THE JOURNAL OF FINANCE • VOL. XLI, NO. 1 • MARCH 1986

Efficiency Tests of the Foreign Currency Options Market

JAMES N. BODURTHA, JR. and GEORGES R. COURTADON*

ABSTRACT

Based on a new options transactions data base from the Philadelphia Stock Exchange Foreign Currency Options Market, this paper examines the importance of the effect of nonsynchronous prices and transaction costs on the usual option market efficiency tests. The tests conducted are based on the transaction cost adjusted early exercise and put-call parity pricing boundaries applicable to the American foreign currency options market. The test results show that the put-call parity boundary tests are sensitive to both nonsynchronous prices and transaction costs. The early exercise boundary tests are sensitive to transaction costs but are not very sensitive to simultaneity of the option price and the underlying spot price. Under the no-transaction costs scenario, a large number of early exercise boundary violations is found even when simultaneous spot and option prices are used. These violations disappear when actual transaction costs are taken into account.

SINCE DECEMBER 1982, FOREIGN currency options have been offered in a number of exchange markets and a dealer market. Exchange markets for foreign currency options exist on the Philadelphia, Montreal, Vancouver, and Amsterdam stock exchanges. The first three markets all trade options denominated in U.S. dollars on the British pound, Canadian dollar, Deutsche mark, Japanese yen, and Swiss franc. The Philadelphia Stock Exchange (PHLX) also trades French franc options. The Amsterdam Exchange trades options on the U.S. dollar denominated in Dutch guilders and Deutsche marks, as well as options on the British pound denominated in U.S. dollars. Finally, the London Stock Exchange trades British pound options. This study will examine the efficiency of the foreign currency options market of the PHLX, which is the predominant exchange market for foreign currency options.

The efficiency tests that we will use draw on the work of Merton [10] and Gould and Galai [6]. These tests are based on the principle that an asset (or a portfolio of assets) which has a future stream of cashflows at least equal to the

* The Ohio State University and New York University, respectively. This study could not have been undertaken without the efforts of Arnie Staloff of the Philadelphia Stock Exchange. Comments on a previous draft of the paper by the participants in the Ohio State University Economics/Finance Colloquium and in the 1984 European Finance Association Meetings are gratefully acknowledged. Specific comments by J. Huston McCulloch, Rene Stulz, and an anonymous referee of this journal have been particularly helpful in the revision of this work. This work has been supported by a grant from the School of Administrative Science at Ohio State University. All errors and omissions are the authors' responsibility.

stream of cashflows of another asset should be worth at least as much as this latter asset. Based on this principle, we derive a set of boundary conditions for the foreign currency options market which must be satisfied by both put and call options. Violations of these boundary conditions will mean a violation of rational option pricing, i.e., a violation of market efficiency. Two types of boundary conditions are derived: early exercise boundary conditions and put-call parity boundary conditions.

Although the previous work in this area is substantial, this study extends upon the previous literature in several ways.[1] It is the only test of efficiency of the foreign currency options market which is based on transactions data and which takes into account the observations made by Phillips and Smith [11] regarding the effects of transaction costs and trade feasibility on market efficiency tests. Finally, this study is the only test of put-call parity on a large transactions database which takes into account transaction costs and simultaneity of the option price with the price of the underlying commodity or security.

The organization of this paper is as follows. In the first section, we derive a set of eight boundary conditions which must be satisfied by American options on foreign currencies under a full transaction costs scenario. The second section presents the data used in testing the boundary conditions derived in the first section. In Section III, we present the results of our tests. To emphasize the importance of simultaneous spot and options prices and of transaction costs, three sets of results are presented. The first set of results is obtained by testing the boundary conditions with closing prices under the no-transaction costs scenario. The second set of results is derived from testing the same boundary conditions with simultaneous option and spot currency prices under the no-transaction costs scenario. Finally, the third set of results is derived from testing the boundary conditions with simultaneous option and spot currency prices under the full transaction costs scenario. Our conclusions are presented in Section IV.

I. Boundary Conditions for the Foreign Currency Options Market

In this section, we will derive a set of eight boundary conditions which must be satisfied by currency options under a full transaction costs scenario. Four of these boundaries must be satisfied by call option prices while the remaining four must be satisfied by put option prices. Violations of these boundary conditions will imply that the stream of future cashflows promised by the option could have been bought at a cost lower than the option price. If these violations are severe enough, arbitrage gains will be present. We will test the boundary conditions we identify for the foreign currency options traded on the PHLX both for the purchase of dominated claims and for arbitrage opportunities. The following definitions are used in our discussion of these boundary conditions:

[1] These tests follow Gould and Galai [6], Galai [5], Klemkosky and Resnick [8, 9], Bhattacharya [1], and Shastri and Tandon [12].

a ask price indicator
b bid price indicator
S_k spot price; $k = a, b$
C call option price
P put option price
r_k U.S. nominal riskless rate; $k = a, b$
r_{fk} foreign nominal riskless rate; $k = a, b$
E option exercise price
t current date
T maturity date of the option
T_C cost of purchasing a call
T_P cost of purchasing a put
T_E^C cost of call exercise
T_E^P cost of put exercise
T_S maximum bid-ask spread over the period

The first set of boundary conditions can be derived from the values of the options if exercised. For both put and call options, the existence of an option trade implies that the option was sold by one party. Therefore, rationality and market efficiency require that this sale should not have been dominated by the action of exercising the option. Algebraically, these conditions are expressed as:

$$C \geq S_b - E - T_E^C \tag{1}$$

$$P \geq E - S_a - T_E^P. \tag{2}$$

Alternatively, an efficient market should not provide arbitrage opportunities. Arbitrage opportunities would result if it were profitable to purchase an option and then exercise it. The boundary conditions on option prices related to this action are weaker than conditions (1) or (2). The restrictions of this arbitrage activity on option prices can be stated as:

$$C \geq S_b - E - T_E^C - T_C \tag{3}$$

$$P \geq E - S_a - T_E^P - T_P. \tag{4}$$

Another set of boundary conditions can be developed by creating portfolios of assets which dominate call and put options. To clarify the exposition, we will first derive these boundary conditions in the case where there are no transaction costs.

Following Cox and Rubinstein [4][2], we can prove that the value of an American call option on a foreign currency under a no-transaction costs scenario is never greater than:

(a) the price of an otherwise identical put,
(b) plus the value of a unit of the spot currency,
(c) less the present value of the exercise price.

[2] See proposition 4, page 152.

In other words, we have:[3]

$$S + P - Ee^{r(T-t)} \geq C. \tag{5}$$

This inequality has to hold since, if it was reversed, an investor would make a riskless arbitrage opportunity by selling the call, buying the put and the unit of currency, and borrowing the present value of the exercise price.[4] In the same way, the Cox and Rubinstein analysis can be used to show that, under a no-transaction costs scenario, the price of an American put option on a foreign currency is never greater than:

(a) the price of an otherwise identical call,
(b) plus the exercise price,
(c) less the dollar value of a zero coupon bond which promises to pay one unit of the currency on the maturity date of the option.

Equivalently,

$$E + C - Se^{-r_f(T-t)} \geq P. \tag{6}$$

If this inequality does not hold, an investor will make a riskless arbitrage opportunity by selling the put, lending an amount of dollars equal to the exercise price, buying the call, and selling the zero coupon bond denominated in the foreign currency which promises to pay one unit of the foreign currency on the maturity date of the option.[5]

The derivation for the full transaction costs scenario of the dominance and arbitrage boundary conditions which are equivalent to Equations (5) and (6) is presented in Tables I and II. First, consider position B in Table I. This position is constructed by purchasing a put, lending one unit of the foreign currency, and borrowing the discounted value of the put option exercise price less the sum of the put option exercise cost and the maximum spot currency bid-ask spread. Position B never pays out less than a call option written with the same exercise price as the put option. Therefore, if we are able to find instances where a call option price is greater than the cost of constructing position B, the dominance condition is violated. A market inefficiency would exist. The boundary condition implied by the existence of position B at the time of a call option trade is:

$$S_a + P + Ee^{-r_b(T-t)} + T_S + T_E^P + T_P \geq C + T_C. \tag{7}$$

A similar boundary condition can be developed to dominate put positions. Position B in Table II is constructed by purchasing a call, borrowing the

[3] We assume a zero bid-ask spread and ignore in this case the bid or ask subscript.

[4] This portfolio would constitute an arbitrage opportunity since the investor would make money by creating the portfolio and would be guaranteed a non-negative cashflow at least equal to the interest received on the unit of currency as long as the call option was not exercised.

[5] This portfolio constitutes an arbitrage opportunity since the investor receives a positive cashflow when the portfolio is created and is sure not to face any loss on the portfolio whether or not the put is exercised early. For additional details, see proposition 4 on page 152 of Cox and Rubinstein. It is also important to note that this boundary condition is still valid even if the foreign interest rate is stochastic. As long as this rate remains positive, the investor has the guarantee of not facing any loss if the put is exercised prematurely.

Table I

Derivation of Foreign Currency Call Option Price Boundary

		Position at any Time u ($t < u \leq T$) Given:		
	Cashflow at Time t	$S_a \leq E - T_E^P$	$E - T_E^P \leq S_a \leq E + T_E^C$	$E + T_E^C \leq S_b$
A: Buy Call	$-(C + T_C)$	0	0	$S_b - E - T_E^C$
B: Buy Put	$-(P + T_C)$	$E - S_a - T_E^P$	0	0
Lend one unit of foreign currency	$-S_a$	$S_b e^{r_{fa}(u-t)}$	$S_b e^{r_{fa}(u-t)}$	$S_b e^{r_{fa}(u-t)}$
Borrow face value $= E - (T_E^P + T_S)e^{r_b(T-t)}$	$Ee^{-r_b(T-t)} - T_E^P - T_S$	$(T_E^P + T_S)e^{r_b(u-t)} - Ee^{r_b(T-u)}$	$(T_E^P + T_S)e^{r_b(u-t)} - Ee^{-r_b(T-u)}$	$(T_E^P + T_S)e^{r_b(u-t)} - Ee^{-r_b(T-u)}$

Notes: position B never pays off less than position A. Therefore, position B must cost at least as much as A, so that:

$$S_a + P - Ee^{-r_b(T-t)} + T_S + T_E^P + T_P - T_C \geq C \geq 0.$$

Table II

Derivation of Foreign Currency Put Option Price Boundary

		Position at any Time u ($t < u \leq T$) Given:		
	Cashflow at Time t	$S_a \leq E - T_E^P$	$E - T_E^P \leq S_a \leq E + T_E^C$	$E + T_E^C \leq S_b$
A: Buy Put	$-(P + T_P)$	$E - S_a - T_E^P$	0	0
B: Buy Call	$-(C + T_C)$	0	0	$S_b - E - T_E^C$
Borrow $e^{-r_{fb}(T-t)}$ of foreign currency	$S_b e^{-r_{fb}(T-t)}$	$-S_a e^{-r_{fb}(T-u)}$	$-S_a e^{-r_{fb}(T-u)}$	$-S_a e^{-r_{fb}(T-u)}$
Lend $E + T_S + T_E^C$	$-(E + T_S + T_E^C)$	$(E + T_S + T_E^C)e^{r_a(u-t)}$	$(E + T_S + T_E^C)e^{r_a(u-t)}$	$(E + T_S + T_E^C)e^{r_a(u-t)}$

Notes: position B never pays off less than position A. Therefore, position B must cost at least as much as A, so that:

$$E + C - S_b e^{-r_{fb}(T-t)} + T_C + T_S + T_E^C - T_P \geq P \geq 0.$$

discounted value of one unit of foreign exchange, and lending a quantity of dollars equal to the sum of the call option exercise price, the maximum bid-ask spread on the spot currency over the period, and the cost of exercising the call option. Since position B of Table II never pays less than the put, we must have:

$$E + C - S_b e^{-r_{fb}(T-t)} + T_S + T_E^C + T_C \geq P + T_P. \tag{8}$$

As in the case of the early exercise conditions (1) and (2), a no-arbitrage condition can be developed from the dominance-motivated boundary conditions (7) and (8). In these cases, which represent more severe violations of market efficiency, the call (put) dominated by position B in Table I (II) could be shorted to purchase position B. For calls and puts, respectively, the resulting arbitrage motivated boundary conditions are:

$$S_a + P - Ee^{-r_b(T-t)} + T_S + T_E^P + T_P \geq C - T_C \tag{9}$$

$$E + C - S_b e^{-r_{fb}(T-t)} + T_S + T_E^C + T_C \geq P - T_P. \tag{10}$$

The arbitrage-motivated boundary conditions are weaker than the dominance-motivated boundary conditions. Of course, the boundary conditions are the same in the no-transactions cost case.

II. The Data

In order to conduct the tests described in the previous section, we need information on transaction costs and on simultaneous foreign currency option prices, foreign currency spot prices, and domestic and foreign interest rates for default-free claims matching the maturities of the option contracts. The source for simultaneous foreign currency option prices and foreign currency spot prices is the transactions surveillance report compiled daily by the PHLX.[6] This report contains the following information for each option trade: date of trade; currency; maturity date; exercise price; time of trade; number of contracts traded; option price; and the actual spot bid and ask quotes reported by Telerate from the interbank market. The study uses all verified trades on the PHLX from February 28, 1983 to September 14, 1984. We choose this period because February 28, 1983 is the beginning of the first week when all five currency options were trading, and September 14, 1984 is the expiration date of the September maturity option, thus allowing seven maturity months to expire during the period. A total of 52,509 trades are used.

Simultaneous observations for domestic interest rates are not available. Instead, we have used daily observations of bond equivalent Treasury bill rates for U.S. Treasury bills maturing closest to the option maturity dates. These rates are computed from the quoted discount yields given daily in the *Wall Street Journal.* For maturities under six months, Treasury bills which mature the day after the option expiration date are available. For longer maturities, the Treasury bill with the closest maturity matures at most two weeks before or after the option expiration date.

Given the Treasury bill rates, simultaneous observations for foreign interest rates are implied from the corresponding currency futures prices. This task is

[6] See Bodurtha [2].

made easy by the fact that the currency futures contracts traded on the International Money Market (IMM) are very closely related in terms of maturity to the currency options traded on the PHLX,[7] and by the fact that futures price quotations matching the currency option trades, in terms of time of trade, are available from the IMM Statistics Department Quote Capture Report. For each transaction on the IMM, trade date, currency, maturity, time of trade, type of trade, and trade price are available from this source. A transaction cost-adjusted interest rate parity (IRP) relation is used to impute the foreign interest rate.[8] Using the IRP relation to calculate the foreign interest rate, we set the foreign nominal discount factor equal to the product of the U.S. domestic discount factor times the ratio of the futures bid price to the spot ask price. This calculation gives us an estimate of the foreign bid nominal interest rate which is needed in boundary conditions (8) and (10).

Finally, when testing the boundary conditions derived in Section I under the scenario with transaction costs, a market participant executing trades must be chosen to identify the relevant transaction costs. The PHLX Foreign Currency Options Market is based on a specialist trading system. In addition, market makers are assigned to each currency to support the specialist by taking up to fifty percent of all trades in certain markets. The specialists and market makers offer bid and offer quotes throughout the trading day from 8:30 A.M. to 2:30 P.M. Eastern time. Unlike the specialist, the market maker does not have to conduct a market in the assigned currency option. Because of this, the market maker should be the low marginal cost trader. We have, therefore, chosen the market maker as the relevant market participant. The market maker's transaction costs are estimated to be:[9]

Transaction costs per contract (T_k, $k = P, C$)	
OCC initial fee	\$ 0.05
PHLX \$2 broker fee	\$ 2.00
PHLX exchange fee	\$ 0.05
PHLX proportional value charge	0.12%
Exercise cost per line item (T_E^k, $k = P, C$)	
OCC exercise fee per line item	\$35.00
IMM fee per contract	\$ 0.25
Cost of foreign exchange trade	\$50.00

[7] The last day of trading for foreign currency options is the Friday preceding the third Wednesday of the maturity months (March, June, September, and December). Futures trade until the Monday preceding the third Wednesday of the same maturity months. Both maturing currency options and futures require settlement on that Wednesday.

[8] This computation ignores the marking to the market of the futures contract. Since domestic and foreign rates of interest are stochastic, the futures price will differ from the forward price because of the marking to the market of the futures contract. However, several studies, e.g., Cornell and Reinganum [3], have shown that this difference is small. On that basis, we assume that the futures price can be used instead of the forward price to impute the foreign interest rate.

[9] The estimate of the maximum spot bid-ask spread, T_S, necessary for our boundary tests, is estimated within sample for each currency. Unfortunately, option bid-ask prices are not available after September 30, 1983. Therefore, the option trade price must be used in our tests. Nonetheless, use of the appropriate bid or ask option price during the period where it is available does not affect our results significantly. The cost of capital for an exchange seat is not considered as an added cost in this study (see Phillips and Smith [11]).

III. Test Results

In this section, we present three sets of results. The first set of results corresponds to the test of the boundary conditions in Section I on closing prices under the no-transaction costs scenario. The second set of results is obtained by testing the boundary conditions on simultaneous transaction prices under the no-transaction costs scenario. Finally, the third set of results is derived from testing the boundary conditions on simultaneous transaction prices under a full transaction costs scenario.

All of the test results are reported for three nonoverlapping periods. The first period runs from February 28, 1983 to September 14, 1983. This includes the first three option maturity months. Market trading activity was relatively low in this period, with 5,906 transactions and 2,828 last trades. The next two periods each contain two option exercise months. The second period runs from September 17, 1983 to March 16, 1984, and the third from March 19, 1984 to September 14, 1984. The second period includes 20,604 transactions and 5,063 last trades while the third contains 25,999 transactions and 7,209 last trades. The last trade information is necessary to conduct the tests with closing prices and no transaction costs.

It is interesting to note that these periods differ with respect to market activity and currency movements. As shown in Table III, the first two periods exhibit increases and decreases in currency prices, while the last period shows a rising dollar. As far as trading activity is concerned, trading was much less active in the first period than in the following two periods. Trading activity by currency and type of option during the three periods is also presented in Table III.

The results of the first set of tests, presented in Table IV, are not surprising. When last daily option and spot prices[10] are used and the no-transaction costs assumption is made, we find violations of the boundary conditions.[11] These results are consistent with the results obtained by Shastri and Tandon [12]. It is also interesting to note that boundaries (2) and (6) are the boundaries with the largest amount of violations. This is especially true for the Swiss franc and Deutsche mark. This result can be explained in part by the fact that overall currency prices decreased over the three sample periods, thus putting the put-linked boundaries under more pressure of being violated. The zero transaction costs assumption and nonsimultaneous prices are the other causes of the violations, as the next two sets of results will show.

Table V reports the sample composition and the results of the second set of tests, which ignore transaction costs but use simultaneous transaction prices. Comparing these results to those in Table IV shows that the simultaneity of spot and option prices is relatively more important in reducing the number of violations of the put-call boundaries (5) and (6) than it is in reducing the number of

[10] The last daily currency spot price is the spot price at the time of the last trade of the day of any option written on the relevant currency.

[11] Under the no transaction costs scenario, dominance-motivated boundaries and arbitrage-motivated boundaries will be the same. Therefore, the number of boundaries collapses to four. These boundaries are also derived in Grabbe [7].

Table III

Beginning of Period, High, Low, and End of Period Foreign Currency Values for the Sample Periods in Dollars

Period	British Pound	Canadian Dollar	Deutsche Mark	Japanese Yen	Swiss Franc
2/28/83–9/16/83					
Beginning	1.5073	0.8145	0.4104	0.004208	0.4830
High	1.6060	0.8180	0.4186	0.004337	0.4947
Low	1.4530	0.8075	0.3641	0.004051	0.4555
End	1.5008	0.8104	0.3750	0.004114	0.4626
9/19/83–3/16/84					
Beginning	1.5140	0.8110	0.3769	0.004138	0.4654
High	1.5157	0.8129	0.3935	0.004489	0.4801
Low	1.3925	0.7847	0.3515	0.004117	0.4420
End	1.4455	0.7876	0.3804	0.004421	0.4631
3/19/84–9/14/84					
Beginning	1.4378	0.7827	0.3786	0.004412	0.4609
High	1.4485	0.7848	0.3877	0.004484	0.4663
Low	1.2645	0.7488	0.3293	0.004043	0.3984
End	1.2645	0.7611	0.3293	0.004069	0.3984

Foreign Currency Option Trading Activity by Period and Contract (No. of Trades)

	British Pound		Canadian Dollar		Deutsche Mark		Japanese Yen		Swiss Franc	
Period	Call	Put	Call	Put	Call	Put	Call	Put	Call	Put
2/28/83–9/16/83	1,082	334	146	121	1,117	587	656	361	870	632
9/19/83–3/16/84	1,752	742	415	239	5,373	1,725	5,011	966	3,355	1,026
3/19/84–9/14/84	2,489	1,336	978	980	6,527	2,530	3,419	1,338	4,634	1,768

violations of the early exercise boundaries (1) and (2), although the proportion of violations of boundaries (1) and (2) decreases when simultaneous prices are used. These early exercise boundary violations remain concentrated on the put-linked boundary for the Swiss franc and the Deutsche mark. As the third set of results will show, these remaining violations disappear almost entirely when transaction costs are taken into account.

Table VI reports the final set of results. Simultaneous spot and option prices are used, and transaction costs are explicitly accounted for in this final set of tests. The table shows that only 31 option trades out of 52,509 violate the early exercise arbitrage boundaries, and that only one put-call pair out of 3,998 violates a put-call boundary. This is a clear illustration that a study of market efficiency based on the testing of rational pricing boundaries must be done with transaction costs and simultaneous prices.

It remains that some of the boundary violations in Table VI are quite large. During the first period, on April 28, 1983, six Swiss franc put trades violated the early exercise boundary by over $1,000 each. During the second period, one early exercise boundary violation of $200 and four of approximately $100 each occurred. The one profitable put-call parity violation would have yielded $600 on October 25, 1983 for the Deutsche mark. The other violations in the second period were small. Finally, the third period showed only two violations of approximately $100 each, while the other violations were again small.

Table IV

Option Price Boundary Tests Using Last Daily Spot and Option Trade Data and No Transaction Costs

Sample Composition				
Period	Trades	Calls	Puts	Put-Call Pairs
2/28/83–9/16/83	2,828	1,761	1,067	509
9/19/83–3/16/84	5,063	3,431	1,632	1,159
3/19/84–9/14/84	7,209	4,776	2,433	1,561
Total	15,100	9,968	5,132	3,229

No. of Violations and Percentage of Violations (in parentheses)				
	Boundary*			
Period	(1)	(2)	(5)	(6)
2/28/83–9/16/83	30	121	6	15
	(1.7)	(11.3)	(1.2)	(2.9)
9/19/83–3/16/84	58	143	16	15
	(1.7)	(8.8)	(1.4)	(1.3)
3/19/84–9/14/84	19	372	2	26
	(0.4)	(15.3)	(0.1)	(1.7)

Percentage of Violations for Each Currency for the Entire Sample Period				
	Boundary*			
Currency	(1)	(2)	(5)	(6)
British Pound	1.91	8.24	1.45	0.90
Canadian Dollar	1.58	8.53	0.00	0.00
Deutsche Mark	1.35	14.69	0.75	1.79
Japanese Yen	0.83	9.66	0.61	0.91
Swiss Franc	0.20	16.82	0.53	3.48

* Boundary definitions: (1) $C \geq S - E$; (2) $P \geq E - S$; (5) $S + P - Ee^{-r(T-t)} \geq C$; (6) $E + C - Se^{-\eta(T-t)} \geq P$.

IV. Conclusions

The observations of Phillips and Smith [11] clearly motivate the need to undertake careful analysis of market transaction costs and feasible trading rules in conducting option market efficiency tests. This paper incorporates such analysis in testing the efficiency of the foreign currency options market of the PHLX. We find that the market is efficient when the tests use simultaneous prices and transaction costs.

A sensitivity analysis of the efficiency test results with respect to the nonsynchronous price bias and zero transaction costs bias is also conducted. When the tests are conducted using last-traded prices under a zero transaction costs assumption, a large proportion of violations of the put early exercise boundary is found, as well as a fair proportion of put-call parity boundary violations. When the tests are conducted with spot price quotes simultaneous to the option trades, thus correcting the nonsynchronous price bias, we obtain a moderate reduction in the proportion of violations of the early exercise boundaries and a sharp decrease in the violations of the put-call parity boundaries. Therefore, put-call parity violations appear to be more sensitive to the nonsynchronous price bias.

Table V

Option Price Boundary Tests Using Simultaneous Spot and Option Trade Data and No Transaction Costs

Sample Composition					
				Put-Call Pairs*	
Period	Trades	Calls	Puts	Boundary (5)	Boundary (6)
2/28/83–9/16/83	5,906	3,871	2,035	425	399
9/19/83–3/16/84	20,604	15,906	4,698	1,974	1,586
3/19/84–9/14/84	25,999	18,047	7,952	2,112	2,013
Total	52,509	37,824	14,685	4,511	3,998

No. of Violations and Percentage of Violations (in parentheses)				
	Boundary**			
Period	(1)	(2)	(5)	(6)
2/28/83–9/16/83	45	158	1	4
	(1.2)	(7.8)	(0.3)	(0.9)
9/19/83–3/16/84	284	243	1	9
	(1.8)	(5.2)	(0.1)	(0.5)
3/19/84–9/14/84	30	583	1	9
	(0.2)	(7.3)	(0.0)	(0.4)

Percentage of Violations for Each Currency for the Entire Sample Period				
	Boundary**			
Currency	(1)	(2)	(5)	(6)
British Pound	1.22	4.15	0.20	0.39
Canadian Dollar	0.84	5.60	0.00	0.00
Deutsche Mark	0.77	8.26	0.05	0.32
Japanese Yen	1.85	4.62	0.00	0.64
Swiss Franc	0.15	8.35	0.11	1.08

* Put-call pairs must trade within fifteen minutes of each other. The different number of pairs for boundary tests (5) and (6) is due to the need of a matching futures contract price to infer the foreign interest rate in boundary (6).

** Boundary conditions (1), (2), (5), and (6) are defined as in Table IV.

Table VI

Option Price Boundary Tests Using Simultaneous Spot and Option Trade Data and Transaction Costs [No. of Violations and Percentage of Violations (in parentheses)]*

	Boundary**							
Period	(1)	(2)	(3)	(4)	(7)	(8)	(9)	(10)
2/28/83–9/16/83	0	16	0	12	0	0	0	0
	—	(0.8)	—	(0.6)	—	—	—	—
9/19/83–3/16/84	10	9	9	3	0	1	0	1
	(0.1)	(0.2)	(0.1)	(0.1)	—	(0.1)	—	(0.1)
3/19/84–9/14/84	2	6	2	6	0	0	0	0
	(0.0)	(0.1)	(0.0)	(0.1)	—	—	—	—

* The sample composition is the same as in Table V.

** The boundary conditions are defined in Section I.

Finally, when simultaneous prices are used concomitantly with positive transaction costs, most violations of rational pricing boundaries disappear. In particular, there is a very sharp decrease in the proportion of early exercise boundary violations with respect to the case where the transaction costs are ignored. The early exercise boundary violations thus seem to be more sensitive to the zero transaction costs bias than to the nonsynchronous price bias.

REFERENCES

1. Mihir Bhattacharya. "Transactions Data Tests of Efficiency of the Chicago Board Options Exchange." *Journal of Financial Economics* 12 (August 1983), 161–85.
2. James N. Bodurtha, Jr. "PHLX Currency Option Surveillance Report and OCC Exercise History: A Data Base." Mimeograph, 1984.
3. Bradford Cornell and Marc R. Reinganum. "Forward and Futures Prices: Evidence from the Foreign Exchange Markets." *Journal of Finance* 36 (December 1981), 1035–45.
4. John C. Cox and Mark Rubinstein. *Options Markets.* NJ: Prentice-Hall, 1985.
5. Dan Galai. "Test of Market Efficiency of the Chicago Board Options Exchange." *Journal of Business* 50 (April 1977), 167–97.
6. J. P. Gould and Dan Galai. "Transactions Costs and the Relationship between Put and Call Prices." *Journal of Financial Economics* 1 (July 1974), 107–29.
7. J. Orlin Grabbe. "The Pricing of Call and Put Options on Foreign Exchange." *Journal of International Money and Finance* 2 (December 1983), 239–53.
8. Robert C. Klemkosky and Bruce G. Resnick. "Put-Call Parity and Market Efficiency." *Journal of Finance* 34 (December 1979), 1141–55.
9. ———. "An Ex Ante Analysis of Put-Call Parity." *Journal of Financial Economics* 8 (December 1980), 363–78.
10. Robert C. Merton. "The Theory of Rational Option Pricing." *Bell Journal of Economics* 4 (Spring 1973), 141–83.
11. Susan M. Phillips and Clifford W. Smith. "Trading Costs for Listed Options: The Implications for Market Efficiency." *Journal of Financial Economics* 8 (June 1980), 179–201.
12. Kuldeep Shastri and Krishore Tandon. "Valuation of Foreign Currency Options: Some Empirical Tests." Graduate School of Business, University of Pittsburgh, February 1984.