*	3.97*	4.24*	4.24*	4.34*	3.93*
Test 2	184.1*	183.3*	183.8*	180.8*	259.3*	256.2*	258.0*	253.2*
Test 3		14.2*	11.2*	12.7*		13.7*	14.4*	13.7*
Test 4		12.7*	14.5*	14.5*		13.6*	11.1*	13.6*
Test 5		.27	0.16	1.69		.14	.60	.02
AIC	-8304.4	-8297.7	-8299.8	-8299.6	-8630.1	-8623.9	-8631.5	-8623.7
Thresh. Value		-.0353	.0238	.0508		.0325	-.0198	.0326
Percentile		15.5%	85.1%	85.1%		85.1%	15.1%	72.5%

Currency:	**¥/$**			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.457*			
	(.04)			
$\mathbf{I_t \cdot z_{t-1}}$		-.545*	-.527*	-.545*
		(.05)	(.05)	(.05)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.504*	-.530*	-.516*
		(.04)	(.05)	(.05)
Test 1	4.24*	4.94*	4.92*	4.93*
Test 2	259.3*	188.0*	185.6*	187.0*
Test 3		10.1*	10.2*	9.83*
Test 4		10.5*	10.6*	10.78*
Test 5		1.73	0.01	1.03
AIC	-8551.7	-8546.2	-8546.3	-8547.1
Thresh. Value		-.0308	.0069	.0428
Percentile		15.1%	61.7%	83.2%

Table 4 (cont.)

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision

Notes: The basic cointegration model may be written as $E_t(s_{t+k}) = \varphi_0 + \varphi_1 \cdot s_{t+k} + z_{t+k}$ ((11) in the text), so the z_{t-1} term is the lagged error-correction term. Model 1 refers to a symmetric error-correction model which is given by (19) in the text. Model 2 refers to an asymmetric error-correction model with a single threshold related to the value of the lagged cointegration regression error (see (20a) in the text). Model 3 refers to an asymmetric error-correction model with a single threshold related to the change in the value of the lagged cointegration regression error (i.e., a momentum threshold specification) (see (20a) in the text). Model 4 refers to an asymmetric error-correction with a single threshold related to the absolute value of the cointegrating regression error (see (20a) in the text). Standard errors are reported in parentheses beneath the estimate.

Test 1 is an F-test of the null hypothesis that all lagged values of the change in the expected exchange rate are zero in the error-correction model. Test 2 is an F-test of the null hypothesis that all lagged values of the changes in the spot rate are zero in the error-correction model. The critical values at the one per cent (five per cent) level are 6.69 (3.86). Test 3 is a t-test for the null hypothesis that the coefficient on the $I_t \cdot z_{t-1}$ term is –1. Test 4 is a t-test for the null hypothesis that the coefficient on the $(1 - I_t) \cdot z_{t-1}$ term is –1. Test 5 is a t-test of the null hypothesis that the coefficients on each of the error correction terms (i.e., the $I_t \cdot z_{t-1}$ and $(1 - I_t) \cdot z_{t-1}$) are equal. We indicate statistical significance at the one, five and 10 per cent level by *, **, and ***.

AIC is the Akaike Information Criteria value for the indicated model. Thresh. value is the (estimated) value of the threshold for a particular model. Percentile indicates the portion of the observations on the threshold variable in the sample that are below the threshold value.

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Appendix A

Empirical Results from Gregory-Hansen Structural Shift-Robust Unit Root Tests Applied to Cointegration Regression Error Series

Panel A: One-Week Ahead Forecasts

	Augmented Dickey-Fuller Test			Phillips-Perron Tests			
Currency	**t-stat**	**AR lag**	**Breakpoint**	**Z_t**	**Breakpoint**	**Z_a**	**Breakpoint**
SFr/$	-21.06*	0	73	-21.08*	73	-464.99*	73
DM/$	-20.15*	0	87	-20.17*	87	-443.92*	87
$/£	-19.11*	0	244	-19.13*	244	-416.65*	244
¥/$	-9.60*	5	123	-21.67*	120	-475.31*	120
C$/US$	-13.67*	2	202	-19.67*	199	-427.31*	199

Panel B: Four-Week Ahead Forecasts

		Augmented Dickey-Fuller Test			Phillips-Perron Tests			
Currency	**Week**	**t-stat**	**AR lag**	**Breakpoint**	**Z_t**	**Breakpoint**	**Z_a**	**Breakpoint**
C$/US$	1	-11.60*	0	60	-11.93*	50	-131.74*	50
	2	-11.11*	0	101	-11.16*	49	-123.08*	101
	3	-10.41*	0	59	-10.73*	49	-118.83*	49
	4	-9.84*	0	24	-10.14*	49	-112.10*	49
DM/US$	1	-9.60*	0	20	-9.64*	20	-104.51*	20
	2	-9.26*	0	20	-9.30*	20	-100.98*	20
	3	-10.13*	0	20	-10.17*	20	-112.01*	20
	4	-9.62*	0	59	-9.66*	19	-107.39*	59
SFr/$	1	-8.69*	0	20	-8.75*	20	-95.25*	20
	2	-9.51*	0	19	-9.55*	19	-104.27*	19
	3	-9.29*	0	18	-9.33*	18	-101.79*	18
	4	-9.69*	0	19	-9.73*	19	-106.72*	19
$/£	1	-9.11*	0	20	-9.14*	20	-98.23*	20
	2	-9.26*	0	20	-9.30*	20	-100.98*	20
	3	-10.13*	0	20	-10.17*	20	-112.01*	20
	4	-9.62*	0	59	-9.66*	19	-107.39*	59
¥/$	1	-10.67*	0	31	-10.71*	31	-118.38*	31
	2	-9.46*	0	51	-10.23*	31	-112.89*	31
	3	-8.97*	0	30	-9.11*	31	-98.94*	31
	4	-10.56*	0	30	-10.61*	30	-116.53*	30

Notes: In Panel B, the week column indicates the week each month whose observations are retained in the sample. Rejection of the null hypothesis at the one (five) per cent level is indicated by a * (**). Critical values are reported in Gregory and Hansen (1996).

Appendix B

In Appendix Table B-1, we report estimates of our error-correction models for four currencies (our set minus the C$) at the one-week, two-week, and three-month horizon. For each currency, we used a continuous set of data for each consisting of 64 observations on the one-week ahead forecasts and 57 observations on the two-week and three-month ahead forecasts. The specific data we use in this portion of our work covers the October 24, 1984 – February 5, 1986 period for the one-week ahead forecasts and the January 5, 1983 – October 10, 1984 period for the other forecast horizons.

At the one-week horizon (Appendix Table B-1, Panel A), we find the AIC criterion picks a simple (linear) error-correction model for Germany, Japan, and the U.K., but a Band-TAR model for Switzerland. We find strong error-correction effects for each data series. The coefficient on the lagged cointegration error term ranges from -.78 to -.99 and all the estimates are statistically significantly different from zero with p-values less than .01. Lagged changes in expected rates are never significant at this forecast horizon, and lagged changes in spot exchange rates only matter for the ¥/$ rate. Much as we found in the previous subsection, error-correction dominates all other explanations of changes in expected exchange rates at the shortest forecast horizon.

At the two-week horizon (Appendix Table B-1, Panel B), the AIC criterion picks a simple (linear) error-correction model for all currencies. Error-correction effects are still important: the coefficient estimates range from -.55 to -.88 and all are statistically significantly different from zero with p-values less than .01. Lagged changes in expected spot rates are never significant contributors, but lagged changes in spot rates are significant contributors to the model for Japan (the same as at the one-week horizon), Switzerland, and the U.K. For Germany, error-correction still constitutes the sole explanation of changes in expected exchange rates.

We find a somewhat different picture at the three-month horizon, however. The data still prefer a simple (linear) error-correction model for each currency, but the error-correction terms are much smaller ranging from -.17 to -.24. In addition, only three are marginally statistically significant and then only at the 10 per cent level. Perhaps most intriguing, the relatively smaller error-correction effects are not balanced by greater importance for lagged changes in expected or actual rates. Indeed, none of the lagged terms contribute in a statistically significant way to our empirical models of changes in expected rates.

We conclude that our principal findings on error-correction and changes in expected exchange rates discussed earlier in this section also appear to hold in the data set used by Frankel and Froot in their important work in this area. It is an interesting question whether the same holds in the survey data sets constructed and used by Ito and his collaborators and MacDonald and his collaborators.

Appendix Table B-1

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision for Frankel and Froot Data

Panel A: 1-week ahead forecasts

Currency:	$/£				DM/US$			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
z_{t-1}	-.989*				-.902*			
	(.271)				(.228)			
$I_t \cdot z_{t-1}$		-.994*	-1.057*	-.975*		-.954*	-.866*	-1.057*
		(.287)	.268()	(.272)		(.288)	(.251)	(.256)
$(1 - I_t) \cdot z_{t-1}$		-.985*	-.865*	-.839*		-.899*	-.926*	-.856*
		(.276)	(.280)	(.282)		(.230)	(.233)	(.239)
Test 1	.21	.20	.09	.16	.19	.157	.16	.04
Test 2	.42	.42	.67	1.10	2.25	2.18	2.14	2.66
Test 3		.02	.21	.09		.158	.53	.22
Test 4		.05	.48	.57		.44	.32	.60
Test 5		.01	2.92***	1.60		.07	.17	1.23
AIC	-959.5	-951.5	-955.7	-954.3	-994.6	-986.8	-988.0	-988.5
Thresh. Value		.0213	-.0158	.0213		.0166	-.0005	.0318
Percentile		79.0%	32.3%	62.9%		83.9%	50.0%	85.5%

Currency:	SFr/$				¥/$			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
z_{t-1}	-.986*				-.780*			
	(.254)				(.223)			
$I_t \cdot z_{t-1}$		-1.161*	-.989*	-.990*		-.432	-.814*	-.808*
		(.247)	(.268)	(.222)		(.372)	(.225)	(.242)
$(1 - I_t) \cdot z_{t-1}$		-.904*	-.981*	-.533*		-.845*	-.718*	-.742*
		(.230)	(.267)	(.245)		(.243)	(.270)	(.244)
Test 1	.30	.45	.29	.09	.02	.45	.00	.00
Test 2	.48	.34	.46	2.91***	4.71**	3.742***	4.94**	4.82**
Test 3		-.66	.04	.04		1.53	.83	.79
Test 4		.41	.07	1.91***		.64	1.05	1.06
Test 5		4.05**	.00	12.0*		1.72	.33	.18
AIC	-919.8	-916.4	-912.6	-923.6	-1032.0	-1026.0	-1025.8	-1026.7
Thresh. Value		.0089	-.0085	.0089		.0105	-.0147	.0086
Percentile		63.3%	40.0%	36.7%		79.0%	17.7%	53.2%

Appendix Table B-1 (cont.)

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision for Frankel and Froot Data

Panel B: 2-week ahead forecasts

Currency:	$/£				DM/US$			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
z_{t-1}	-.546*				-.875*			
	(.214)				(.300)			
$I_t \cdot z_{t-1}$		-.527**	-.545*	-.510*		-.884*	-.811*	-.817*
		(.258)	(.218)	(.244)		(.302)	(.323)	(.344)
$(1 - I_t) \cdot z_{t-1}$		-.551*	-.605*	-.562*		-.739*	-.884*	-.896*
		(.220)	(.285)	(.220)		(.364)	(.307)	(.305)
Test 1	.53	.54	.14	.57	.23	.15	.29	.11
Test 2	11.13*	10.8*	9.12*	11.0*	2.63	2.91***	2.82	2.58
Test 3		1.84***	2.08**	2.01***		.38	.59	.53
Test 4		2.04**	1.38	1.99***		.72	.38	.34
Test 5		.03	.10	.15		.80	.25	.32
AIC	-781.5	-774.7	-778.5	-775.3	-775.4	-768.9	-772.0	-773.7
Thresh. Value		.0133	-.0216	.0222		-.0215	.0048	.0271
Percentile		80.9%	19.1%	83.2%		19.1%	55.3%	78.7%

Currency:	SFr/$				¥/$			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
z_{t-1}	-.749*				-.608*			
	(.301)				(.166)			
$I_t \cdot z_{t-1}$		-.805*	-.790*	-.538***		-.709*	-.501*	-.635*
		(.321)	(.303)	(.382)		(.208)	(.183)	(.201)
$(1 - I_t) \cdot z_{t-1}$		-.630*	-.684*	-.816*		-.529*	-.640*	-.592*
		(.309)	(.334)	(.308)		(.167)	(.173)	(.172)
Test 1	.83	.47	.96	.15	.01	.00	.00	.00
Test 2	3.62***	3.52***	3.59**	2.39	13.2*	15.1*	14.0*	12.9*
Test 3		.61	.69	1.21		1.39	2.72*	1.81***
Test 4		1.20	.95	.60		2.81*	2.08**	2.38**
Test 5		1.53	.47	.94		2.26	1.08	.15
AIC	-780.0	-773.8	-773.1	-776.1	-829.8	-828.8	-824.1	-826.0
Thresh. Value		-.0164	-.0004	.0239		.0155	.0016	.0191
Percentile		19.6%	45.7%	84.8%		80.9%	51.1%	74.5%

Appendix Table B-1 (cont.)

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision for Frankel and Froot Data

Panel C: 3-month ahead forecasts

Currency:	**$/£**				**DM/US$**			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.224***				-.166***			
	(.156)				(.112)			
$\mathbf{I_t \cdot z_{t-1}}$		-.081	-.090	-.281		-.218	-.390*	-.136
		(.223)	(.193)	(.205)		(.274)	(.127)	(.126)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.400**	-.366**	-.174		-.156	.007	-.218
		(.184)	(.186)	(.206)		(.126)	(.134)	(.175)
Test 1	.00	.01	.10	.01	.18	.09	.56	.31
Test 2	.18	.81	.13	.31	.83	.78	.88	.97
Test 3		4.12*	4.71*	3.51*		2.86*	4.79*	6.86*
Test 4		3.27*	3.42*	4.02*		6.70*	7.53*	4.46*
Test 5		1.48	1.52	.15		.05	6.22**	.17
AIC	-683.7	-677.3	-678.5	-675.9	-676.1	-670.7	-675.1	-669.3
Thresh. Value		-.0126	-.0059	.0302		.0402	.0034	.0402
Percentile		31.9%	40.4%	70.2%		83.0%	57.4%	66%

Currency:	**SFr/$**				**¥/$**			
Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Threshold Type:	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$	None	z_{t-1}	Δz_{t-1}	$\lvert z_{t-1}\rvert$
$\mathbf{z_{t-1}}$	-.244***				-.152			
	(.142)				(.122)			
$\mathbf{I_t \cdot z_{t-1}}$		-.205	-.514***	-.272		-.294**	-.068	-.159
		(.277)	(.258)	(.230)		(.154)	(.148)	(.125)
$\mathbf{(1 - I_t) \cdot z_{t-1}}$		-.253***	-.187	-.232		.051	-.249	-.046
		(.149)	(.204)	(.153)		(.168)	(.165)	(.317)
Test 1	1.29	1.20	.63	1.26	.05	.21	.02	.00
Test 2	1.13	1.03	1.37	1.07	.01	.11	.05	.05
Test 3		2.88*	1.88***	3.16*		4.59*	6.30*	6.75*
Test 4		5.00*	3.99*	5.01*		6.25*	4.55*	3.01*
Test 5		.03	1.33	.03		2.26	1.06	.13
AIC	-664.5	-656.7	-659.5	-657.7	-729.0	-727.2	-724.8	-722.0
Thresh. Value		.0396	.0220	.0495		-.0195	-.0066	.0098
Percentile		84.8%	78.3%	87.0%		29.8%	42.6%	34.0%

Appendix Table B-1 (cont.)

Estimates of Univariate and Multivariate Error-Correction Models of Expected Exchange Rate Revision for Frankel and Froot Data

Notes: The basic cointegration model may be written as $E_t(s_{t+k}) = \varphi_0 + \varphi_1 \cdot s_{t+k} + z_{t+k}$ ((11) in the text), so the z_{t-1} term is the lagged error-correction term. Model 1 refers to a symmetric error-correction model which is given by (19) in the text. Model 2 refers to an asymmetric error-correction model with a single threshold related to the value of the lagged cointegration regression error (see (20a) in the text). Model 3 refers to an asymmetric error-correction model with a single threshold related to the change in the value of the lagged cointegration regression error (i.e., a momentum threshold specification) (see (20a) in the text). Model 4 refers to an asymmetric error-correction with a single threshold related to the absolute value of the cointegrating regression error (see (20a) in the text). Standard errors are reported in parentheses beneath the estimate.

Test 1 is an F-test of the null hypothesis that all lagged values of the change in the expected exchange rate are zero in the error-correction model. Test 2 is an F-test of the null hypothesis that all lagged values of the changes in the spot rate are zero in the error-correction model. The critical values at the one per cent (five per cent) level are 6.69 (3.86). Test 3 is a t-test for the null hypothesis that the coefficient on the $I_t \cdot z_{t-1}$ term is –1. Test 4 is a t-test for the null hypothesis that the coefficient on the $(1 - I_t) \cdot z_{t-1}$ term is –1. Test 5 is a t-test of the null hypothesis that the coefficients on each of the error correction terms (i.e., the $I_t \cdot z_{t-1}$ and $(1 - I_t) \cdot z_{t-1}$) are equal. We indicate statistical significance at the one, five and 10 per cent level by *, **, and ***.

AIC is the Akaike Information Criteria value for the indicated model. Thresh. value is the (estimated) value of the threshold for a particular model. Percentile indicates the portion of the observations on the threshold variable in the sample that are below the threshold value.

Appendix C

We also compiled some evidence of asymmetries in existing models of exchange rate expectation adjustment. In this appendix, we report results from that investigation.

Another way to approach the issue of nonlinearity in expected exchange rates is to focus on potential nonlinearities in existing models of exchange rate expectation revision. To do this, we may use the threshold effects tests and estimation methods developed by Hansen (1996, 1998, and 1999) to test for (and then estimate) omitted threshold effects in existing, non-cointegration-based models (i.e., (4) – (6)). While details of the estimation technique are available in the original papers, the basic idea behind his approach is accessible even to non-specialists. Hansen (1999) considers a threshold regression model of the form

$$y_i = \begin{cases} \beta_1 \cdot x_i + e_i & q_i \leq \gamma \qquad \text{(C-1)} \\ \beta_2 \cdot x_i + e_i & q_i > \gamma \qquad \text{(C-2)} \end{cases}$$

where q_i is the threshold variable used to split the sample.[29] He estimates the model's parameters by concentrating the sum of squares function and minimizing this function with a grid search over the set of possible γ values. Hansen (1996, 1999) also develops a likelihood ratio test for threshold effects that can be applied to a linear regression model first as a type of diagnostic test. His estimator for β_1, β_2, and γ can then used to estimate the threshold and the slope coefficients. Hansen (1999) also provides distribution theory so that classical probability statements may be made concerning the threshold and slope coefficients. The underlying distributions are not standard; details are in the original paper.

We applied Hansen's likelihood ratio test for threshold effects to expected exchange rate adjustment models given by (5) and (6) in the text. We also specified a purely autoregressive model of expected exchange rate changes:

Autoregressive

$$\begin{aligned} E_t(S_{t+k}) - E_{t-1}(S_{t+k-1}) = \gamma_0 + \gamma_1 \cdot [E_{t-1}(S_{t+k-1}) - E_{t-2}(S_{t+k-2})] \\ + \gamma_2 \cdot [E_{t-2}(S_{t+k-2}) - E_{t-3}(S_{t+k-3})] \\ + \gamma_3 \cdot [E_{t-3}(S_{t+k-3}) - E_{t-4}(S_{t+k-4})]\ . \end{aligned} \qquad \text{(C-3)}$$

We applied Hansen's methods to this equation, too.

In Appendix Table C-1, we report the results from applying Hansen's test to three expected exchange rate adjustment models with four different potential threshold variables. The four threshold variables are the lagged cointegration error, the second lag of the cointegration error, the lagged change in the exchange rate, and the cumulative change in the exchange rate over the past four weeks. In these experiments, we only use the one-week ahead data and, with the obvious exception, we report test results only for the case of a single lag on the threshold variable.

For extrapolative and adaptive expectations, Hansen's test indicates a threshold captured by the lagged cointegration error. In every other case involving these two models where there is a large test statistic, the implied sample split left less than 10 observations in one of the two samples. Because of this, we treat those few cases as probably driven by a few outliers, not a fundamental part of the data generating process. For autoregressive expectations by contrast, Hansen's test indicates a threshold captured by the lagged change in exchange rates.

29. An alternative, single equation formulation is given by $y_i = \beta \cdot x_i + \delta_1 \cdot x_i(\gamma) + e_i$ where the dummy variable $d_i(\gamma) = \{q_i \leq \gamma\}$, $\{\cdot\}$ is the indicator function, $x_i(\gamma) = x_i d_i(\gamma)$, and $\beta = \beta_2$.

With these results in mind, we then used Hansen's method to estimate extrapolative, adaptive, and autoregressive models of expected exchange rate adjustments for all but the DM/$ rate. We discovered that the algorithm inevitably produced very unsatisfactory results when applied to the DM/$ rates. Panel A of Appendix Table C-2 reports estimates of the extrapolative models across the remaining four exchange rates. We find clear evidence of significantly different adjustments across the two regimes. When the cointegration error is large and positive, expected exchange rates are much more strongly affected by the lagged exchange rate change than when the cointegration error is below the threshold. Note also that the fit of the regression to the above the threshold sample is dramatically better than the other sample.

We report estimates of the expectations model in Panel B of Appendix Table C-2. We find that lagged changes in expected rates are never significant determinants of current expected exchange rate revisions. Lagged changes in spot rates are always statistically significant determinants of changes in expected exchange rates. As in the case of extrapolative expectations, a large, positive cointegration error means that expected exchange rates are much more strongly affected by the lagged exchange rate change. We also find that the fit of the regression is dramatically better for the above-the-threshold sample than the other sample.

Finally, the estimates of the autoregressive expectations models in Panel C, Appendix Table C-2 clearly indicate an inferior fit by comparison with the other models. The intercept estimates are remarkably different across the models, but the lagged changes in expected rates are rarely significant determinants of revisions in expected exchange rates. It appears that the principal impact of the threshold variable is to shift the size of the intercept estimate.

To sum up, using Hansen's approach, we find clear evidence of threshold effects in the single equation extrapolative, adaptive, and autoregressive models of expected exchange rate adjustments. For extrapolative and adaptive models, the threshold variable is the lagged cointegration error. In the autoregressive model, we found the threshold variable to be the lagged changes in the spot rate. The fit of this model was quite inferior to the other models, however. Existing univariate models of expectation revision appear to be misspecified.

Appendix Table C-1

Hansen Threshold Effects Tests in Univariate Expectations Revision Models

Expectations Model	Currency				
Extrapolative	**C$**	**DM**	**SFr**	**£**	**¥**
Threshold Variable					
$\|E_{t-1}(S_t) - S_t)\|$	23.80*	37.12*	33.40*	27.16*	31.78*
$\|E_{t-2}(S_{t-1}) - S_{t-1})\|$	11.29	7.36	11.49	8.16	12.69*
$\|Log(S_t/S_{t-1})\|$	8.13	4.96	5.71	5.66	5.55
$Log(S_t/S_{t-4})$	7.15	16.56*	10.96	7.68	15.93*
Adaptive					
$\|E_{t-1}(S_t) - S_t)\|$	17.53*	37.04*	33.49*	30.60*	32.23*
$\|E_{t-2}(S_{t-1}) - S_{t-1})\|$	5.89	6.76	7.99	5.48	7.00
$\|Log(S_t/S_{t-1})\|$	8.23	10.09	6.91	8.29	5.97
$Log(S_t/S_{t-4})$	3.87	14.55*	11.83	12.32*	16.58*
Autoregressive					
$\|E_{t-1}(S_t) - S_t)\|$	25.87*	5.60	10.01	9.52	7.83
$\|E_{t-2}(S_{t-1}) - S_{t-1})\|$	9.28	11.23	11.50	17.95*	7.13
$\|Log(S_t/S_{t-1})\|$	212.70*	159.92*	233.21*	206.99*	213.58*
$Log(S_t/S_{t-4})$	19.41*	12.40	11.37	9.11	9.18

Notes to table: The likelihood ratio test statistic for the null of no threshold effect is reported in the columns. The distribution of this test statistic is non-standard, but rejection of the null hypothesis at the one per cent (five per cent) level is indicated in the table by a * (**).

Appendix Table C-2

Estimates of Hansen Univariate Threshold Models of Expectation Revisions

Panel A: Extrapolative Expectations Model

	C$		SFr		£		¥	
Variables / Statistics	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**
ΔS_{t-1}	.331*	.862*	.194***	.921*	.372*	.934*	.226*	.953*
	(.108)	(.050)	(.097)	(.019)	(.082)	(.020)	(.093)	(.025)
ΔS_{t-2}	.098***	.135	.090**	.150*	.055	.148*	.004	.070**
	(.028)	(.042)	(.028)	(.026)	(.029)	(.031)	(.045)	(.029)
Observations	210	270	111	369	211	269	177	303
R^2	.177	.769	.094	.834	.147	.881	.033	.867
Threshold Value	.346*		.522*		.743*		.579*	
Joint R^2	.732		.816		.846		.821	

Panel B: Adaptive Expectations Models

	C$		SFr		£		¥	
Variables / Statistics	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**
$\Delta E(S_{t-1})$	.052	.012	.031	-.053	-.006	.021	.002	.027
	(.025)	(.038)	(.036)	(.033)	(.026)	(.023)	(.044)	(.033)
ΔS_{t-1}	.264**	.863*	.285	.925*	.277*	.936*	.226**	.951*
	(.111)	(.051)	(.080)	(.021)	(.094)	(.021)	(.093)	(.025)
Observations	220	260	167	313	192	288	177	303
R^2	.141	.761	.111	.832	.077	.865	.033	.458
Threshold Value	.370*		.776*		.664*		.579*	
Joint R^2	.719		.799		.925		.818	

Appendix Table C-2 (cont.)

Estimates of Hansen Univariate Threshold Models of Expectation Revisions

Panel C: Autoregressive Expectations Models

	C$		SFr		£		¥	
Variables / Statistics	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**	**Below**	**Above**
Intercept	-.314*	.569*	-1.122*	1.216*	-1.367*	.777*	-1.802*	.600*
	(.025)	(.035)	(.081)	(.074)	(.096)	(.060)	(.110)	(.054)
$\Delta E(S_{t-1})$	.069	-.063	-.071	-.016	.079	.005	-.045	.022
	(.046)	(.053)	(.061)	(.053)	(.051)	(.035)	(.087)	(.038)
$\Delta E(S_{t-2})$	-.076	-.108**	.025	.036	-.006	-.045	.073	.105**
	(.063)	(.051)	(.061)	(.046)	(.072)	(.048)	(.097)	(.037)
$\Delta E(S_{t-3})$	.039	-.059	.011	.109**	-.029	-.096	-.064	.096
	(.038)	(.055)	(.044)	(.047)	(.046)	(.055)	(.083)	(.036)
Observations	296	184	249	231	176	304	121	359
R^2	.021	.038	.010	.027	.010	.020	.015	.035
Threshold Value	.126*		.105**		-.286*		-.721*	
Joint R^2	.478		.482		.471		.773	

Notes: T-statistics are reported in parentheses beneath parameter estimates. In the row marked observations, we report the number of observations in the indicated portion of the sample split by the estimated value of the threshold variable. In the row marked threshold value, we report the estimated threshold. The distribution of this estimate is not standard, but statistical significance at the one per cent (five per cent) level is indicated by * (**). In the row marked R^2, we indicate the R^2 for an OLS regression on the observations in the indicated subsample. In the row marked Joint R^2, we report an overall measure of fit across both parts of the sample.