Econometric Modeling for Transaction Cost-Adjusted Put-Call Parity: Evidence from the Currency Options Market

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Abstract

Due to the mispricing of options, no-arbitrage condition put-call parity (PCP) violations lead to inefficiency in the currency options market. Through transaction costs, the effects of these violations are reduced to negligible levels, indicating that PCP is not a sufficient condition for an options market efficiency test. Thus, this study developed a transaction cost-adjusted put-call parity (TC-Adj-PCP) econometric model to examine the efficiency of options markets. The fundamental analysis of the proposed model concludes that transaction costs represent an omitted variable for the PCP model, where the uniqueness of this variable is demonstrated under PCP in the context of options market efficiency. The novelty of the TC-Adj-PCP model resolves controversial transaction costs issues for traders and researchers.

1. Introduction

Currency options market efficiency ensures that options are priced correctly. Furthermore, accurate market prices can be used as the market's best forecast for future options prices (Hoque et al., 2009). The efficiency of an options market can be determined by testing the PCP relationship under the conditions, in which the market is assumed to be frictionless. The PCP is a no-arbitrage condition that must hold between a European call and put written on the same underlying currency and with the same strike price and maturity. However, real financial markets are not frictionless; as a result, an extensive literature on options market efficiency has incorporated PCP tests with transaction costs.

Previous studies have relied on the degree of PCP violations that leads to arbitrage profiting to determine the efficiency of options markets. In these cases, PCP may 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 profit can be considered outliers. Transaction costs can also contribute to filter these outliers to estimate reasonable arbitrage profits and thus arrive at options market efficiency. The role of transaction costs is undoubtedly important to establish options market efficiency based on the degree of arbitrage profit.

A systematic analysis has been conducted by Phillips and Smith (1980) with regard to the transaction costs facing traders in an organized options market. They divide transaction costs into explicit costs and implicit costs. Together, explicit and implicit costs include all commissions and bid-ask spreads, respectively.

The explicit costs of commissions 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 a given asset in the market. Phillips and Smith (1980) also document the ranges of transaction costs for which individual investors, options market makers and arbitrageurs initiate trades in either stocks or options. Their studies indicate relatively high transaction costs incurred by an individual investor but refute the assumptions of several previous researchers that market-maker transaction costs are negligible. Their results indicate that an increase in transaction costs increases the width of the band within which prices can swing without creating arbitrage opportunities. Furthermore, as Bhattacharya (1983) points out, not all transactions occur at the bid or ask price; a significant percentage occurs within the bid/ask spread.

The PCP tests conducted by Keim (1989) and Yadav and Pope (1990) estimate the average bid-ask spread at 1 percent. Subsequently, Puttonen (1993) uses an estimate of a 2 percent bid-ask spread for the Helsinki Stock Exchange, which is regarded as having thinner trading than its U.S. and English counterparts, and the FOX index, which consists of the 25 most liquid stocks. Nisbet (1992) identifies a significant number of PCP deviations in the presence of bid-ask spreads that almost disappear when commissions are taken into account with bid-ask spreads as transaction costs. Chateauneuf et al. (1996) points out that bid-ask spreads differ from the traditional formalization of proportional transaction costs. Brunetti and Torricelli (2005) suggest that other types of costs (e.g., clearing fees or short selling costs) should be considered in addition to bid-ask spreads; thus commissions must be more precise about the transaction costs.

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

A summary of the literature clearly indicates that, without transaction costs, PCPalone is not sufficient to generate conclusions regarding the efficiency of currency options markets. We have therefore developed a TC-Adj-PCP econometric model by including the transaction-cost term under PCP. To check the model validity, we then conducted an omitted variable test for the transaction cost term. The results suggested that the transaction costs represent an omitted variable for PCP model. Next, the TC-Adj-PCP model was employed to examine the options market efficiency for the Australian dollar (AUD), British pound (BP), Canadian dollar (CAD), Euro (EUR), Japanese yen (JPY) and Swiss franc (SF). The overall findings support that all of the sample currency options markets are efficient. The novelty of the TC-Adj-PCP model adds a new dimension to the literature on currency options market efficiency tests by resolving controversial issues related to transaction estimation.

The reminder of the paper is organized as follows. Section 2 describes the research methods and data. Section 3 analyzes and interprets the empirical analysis. Section 4 provides a discussion on the findings presented in the paper.

2. Methods and Data

In this section, we first develop the PCP and TC-Adj-PCP econometric models followed by a discussion on the data. The descriptions of the variable notations used in this study are presented in Table 1. The name of the variables and their notations are given in columns 1 and 2, respectively. In the last column, each notation is described in detail.

Table 1: Notations and descriptions of the variables

Variable	Notation	Description
Market call price	C_t	Observed call price in domestic currency at time t.
Market put price	P_t	Observed put price in domestic currency at time t.
Estimated call price	C_t^e	Estimated call price in domestic currency at time t.
Estimated put price	P_t^e	Estimated 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 are estimated by decomposition of error term

The PCP condition for foreign currency options was developed by Giddy (1983) and Grabbe (1983); this condition must be satisfied to prevent arbitrage possibilities. The PCP condition is based on the arbitrage principle as stated in equation (1).

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

where $\forall_j = AUD, BP, CAD, EUR, JPY, SF$. The next step is to rearrange equation (1) as the PCP regression model, as presented in equation (2).

$$(C_{tj} - P_{tj}) = \lambda_1 \left(S_{tj}e^{-R_{tj}^f} - X_{tj}e^{-R_{tj}^d T} \right) + \varepsilon_{tj}. \tag{2}$$

The PCP regression model in equation (2) conforms with options trading strategy, as the call price (C_{tj}) and put price (P_{tj}) are equal when both options are written at the money (i.e., $S_{tj} = X_{tj}$). Furthermore, consider that $(C_{tj} - P_{tj}) = Y_{tj}$ and $\left(S_{tj}e^{-R_{ti}^f} - X_{tj}e^{-R_{tj}^d T} \right) = X_{tj}$. In this case, equation (2) then becomes equation (3).

$$Y_{tj} = \lambda_1 X_{tj} + \varepsilon_{tj}. \tag{3}$$

Under the null hypothesis that the PCP condition is valid, the slope coefficient λ_1 should equal 1 in order for the options market to be efficient.

Next, the TC-Adj-PCP econometric model is expressed as equation (4).

$$Y_{tj} = \lambda_1 X_{tj} + \lambda_2 TC_{tj} + \varepsilon_{tj}. \tag{4}$$

The derivation of equation (4) is described in the appendix. Under the joint null hypothesis, the slope coefficients (λ_1 and λ_2) should jointly equal 1 in order for the options market to be efficient. Furthermore, to check the validity of equation (4), we applied the following procedure to examine whether transaction costs represent an omitted variable.

1. Regress Y_{tj} on X_{tj} as in equation (3) to generate the residual $\hat{\varepsilon}_{tj}$.

2. Then, following Pagan and Hull (1983), regress $\hat{\varepsilon}_{tj}$ on X_{tj} and TC_{tj} as in equation (5) with the test hypothesis that the slope coefficient of TC_{tj} is zero (i.e., $\lambda_2 = 0$):

$$\hat{\varepsilon}_{tj} = \lambda_1 X_{tj} + \lambda_2 TC_{tj} \tag{5}$$

Note that regression analyses conduct$_{ed}$ for equations (3), (4) and (5) address potential autocorrelation and conditional heteroskedasticity following by Hoque et al. (2008); these analyses show unbiased and consistent inferences for λ_1 and λ_2.

2.1. Data

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

3. Empirical Analysis

This section describes the results of the analysis of the PCP and TC-Adj-PCP models with regard to currency options market efficiency. First, a test is conducted on the PCP econometric model as stated in equation (3). To obtain unbiased and consistent estimation for the coefficient of equation (3), serial correlation and ARCH effects are tested using the ARMA and GARCH models, respectively. The regression results are summarized in Table 2.

Table 2: The PCP model regression test results

Currency	Slope (λ_1)	Serial Correlation		ARCH	
	Coefficient	F-Statistic	ARMA	F-Statistic	GARCH
AUD	0.2939	1.0201	(1,2)	0.0201	(1,1)
	(0.0000)	(0.3614)		(0.8874)	
BP	0.3844	1.25894	(1,1)	1.2364	(1,1)
	(0.0000)	(0.2848)		(0.2667)	
CAD	0.4303	1.1193	(1,0)	0.1833	(0,0)
	(0.0000)	(0.3274)		(0.6688)	
EUR	0.5564	0.5251	(1,1)	0.4512	(0,0)
	(0.0000)	(0.5919)		(0.5021)	
JPY	-0.7012	4.4494	(2,0)	0.3005	(1,1)
	(0.0000)	(0.0122)		(0.5838)	
SF	0.4846	1.6734	(1,1)	1.1254	(0,0)
	(0.0000)	(0.1887)		(0.2893)	

Notes: Tests of $\lambda_1 = 1$. The p-values are in parentheses below the slope coefficients and the F-Statistic. The null hypothesis of the LM test is that there is no serial correlation in the residual up a lag of 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 p-values indicate whether the null hypotheses of the LM tests for serial correlation and ARCH should be rejected.

The p-values in parenthesis for the F-statistic indicate that the tests failed to reject the null hypothesis that the data had no serial correlation or ARCH in the residual for all currencies. Furthermore, the reported p-values of the t-statistic in parentheses for slope (λ_1) coefficient demonstrated that the estimated slope coefficients are statistically different from zero and less than 1. The results are very similar to the findings of Hoque et al. (2008) and suggest that the PCP condition does not hold for all sample currency options markets.

Next we conducted the regression test for equation (5) with respect to serial correlations and ARCH effects to determine whether transaction cost is an omitted variable. The omitted variable test results are given in Table 3. The reported p-values in parentheses for the F-statistics failed to reject the null hypothesis that the data showed no serial correlation or ARCH in the residual for all currencies. The slope coefficients λ_1 and λ_2 are presented in columns (2) and (3), respectively, of Table (3). The p-values of the t-statistics are reported in parentheses below the slope coefficients. Furthermore, the null hypothesis H_0: $\lambda_2 = 0$ cannot be rejected at any reasonable significance level, indicating that the slope coefficients of TC_{tj} are statistically different from 0 in all cases. The overall results suggest that TC_{tj} is an omitted variable that leads to the validity of the TC-Adj-PCP model, as indicated in equation (4).

Table 3:   Test for transaction cost as an omitted variable

Currency	Slope (λ_1)	Slope (λ_2)	Serial Correlation		ARCH	
	Coefficient	Coefficient	F-Statistic	ARMA	F-Statistic	GARCH
AUD	0.0255	0.6864	1.5249	(0,0)	0.0024	(1,1)
	(0.0003)	(0.0000)	(0.2187)		(0.9611)	
BP	-0.0130	0.4292	0.5556	(0,0)	0.5595	(1,1)
	(0.4307)	(0.0000)	(0.5741)		(0.4549)	
CAD	-0.3232	0.8743	1.4013	(1,0)	0.0046	(0,0)
	(0.0000)	(0.0000)	(0.2473)		(0.9461)	
EUR	-0.1220	0.6679	1.3875	(0,0)	0.0067	(0,0)
	(0.0001)	(0.000)	(0.2507)		(0.9347)	
JPY	0.2319	-0.3775	1.9687	(0,4)	0.0003	(1,1)
	(0.0000)	(0.0000)	(0.1408)		(0.9837)	
SF	-0.1693	0.4743	1.9853	(0,0)	1.7519	(0,0)
	(0.0004)	(0.0000)	(0.1385)		(0.1863)	

Notes: Tests of H_0: $\lambda_2 = 0$. The p-values are in parentheses below the slope coefficients and the F-statistic. The null hypothesis of the LM test is that there is no serial correlation in the residual up to a lag of 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 p-values indicate whether the null hypotheses of the LM tests for serial correlation and ARCH should be rejected.

Next, we used equation (4) for regression analysis to address serial correlation and the ARCH effect for the TC-Adj-PCP model to determine currency options market efficiency for the sample currencies. The test results are presented in Table 4. The reported p-values in parentheses under the F-statistic failed to reject the null hypothesis that the data showed no serial correlation or ARCH in the residual for all currencies. The p-values of the t-statistics are presented in parentheses under the slope coefficients λ_1 and λ_1 in Table 4. The slope coefficients λ_1 are statistically different from zero and less than 1. Similarly, the slope coefficients λ_2 are statistically different from zero and less than 1.

Table 4: TC-Adj-PCP model regression test results

Currency	Slope (λ_1)	Slope (λ_2)	Serial Correlation		ARCH	
	Coefficient	Coefficient	F-Statistic	ARMA	F-Statistic	GARCH
AUD	0.1901	0.71885	0.5830	(1,2)	0.4988	(1,1)
	(0.0000)	(0.0000)	(0.5586)		(0.4804)	
BP	-0.1144	0.8912	0.2992	(1,2)	4.2207	(0,0)
	(0.0044)	(0.0000)	(0.7416)		(0.0405)	
CAD	0.1662	0.7666	0.8329	(0,0)	0.89081	(1,1)
	(0.0006)	(0.0000)	(0.4354)		(0.3458)	
EUR	0.2722	0.6570	1.8607	(1,1)	0.1416	(1,1)
	(0.0000)	(0.000)	(0.1567)		(0.7069)	
JPY	-0.5426	-0.4419	1.9405	(1,3)	0.8465	(1,1)
	(0.0000)	(0.0000)	(0.1448)		(0.3580)	
SF	-0.1300	0.9165	1.7093	(0,0)	0.0899	(0,0)
	(0.0058)	(0.0000)	(0.1821)		(0.7644)	

Notes: Tests of $H_0:\lambda_1=0$ and $\lambda_2=0$. The p-values are in parentheses below the slope coefficients and the F-Statistic. The null hypothesis of the LM test is that there is no serial correlation in the residual up to a lag of 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 p-values indicate whether the null hypotheses of the LM tests for serial correlation and ARCH should be rejected.

Finally, the joint null hypothesis H_0: $\lambda_1 + \lambda_2 = 1$ is tested, and the results are presented in Table 5. The regression results for slope coefficients λ_1 and λ_2 from Table 4 are reproduced in Table 5 with the standard errors using t-tests. The standard errors are given in parentheses below the slope coefficients λ_1 and λ_2. To test the joint null hypothesis, a Wald test was conducted, and the results are also presented in Table 5. Under the Wald test, the p-values below the F-statistics in parentheses indicate that the joint null hypothesis H_0: $\lambda_1 + \lambda_2 = 1$ cannot be rejected at the 1 percent level of significance for all currencies. The evidence of the econometric analysis strongly suggests that the TC-Adj-PCP condition holds for all currencies, which in turn leads to an efficient currency options market.

Table 5: Analysis of joint slopes coefficients equal to 1

Currency	Slope ($\lambda_1 + \lambda_2 = 1$)		Wald tests F-Statistics (P-value)
	T-tests Slope (λ_1) Coefficients (Std. error)	T-tests Slope (λ_2) Coefficients (Std. error)	
AUD	0.1901	0.7188	1.4627
	(0.0345)	(0.0738)	(0.2271)
BP	-0.1144	0.8912	0.0024
	(0.0399)	(0.0878)	(0.9610)
CAD	0.1662	0.7666	1.9640
	(0.0486)	(0.0691)	(0.1617)
EUR	0.2722	0.6570	2.0357
	(0.0453)	(0.0652)	(0.1543)
JPY	0.5426	-0.4419	0.0433
	(0.0390)	(0.0469)	(0.8353)
SF	-0.1300	0.9165	0.1485
	(0.0469)	(0.0912)	(0.7002)

Notes: Tests of $H_0:\lambda_1 + \lambda_2 = 1$. The regression slope coefficients from Table 4 are reproduced in Table 5 with standard errors. The standard errors are in parenthesis below the slope coefficients. For the Wald test, the p-values are in the parentheses below the estimated coefficients.

4. Conclusion

Undoubtedly, transaction costs play an important role in determining genuine arbitrage opportunities by filtering non-attractive arbitrage profit generated from PCP violations. The PCP condition with no transaction costs, therefore, is not adequate to conclude options market efficiency based on arbitrage profit strategy. Consequently, this study has proposed the TC-Adj-PCP econometric model to test currency options market efficiency. To further check the validity of the TC-Adj-PCP model, we conducted an omitted variable test for the transaction cost term.

Once we established that the proposed model was correctly specified, regression analysis was conducted for the TC-Adj-PCP econometric model while also testing for serial correlation and the ARCH effect to obtain unbiased and consistent inferences for slope coefficients. The overall regression results suggest that the TC-Adj-PCP model holds for options market efficiency. It clearly indicates that currency options market efficiency depends on the appropriate treatment of transaction costs along with the PCP test. Note that Hoque et al. (2008) and Mittnik and Rieken (2000) fail to conclude that the options market is efficient, as they use a PCP econometric model without taking into consideration transaction costs.

The use of the proposed TC-Adj-PCP model allows us to address two key issues with regard to debates surrounding transaction costs. First, it proved that transaction cost adjustment is an important consideration in a PCP model in the context of arbitrage profit strategies. Second, the robustness of the TC-Adj-PCP model eliminated the dependence of transaction costs on crude proxies for options market efficiency. Because options market efficiency leads to options pricing accuracy, traders and investors can use this innovative TC-Adj-PCP model to determine market efficiency to make decisions with regard to trading options. Similarly, researchers can employ the proposed model to examine options market efficiency in further studies. In our future work, we intend to examine the Philadelphia Stock Exchange, which has begun trading options on the Swedish krona, the South African rand, the Mexican peso, and the New Zealand dollar under World Currency Options. We plan to employ the TC-Adj-PCP model for these four newly-developed currency options markets to further justify its appropriateness for testing the efficiency of currency options markets in general.

Appendix

In this appendix, the TC-Adj-PCP econometric model is derived for European options. Because call and put both options are written at the same strike and maturity, if one option (e.g., put) is written in-the-money (ITM), the other option (e.g., call) should be written out-of-the-money (OTM). If the option traders write an ITM put option, an OTM call option price should be estimated using equation (A1).

$$C_{tj}^e = | X_{tj} - S_{tj} - P_{tj} | . \tag{A1}$$

Similarly, if the option traders write an ITM call option, an OTM put option price should be estimated using equation (A2).

$$P_{tj}^e = | S_{tj} - X_{tj} - C_{tj} | . \tag{A2}$$

Given observed call and put market prices, the PCP condition in equation (1) can be rearranged as equation (A3).

$$\left(C_{tj} - P_{tj} \right) = \left(S_{tj} e^{-R_{tj}^f} - X_{tj} e^{-R_{tj}^d T} \right) . \tag{A3}$$

Similarly, with estimated call and put price as stated in equations (A1) and (A2), respectively, the PCP condition in equation (1) can be written as follows.

$$\left(C_{tj}^e - P_{tj}^e \right) = \left(S_{tj} e^{-R_{tj}^f} - X_{tj} e^{-R_{tj}^d T} \right) . \tag{A4}$$

The difference between equations (A3) and (A4) can be expressed as follows.

$$\left(C_{tj} - P_{tj} \right) - \left(C_{tj}^{est} - P_{tj}^{est} \right) = 0 . \tag{A5}$$

For options mispricing (that is, either over- or underpriced), equation (A5) indicates that the difference of mispriced call and put prices can be offset by the difference between the estimated call and put prices. In previous studies, we found that PCP violations due to options mispricing were reduced with transaction cost, indicating that the mispricing of the options was offset by transaction costs. We therefore consider the difference in the estimated call and put prices as transaction cost (TC_{tj}), and Equation (A5) can thus be written as follows.

$$\left(C_{tj} - P_{tj}\right) - TC_{tj} = 0. \tag{A6}$$

Furthermore, when call and put both options are trading at-the-money (ATM), then S = X, and so the right-hand side of Equation (A3) equals zero.

$$\left(S_{tj}e^{-R_{tj}^f} - X_{tj}e^{-R_{tj}^d T}\right) = 0. \tag{A7}$$

From equations (A6) and (A7), we can derive equation (A8).

$$\left(C_{tj} - P_{tj}\right) - TC_{tj} = \left(S_{tj}e^{-R_{tj}^f} - X_{tj}e^{-R_{tj}^d T}\right). \tag{A8}$$

Noting that $\left(C_{tj} - P_{tj}\right) = Y_{tj}$ and $\left(S_{tj}e^{-R_{ti}^f} - X_{tj}e^{-R_{tj}^d T}\right) = X_{tj}$, we then develop the TC-Adj-PCP econometric model as follows.

$$Y_{tj} = \lambda_1 X_{tj} + \lambda_2 TC_{tj} + \varepsilon_{tj}. \tag{A9}$$

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