TRANSACTION COST DISCOVERY BY DECOMPOSITION OF THE ERROR TERM: A BOOTSTRAPPING APPROACH

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ABSTRACT

There is agreement regarding the fundamental role of transaction costs in determining currency options market efficiency. However, the estimation of transaction costs in this relationship is controversial. In this study, a bootstrapping approach is adapted to decompose the error term of the put-call parity regression analysis in order to estimate transaction costs. The currency option market is more than 95 percent efficient with the estimated transaction costs. This robust transaction cost calculation will be valuable to traders and researchers as it eliminates dependence on crude proxies for transaction costs.

JEL: G13; G14

KEYWORDS: Transaction costs, error term decomposition, put-call parity, serial correlation, ARCH

INTRODUCTION

Efficiency is the key factor in the functioning and development of options markets. Further, efficiency represents the equilibrium market price, which can be used as the market's best forecast of the future options price (Hoque et al, 2009). The efficiency of an options market can be investigated by testing the put-call parity (PCP) relationship in the usual setting where the market is assumed to be frictionless. The PCP is a no-arbitrage relationship that must hold between the prices of a European call and a European put written on the same underlying currency, and having the same strike price and time to expiration. However, real financial markets are not frictionless, and therefore there is extensive literature on options market efficiency regarding the design of a PCP test with transaction costs.

Furthermore, previous research has relied on the number of PCP violations that lead to arbitrage profits in order to determine options market efficiency. The PCP can be violated even for a fraction of a cent of arbitrage profit per unit of foreign currency options. PCP violations that generate non-attractive arbitrage profits can be considered outliers. The transaction costs can also contribute to filtering of these outliers in order to estimate reasonable arbitrage profits to deduce the efficiency of the options market. Undoubtedly, transaction costs play an important role in establishing options market efficiency based on an arbitrage profit strategy.

The remainder of this paper is organized as follows. Section 2 briefly discusses the relevant literature. Section 3 describes the research methodology and the data. Section 4 provides analysis and interpretations of the empirical findings. Section 5 concludes the paper.

LITERATURE REVIEW

Phillips and Smith (1980) provided a systematic analysis of the transaction costs facing traders in the organized options market. They included explicit costs, in the form of commissions and other fees, and implicit costs such as bid-ask spreads for the pricing of transaction services. The explicit costs of commissions and other fees are institution-dependent. The implicit cost of the bid-ask spread is the difference between the highest quote to buy and the lowest offer to sell the asset in the market. Phillips and Smith (1980) also documented the transaction cost ranges for individual investors, options market

makers and arbitrageurs when they initiate trades in either stocks or options. That study indicated that relatively high transaction costs are incurred by individual investors, but refuted the assumption of several previous researchers that market maker transaction costs are negligible. The results indicated that the larger the transaction costs, the wider the band within which prices can swing without creating arbitrage opportunities. Further, Bhattacharya (1983) observed that not all transactions occur at the bid or ask price; a significant percentage occur within the bid/ask spread.

Keim (1989) and Yadav and Pope (1990) estimated an average bid-ask spread of 1 percent in their PCP tests. Subsequently, Puttonen (1993) used an estimate of a 2 percent bid-ask spread for the Helsinki Stock Exchange, which is much more thinly traded than its U.S. and English counterparts, and the FOX index, which consists of the 25 most liquid stocks. Nisbet (1992) identified significant numbers of PCP deviations in the presence of bid-ask spreads which almost entirely disappear when commissions are taken into account with bid-ask spreads as transaction costs. Chateauneuf et al. (1996) observed that bid-ask spreads differ from the traditional formalization of proportional transaction costs. Brunetti and Torricelli (2005) suggested that other types of costs (e.g., clearing fees, short selling costs) should also be considered in addition to bid-ask spreads and commissions in order to compute the transaction costs more precisely.

El-Mekkaoui and Flood (1998) conducted PCP tests on exchange-traded (PHLX) German mark options market efficiency in the presence of transaction costs using intra-daily data. In that study, a foreign exchange transaction fee of 0.0625 percent was taken from Surajaras and Sweeney (1992). Note that Rhee and Chang (1992) used a transaction cost of 0.0409 percent for the spot Deutsche Mark (DEM). Mittnik and Rieken (2000) examined the informational efficiency of the relatively new German DAX-index options market in the presence of transaction costs. In that study, a fee of DM0.40 per contract for market makers trading DAX options at the German options and futures exchange (DTB) and 0.1 percent of the index value (half of the lowest discount-broker fee charged to private investors for trading German stocks) represented the trading costs. Hoque et al. (2008) used spot foreign exchange market spreads as a crude proxy for the transaction costs, because a reliable series of option market bid-ask quotes was not available for that sample.

We summarize the findings of the literature on transaction costs as follows. Transaction costs vary across markets and currencies. There are two major categories of transaction costs: explicit (fixed transaction costs) and implicit (variable transaction costs). Fixed transaction costs (FTC) are institution-dependent and consist of all fees and commissions. Variable transaction costs (VTC) are currency-dependent and crucial to the accuracy of the estimates. In previous studies, options market bid-ask spreads or a percentage of the bid-ask spreads were used as proxies for VTC. In some studies, VTC was obtained from foreign exchange market bid-ask spreads due to the lack of available option market bid-ask spreads for the sample. In general, the literature does not provide a standard method to estimate transaction costs, particularly the VTC.

Hoque et al. (2008) proposed the decomposition of the error term of PCP statistical analysis in order to examine the effects of transaction costs on PCP violation. Following them, we decompose the error term by employing a bootstrapping approach to estimate the transaction costs. This study addressed the controversial issue of transaction costs by implementing a standard method that eliminates the dependence on crude proxies for transaction costs. This paper includes six major currencies of world currency options (WCO) traded in the Philadelphia Stock Exchange (PHLX): Australian dollar (AUD), British pound (BP), Canadian dollar (CAD), Euro (EUR), Japanese yen (JPY) and Swiss franc (SF).

METHODOLOGY AND DATA

We begin this section with descriptions of notations for variables used in this paper. In Table 1, names of the variables are given in column 1, followed by notations in column 2. In the last column, each variable is described in detail.

Table 1: Notations and Descriptions of the Variables

Variables	Notations	Descriptions
Call price	C_t	Call price in domestic currency at time t.
Put price	P_t	Put price in domestic currency at time t.
Spot price	S_t	Spot price in domestic currency at time t for one unit of foreign currency.
Strike price	X_t	Option exercise price in domestic currency at time t for one unit of foreign currency.
Domestic interest rate	R_t^d	Domestic currency risk-free interest rate at time t.
Foreign interest rate	R_t^f	Foreign currency risk-free interest rate at time t.
Option life	T	Expiration time of the option.
Transaction costs	TC_t	Total transaction costs estimated by decomposition of the error term

Giddy (1983) and Grabbe (1983) were among the first to develop relationships for put and call options; these included the PCP theorem for foreign currency, which must be satisfied to prevent dominance or arbitrage possibilities. The PCP relationship is based on the arbitrage principle, as stated in Equation (1),

$$C_{tj} + X_{tj}e^{-R_{tj}^d T} = P_{tj} + S_{tj}e^{-R_{tj}^f} , \qquad (1)$$

where $\forall_j$ = AUD, BP, CAD, EUR, JPY, SF.

If this relationship is violated, an arbitrage opportunity arises for a conversion or reversal strategy. The conversion strategy involves buying the foreign currency, writing a call, buying an equivalent put, and borrowing the present value of the exercise price. If an arbitrage opportunity does not exist, the present value of conversion strategy should be

$$\left(C_{tj} + X_{tj}e^{-R_{tj}^d T} - P_{tj} - S_{tj}e^{-R_{tj}^f} - TC_{tj} \right) \le 0 . \qquad (2)$$

Conversely, a reversal strategy consists of writing a put, buying a call, shorting the foreign currency, and lending an amount equivalent to the present value of the exercise price. If there is no arbitrage opportunity, the present value of the reversal strategy should be

$$\left(P_{tj} + S_{tj}e^{-R_{tj}^f} - C_{tj} - X_{tj}e^{-R_{tj}^d T} - TC_{tj} \right) \le 0 . \qquad (3)$$

In an efficient options market, these two strategies should not yield any profit. The testable PCP conditions then become

$$\psi_{cj} = \left(C_{tj} + X_{tj}e^{-R_{tj}^d T} - P_{tj} - S_{tj}e^{-R_{tj}^f} - TC_{tj} \right) \qquad (4)$$

and

$$\psi_{rj} = \left(P_{tj} + S_{tj}e^{-R_{tj}^f} - C_{tj} - X_{tj}e^{-R_{tj}^d T} - TC_{tj} \right), \tag{5}$$

where ψ_{cj} and ψ_{rj} are the arbitrage profits under the conversion and reversal strategies, respectively, when the options market is not efficient. Thus, testing all the above PCP conditions is equivalent to testing the hypothesis that the foreign currency options market is efficient when $\psi_{ij} \leq 0$, where $i = c$ (conversion) and r (reversal).

Further rearranging Equation (1), we set $(C_{tj} - P_{tj}) = Y_{tj}$ and $\left(S_{tj}e^{-R_{ti}^f} - X_{tj}e^{-R_{tj}^d T} \right) = X_{tj}$ to develop regression equation (6),

$$Y_{tj} = \lambda_0 + \lambda_1 X_{tj} + \varepsilon_{tj}. \tag{6}$$

Following Hoque et al. (2008), who accommodates the potential autocorrelation and conditional heteroskedasticity in order to have unbiased and consistent inferences for λ_0 and λ_1 in Equation (6), note that under the null hypothesis that PCP is valid, the coefficients λ_0 and λ_1 should be 0 and 1, respectively, to conclude that the options market is efficient. Hoque et al. (2008) found that the null hypothesis is rejected for options market efficiency, whereas previous studies had found that the options market is essentially efficient with the transaction costs. We therefore assume that the error term of Equation (6) consists of the effects of transaction costs. The estimated error term can be expressed as in Equation (7),

$$\hat{\varepsilon}_{tj} = Y_{tj} - \hat{\lambda}_0 - \hat{\lambda}_1 X_{tj}. \tag{7}$$

The following two steps are used to estimate FTC and VTC, respectively, by decomposition of the error term.

Step 1: The FTC and the average value of the FTC are estimated in Equations (8) and (9), respectively,

$$FTC_{tj} = \left(Y_{tj} - X_{tj} \right), \tag{8}$$

$$E\left(FTC_j \right) = \frac{1}{n} \sum_{t=1}^{n} FTC_t. \tag{9}$$

Step 2: The VTC is the difference of the error term and the FTC as in Equation (10),

$$VTC_{tj} = \hat{\varepsilon}_{tj} - FTC_{tj}. \tag{10}$$

Substituting the values of the error term and FTC from Equations (7) and (8), respectively, in Equation (10) and rearranging the terms, we obtain Equation (11),

$$VTC_{tj} = \left(1 - \hat{\lambda}_1 \right) X_{tj} - \hat{\lambda}_0. \tag{11}$$

Since the error term is not normally distributed, we apply bootstrapping for Equation (12) generate the minimum and maximum VTC from the error term for the VTC condition as stated in Equation (11),

$$\hat{\varepsilon}_{tj} = \left(1 - \hat{\lambda}_1 \right) X_{tj} - \hat{\lambda}_0. \tag{12}$$

The bootstrapping is conducted through the "model solution" process of Eviews using the stochastic simulation, 10,000 repetitions and the Newton Solution Algorithm. The average values of the minimum and maximum VTC are estimated in Equations (13) and (14), respectively,

$$E\left(VTC_j^{min}\right) = \frac{1}{n}\sum_{t=1}^{n} VTC_t \, , \qquad\qquad (13)$$

$$E\left(VTC_j^{max}\right) = \frac{1}{n}\sum_{t=1}^{n} VTC_t \, . \qquad\qquad (14)$$

Data

In this study, PCP tests were conducted for six major currency options (AUD, BP, CAD, EUR, JPY and SF) of the WCO market, traded in PHLX. The WCO market started trading on July 24, 2007 (Offshore A-Letter, 2007), but the data are available from 18 December 2007 in the DATASTREM. This study therefore includes the put-call pairs of the sample currencies from December 18, 2007 to October 7, 2009, which represents total number of 472 daily observations for each currency. The expiration dates of the options are within 90 days on the same cycle as those of stock options, i.e., the third Friday of the month. Each currency options contract represents 10,000 units of the underlying currency, except for Japanese yen (1,000,000). The WCO contract size is smaller than that of the existing currency options contract. Further, the data set consists of the daily closing spot exchange rates and daily risk-free interest rates for all currencies for the sample period which also obtained from DATASTREAM.All of these data are available on request.

EMPIRICAL RESULTS

The PCP econometric analysis was conducted for Equation (6), accommodating serial correlation and ARCH effects using ARMA and GARCH models, respectively. The results are summarized in Table 2. The P-values in parentheses for the F-statistic indicate failure to reject the null hypothesis of no serial correlation and ARCH in the residual for all currencies. Further, the null hypothesis $H_0: \lambda_0 = 0$, cannot be rejected at any reasonable significance level for BP and EUR, but the intercepts (λ_0) are statistically different from 0 in all cases except BP and EUR. However, the estimates of the slopes (λ_1) are all statistically different from zero and less than 1. The overall results suggest that the PCP does not hold for all sample currency options markets.

Table 2: Regression Tests Accommodating Serial Correlation and ARCH Effects

Currency	Intercept (λ_0)	Slope (λ_1)	Serial Correlation		ARCH	
	Coefficient	Coefficient	F-Statistic	ARMA	F-Statistic	GARCH
AUD	-0.0015	0.2595	2.0934	(3,0)	0.0404	(1,1)
	(0.0000)	(0.0000)	(0.1244)		(0.8408)	
BP	-0.0008	0.3468	0.5849	(1,1)	1.2368	(1,1)
	(0.0937)	(0.0000)	(0.5576)		(0.2666)	
CAD	0.0006	0.5364	1.1733	(1,0)	0.1741	(0,0)
	(0.0017)	(0.0000)	(0.3103)		(0.6767)	
EUR	0.0006	0.5963	0.4823	(1,1)	0.4137	(0,0)
	(0.1274)	(0.000)	(0.6177)		(0.5204)	
JPY	0.1965	0.8310	1.5407	(1,1)	0.1103	(1,1)
	(0.0000)	(0.0000)	(0.2153)		(0.7400)	
SF	0.0014	0.5082	0.2626	(2,3)	0.2039	(0,0)
	(0.0000)	(0.0000)	(0.7692)		(0.6518)	

Notes: This table shows the regression estimates of the equation: $Y_{tj} = \lambda_0 + \lambda_1 X_{tj} + \varepsilon_{tj}$. Tests of $H_0:\lambda_0=0$ and $\lambda_1=1$. The P-values are in parentheses below the estimated coefficients and F-statistics. The null hypothesis of the LM test is that there is no serial correlation in the residual up to the lag order p, where the number of lag p = max(r, q) for ARMA (r, q). Similarly, the null hypothesis of the ARCH LM test is that there is no ARCH up to the order given in the residual. The null hypotheses of the LM tests for serial correlation and ARCH are rejected.

The FTC and VTC represent two major categories of transaction costs (TC) estimated by decomposition of the error term, and are presented in Table 3. The average value of FTC is estimated using Equation (9). Similarly, the average values of Min (minimum) VTC and Max (maximum) VTC are obtained from Equations (13) and (14), respectively. Note that FTC, Min VTC and Max VTC are estimated in terms of U.S. dollars per unit of foreign currency options. The width of the TC swing boundary is the difference between Min VTC and Max VTC from columns 3 and 4, respectively [e.g., for AUD, 0.018429 = 0.010348-(-0.008081)]. The TC swing boundary is the band within which non- attractive arbitrage profits due to PCP violations can swing without creating real arbitrage opportunities. In other words, the profit amount within this band will disappear with appropriate transaction costs.

Table 3: Transaction Costs Estimates by Decomposition of The Error Term

Currency	FTC	Min VTC	Max VTC	TC swing boundary
AUD	0.002124	-0.008081	0.010348	0.018429
BP	0.002423	-0.008657	0.016075	0.024732
CAD	0.001255	-0.004765	0.006802	0.011567
EUR	0.001836	-0.005009	0.007126	0.012135
JPY	0.000019932	-0.00005319	0.00007101	0.012420
SF	0.002356	-0.004123	0.004266	0.008389

Note: The FTC estimates of the equation: $E(FTC_j) = \frac{1}{n}\sum_{t=1}^{n} FTC_t$. *The Min VTC and Max VTC estimate of the equations*

$E(VTC_j^{min}) = \frac{1}{n}\sum_{t=1}^{n} VTC_t$ *and* $E(VTC_j^{max}) = \frac{1}{n}\sum_{t=1}^{n} VTC_t$, *respectively. The FTC, Min VTC and Max VTC are in terms of U.S dollars per unit of foreign currency (FC) options. Since JPY contract size is 1,000,000, the TC swing boundary for JPY is estimated for contract size 10,000 as 0.0012420 [(0.00007101+0.00005319)*100] to permit comparison with other currencies.*

Next, in Table 4, the FTC and VTC are computed in terms of U.S. dollars per contract of foreign currency options using the information reported in Table 3. Column 2 of Table 4 presents the sample foreign currency options contract size. The FTC in column 3 is calculated as the contract size multiplied by the value of FTC as reported in Table 3 [e.g., for AUD, 21.24 = (10,000 x 0.002124)]. Further, the FTC of all the sample currencies except CAD range from 18.36 to 24.23 U.S. dollars. This indicates that the FTC for currencies traded in the PHLX are reasonably close and institution-dependent. The result is consistent with the literature. The Min VTC in column 4 is estimated as the contract size multiplied by the Min VTC (absolute value) as reported in Table 3[e.g., for AUD, 80.81 = (10,000 x 0.008081)]. Similarly, the Max VTC in column 5 is the product of contract size and the value of Max VTC obtained from Table 3. The Min TC in column 6 is the sum of the FTC (column 3) and the Min VTC (column 4). Similarly, the Max TC in column 7 is sum of the FTC (column 3) and the Max VTC (column 5). Both the Min TC and Max TC vary across the currencies. We further observed that the larger the transaction costs (Min TC or Max TC), the wider the TC swing boundary as reported in Table 3. Phillips and Smith (1980) found similar results in their study.

Table 4: Estimates of Transaction Costs (TC)

Currency	Contract size	FTC	Min VTC	Max VTC	Min TC	Max TC
AUD	10,000	21.24	80.81	103.48	102.05	124.72
BP	10,000	24.23	86.57	160.75	110.80	184.98
CAD	10,000	12.55	47.65	68.02	60.20	80.57
EUR	10,000	18.36	50.09	71.26	68.45	89.62
JPY	1,000,000	19.93	53.19	71.01	73.12	90.94
SF	10,000	23.56	41.23	42.66	64.79	66.22

Note: All costs are in terms of U.S. dollars per contract of foreign currency (FC) options.

Finally, we conducted PCP tests without TC ($TC_{tj}= 0$) and with TC ($TC_{tj}\neq 0$) using Equations (4) and (5) for the conversion and reversal strategies, respectively. The PCP violations under different test conditions are presented in Table 5. Without TC, the average PCP violations for all currencies are 75.56 and 24.44 percent under the conversion and reversal strategies, respectively. This means that PCP is always violated, as the sum of the PCP violations is 100 (75.56+24.44) percent for the conversion and reversal strategies. This result is not accurate, however, as it also includes the PCP violations that generated arbitrage profits within the TC swing boundary, as discussed in Table 3. Consequently, the systematic analysis of transaction costs is required to determine the PCP violations by excluding non-attractive arbitrage profits.

Table 5: Put-call Parity (PCP) Violations

Currency	PCP test without TC		PCP test with TC			
	Conversion strategy	Reversal strategy	Conversion strategy		Reversal strategy	
	Violation	Violation	Min violation	Max violation	Min violation	Max violation
AUD	67.58	32.42	2.33	5.08	1.06	1.06
BP	65.89	34.11	0.85	8.26	0.21	0.42
CAD	70.76	29.24	3.39	4.87	0.21	0.64
EUR	69.70	30.30	5.08	8.69	0.42	0.64
JPY	88.56	11.44	2.33	3.18	1.27	1.27
SF	90.89	9.11	3.18	3.60	0.64	0.64
Average	75.56	24.44	2.86	5.61	0.64	0.78

Note: The equations $\psi_{cj} = \left(C_{tj} + X_{tj}e^{-R_{tj}^{d}T} - P_{tj} - S_{tj}e^{-R_{tj}^{f}} - TC_{tj} \right)$ *and* $\psi_{rj} = \left(P_{tj} + S_{tj}e^{-R_{tj}^{f}} - C_{tj} - X_{tj}e^{-R_{tj}^{d}T} - TC_{tj} \right)$ *generate PCP violations in*

percent under conversion and reversal strategy, respectively. The total number of PCP violation for each currency is the number of observations (472 for each currency) multiplied by the percentage of PCP violations as reported in the table.

In Table 5, the Min violation and Max violation of PCP are determined using the Max TC and Min TC obtained from Table 4, respectively. Under the conversion strategy, the average Min violation and Max violation for all currency are 2.86 and 5.61 percent, respectively. Similarly, the average Min violation and Max violation are 0.64 and 0.78, respectively, for the reversal strategy. Moreover, for the conversion and reversal strategy together, the total average Min violation and Max violation are 3.50 (2.86+0.64) and 6.39 (5.61+0.78) percent, respectively. This means that the PCP violation varies from 3.50 to 6.39 percent, and indicates that the options market is efficient for 93.61 (100-6.40) to 96.50 (100-3.5) percent of the cases. The overall results suggest that on average, currency options markets are efficient for more than 95 [(93.61+96.50)/2] percent of cases, with appropriate transaction costs.

CONCLUSION

This study addressed the controversial issue of transaction costs for currency options market traders as well as for researchers by implementing a simple and elegant approach to estimate them. We decomposed the error term generated from PCP econometric analysis in order to estimate two major types of transaction costs: FTC (fixed transaction costs) and VTC (variable transaction costs). Since the error term is not normally distributed, we apply the bootstrapping approach for decomposition of the error term. This paper includes six major currencies of world currency options (WCO) traded in the Philadelphia Stock Exchange (PHLX): Australian dollar (AUD), British pound (BP), Canadian dollar (CAD), Euro (EUR), Japanese yen (JPY) and Swiss franc (SF).

For all sample currencies except CAD, the FTC is between 18.36 and 24.23 U.S. dollars, which indicate that the FTC is reasonably close for the sample currencies traded in PHLX. It confirms that the FTC is institution-dependent. The result is consistent with the findings of Phillips and Smith (1980). In the

literature, bid-ask spreads are used as a proxy for VTC, which is currency-dependent. In this study, we found similar results, i.e., that the Min VTC and Max VTC vary across currencies. We further observed that the larger the transaction costs (Min TC or Max TC), the wider the TC swing boundary. This is consistent with the findings of Phillips and Smith (1980) in their systematic analysis of transaction costs. Overall, it is evident that the estimated transaction costs in this study are accurate and reliable.

Next, we determined the Min violation and Max violation of PCP with Max TC and Min TC, respectively. We found that the average PCP violations range from 3.50 to 6.39 percent. This means that the efficiency of the options market varies from 93.61 (100-6.40) to 96.50 (100-3.5) percent. The overall results suggest that on average, the currency options market is efficient for more than 95 [(93.61+96.50)/2] percent cases when the appropriate transaction costs are applied. The robustness of transaction cost discovery in this study will eliminate the dependence of transaction costs on crude proxies. Traders and researchers can use this approach as a standard method to estimate transaction costs accurately and reliably. Since the error term is usually designed to capture unknown factors, the estimated transaction costs might include other unknown information. We therefore intend in our future work to design a model that obtains transaction costs precisely after filtering out information other than transaction costs.

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