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Valuation of Foreign Currency Options: Some Empirical Tests

Kuldeep Shastri and Kishore Tandon*

Abstract

This paper investigates the efficiency of the market for foreign currency options with the help of a modified version of the Black-Scholes model. The evidence in the *ex post* tests is inconsistent with this hypothesis since we find a large number of opportunities for abnormal profits. A second set of tests is conducted on an *ex ante* basis to determine whether these profit opportunities exist even if the execution of the strategy is delayed by one day. The evidence from these tests provides more support for the hypothesis of market efficiency.

I. Introduction

One of the latest innovations in the financial markets that allows multinational corporations, banks, and currency speculators to hedge their exposure to movements in exchange rates has been the option on foreign currency. In this paper, we investigate the pricing mechanism of call and put options written on foreign currencies, and test the efficiency of the market in which they are traded.

The efficiency of this market for foreign currency options is tested using a specific option pricing model developed by Biger and Hull [2], Garman and Kohlhagen [7], and Grabbe [11].[1] Though the foreign currency options under consideration are American in nature, the models used here are applicable to European options. Since the purpose of this paper is to test the efficiency of the foreign currency options market, it is perfectly legitimate to use a European pricing model to develop trading strategies involving American options. The existence of significant profits from such strategies would then be evidence of market inefficiencies. Another justification for the use of European models to price these American options comes from the literature on early exercise of equity options. Roll [14] has shown that for small dividends the probability of early exercise is

* Graduate School of Business, University of Pittsburgh, Pittsburgh, PA 15260, and Department of Finance, Baruch College, CUNY, New York, NY 10010, respectively. The authors thank the referees and the *JFQA* Managing Editor for their many comments and suggestions. Financial support through a faculty research grant from the Graduate School of Business, University of Pittsburgh is gratefully acknowledged.

[1] This model is identical to the one developed by Merton [13] for equity options with the underlying security paying continuous dividends. In the case of foreign currency options, the foreign interest rate is akin to the continuous dividend rate.

very low for calls. Geske and Shastri [9] have shown that a small dividend can substantially reduce the probability of early exercise for puts. Thus, if we view the foreign interest rate as a continuous dividend, these results can be applied to foreign currency options. Therefore, we would expect problems with the use of the call option pricing model only in cases where the foreign interest rate is high and problems with the use of the put option pricing model only when interest rates are close to zero. In addition, Shastri and Tandon [15] compare the pricing performance of European and American models for foreign currency options and find that these two prices are very "close" to each other.[2]

Section II sets out the notation used in this paper, and presents the model that will be tested here. Section III describes the data used to test the efficiency of the market for foreign currency options. The next section presents three alternatives for measuring future exchange rate variability, and contains a test of the predictive ability of each one of these proxies. In Section V, we examine the ability of hedging strategies to produce excess profits when an option's market price deviates from its model price. The tests in this section are in both the *ex post* and *ex ante* form. The *ex post* tests assume that the trading strategy can be executed immediately at the market prices that indicate deviations from the model, while, in the *ex ante* tests, the strategy is executed at the price quoted the next day. The results of these tests indicate that the *ex post* hedging strategy yields abnormal profits, but these excess returns disappear if the execution of the strategy is delayed by one day. Our *ex ante* results are to be interpreted with caution since they are based on daily closing prices. Statements regarding market efficiency would depend on how quickly a market participant can execute a transaction. If they can duplicate the *ex post* strategy, the market would be inefficient. However, if they can only duplicate the *ex ante* strategy, the market would be efficient. Section VI contains a summary of our results and concludes the paper.

II. The Model

In this section, we present the model that is tested empirically in this paper. We use notation as follows:

S_t = the spot price at time t of a unit of foreign currency,

C_t = the domestic currency price at time t of a call written on one unit of foreign currency,

P_t = the domestic currency price at time t of a put written on one unit of foreign currency,

$B_{t,T}$ = the domestic currency price at time t of a pure discount bond that pays one unit of domestic currency at time T,

$B^*_{t,T}$ = the foreign currency price at time t of a pure discount bond that pays one unit of foreign currency at time T,

T = the expiration date of the option,

X = the domestic currency exercise price for an option on foreign currency,

[2] The American pricing model used in [15] is based on a model by Geske and Johnson [8] for pricing American puts on stocks.

σ = volatility of the spot currency price, and

$N(\cdot)$ = cumulative normal distribution function.

Employing the now familiar assumptions of frictionless markets, constant interest rates, and geometric Brownian Motion for the currency spot price, a model for the valuation of foreign currency options can now be derived.[3] The valuation formula for European call options on foreign currency is

$$C_t = S_t B^*_{t,T} N\left(d_1 + \sigma\sqrt{T-t}\right) - XB_{t,T}N\left(d_1\right),$$

(1)

$$\text{where} \quad d_1 = \frac{\ln\left[S_t B^*_{t,T} / XB_{t,T}\right] - 1/2\sigma^2(T-t)}{\sigma\sqrt{T-t}}.$$

Using Put-Call parity and equation (1) for a call option, the valuation formula for European put options on foreign currency is

(2)
$$P_t = XB_{t,T}N\left(-d_1\right) - S_t B^*_{t,T} N\left(-d_1 - \sigma\sqrt{T-t}\right).$$

The inputs to the above models consist of five observable variables—the price of the underlying asset (the spot exchange rate S), the exercise price (X), the time to maturity ($T - t$), the price of a domestic bond ($B_{t,T}$), and the price of a foreign bond ($B^*_{t,T}$)—and one variable that is not directly observable—the volatility of the spot exchange rate (σ). The next section describes the sources used to collect data on the five observable variables, and the section following it presents the techniques used here to obtain proxies for the unobservable volatility.

III. The Data

The tests of the model for foreign currency options are based on data for the following four currency options—the British pound, the German mark, the Japanese yen, and the Swiss franc.[4] The data consist of daily closing prices for each option traded on the Philadelphia Stock Exchange, daily spot exchange rates, and daily Eurocurrency interest rates for the period December 14, 1982, to February 15, 1984.[5,6] The total number of observations across all four currencies is 6750, with 4410 being calls and the remaining 2340 being puts. We use fewer observations in the hedging strategy tests because we eliminate an observation on an option on date t if we do not find a trade on the same option on date ($t + 1$), and trade on either date ($t + 2$) or date ($t + 3$), i.e., an option that does not have three "consecutive" trades. This screening process leaves us with 2251 (t, $t + 1$) pairs and (t, $t + 1$, $t + 2$) triplets of observations on calls, and 771 pairs and triplets of observations on puts.

[3] See [2] and [7].

[4] Options on Canadian dollars are not included in the sample because of infrequent trading.

[5] The data on closing option prices and closing spot exchange rates is obtained from *The Wall Street Journal*. The Eurocurrency data are collected from the *London Financial Times*.

[6] The Eurocurrency interest rates are used to determine daily domestic and foreign bond prices, i.e., $B_{t,T}$ and $B^*_{t,T}$, respectively.

In analyzing the results, it should be kept in mind that the use of closing prices from *The Wall Street Journal* have some problems since they are not necessarily transaction prices, they do not always reflect a synchronization between the option price and the price of the underlying foreign currency, and they do not give any indication of the depth of the market at that price. As a result, any reported violation may be artificial, rather than an opportunity to make excess returns.

IV. Estimates of Exchange Rate Volatility: A Comparison

We use three different estimates for the volatility of exchange rates. First, we use a daily estimate derived from a sample of the 40 latest observations on spot exchange rates. This estimate is a historical standard deviation (HSD) and is calculated as follows

$$\text{HSD}_t^2 = \sum_{j=t-39}^{t-1} \left(R_j - \overline{R}\right)^2 / 38, \tag{3}$$
$$\text{where} \quad R_j = \ln(S(j)/S(j-1))$$
$$\text{and} \quad \overline{R} = \sum_{j=t-39}^{t-1} R_j / 39.$$

We use the measure of volatility based on spot exchange rates even though a preferred measure would be the average volatility of forward rates, the average being taken over the maturity of the forward/option contract, since that includes information regarding interest-rate volatility. However, we do not use this measure since forward rates are not available for the specific maturity months of the options on foreign currencies. In addition, our measure of volatility would differ from the volatility of forward-prices-to-option-maturity only in those periods in which the foreign/domestic interest-rate differential changes substantially. Since, in our period of study, the differential is fairly stable for all four currencies, the use of spot-rate volatility should not induce any biases.

Our two other estimates are based on a volatility measure first introduced by Latane and Rendleman [12]. This measure is the standard deviation implied in actual option prices on the assumption that investors price options according to the models given by equations (1) and (2). Thus, option prices on day $(t-1)$ are used to obtain an implied standard deviation. This implied standard deviation is then used as an estimate of the volatility on day t. The two estimates of implied standard deviation are similar to those used by Beckers [1].

The first estimate of the implied standard deviation is the one that minimizes the weighted sum of squared deviations between market price and the corresponding model price, i.e., it is that value of σ that minimizes

$$f(\sigma) = \sum_{i=1}^{I} w_i \left[Y_{\text{mkt}}^i - Y_{\text{mod}}^i\right]^2, \tag{4}$$

where Y = C or P depending on whether the option is a call or put, respectively;

$w_i = \delta Y^i_{mod}/\delta\sigma$;

i = refers to option i;

I = number of options on a given currency on day $t - 1$.

This estimate of implied standard deviation is labeled WISD.

The second alternative considered consists of simply using the implied standard deviation for the most sensitive option (SISD).[7] The second measure is also used because WISD could be an upward biased measure of the "true" variance, since we are applying a European pricing model to price in-the-money American options.

All three standard deviations should reflect the expected future variability of the spot exchange rate. A simple test of the predictive ability of each one of these alternative measures would be to compare each of the estimates on day t with the actual volatility of the spot exchange rate over the period of $(t + 1)$ to $(t + 40)$, (FSD). Thus, a regression of the following type then can be used to compare the three estimates

$$\text{(5)} \qquad FSD = \alpha + \beta X + u, \quad \text{for } X = \text{HSD, WISD, SISD}.$$

The R^2 would give an indication of the explanatory power of the alternative measures.

The results of this test are reported in Table 1. These results indicate that for all countries (except Germany), the two implied standard deviation estimates tend to outperform the HSD in predicting the actual volatility of spot rates.[8] In addition, a comparison between WISD and SISD measures reveals that the latter performs almost as well as the former. Thus, most of the relevant information is reflected in the price of an at-the-money option.

TABLE 1

Regression Test of the Predictive Ability of Different Measures of σ

$FSD = \alpha + \beta X$

Country	X	α	$t(\alpha)$	β	$t(\beta)$[a]	R^2
U.K.	HSD	0.045	8.31*	0.512	−9.20*	0.27
	WISD	0.032	7.72*	0.626	−9.46*	0.51
	SISD	0.040	10.73*	0.564	−12.08*	0.50
Japan	HSD	0.05	10.75*	0.348	−14.26*	0.21
	WISD	0.036	6.72*	0.384	−14.68*	0.28
	SISD	0.045	8.63*	0.318	−16.51*	0.22
Germany	HSD	0.130	21.45*	−0.379	−23.10*	0.16
	WISD	0.095	15.41*	−0.02	−20.91*	0.01
	SISD	0.084	14.84*	0.072	−20.24*	0.01
Switzerland	HSD	0.067	20.41*	0.199	−26.03*	0.14
	WISD	0.068	22.39*	0.157	−33.29*	0.15
	SISD	0.064	22.48*	0.192	−29.84*	0.23

[a] $t(\beta)$ is based on the null hypothesis that $\beta = 1$.

* Indicates significance at the 95% level.

[7] The option used to derive this estimate is the one that is closest to being "at-the-money," i.e., we picked the option closest to $S/X = 1$, in the range of $0.97 \leq S/X \leq 1.03$.

[8] These results are based on our complete sample.

Tables 2 and 3 present the results of a comparison of put and call market prices with the corresponding model prices for each one of the three estimates of volatility.[9] It can be seen from these tables, that all three measures of volatility, when used in equations (1) and (2), result in model prices that deviate substantially from the corresponding market prices. There are no observable patterns in these deviations except when the HSD measure is used to obtain the model prices. Use of the HSD measure yields model prices that are, on an average, lower than market prices. For our sample, the historical standard deviation results in higher market prices for 5025 options or approximately 75 percent of the 6750 observations. In addition, most of the 1725 underpriced options have a life of less than 60 days.[10] A comparison of the two implied standard deviations shows that the SISD measure is more biased towards overpricing than the WISD measure. In addition, the mispricing is larger (in absolute value) when SISD is used as a model input instead of WISD.

TABLE 2

Comparison of Market and Model Prices for Calls

$\Delta = C_{mkt} - C_{mod}$

	Sample	U.K.	Japan	Germany	Switzerland
			A. Historical Standard Deviation		
Mean $\Delta > 0$	$107.82	$50.77	$136.29	$116.05	$108.02
Mean $\Delta < 0$	−$67.68	−$44.84	−$50.76	−$105.01	$49.15
% $\Delta > 0$	72.72	56.34	86.26	66.80	82.26
			B. Implied Standard Deviation #1 (WISD)		
Mean $\Delta > 0$	$50.64	$43.42	$56.12	$41.04	$63.61
Mean $\Delta < 0$	−$53.60	−$34.83	−$62.13	−$49.45	−$68.51
% $\Delta > 0$	47.76	47.33	44.64	48.76	49.91
			C. Implied Standard Deviation #2 (SISD)		
Mean $\Delta > 0$	$63.07	$50.29	$74.34	$57.18	$72.96
Mean $\Delta < 0$	−$58.52	−$40.60	−$66.52	−$53.94	−$71.18
% $\Delta > 0$	58.68	57.13	56.04	65.33	54.71

In conclusion, we have shown in this section that the market prices of foreign currency options deviate substantially from their corresponding model prices for all three measures of exchange rate volatility. This evidence can be viewed as support for rejection of the hypothesis that the option pricing models in equations (1) and (2) are valid and/or that the market for foreign currency options is efficient.

It could be argued that the above reported mispricings are caused by the fact that we have used European models to price American options. In the literature on equity options, it is well known that the use of European models to price American calls represents a major measurement problem only if the dividends on the underlying security are not "small." In the case of foreign currency calls, the use of a European model would represent a major measurement problem only if

[9] The dollar amounts reported in the tables in this paper are for one standard contract. The contract size differs for various currencies—12,500 pounds for the United Kingdom, 6,250,000 yen for Japan, 62,500 marks for Germany, and 62,500 francs for Switzerland.

[10] An option is considered overpriced if its market price is above its model price.

TABLE 3

Comparison of Market and Model Prices for Puts

$\Delta = P_{mkt} - P_{mod}$

	Sample	U.K.	Japan	Germany	Switzerland
			A. Historical Standard Deviation		
Mean $\Delta > 0$	\$133.49	\$51.65	\$138.78	\$148.61	\$162.70
Mean $\Delta < 0$	−\$56.02	−\$46.51	−\$47.37	−\$75.22	−\$50.95
% $\Delta > 0$	77.69	61.12	87.00	76.44	84.80
			B. Implied Standard Deviation #1 (WISD)		
Mean $\Delta > 0$	\$92.87	\$44.40	\$91.70	\$97.73	\$125.30
Mean $\Delta < 0$	−\$48.77	−\$37.70	−\$53.04	−\$43.66	−\$59.01
% $\Delta > 0$	55.56	53.38	49.14	61.33	56.58
			C. Implied Standard Deviation #2 (SISD)		
Mean $\Delta > 0$	\$97.67	\$50.23	\$93.73	\$109.88	\$124.08
Mean $\Delta < 0$	−\$53.60	−\$41.84	−\$53.46	−\$48.90	−\$66.87
% $\Delta > 0$	64.15	61.70	58.32	72.66	62.07

the foreign interest rate is large in comparison to the domestic interest rate. For the four currencies under consideration in this paper, interest rates over the period of our study average as follows:

Germany : 4-6%

Japan : 6-6.5%

Switzerland : 2-4%

U.K. : 9.5-11.5%

U.S. : 9-11%.

As can be seen above, it is only in the case of the United Kingdom that domestic and foreign interest rates are comparable. Thus, we feel that early exercise of calls is not a problem for three of the four currencies under consideration. This, in turn, implies that the use of European models to price American calls on foreign currency will not cause the above mispricings except (possibly) in the case of the British pound.

For puts, Geske and Johnson [8] have shown that the difference between European and American prices is extremely small when the underlying security pays dividends. They generate European and American put prices for a variety of cases and find that the average error is approximately \$4 per option contract (an average percentage error of approximately 1.25 percent) for a dividend yield of 5 percent. Since this error is sufficiently small in comparison to the difference between market and model prices, the mispricings reported above for puts do not arise because of the use of a European model.

In the next section, we examine the question of market efficiency in a little more detail by developing a trading strategy that could be used to take advantage of an observed mispricing and by studying the performance of this strategy.

V. The *Ex Post* and *Ex Ante* Hedging Tests

To test market efficiency, one must investigate whether excess (abnormal) profit opportunities exist in the market. If these opportunities exist and persist over time, it can then be argued that the market is inefficient for the period investigated. If profitable opportunities do not materialize, then the market is efficient with respect to the trading rule used.

In this section, we test for the profitability of a hedging strategy that is based on the models presented in Section II. We consider two forms of the hedging strategy. The first, called the *ex post* strategy, assumes that the strategy can be executed at the market prices that indicate deviations from the corresponding model prices. The second form, called the *ex ante* strategy, assumes that an observed deviation serves only as a signal that triggers a transaction at the next day's price.[11]

A. The Hedging Strategy

Consider a portfolio that is composed of one call option, α units of a foreign bond and β units of a domestic bond.[12] The domestic currency (dollar) value at time t of this portfolio is

$$\text{Value} = C_t + \alpha S_t B^*_{t,T} + \beta B_{t,T}. \tag{6}$$

If C_t is given by equation (1), $\alpha = -N(d_1 + \sigma\sqrt{T-t})$, and $\beta = XN(d_1)$, then using equation (6), it can be shown that a long position in a domestic bond is equivalent to a long position in $(-\alpha/\beta)$ foreign bonds, and a $(1/\beta)$ written (short) position in a call option.[13] Thus, if an option is overpriced, a portfolio composed of $(1/\beta)$ written calls and $(-\alpha/\beta)$ bought foreign bonds would yield a higher return than a long position in a domestic bond. Similarly, if an option is underpriced, a portfolio composed of $(1/\beta)$ bought calls, and borrowing an amount equivalent to $(-\alpha/\beta)$ foreign bonds, would yield a higher return than a short position in a domestic bond.

The trading strategy for calls that is tested in subsequent sections is based on the above observations and is described below:[14,15]

1) at time t, equation (1) is used to determine the model price of the call option, C_t^{mod};
2) if the call is overpriced ($C_t^{\text{mkt}} > C_t^{\text{mod}}$), then we form a portfolio composed

[11] It has been argued in the literature that the first test can only indicate the existence of contemporaneous deviations from equilibrium, while the second is a "true" test of market efficiency (for example, see [6]).

[12] The bonds have a maturity that is the same as the call option.

[13] See [11] for details.

[14] The equations given here are for the *ex post* version of the hedging strategy.

[15] The European model price represents a lower bound on the value of an option. Thus, a profit opportunity exists, if an option has a market price lower than the corresponding European model price. Thus, even if one questions the use of the model in general, the trading strategy developed in this paper is definitely legitimate for underpriced puts and calls. With this in mind, we report the results separately for both underpriced as well as overpriced options. In addition, we recognize the fact that we are only misclassifying those options whose prices fall in between the European and American model prices. Therefore, options that are overpriced a lot in comparison to European model prices will, in all probability, be overpriced relative to an American model. Keeping this in mind, we report results using a filter rule.

of $(1/\beta)$ written calls, and $(-\alpha/\beta)$ bought foreign bonds. The cost of this portfolio is[16,17]

$$V = \left(\frac{-\alpha}{\beta}\right) S_t B^*_{t,T} - \left(\frac{1}{\beta}\right) C_t . \tag{7}$$

The portfolio is liquidated at the next trade. The excess return on this portfolio is then defined as[18]

$$R = \left(\frac{-\alpha}{\beta}\right) S_{t+1} B^*_{t+1,T} - \left(\frac{1}{\beta}\right) C_{t+1} - \frac{VB_{t+1,T}}{B_{t,T}} ; \tag{8}$$

3) if the call is underpriced, then we follow exactly the opposite strategy.

The trading strategy for puts is developed using arguments that are similar to those used above. The strategy is as follows:

1) At time t, equation (2) is used to determine the model price of the put options, P_t^{mod}.
2) If the put is overpriced ($P_t^{\text{mkt}} > P_t^{\text{mod}}$), then we form a portfolio composed of $(-1/\beta)$ written puts, and borrowing equivalent to $(-\alpha/\beta)$ foreign bonds, where $\alpha = N(-d_1 - \sigma\sqrt{T-t})$ and $\beta = -XN(-d_1)$. The cost of this portfolio is

$$V = \left(\frac{\alpha}{\beta}\right) S_t B^*_{t,T} + \left(\frac{1}{\beta}\right) P_t . \tag{9}$$

The portfolio is liquidated at the next trade to yield excess returns of[19]

$$R = \left(\frac{\alpha}{\beta}\right) S_{t+1} B^*_{t+1,T} + \left(\frac{1}{\beta}\right) P_{t+1} - \frac{VB_{t+1,T}}{B_{t,T}} . \tag{10}$$

3) If the put is underpriced, then we follow exactly the opposite strategy.

B. The Results of the *Ex Post* Tests

The results for the *ex post* version of the hedging strategy for calls are reported in Tables 4 and 5. The excess returns reported in Table 4 indicate that in over one-half of the four currencies, the hedging strategy successfully translates an observed deviation of market from model prices into positive excess (abnor-

[16] For the *ex ante* version of the strategy, the cost of the portfolio is given by

$$V = \left(\frac{-\alpha}{\beta}\right) S_{t+1} B^*_{t+1,T} - \left(\frac{1}{\beta}\right) C_{t+1} ,$$

where α and β are calculated based on values at time t.

[17] The strategy outlined here ignores the bid-ask spread. It is assumed that one can buy (and write) options at the closing prices reported in *The Wall Street Journal*.

[18] For the *ex ante* version of the strategy, the excess return is given by substituting $t + 2$ for $t + 1$, and $t + 1$ for t in equation (8).

[19] Equations (9) and (10) are for the *ex post* version of the strategy. The corresponding equations for the *ex ante* strategy are obtained by substituting $t + 2$ for $t + 1$, and $t + 1$ for t in equations (9) and (10).

mal) profits. While the values for the average profits change with the volatility measure, the qualitative results are unchanged, i.e., the hedging strategy seems to have the ability to distinguish between profitable and unprofitable investments:

TABLE 4

Excess Returns from *Ex Post* Hedging Strategy for Calls

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
			A. Overpriced Calls			
HSD	Mean ($)	2.95	−0.71	0.99	8.84	0.63
	T-Statistic	1.50	−0.86	4.34*	1.31	2.26*
	% Positive	57.22	57.66	58.98	55.10	57.38
SISD	Mean ($)	1.11	−0.01	1.26	1.44	1.18
	T-Statistic	3.63*	−0.13	3.41*	1.89	4.02*
	% Positive	60.40	52.78	65.20	58.93	62.86
WISD	Mean ($)	2.06	−0.22	4.49	2.01	1.14
	T-Statistic	2.44*	−0.60	1.36	3.12*	4.12*
	% Positive	64.63	57.58	67.27	66.32	63.91
			B. Underpriced Calls			
HSD	Mean ($)	0.62	0.19	1.06	0.56	1.51
	T-Statistic	5.05*	3.42*	2.43*	2.73*	1.24
	% Positive	61.27	62.50	64.15	59.16	63.64
SISD	Mean ($)	0.61	0.41	0.06	1.16	0.70
	T-Statistic	4.31*	1.31	0.24	3.37*	3.11*
	% Positive	59.98	57.69	58.21	65.37	58.02
WISD	Mean ($)	0.66	0.12	0.23	1.21	0.78
	T-Statistic	6.91*	2.66*	1.57	5.55*	3.63*
	% Positive	59.22	56.65	55.09	63.96	58.98

Note: The mean return is dollars/contract/day.
* Indicates significance at the 95% level.

The above conclusions receive further support from the tests in which the hedging strategy is executed only if the deviation of market price from the corresponding model price is more than $50. Table 5 presents the results of these tests. As one would expect, the significance level of the excess returns increases with the implementation of the filter rule. In addition, the excess returns in this case are substantially higher than the nonfiltered excess returns.

The results of the nonfiltered and filtered *ex post* tests for puts are presented in Tables 6 and 7, respectively. The results in this case have patterns that are very similar to those obtained for calls. The only major difference in these results is that, with calls, all three measures of standard deviation perform equally well in detecting profitable trading opportunities, while, with puts, one measure of standard deviation—the WISD measure—seems to perform better than the other two measures.

The above tests indicate that the hedging strategy can yield abnormal profits, given full information on the prices at which the transactions are executed.[20]

[20] This statement is especially true when we use a filter rule.

TABLE 5

Excess Returns from *Ex Post* Hedging Strategy for Calls
Strategy Executed only if Call is Mispriced by More than $50

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
			A. Overpriced Calls			
	Mean ($)	4.43	0.32	1.20	12.01	1.04
HSD	*T*-Statistic	1.57	2.22*	5.06*	1.32	4.19*
	% Positive	59.71	63.75	61.98	56.20	59.94
	Mean ($)	2.15	0.04	1.11	3.87	1.71
SISD	*T*-Statistic	3.40*	0.13	4.55*	2.25*	4.95*
	% Positive	64.94	58.18	65.97	64.86	66.22
	Mean ($)	3.47	0.73	1.89	7.27	2.58
WISD	*T*-Statistic	4.98*	2.80*	4.75*	2.95*	5.69*
	% Positive	75.00	74.07	68.81	82.61	75.00
			B. Underpriced Calls			
	Mean ($)	1.01	0.27	2.97	0.83	4.04
HSD	*T*-Statistic	4.61*	2.42*	2.14*	3.18*	2.56*
	% Positive	65.82	66.13	81.82	63.39	78.95
	Mean ($)	1.06	0.57	0.44	2.06	1.10
SISD	*T*-Statistic	3.82*	3.37*	1.07	2.42*	2.46*
	% Positive	66.20	77.50	61.73	70.77	62.38
	Mean ($)	1.37	0.37	0.71	2.29	1.45
WISD	*T*-Statistic	6.37*	2.70*	2.25*	4.97*	3.16*
	% Positive	68.66	63.46	66.67	75.45	65.69

* Indicates significance at the 95% level.

We now test for the existence of these excess returns when the execution of the strategy is delayed by one trading day.

C. The Results of the *Ex Ante* Tests

In performing *ex ante* tests, it is assumed that an observed deviation serves only as a signal that triggers a transaction at the next day's price. Thus, the investigation of market efficiency is now from the point of view of a trader who observes a deviation and then tries to exploit it the next day. However, in this case, there is no guarantee that the prices the next day still will be favorable to the trader. Positive profits in these *ex ante* tests would indicate market inefficiency, while nonpositive profits could be viewed as support for market efficiency. Of course, statements regarding the efficiency of the market for members would depend on how quickly they can execute a transaction. A glance at Tables 8 and 9 indicates that the profit reported *ex post* for calls disappears if the execution of the strategy is delayed by one day. Almost all the profits reported in these tables are not significantly different from zero as indicated by the *t*-statistics. In addition, for almost all the overpriced calls, this delay in execution actually results in a change in sign of excess returns from positive to negative. The *ex ante* profits for the underpriced calls are still positive, but insignificantly so.

The *ex ante* results for puts are presented in Tables 10 and 11 and follow a pattern very similar to those for calls. The delay of execution by one day causes

TABLE 6
Excess Returns from *Ex Post* Hedging Strategy for Puts

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
		A. Overpriced Puts				
	Mean ($)	1.05	0.25	1.35	0.63	1.59
HSD	*T*-Statistic	3.93*	1.62	1.51	1.81	4.34*
	% Positive	62.08	62.32	65.41	58.38	63.37
	Mean ($)	1.01	0.14	1.24	0.77	1.78
SISD	*T*-Statistic	4.45*	1.45	1.40	2.86*	4.98*
	% Positive	63.27	60.00	66.67	61.45	65.49
	Mean ($)	1.23	0.23	2.06	0.99	1.49
WISD	*T*-Statistic	3.82*	2.21*	1.67	3.23*	2.98*
	% Positive	65.34	63.93	71.79	61.34	65.96
		B. Underpriced Puts				
	Mean ($)	0.63	0.12	1.26	0.38	1.46
HSD	*T*-Statistic	3.79*	2.39*	2.11*	1.20	3.25*
	% Positive	61.32	63.24	67.86	58.11	59.52
	Mean ($)	0.42	0.14	0.39	0.56	0.46
SISD	*T*-Statistic	2.58*	2.39*	0.99	1.93	1.33
	% Positive	55.80	68.67	47.06	61.29	50.50
	Mean ($)	0.25	0.15	0.50	0.28	0.12
WISD	*T*-Statistic	1.85	2.92*	1.46	1.17	0.40
	% Positive	53.22	65.79	50.60	53.57	46.67

* Indicates significance at the 95% level.

the excess profits to go from being significant to being insignificant, with the only exceptions being put options on the Swiss franc. This result is also robust to changes in the filter rule.[21]

VI. Summary and Conclusions

This paper tests the hypothesis that the market for foreign currency options is efficient. The tests are based on a European option pricing model.[22] The results here indicate that, based on this model, there exists a substantial number of profit opportunities in this market. It is also shown that a trader in the market could make significant abnormal profits if he could execute a hedging strategy at the market prices that indicates deviations from the corresponding model prices. In addition, it is shown that these profit opportunities disappear if the transaction is delayed by one day. Therefore, the results of these *ex ante* tests suggest that the foreign currency market on the Philadelphia Stock Exchange (PHLX) is efficient during the period investigated, and abnormal profit opportunities do not exist for

[21] We also tried a $100 filter in the *ex ante* tests. The results for that filter are identical to the nonfilter and $50-filter tests.

[22] The tests conducted here are for one version of this model. Biger and Hull [2], Garman and Kohlhagen [7], and Grabbe [11] derive a second version of this model by using interest rate parity in which the option price is a function of the forward price instead of the spot exchange rate and the foreign bond price. We do not use this version of the model since forward rates are not available for the specific maturity months of the options on foreign currencies.

TABLE 7

Excess Returns from *Ex Post* Hedging Strategy for Puts
Strategy Executed only if Put is Mispriced by More than $50

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
			A. Overpriced Puts			
	Mean ($)	1.45	0.66	1.35	0.93	2.24
HSD	*T*-Statistic	4.16*	1.94	1.27	2.81*	4.90*
	% Positive	66.49	71.43	67.96	63.41	67.23
	Mean ($)	1.59	0.35	2.53	0.99	2.21
SISD	*T*-Statistic	4.43*	1.43	1.73	2.67*	4.44*
	% Positive	65.00	70.83	65.00	60.00	68.85
	Mean ($)	2.24	0.84	4.59	1.38	1.92
WISD	*T*-Statistic	3.67*	3.12*	1.97*	2.80*	2.72*
	% Positive	72.41	93.33	78.99	65.96	68.00
			B. Underpriced Puts			
	Mean ($)	1.03	0.19	1.62	0.98	4.20
HSD	*T*-Statistic	4.04*	2.00*	3.11*	2.43*	2.97*
	% Positive	70.27	60.87	88.89	67.57	100.00
	Mean ($)	0.71	0.49	0.96	1.32	0.31
SISD	*T*-Statistic	2.46*	3.97*	1.89	2.52*	0.59
	% Positive	61.47	90.00	60.00	77.27	48.94
	Mean ($)	1.09	0.34	1.53	1.03	1.06
WISD	*T*-Statistic	4.03*	3.59*	2.44*	2.17*	2.17*
	% Positive	67.39	76.92	69.70	68.09	62.22

* Indicates significance at the 95% level.

nonmembers of the Foreign Currency Options section in the PHLX. Statements regarding the efficiency of the market for members would depend on how quickly the members can execute a transaction. On one extreme, if they can duplicate only the *ex post* strategy, the market would be inefficient from their point of view. On the other extreme, if they can duplicate only the *ex ante* strategy, the market would be efficient. The amount of time they can wait to execute the transaction and still realize excess returns is a question that cannot be addressed using our data, and is left for future research.

TABLE 8

Excess Profits from *Ex Ante* Hedging Strategy for Calls

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
		A. Overpriced Calls				
	Mean ($)	−0.36	0.35	−0.16	−0.99	−0.26
HSD	*T*-Statistic	−0.66	0.34	−0.28	−0.62	−0.39
	% Positive	53.54	49.55	56.73	53.88	51.77
	Mean ($)	−0.52	−0.18	0.13	−0.23	−1.93
SISD	*T*-Statistic	−0.99	−0.72	0.58	−0.64	−0.87
	% Positive	52.01	50.46	56.14	49.33	53.02
	Mean ($)	−0.62	0.18	−1.34	−0.84	−0.13
WISD	*T*-Statistic	−1.34	0.37	−0.82	−1.67	−0.25
	% Positive	51.95	52.12	58.27	47.78	51.32
		B. Underpriced Calls				
	Mean ($)	0.40	−0.05	0.59	0.54	0.82
HSD	*T*-Statistic	2.71*	−1.12	1.49	2.67*	1.04
	% Positive	52.29	47.16	47.17	57.63	49.35
	Mean ($)	0.14	−0.26	0.56	0.03	0.20
SISD	*T*-Statistic	0.70	−0.79	1.11	0.07	0.66
	% Positive	48.66	52.20	43.28	49.35	49.79
	Mean ($)	0.07	0.04	0.29	−0.07	0.07
WISD	*T*-Statistic	0.47	0.71	0.74	−0.27	0.25
	% Positive	48.89	51.50	45.66	50.41	47.66

* Indicates significance at the 95% level.

TABLE 9

Excess Profits from *Ex Ante* Hedging Strategy for Calls
Strategy Executed only if Call is Mispriced by More than $50

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
		A. Overpriced Calls				
	Mean ($)	−0.63	−1.35	0.34	−2.62	0.53
HSD	*T*-Statistic	−1.03	−0.89	1.59	−1.36	2.29*
	% Positive	54.60	52.50	58.33	52.62	53.03
	Mean ($)	0.44	−0.06	0.42	0.53	0.49
SISD	*T*-Statistic	2.01*	−0.25	1.56	1.03	1.77
	% Positive	53.90	50.91	58.12	49.10	56.76
	Mean ($)	−0.04	−0.07	−0.31	−0.27	0.38
WISD	*T*-Statistic	−0.14	0.50	−0.72	−0.40	1.21
	% Positive	51.16	62.96	50.46	42.39	56.03
		B. Underpriced Calls				
	Mean ($)	0.31	0.00	0.06	0.47	−0.07
HSD	*T*-Statistic	1.75	0.04	0.06	1.83	−0.17
	% Positive	54.18	51.61	36.36	56.83	47.37
	Mean ($)	0.38	−0.04	0.25	−0.03	0.92
SISD	*T*-Statistic	1.17	−0.35	0.67	−0.03	1.46
	% Positive	48.78	50.00	45.68	55.38	46.53
	Mean ($)	0.31	−0.10	0.42	0.16	0.60
WISD	*T*-Statistic	1.11	−1.59	1.19	0.26	0.94
	% Positive	50.14	48.08	51.72	52.73	47.06

* Indicates significance at the 95% level.

TABLE 10

Excess Returns from *Ex Ante* Hedging Strategy for Puts

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
			A. Overpriced Puts			
	Mean ($)	0.41	0.14	−0.17	0.44	0.94
HSD	*T*-Statistic	0.55	1.23	−0.06	0.99	2.53*
	% Positive	58.50	50.72	60.15	56.22	62.79
	Mean ($)	−0.20	0.15	−2.74	0.22	1.01
SISD	*T*-Statistic	−0.24	1.86	−0.68	0.74	2.22*
	% Positive	57.96	57.50	59.14	52.41	65.49
	Mean ($)	−0.60	0.09	−3.45	−0.11	0.72
WISD	*T*-Statistic	−0.55	0.97	−0.71	−0.32	1.22
	% Positive	55.68	55.74	60.26	49.58	59.57
			B. Underpriced Puts			
	Mean ($)	0.57	−0.03	0.53	0.86	1.06
HSD	*T*-Statistic	2.83*	−0.52	0.84	2.26*	1.69
	% Positive	53.77	47.06	53.57	56.76	59.52
	Mean ($)	0.18	0.04	−0.08	0.45	0.17
SISD	*T*-Statistic	1.02	0.71	−0.20	1.30	0.50
	% Positive	50.16	57.89	41.18	52.69	49.50
	Mean ($)	−0.05	−0.01	−0.24	0.03	−0.03
WISD	*T*-Statistic	−0.31	−0.23	−0.55	0.12	−0.10
	% Positive	45.58	51.32	43.37	47.14	41.67

* Indicates significance at the 95% level.

TABLE 11

Excess Returns from *Ex Ante* Hedging Strategy for Puts
Strategy Executed only if Put is Mispriced by More than $50

Estimate of σ		Sample	U.K.	Japan	Germany	Switzerland
			A. Overpriced Puts			
	Mean ($)	0.74	0.08	1.10	0.18	1.16
HSD	*T*-Statistic	2.00*	0.35	0.99	0.44	2.29*
	% Positive	60.32	50.00	60.19	59.35	63.87
	Mean ($)	0.44	0.32	−0.57	−0.16	1.92
SISD	*T*-Statistic	1.17	1.94	−0.46	−0.34	2.67*
	% Positive	57.00	58.33	60.00	45.33	68.85
	Mean ($)	0.18	0.21	−0.26	−0.89	1.46
WISD	*T*-Statistic	0.36	1.63	−0.16	−1.44	1.76
	% Positive	53.10	53.33	63.34	38.30	60.00
			B. Underpriced Puts			
	Mean ($)	0.21	−0.02	1.16	0.22	−0.52
HSD	*T*-Statistic	0.74	−0.29	1.30	0.44	−0.55
	% Positive	45.95	43.48	66.67	43.24	40.00
	Mean ($)	−0.06	0.01	0.05	−0.06	−0.16
SISD	*T*-Statistic	−0.21	0.05	0.10	−0.06	−0.35
	% Positive	48.62	70.00	46.67	54.55	42.55
	Mean ($)	−0.23	−0.05	−0.36	0.26	−0.15
WISD	*T*-Statistic	−0.70	−0.44	−0.42	−0.49	−0.27
	% Positive	44.20	46.15	48.48	40.43	44.44

* Indicates significance at the 95% level.

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