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Commentary

Campbell R. Harvey Duke University

Laura Kodres's paper develops econometric methodology to test the "unbiasedness hypothesis" for foreign currency futures. This hypothesis, originally suggested by Samuelson [1965], suggests that futures prices should be a martingale. This implies:

$$F_{tk} = E[F_{t+1:k-1}|\Omega_t],$$

where $F_{t,k}$ is the price of a futures contract observed at time t with k days to expiration and Ω_t is the collection of all relevant information available to investors. One can think of regressing F_{t+1} on F_t and checking whether the slope coefficient is equal to unity and the intercept is zero.

There are a number of papers that test this hypothesis. Hodrick and Srivastava [1987] apply a transformation (subtract and divide by the spot rate, S_i) to the data to induce stationarity and test whether the forecast error:

$$\epsilon_{t+1} = \frac{F_{t+1,k-1} - S_t}{S_t} - \alpha - \beta \left[\frac{F_{t,k} - S_t}{S_t} \right]$$

is orthogonal to a prespecified set of instrumental variables. They strongly reject the unbiasedness hypothesis for *all* of the actively traded currencies. McCurdy and Morgan [1987] apply a different transformation to the data and estimate:

$$f_{t+1,k-1} - f_{t,k} = \gamma_0 + \gamma_1(f_{t,k} - f_{t-1,k+1}) + e_{t+1},$$

where f represents the natural logarithm of the futures price. They test whether $\{\gamma_0, \gamma_1\} = \{0,0\}$. They assume the error process follows a GARCH-M process and reject the unbiasedness hypothesis for only two of the five currencies.

Kodres contribution is to note that the results of both of these studies could be biased because they have handled price limits improperly. Price limits could be causing Hodrick and Srivastava [1987] to spuriously reject the model. McCurdy and Morgan [1987] remove the data that are limit moves. This could reduce the power of their tests.

Kodres pursues the McCurdy and Morgan [1987] transformation and provides maximum-likelihood estimation of a model that explicitly accounts for the price limits. Her results are consistent with McCurdy and Morgan. There are a number of suggestions that I would like to offer.

First, on the right-hand side of the regression, Kodres substitutes the futures prices implied by "covered interest arbitrage" when there is a limit move. She correctly argues that you cannot use the proxy variable on the left-hand side if there is significant autocovariance in the measurement errors and the variance of the measurement errors is large. But it is possible to directly test proxy measurement errors—at least on nonlimit move days. If there is no significant autocovariance and the variance of the measurement errors is small, then it is possible to modify the data in both the Hodrick and Srivastava [1987] and the McCurdy and Morgan [1987] and reexecute their tests.

The second point applies to the data used in all of these studies. The futures price that is used is the "settlement price." This is not a transaction price. While the settlement is supposedly set to reflect the transaction prices over the last few minutes of trading, sometimes there are other considerations that are taken into account by the

pit committee (like their own positions). The model relates transactions to transactions. If the settlement price is an average price, then the error structure of the model must be modified to allow for a moving average process. In other words, testing the model with average prices will induce serial correlation into the errors. The estimation techniques must take that serial correlation into account. Since the degree of time averaging may change each day, it seems more desirable to go with transaction prices.

Third, there is a timing issue. Trading for the currency futures does not halt at the same time. On regular trading days the Swiss franc closes at 1:16 (CST), Deutsche mark at 1:20, Japanese yen at 1:22, British pound at 1:24, and the Canadian dollar at 1:26. On the last trading day of the contract, the Swiss franc closes at 9:16 (CST), Deutsche mark at 9:18, Japanese yen at 9:19, British pound at 9:20, and the Canadian dollar at 9:21. While the differences in the closing times are small, it is still important not to use the settle price or even the last trade price in a joint test of the unbiasedness of all currencies.

Consider estimating the following model:

$$u_{t+1} = \Delta f_{t+1} - \alpha - \Delta f_t \beta$$

$$E[u_{t+1}|Z_t] = 0$$

with Hansen's [1982] Generalized Method of Moments where Δf_{t+1} is an *n*-dimensional row vector of changes in the log of the futures price for *n* foreign currencies realized at time t+1. The $1 \times n$ parameter vector, α , represents the drift of the processes and can be restricted to zero in the estimation. The β is an $n \times n$ diagonal coefficient matrix. The Z_t represents the prespecified information set, which is assumed to include a constant and Δf_t . If we restrict n=1, then the estimation will deliver ordinary least squares parameters and White [1980] standard errors.

Suppose that we estimate a system of five currencies. In this case, there are 10 parameters and 30 orthogonality conditions (6 instruments times 5 equations) leaving 20 overidentifying restrictions. Roughly speaking, the idea of this

test is to check if the forecast error, u_{t+1} , is uncorrelated with information, Z_t , available at time t. If there is correlation, then we have left something out of the forecasting model, i.e., the model is misspecified. Now consider the timing issue. If the i^{th} currency closes trading at 1:16 and if there is news between 1:16 and 1:26 that has an impact on all currencies, then u^i_{t+1} will be related to the elements of Z_t that are dated between 1:16 and 1:26. This could cause one to spuriously reject the orthogonality conditions.

I am bothered by the large discrepancy in the empirical results on the unbiasedness hypothesis. Kodres and McCurdy and Morgan only reject the hypothesis for two currencies using maximum-likelihood techniques, yet Hodrick and Srivastava strongly reject the hypothesis using an instrumental variables technique. Kodres and McCurdy and Morgan argue that the difference in data transformations is driving the results. McCurdy and Morgan use the Hodrick and Srivastava transformation in some of their tables (using the maximumlikelihood methodology) and get results indicating a rejection of the hypothesis for all five currencies. What is missing from Kodres and McCurdy and Morgan is a test of their transformation using the instrumental variables technique. While the GMM is generally less efficient than maximum likelihood (that is, when the error structure has been correctly specified in the ML), the GMM also provides a very intuitive test when the model is overidentified to check to see if forecast errors are uncorrelated with items in the investor's information set.

The fourth, and perhaps the most important, criticism that I have deals with the assumptions on the error structure. The martingale hypothesis does not imply that the error process is conditionally homoscedastic. Indeed, Hodrick and Srivastava [1987] and McCurdy and Morgan [1987] allow for conditional heteroscedasticity. While it is clearly an improvement to build the econometric methodology to handle price limits, the cost of this (at the present time) is the assumption of conditional homoscedasticity that Kodres makes. If the errors are conditionally

heteroscedastic, then it is not clear that the results are an improvement over previous studies.

Finally, Kodres mentions that "preliminary testing using Ljung-Box [1978] tests indeed shows conditional heteroscedasticity to be a problem". McCurdy and Morgan [1987] assume a process for the conditional heteroscedasticity and find that the heteroscedasticity parameters are significant. Hodrick and Srivastava [1987] do not explicitly model the conditional heteroscedasticity (nor do they test for it) but their estimation routine allows for conditionally heteroscedastic errors. Since I have not seen any direct tests for heteroscedasticity, I thought that I would provide some.

I have collected transactions data from the Futures and Options Research Center (FORCE) at Duke University. These transaction prices represent the price that is closest to 1:16 p.m. CST on regular trading days and the price that is closest to 9:16 a.m. CST on the last trading day. I use the same transformation as Kodres and McCurdy and Morgan. The data set spans February 22, 1985, to May 10, 1988 (price limits were abolished on February 22, 1985).

Three tests of conditional heteroscedasticity are presented. The Breusch-Pagan [1979] and White [1980] tests check for heteroscedasticity of an unspecified form. Engle's [1982] test checks for heteroscedasticity of the autoregressive (ARCH) form. In all of the tests, the first step is to estimate the martingale test equation and calculate the residual series, \hat{e}_t . In the Breusch-Pagan test, the variance of the residual series is

calculated,
$$\hat{\sigma}^2 = \sum_{t=1}^{T} \frac{\hat{e}_t^2}{T}$$
. Next, the following

regression is run:

$$\frac{\hat{e}_t^2}{\hat{\sigma}^2} = Z_t \alpha + v_t,$$

where there are s variables (including a constant) in Z_r . One half of the regression sum of squares is distributed χ^2_{s-1} . In White's test, the following regression is run:

$$\hat{e}_{t}^{2} = \alpha_{0} + \sum_{j=1}^{K} \sum_{k=j}^{K} \alpha_{s} X_{ij} X_{ik} + u_{t},$$

where X represents the right-hand side variables in the martingale regression. The number of observations times the R^2 of the regression is distributed $\chi^2_{\underline{K(K+1)}}$. In our case, the X variables

are a constant and the lagged change in the (log of the) futures price (K = 2). So we would regress the squared residual series on a constant, the lagged change in the futures price and the square of the lagged change in the futures price. Notice that the degrees of freedom are 2 (a redundant regressor—the constant—is dropped). The final test involves a specific functional form for the conditional heteroscedasticity. In Engle's test of autoregressive conditional heteroscedasticity, one estimates:

$$\hat{e}_t^2 = \alpha_0 + \sum_{i=1}^{j} \alpha_i \hat{e}_{t-i}^2 + w_t$$

The number of observations times the R^2 is distributed χ_j^2 .

The results in Table 1 suggest that there is some evidence against the null hypothesis of conditional homoscedasticity for all five currencies. The White and Engle tests provide strong evidence against conditional homoscedasticity for the British pound. The Breusch-Pagan test does not provide evidence against the null when the instruments are the lags in the changes in the futures prices for all five currencies. If the instrument list is augmented to include the squares of the lagged changes in the futures prices, then there is strong evidence against the null. Figure 1 plots the standardized squared residuals (the left-hand side variable in the Breusch-Pagan regression) for the British pound. This graph provides evidence against the hypothesis of homoscedasticity. All three tests reject conditional homoscedasticity for the Canadian dollar and the Japanese yen. The Breusch-Pagan

Table 1. Tests of heteroscedasticity^a for foreign currency futures: daily data^{b,c} February 22, 1985—May 10, 1988 (812 observations)

$$\Delta f_{t+1} = \alpha + \beta \Delta f_t + e_t$$

	Breusch-Pa	h-Pagan ^a	White		Engle	
Currency	X2 .	P-value*	${\chi^2}$	P-value	X3	P-value
British pound	8.02	.155	21.88	.000	35.95	.000
Canadian dollar	52.55	.000	47.57	.000	21.76	.001
Deutsche mark	28.19	.000	5.32	.070	7.88	.163
Swiss franc	19.29	.002	1.96	.376	3.04	.694
Japanese yen	32.21	.000	6.40	.041	12.97	.024

^aSee Breusch-Pagan [1979], White [1980], and Engle [1982].

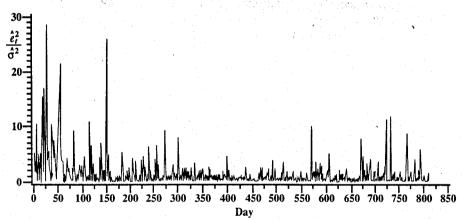
b Transaction prices collected at 1:16 p.m. (CST) for all regular trading days and 9:16 p.m. on the last trading day of the contract.

 $^{c}\Delta f_{t}$ represents the change in the natural logarithm of the futures price.

 $^{d}\Delta$ The instrument list in the Breusch-Pagan test includes a constant and the first lag of the (log) change in the futures price for all five currencies.

P-value is the probability that a χ^2 variate exceeds the sample value of the statistic.

Figure 1. British pound: standardized squared residuals^a, daily data February 22, 1985-May 10, 1988



^a The standardized squared residuals are the left-side variable in the Breusch-Pagan test for heteroscedasticity.

test provides evidence against the homoscedasticity for the Deutsche mark and the Swiss franc at the 1 percent level but the other two tests do not provide evidence against the hypothesis.

The empirical results suggest that there is some form of residual heteroscedasticity present for the currency futures. These diagnostic tests suggest that the econometric methodologies applied to these data must be heteroscedasticity-consistent. While autoregressive conditional heteroscedasticity is present in most of the currencies, the results of the Breusch-Pagan

tests indicate that the variance may be a function of more than lagged variances. This suggests that an ARCH estimator may not be the route to go to improve the specification. Of course, heteroscedasticity may be indicative of a missing regressor. Indeed, if there is time variation in risk premia, then we have omitted an important variable and fundamentally misspecified the model.

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