Covered Interest Parity in Emerging Markets*

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Abstract

While emerging forward exchange markets (EMs) have been rapidly developed, market efficiency has been rarely examined for EMs yet. To properly test the market efficiency for EMs, we set up a simple model to account for EM-specific realistic features. Based on the new model, we develop a modified covered interest parity (CIP) condition which is featured with a neutral band associated with both transaction costs and borrowing spreads. We then apply the modified CIP condition into Korean forward exchange market and provide empirical analysis results for Korean market which can also be useful for analyzing other EMs. The empirical results suggest that we may run the risk of over-rejecting market efficiency by ignoring foreign currency borrowing spreads in the context of the CIP.

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Keywords: Covered Interst Parity, Emerging Markets, Market Efficiency, Borrowing Spreads, Transaction Costs.

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1 Introduction

The covered interest parity (CIP) has played a central role to test the efficiency hypothesis in a forward exchange market. Until now, the market efficiency has been extensively examined only for several advanced markets whilst emerging markets (EMs) have been rarely studied yet. This may be attributable to the fact that EMs have a relatively short history of free-floating exchange rate system and financial liberalization. In addition, while a development in a forward exchange market is closely associated with a development in money (or capital) markets of the two counterparty currencies, EMs are typically characterized with illiquidity in a money, capital or forward exchange market.

However, some EMs have become more liquid. As of April 2013, several EMs have daily turnover more than 10 billion U.S. dollar for outright forwards plus foreign exchange (FX) swaps, including China, Chinese Taipei, India, Korea, Mexico, Russia, South Africa, and Turkey.[1] Among those eight EMs, only Korean market had daily turnover exceeding 10 billion U.S. dollar as of April 2004, and five markets did so as of April 2007. This development implies that EMs are more likely to be tested for the forward exchange market efficiency hypothesis.

EMs are usually populated with multilayered FX banks: domestic banks (DBs) and global bank subsidiaries (GBSs). Compared to the GBSs, the DBs are typically less credit-worthy, of limited access to international money or capital markets, and faced with higher costs for funding global currencies. Although this heterogeneity in market participants has profound implications for testing the market efficiency for EMs, the traditional CIP does not appropriately take this point into consideration. To properly test the market efficiency for EMs, we aim to develop a modified CIP condition by taking into account the EM-specific heterogeneities in this paper. In addition, EMs usually have relatively less developed forward exchange markets than advanced markets; thus, forward FX transactions may incur high transaction costs in EMs. To account for this fact, we also incorporate transaction costs engaged with forward FX transactions into the modified CIP.

[1] Refer to the triennial central bank survey of foreign exchange and derivatives market activity in 2013 by the Bank for International Settlement.

The modified CIP condition for EMs is featured with a neutral band. By typically assuming transaction costs, the traditional CIP can also obtain a neutral band which is associated with transaction costs. In contrast, the modified CIP condition has the neutral band which is associated not only with transaction costs but also with heterogeneity such as differential funding costs. Under the traditional CIP, if market prices align within the neutral band, any profitable arbitrage transaction is deterred. On the other hand, the modified CIP allows a portion of banks to earn limited profits from arbitrage transactions even within the neutral band, which is possible due to differential funding costs.

We then apply the modified CIP condition into Korean forward exchange market. We utilize unique data for individual bank funding costs of foreign currencies. We employ an endogenous switching model for estimation which is advantageous for correcting estimation biases. We provide empirical analysis results for Korean forward exchange market which can also be useful for analyzing other EMs. We find that foreign currency borrowing spreads play an important role for testing foreign exchange market efficiency. In particular, the conventional CIP framework may tend to over-reject market efficiency in EMs by ignoring borrowing spreads.

The rest of this paper is organized as follows. Section 2 provides a brief literature review on the CIP condition under various situations. Section 3 introduces a new model to incorporate EM-specific features and develops a modified CIP condition. Section 4 offers empirical analysis results for Korean forward exchange market, by describing the data to be used, explaining the estimation method, and providing the estimation results. Section 5 concludes.

2 Literature Review

The CIP implies an exact relation of the interest rates of two currencies and their spot and forward exchange rates for no-arbitrage opportunities by assuming rational agents in a frictionless market. There have been several strands of efforts to account for observable deviations from the CIP. A prominent strand is to take into consideration transaction costs, with examples including Branson (1969), Frenkel and Levich (1975, 1977), Deardorff (1979), Mc-

Cormick (1979), Callier (1981a, 1981b), Bahmani-Oskooee and Das (1985), Clinton (1988), and Woodward (1988), among others. In particular, transaction costs may play a greater role in long-date capital markets. Several studies focus on the long-term CIP, including Popper (1993), and Fletcher and Taylor (1994, 1996).

On the other hand, Levi (1977) and Kupferman and Levi (1978) suggest differential tax rates as a potential factor to account for deviations from the CIP. Measurement errors may be another source of deviations from the CIP. Taylor (1987) utilizes high quality data to minimize the potential effects of measurement errors.

More interest might lie on large deviations from the CIP during turbulent periods than small deviations during normal periods. Frenkel and Levich (1977) and Taylor (1989) study the deviations during turbulent periods. Recently, several works try to explain deviations from the CIP during the 2007-2008 global financial crisis period. Such examples include Baba, Packer, and Nagano (2008), Baba and Packer (2009a, 2009b), Coffey, Hrung, Nguyen, and Sarkar (2009), Genberg, Hui, Wong, and Chung (2009), Jones (2009), Fong, Valente, and Fung (2010), and Griffoli and Ronaldo (2011), among others.

Like our study, Skinner and Mason (2011) also examine forward exchange market efficiency in EMs. Although they take into account credit risk by utilizing credit default swap premia to investigate market efficiency for a long-term period, they employ a standard CIP condition (with transaction costs) for a short-term period. Unlike Skinner and Mason (2011), we try to develop a new model to accommodate EM-specific features to investigate market efficiency for a short-term period.

Our model is closely related with Blenman (1991) who devises the CIP under market segmentation. Agents are differentiated with residency and faced with differential lending and borrowing opportunities. This market segmentation implies a neutral band which is associated with the differences in lending and borrowing rates. This framework allows not only a resident-neutral arbitrage opportunity outside the neutral band but also a resident-specific arbitrage opportunity within it.

Although Blenman (1991) has those features in common with our model, our model differs from Blenman (1991) in several respects. Compared to Blenman (1991), our model contains more realistic features. For example, our model differentiates agents not only with their residency but also with their credit-worthiness. Indeed, EMs are typically populated with many banks having relatively low credit-worthiness. Secondly, while Blenman (1991) allows unlimited arbitrage profits by implicitly assuming infinite elasticities, our model allows only limited arbitrage profits by introducing borrowing constraints. This limited access to international money or capital market is another EM-specific characteristics. Thirdly, FX banks usually have a certain amount of inventories resulting from transactions with their customers. These inventories are incorporated into our model but not into Blenman (1991). Since these customer-related FX transactions are often linked with the balance of payment development of the country, its inclusion can be useful for devising a realistic model. Lastly, our model explicitly takes into account the demand for and the supply of arbitrage funds which are directly tied with market conditions, and it determines the forward exchange rate as an equilibrium market price. Putting these realistic features together, our model presents a modified CIP which can be useful for empirically analyzing EMs.

Another related strand of literature is "elasticity approach" proposed by Prachowny (1970) and Frenkel (1973). This approach introduces a spread between borrowing and lending interest rates and assumes an upward-sloping supply of funds. These features imply the existence of a neutral band. Unlike our model, this approach implicitly assumes homogeneous agents, which is inappropriate for analyzing EMs.

3 Model

In this section, we present a new model incorporating EM-specific features and derive a modified CIP from it.

For comparison, we first express the standard CIP as follows.

$$
\begin{aligned}
F\left(1+i_f\right) &= S\left(1+i_d\right), && (1)\\
i_d - i_f &\simeq f \equiv \frac{F-S}{S}, && (2)\\
D &\equiv (i_d - i_f) - f = 0. && (3)
\end{aligned}
$$

Here, i_d and i_f represent domestic and foreign interest rates, respectively. S and F indicate spot and forward exchange rates, respectively, where an exchange rate is expressed as the domestic-currency-denominated value of one unit of foreign currency. Eq. (1) postulates that the values of one unit of foreign currency in one period should be the same in equilibrium from two alternative investment methods: (i) investment into foreign assets with a hedging forward FX transaction and (ii) investment into domestic assets with a spot FX transaction. f denotes FX swap rate, and Eq. (2) implies that the interest differential, $i_d - i_f$, should be the same with the FX swap rate. The deviation from the standard CIP, denoted by D, is an indication of arbitrage profits. In equilibrium, D should be equal to zero (Eq. (3)) whereas deviations from zero in either direction indicate profitable arbitrage opportunities. This standard CIP implicitly assumes homogeneous agents in frictionless money and FX markets. Therefore, market frictions such as transaction costs are not incorporated into this framework.

Now, we introduce the following assumptions for a new model which is featured with differential foreign currency borrowing costs, capacities, and inventories among FX banks and the existence of transaction costs in forward exchange markets.

Assumptions

A1. There exist a continuum of FX banks indexed by $j \in [0, 1]$ in the economy.

A2. There are two currencies. Spot FX transactions are made at the same spot (denoted by S) exchange rates. The FX banks are faced with ask forward exchange rate (F_a) for buying forwards and bid forward exchange rates (F_b) for selling forwards in inter-bank forward markets. On the other hand, the FX banks make FX transactions at F_a for selling forwards and F_b for buying forwards with their customers in bank-customer transactions. The exchange rate is expressed as the domestic-currency-denominated value of one unit of foreign currency.

A3. The FX banks borrow and lend domestic currency at the same domestic interest rate i_d.

A4. The FX banks lend foreign currency at the foreign interest rate i_f.

A5. The FX banks are differentiated with respect to foreign currency borrowing cost and capacity. In particular, the j-th FX bank can borrow foreign currency up to Y_j at the interest rate $i_f + \lambda_j$.

A6. The borrowing spread λ_j is bounded below by zero and above by $\overline{\lambda}$, i.e., $\lambda_j \in \left[0, \overline{\lambda}\right]$. The FX banks are sorted according to their borrowing spreads in an ascending order.

A7. The FX banks have the same direction of customer-related FX transactions. X_j indicates bank j's customer-related FX forward position, and $X_j \geq 0$ or $X_j \leq 0$ for all j.

A8. The FX banks take their customer-related FX forward position less than their foreign currency funding capacity, i.e., $X_j < Y_j$ for all j.

Assumption 1 unrealistically introduces infinitely many banks in order to simplify the analysis. Assumption 2 includes the transaction costs engaged with forward FX transactions but rules out other kinds of transaction costs for simplification. In addition, we abstract away differences in exchange rates between inter-bank FX transactions and customer-related ones. Given the two forward exchange rates F_b and F_a, the mid forward exchange rate is denoted by F. Assumptions 3 and 4 are the standard ones in the context of the CIP. Assumption 5 contains EM-specific heterogeneities among agents. In particular, the assumption reflects the fact that differences in credit-worthiness among FX banks in an EM result in differential borrowing costs and capacities of foreign currency. Assumption 7 introduces the customer-related FX forward position as an inventory which may affect market equilibrium. Assumptions 6, 7, and 8 contain some innocuous restrictions to simplify the analysis.

We distinguish two cases according to the direction of the customer-related FX forward position.

<Case 1> FX banks have long customer-related FX forward positions (i.e., $X_j > 0$ for all j).

In order to hedge its long customer-related FX forward position, the j-th FX bank will choose the better one between two alternatives: (i) If the bank will borrow foreign currency at $i_f + \lambda_j$ in the international money market and sell it via spot FX transaction, then it will earn $S(1 + i_d) - F_b(1 + i_f + \lambda_j)$ from this method at maturity. (ii) If the bank will borrow foreign currency via buy/sell FX swap and sell it via spot FX transaction, then it will earn zero profit. Table 1 (method (i) and (ii)) demonstrates detailed transactions and cash flows of the two methods.

The foreign currency borrowing spread λ_j determines the j-th FX bank's choice. By equating the two profits from both methods, the indifferent borrowing spread, denoted by λ^*, is determined as follows:

$$F_b = S\frac{1+i_d}{1+i_f+\lambda^*}. \tag{4}$$

Denoting by j^* the FX bank whose borrowing spread is equal to λ^*, the FX banks with lower spreads (i.e., $j < j^*$, thus $\lambda_j < \lambda^*$) will choose to borrow foreign currency in the international money market whereas the FX banks with higher spreads (i.e., $j > j^*$) will choose to buy/sell FX swap in the forward exchange market.

Since the FX banks with higher spreads will earn zero profit, they will enter into the buy/sell FX swap transactions just enough to hedge their customer-related positions. In contrast, the FX banks with lower spreads can earn riskless profits, therefore they want to maximize the profit by borrowing foreign currency up to their borrowing capacities. However, all of the banks with spreads lower than λ^* cannot participate in such transactions because of the existence of transaction costs. Table 1 (method (iii)) shows that only the banks whose spreads are lower than the other indifferent borrowing spread λ^{**} can do so where λ^{**} is less than λ^* and determined as follows:

$$F_a = S\frac{1+i_d}{1+i_f+\lambda^{**}}. \tag{5}$$

Denoting by j^{**} the FX bank whose borrowing spread is equal to λ^{**}, there exist three groups among FX banks: banks belonging to the range $[j^*, 1]$ hedge customer-related positions by entering into buy/sell FX swap; banks belonging to (j^{**}, j^*) hedge customer-related positions by borrowing foreign currency; banks belonging to $(0, j^{**})$ borrow foreign currency up to their borrowing capacity (i.e., Y_j), among which some amount (i.e., X_j) is used for hedging while the rest (i.e., $Y_j - X_j$) is utilized as sell/buy FX swap in the forward exchange market.

The equilibrium forward exchange rate is determined by the demand for and the supply of FX swap in the forward market. The demand for buy/sell FX swap, $Y_{b/s}$ comes from the FX banks with higher spreads:

$$Y_{b/s} = \int_{j^*}^{1} X_j \cdot dj. \tag{6}$$

On the other hand, the supply of buy/sell FX swap (equivalently, the demand for sell/buy FX swap), $Y_{s/b}$ comes from the FX banks with lower spreads:

$$Y_{s/b} = \int_0^{j^{**}} (Y_j - X_j) \cdot dj. \tag{7}$$

By assuming a fixed transaction cost $\mathcal{T}$ (i.e., $F_b = F - \mathcal{T}$, $F_a = F + \mathcal{T}$), the model determines the equilibrium forward exchange rate, F^* as follows: from the equilibrium condition

$$Y_{b/s}(F^*) = Y_{s/b}(F^*), \tag{8}$$

we obtain that

$$\int_0^{j^{**}(F^*)} (Y_j - X_j) \cdot dj = \int_{j^*(F^*)}^1 X_j \cdot dj. \tag{9}$$

Noteworthily, Eqs. (4) and (5) imply that λ^* (λ^{**}) is negatively related with F_b (F_a), and therefore j^* (j^{**}) is also negatively related with F_b (F_a). Since the difference between F and F_b (F_a) is fixed, we obtain the following inequality relations:

$$\frac{dj^*(F)}{dF} < 0, \; \frac{dj^{**}(F)}{dF} < 0, \tag{10}$$

which imply that from (6), we have

$$\frac{dY_{b/s}(F)}{dF} > 0, \tag{11}$$

and from (7), we have

$$\frac{dY_{s/b}(F)}{dF} < 0. \tag{12}$$

Both inequalities ensure the stability of the equilibrium expressed by (8).

In equilibrium, the deviation from the standard CIP belongs to a range within our framework as follows:

$$
\begin{aligned}
D &\in [D^{**}, D^{*}] \simeq [\lambda^{**}(F^{*}), \lambda^{*}(F^{*})], && (13)\\
D^{**} &= (i_d - i_f) - f^{*} - \tau \equiv (i_d - i_f) - \frac{F^{*} + \mathcal{T} - S}{S} \simeq \lambda^{**}(F^{*}), && (14)\\
D^{*} &= (i_d - i_f) - f^{*} + \tau \equiv (i_d - i_f) - \frac{F^{*} - \mathcal{T} - S}{S} \simeq \lambda^{*}(F^{*}). && (15)
\end{aligned}
$$

Several remarks are in order. Importantly, the result (13) implies that a certain amount of deviation from the standard CIP should be interpreted as equilibrium. The equilibrium deviation from the standard CIP is associated not only with transaction costs but also with borrowing spreads. In equilibrium, a portion of banks (i.e., $j<j^{*}(F^{*})$) can earn riskless profits while the rest does not. We call these riskless profits as "bank-specific" profit and the other kind of riskless profits as the "bank-neutral" profit. The latter profits occur in disequilibrium where the actual deviation lies outside the equilibrium range. The bank-specific profits in equilibrium come from relative cost advantages of borrowing foreign currency. The riskless profits in our model are bounded due to the limited capacity of borrowing foreign currency.

The result (13) is a general one, obtained by assuming a positive transaction cost and differentiated foreign currency borrowing spreads. Instead of the general assumptions, if we assume that the transaction cost is zero and foreign currency borrowing spreads are zero for all banks, then our model collapses to the standard one and we obtain the standard result:

$$D = 0. \tag{16}$$

Secondly, if we assume that the transaction cost is zero but foreign currency borrowing spreads are differentiated, then the result is narrowed down to a single equilibrium point instead of a range. That is,

$$
\begin{aligned}
D &= D^{*} \simeq \lambda^{*}(F^{*}), && (17)\\
D^{*} &= (i_d - i_f) - f^{*}.
\end{aligned}
$$

Lastly, if we assume a positive transaction cost but zero borrowing spread, then the result is narrowed down to a range which is independent from borrowing spreads:

$$D \in [-\tau,\ \tau]\,. \tag{18}$$

The following proposition 1 analytically summarizes how the equilibrium deviation from the standard CIP is affected by various factors for the case 1.

Proposition 1 *For the case where the FX banks have long customer-related FX forward positions, (i) the equilibrium deviation from the standard CIP is determined by* (13)*. (ii) If the customer-related FX forward position increases for all banks, then the equilibrium deviation from the standard CIP increases. (iii) If the foreign currency borrowing spread increases for all banks, then the equilibrium deviation from the standard CIP increases. (iv) If the foreign currency borrowing capacity decreases for all banks, then the equilibrium deviation from the standard CIP increases.*

Proof. (ii) Eq. (9) implies that a unanimous increase in all X_j leads to an increase in $j^{**}(F^*)$. From the inequality relation (10), we infer that an increase in $j^{**}(F^*)$ yields a decrease in F^*; therefore, the equilibrium swap rate f^* also decreases. Finally, Eq. (13) implies that D^* (and D^{**}) should increase in response to the decrease in f^*.

(iii) From Eq. (9), we infer that j^{**} remains the same because of no change in X and Y_j. However, an increase in λ_j for all banks implies that λ^* (and λ^{**}) also increases; therefore, the D^* (and D^{**}) also increases.

(iv) From Eq. (6) and (7), we infer that the decrease in all Y_j should be offset by an increase in either j^{**}, j^*, or both. Either an increase in j^{**} but not in j^* or an increase in j^* but not in j^{**} is inconsistent with the assumption of a fixed transaction cost because the fixed amount of transaction cost is associated with the difference between j^{**} and j^*. Therefore, the decrease in all Y_j implies that both j^{**} and j^* increase, thus D^* (and D^{**}) do so. ■

We present a simple numerical example to illustrate how the equilibrium is attained in the model. We assume a hypothetical economy which is characterized with the following parameter values:

$$X_j = 1,\ Y_j = 2,\ \lambda_j = 0.02 \cdot j,\ \text{for all } j \in [0,1]\,,$$

and

$$i_f = 0.01,\ i_d = 0.03,\ S = 1000,\ \mathcal{T} = 1.$$

Then, from Eq. (9) we have

$$1 - j^* = j^{**}.$$

Utilizing that $\lambda^* = 0.02 \cdot j^*$ and $\lambda^{**} = 0.02 \cdot j^{**}$, and subtracting D^{**} (Eq. (14)) from D^* (Eq. (15)) yields

$$2\tau = \lambda^* - \lambda^{**} = 0.02\left(j^* - j^{**}\right),$$

from which we obtain

$$j^{**} = 0.45,\ j^* = 0.55.$$

Then, the following results are straightforward:

$$\begin{aligned}
\lambda^{**}\left(= D^{**}\right) &= 0.009,\ \lambda^*\left(= D^*\right) = 0.011, \\
F_b^* &= 1008.82,\ F_a^* = 1010.80, \\
F^* &= 1009.81,\ f^* = 0.00981, \\
Y_{b/s}\left(F^*\right) &= Y_{s/b}\left(F^*\right) = 0.45.
\end{aligned}$$

Table 2 summarizes the above benchmark situation along with three alternative situations. Situation 1 shows that when foreign currency borrowing spread unanimously increases, the equilibrium deviation from the standard CIP increases. Situation 2 demonstrates that when the customer-related FX forward position (i.e., X_j) increases, the equilibrium deviation from the standard CIP increases. Lastly, situation 3 illustrates that a decrease in foreign currency borrowing capacity also leads to an increase in the equilibrium deviation. All numerical results are consistent with Proposition 1.

<Case 2> FX banks have short customer-related FX forward positions (i.e., $X_j < 0$ for all j).

In order to hedge its short customer-related FX forward position, the j-th FX bank will choose the better one between two alternatives: (i) If the bank will buy foreign currency via spot FX transaction and lend it in the international money market, then it will earn $F_a(1+i_f) - S(1+i_d)$ from this method at maturity. (ii) If the bank will buy foreign currency via spot FX transaction and lend it via sell/buy FX swap, then it will earn zero profit. Table 3 demonstrates the details of the two methods.

Unlike the case 1, all banks are symmetric in making their choices; therefore, two methods should yield the same zero profit in equilibrium, and we obtain the standard CIP result with transaction costs for the case 2; that is,

$$D \in [-\tau, \tau]. \tag{19}$$

Proposition 2 summarizes this result.

Proposition 2 *For the case where the FX banks have short customer-related FX forward positions, the standard CIP result with transaction costs (as expressed by* (19)*) holds despite the existence of heterogeneity among banks.*

The previous two static results show that the equilibrium deviation from the standard CIP critically depends upon the direction of inventory. In reality, however, FX banks continuously make FX transactions with their customers, and the direction of inventory may frequently alternate. In such a dynamic and realistic situation, the unconditional result is more useful than the conditional results (such as Propositions 1 and 2). By combining the conditional results of Propositions 1-(i) and 2, we obtain the unconditional one summarized by the following Proposition 3 which offers the necessary condition to be used for testing the forward exchange market efficiency.

Proposition 3 *The necessary condition for the forward exchange market efficiency is that the deviation from the standard CIP lies within the following range:*

$$D \in [-\tau, D^*], \tag{20}$$

where D^* is defined by (15)*.*

4 Empirical Analysis

In this section, we apply the modified CIP into Korean forward exchange market. Korean financial market is an emerging market and populated with multilayered FX banks. As of December 2013, there exist 18 domestic banks: 7 commercial banks (CBs), 6 regional banks, and 5 specially-purposed banks (SBs). The commercial banks are smaller in size and have lower credit grades than global banks. The regional banks inactively do FX transactions and are excluded in the analysis. Several SBs are guaranteed by Korean government and therefore have relatively higher credit ratings than the CBs. In addition to the DBs, 40 foreign bank subsidiaries do their businesses in Korean financial market. Most of them come from advanced home countries such as U.S., U.K., Japan, France, Germany, Netherlands, and Swiss. These GBSs have their headquarters which are much larger in size and have higher credit ratings than the Korean DBs. In this section, we presents empirical analysis results for Korean forward exchange market, by describing the data to be used, explaining the estimation method, and providing the estimation results.

4.1 Data

In this empirical analysis, we formally test the market efficiency in Korean short-term forward exchange market. In particular, we choose three-month CD market rates as domestic interest rates and three-month U.S. dollar Libor rates as foreign interest rates in the analysis. Accordingly, we use three-month non-deliverable forward (NDF) rates as the relevant forward exchange rate of Korean won (KRW) against U.S. dollar (USD). This choice is based on the fact that short-term maturity markets are typically more liquid than long-term maturity markets. By focusing on relatively liquid markets, our results can be free from a potential market liquidity issue. All of these data are retrieved from Bloomberg.

In our model, we concentrate on the role of foreign currency borrowing spreads as well as transaction costs engaged with forward FX transactions. In general, transaction costs play a smaller role in a short-term maturity analysis, although they play a bigger role in long-term maturity markets. On the other hand, both the spot FX market and the short-term money market in Korea are regarded as sufficiently liquid. In addition, the Libor market is also a very liquid international money market. Based on this reason, we abstract away the other transaction costs.

We utilize the unique data of the foreign currency borrowing spreads of individual Korean DBs which have been collected by the Bank of Korea – Korea's central bank.[2] The data range from the beginning of 2002 on a daily basis and cover ten DBs. Foreign currency borrowings usually occur infrequently. Moreover, borrowing maturities vary, and individual banks differ with respect to their credit ratings. Figure 1 plots the time trend of short-term (i.e., maturity up to one year) U.S. dollar borrowing spreads of individual Korean domestic banks from January 1, 2002 to August 15, 2014.

We try to construct the threshold borrowing spread λ_t^* on a daily basis through the following procedure. To estimate the effects of maturity and the credit rating on the borrowing spreads, we run the following linear regression with the foreign currency borrowing panel data:

$$s_{j,t} = a_0 + a_1 S_t + a_2 M_{j,t} + a_3 M_{j,t}^2 + a_4 C_{j,t} + a_5 C_{j,t}^2 + \varepsilon_{j,t}, \tag{21}$$

where $s_{j,t}$ indicates bank j's borrowing spread at time t, S_t the average borrowing spread, $M_{j,t}$ the borrowing maturity, and $C_{j,t}$ the credit rating of bank j at time t. The average borrowing spread S_t is intended to capture an average effect on that date. The credit rating is transformed into a cardinal variable; based on the Standard and Poors' short-term issuer credit ratings, we assign 1 for 'B', then 2 for 'A-3', 3 for 'A-2', and 4 for 'A-1'. We include both squared maturity and squared credit rating variables in order to account for a

[2] Based on the market concensus, we implicitly assume that the GBSs in Korean financial markets pay zero spread in their foreign currency borrowings (i.e., $\lambda_j = 0$) due to their high credit ratings and reputations.

potential nonlinearity. Then, we adjust the actual spreads into the constant maturity (i.e., 91 days) spreads by using the above estimation results. In our model, only banks with lower borrowing spreads would participate in foreign currency borrowing for the case 1; therefore, the threshold borrowing spread λ_t^* is regarded as the maximum of the observed spreads at time t. For the days with actual foreign currency borrowings, we construct the threshold spread λ_t^* by taking the maximum among the observed constant maturity spreads at time t. For the days with no foreign currency borrowing, we employ cubic spline method to interpolate the threshold spreads.[3]

According to the so-called 'arbitrage paradox' suggested by Grossman and Stiglitz (1976, 1980), violations of the CIP can be rationalized during a short period. If arbitrage is never observed, market participants may not have sufficient incentives to watch the market, in which case arbitrage opportunities could arise. A possible resolution of this paradox is for short-term arbitrage opportunities to arise, inviting traders to exploit them, and hence be quickly eliminated. Based on this notion of arbitrage paradox, we will conduct empirical analysis not only on a daily basis but also on a weekly basis and see if we may have different results by varying time frequency.

Our sample period covers the recent 2007-2009 global financial crisis during which Korean financial markets experienced a severe turbulence in common with other international markets. To account for the effect of the financial crisis, we divide the sample period into two sub-periods: pre-crisis period (January 1, 2002 to July 31, 2007) and post-crisis period (August 1, 2007 to August 15, 2014).

Figure 2 plots the daily time trends of the threshold borrowing spreads λ^* and transaction costs τ (Panel A) and the difference between the both (i.e., λ^*-τ; Panel B), the deviations from the standard CIP (Panel C), and the deviations from the modified CIP (Panel D) in the short-term Korean markets from January 1, 2002 to August 15, 2014. Figure 3 plots the time trends on a weekly basis, and Table 4 provides the summary statistics. Importantly, threshold borrowing spreads λ^* significantly exceed transaction costs τ, particularly during the post-crisis period. For example, during the post-crisis period, the threshold borrowing

[3] In addition, if the calculated λ_t^* is less than the observed τ_t, then we substitute λ_t^* with τ_t in accordance with our model.

spread λ^* is 71 basis points (bps) on average, and the difference between λ^* and τ amounts to 32 bps. The mean deviation from the standard CIP is 193 bps whereas the mean deviation from the modified CIP is narrowed down by 58 bps to 135 bps. This fact implies that the exclusion of the effect of foreign currency borrowing spreads might lead to an over-rejection bias for testing market efficiency.

4.2 Estimation Method

Our model suggests a neutral band $[-\tau, \lambda^*]$ as a necessary condition for a forward market efficiency. The usual linear regression approach such as Bahmani-Oskooee and Das (1985) provides inconsistent estimates, as pointed out by Maasoumi and Pippenger (1989). To correct estimation biases, Fletcher and Taylor (1996) suggest an endogenous switching model and apply it into testing the CIP with transaction costs which contains a neutral band $[-\tau, \tau]$. We will employ the endogenous switching model with slight modifications.

Denoting by D the deviation from the standard CIP, the deviation from the modified CIP $\widetilde{D}$ is defined by

$$\widetilde{D} = \begin{cases} 0, & D \in [-\tau, \lambda^*] \\ -D-\tau, & D \in (-\infty, -\tau) \\ D-\lambda^*, & D \in (\lambda^*, \infty) \end{cases} . \tag{22}$$

This deviation $\widetilde{D}$ is interpreted as a net deviation from the CIP after adjusting borrowing spreads or transaction costs.

Following Fletcher and Taylor (1996), we model the disequilibrium value as

$$\widetilde{D}_t = \alpha + \lambda_t^* \beta + Z_t' \delta + \epsilon_t, \tag{23}$$

where ϵ_t is a normally distributed, serially uncorrelated but (possibly) heteroskedastic disturbance term, and Z_t represents lagged values of λ_t^*, and lagged values of the dependent variable that are used to capture the dynamics of the stochastic process of our observations. We determine the appropriate lag length by sequentially changing the lag length and testing for exclusion with the likelihood ratio statistic. The lag lengths of λ^* and $\widetilde{D}$ are set equal to each other.

As a disequilibrium from the CIP becomes greater, market participants are more likely to seek arbitrage opportunities; therefore, the subsequent disequilibrium value may become more volatile. To account for such dynamic variance structure, we model the variance of ϵ_t as

$$\sigma_t^2 = \gamma_0 + \gamma_1 \widetilde{D}_{t-1}, \tag{24}$$

which is motivated by the absolute form suggested in Engle (1982) and has finite variance for any positive parameter value.

The maximum likelihood function for the above model is

$$L = \prod_{\widetilde{D}=0} \left[1 - \Phi \left(\frac{X_t' \Gamma}{\sigma_t} \right) \right] \cdot \prod_{\widetilde{D}>0} \frac{1}{\sqrt{2\pi\sigma_t^2}} \exp \left[-\frac{1}{2\sigma_t^2} \left(\widetilde{D}_t - X_t' \Gamma \right)^2 \right], \tag{25}$$

where X_t includes λ_t^*, Z_t and a constant, and Γ is the associated parameter vector.

For comparison, we also consider the conventional model which includes only transaction costs but not borrowing spreads. For the conventional model, the deviation from the standard CIP, $\widehat{D}$ is defined by

$$\widehat{D} = \begin{cases} 0, & D \in [-\tau, \tau] \\ |D| - \tau, & D \notin [-\tau, \tau] \end{cases}, \tag{26}$$

and the disequilibrium value is modelled as

$$\widehat{D}_t = \alpha + \tau_t \beta + Z_t' \delta + \epsilon_t, \tag{27}$$

where Z_t represents lagged values of τ_t, and lagged values of the dependent variable. Accordingly, the variance of ϵ_t is modelled as

$$\sigma_t^2 = \gamma_0 + \gamma_1 \widehat{D}_{t-1}. \tag{28}$$

4.3 Empirical Results

We cannot expect the deviations from the standard CIP to be within the neutral band unless both α and β are nonpositive. For example, positive α may suggest that the CIP condition would be violated on average. Similarly, positive β may also imply that the CIP condition would be violated by making $\widetilde{D}$ grow proportional to λ^*.

Table 5 provides the estimation results for the new model which is specified as (23) and (24). On a daily basis, α is insignificantly positive and β is insignificantly negative during the pre-crisis period, suggesting that the CIP largely holds by taking into account not only transaction costs but also borrowing spreads. However, α is significantly positive during the post-crisis, implying market inefficiencies in the context of the modified CIP. This violation of the CIP during the post-crisis period in Korean financial markets is largely consistent with the experiences in international financial markets during the similar periods (see, for example, Baba and Packer (2009b) and Fong, Valente, and Fung (2010)). We have similar results during the whole period which may be dominated by the results during the post-crisis period.

Interestingly, on a weekly basis, α becomes insignificantly positive not only during the post-crisis but also during the whole period; therefore, the estimation results become supportive for market efficiency in Korean forward market. This change in results may provide an evidence on adjustment speed. Korean forward market has experienced deviations from the (modified) CIP on a daily basis; however, such deviations tend to be eliminated in a week.

For comparison, Table 6 provides the estimation results for the conventional model which is specified as (27) and (28). We obtain evidences that the CIP largely holds during the pre-crisis period even without taking into account borrowing spreads. Indeed, the borrowing spreads exceed the transaction costs only by 4.3 bps on average during the pre-crisis period as shown in Table 4. However, significantly positive β is suggestive of market inefficiencies not only on a daily basis but also on a weekly basis during both the post-crisis and the whole period. This difference in results is attributable to the ignorance of borrowing spreads in the conventional model. As Table 4 shows, the borrowing spreads exceed the transaction costs by a sizable amount of 32.2 bps on average during the pre-crisis period. Therefore, the ignorance of borrowing spreads in the context of the CIP may bring in the risk of over-rejecting market efficiency.

In Table 7, we provide the predicted probability of equilibrium which is evaluated by

$$\Pr\left[\widetilde{D}=0\right]=1-\phi\left(\frac{\widehat{\alpha}+\overline{\lambda^{*}}\widehat{\beta}+\overline{Z}'\widehat{\delta}}{\widehat{\gamma}_{0}+\widehat{\gamma}_{1}\overline{\widetilde{D}}}\right), \tag{29}$$

where $\phi(\cdot)$ indicates the standard normal probability density function, and $\widehat{\alpha}$, $\widehat{\beta}$, $\widehat{\delta}$, $\widehat{\gamma}_0$, and $\widehat{\gamma}_1$ are the maximum likelihood estimates of the corresponding parameters, and $\overline{\lambda^{*}}$, $\overline{Z}$, are $\overline{\widetilde{D}}$ denote the corresponding sample means. In addition, we report the conditional mean of the disequilibrium size which is calculated by

$$\begin{aligned} E\left(\widetilde{D}|\widetilde{D}>0\right) &= \widehat{\alpha}+\overline{\lambda^{*}}\widehat{\beta}+\overline{Z}'\widehat{\delta}+\left(\widehat{\gamma}_{0}+\widehat{\gamma}_{1}\overline{\widetilde{D}}\right)\frac{\phi(A)}{\Phi(A)}, \\ A &\equiv \frac{\widehat{\alpha}+\overline{\lambda^{*}}\widehat{\beta}+\overline{Z}'\widehat{\delta}}{\widehat{\gamma}_{0}+\widehat{\gamma}_{1}\overline{\widetilde{D}}}, \end{aligned} \tag{30}$$

where $\Phi(\cdot)$ indicates the standard normal cumulative distribution function. For comparison, we also provide the sample counterparts for both model-based estimates.

Consistent with the previous results, the predicted probability of equilibrium is much higher during the pre-crisis period than during the post-crisis period. For example, the predicted probability of equilibrium during the pre-crisis period is about 43% while the probability is only about 29% during the post-crisis period on a daily basis. Similarly, the conditional mean of the disequilibrium size is smaller during the pre-crisis period than during the post-crisis period. For example, the conditional mean of the disequilibrium size during the pre-crisis period is about 75 bps whereas the size is about 201 bps during the post-crisis period on a daily basis. In all cases, both the model-based estimates and their sample counterparts are similar in size, implying a validity of the model for this empirical analysis.

Understandably, the conventional model tends to under-estimate the predicted probability of equilibrium and over-estimate the conditional mean of the disequilibrium size during the post-crisis period, compared to the new model. Not only the under-estimation of the predicted probability of equilibrium but also the over-estimation of the conditional mean of the disequilibrium size are attributable to the ignorance of borrowing spreads in the conventional model.

5 Conclusion

While emerging forward exchange markets have been rapidly developed, market efficiency has been rarely examined for EMs yet. To properly test the market efficiency for EMs, we develop a modified CIP condition by taking into account the EM-specific heterogeneities in this paper. In particular, we set up a simple model which contains realistic features such as not only FX forward transaction costs but also differential foreign currency borrowing costs and capacities, and customer-related FX inventories among FX banks. Based on the new model, we develop a modified CIP condition which is featured with a neutral band associated with both transaction costs and borrowing spreads.

We then apply the modified CIP condition into Korean forward exchange market and provide empirical analysis results for Korean market which can also be useful for analyzing other EMs. The empirical results suggest that we may run the risk of over-rejecting market efficiency by ignoring foreign currency borrowing spreads in the context of the CIP.

The new model contains transaction costs arising only from forward exchange transactions but not from spot exchange transactions or the associated money market transactions; however, the extension of the model by including the ignored transaction costs would be straightforward, if it is necessary to do so. The new model also includes market conditions (such as customer-related inventories and foreign currency borrowing capacities) which are potentially useful for explaining the changes in the neutral CIP band and the observed deviations from the CIP over time. Extending the analysis into long-term forward exchange markets would be another research direction in the future when long-term FX markets and the associated capital markets are sufficiently developed.

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Table 1. Alternative methods to hedge long customer-related FX position.

This table demonstrates detailed transactions and cash flows of the alternative methods for the j-th FX bank to hedge its long customer-related FX position. U.S. dollar ($) is assumed as a representative foreign currency, and a hypothetical EM domestic currency is denoted by Đ. Foreign currency, domestic currency, and customer transactions are denoted by fc, dc, and ct, respectively.

Current time		Maturity time	
Transaction	Cash flow	Transaction	Cash flow
Method (i)			
a. Borrow fc	+$1	a. Repay fc	-$$(1 + i_f + \lambda_j)$
b. Sell fc	-$1		
	+ĐS		
c. Lend dc	-ĐS	c. Receive dc	+Đ$S\,(1 + i_d)$
		d. Settle ct	+$$(1 + i_f + \lambda_j)$
			-Đ$F_b\,(1 + i_f + \lambda_j)$
Total	0		Đ$[S\,(1 + i_d) - F_b\,(1 + i_f + \lambda_j)]$
Method (ii)			
a. buy/sell FX swap	+$1	a. Settle FX swap	-$1
	-ĐS		+ĐF_b
b. Sell fc	-$1		
	+ĐS		
		c. Settle ct	+$1
			-ĐF_b
Total	0		0
Method (iii)			
a. Borrow fc	+$1	a. Repay fc	-$$(1 + i_f + \lambda_j)$
b. Sell/buy FX swap	-$1	b. Settle FX swap	+$1
	+ĐS		-ĐF_a
c. Lend dc	-ĐS	c. Receive dc	+Đ$S\,(1 + i_d)$
d. Buy forward		d. Settle forward	+$$(i_f + \lambda_j)$
			-Đ$F_a\,(i_f + \lambda_j)$
Total	0		Đ$[S\,(1 + i_d) - F_a\,(1 + i_f + \lambda_j)]$

Table 2. Numerical example for the case 1.

This table demonstrates the results under various numerical assumptions for the case 1 under the new model. Refer to the text for the other parametric assumptions.

	Variable	Benchmark	Situation 1	Situation 2	Situation 3
Assumption	X_j	1	1	1.5	1
	Y_j	2	2	2	1.5
	λ_j	$0.02 \cdot j$	$0.03 \cdot j$	$0.02 \cdot j$	$0.02 \cdot j$
Result	j^{**}	0.45	0.1667	0.675	0.6
	j^{*}	0.55	0.8333	0.775	0.7
	$\lambda^{**}\,[= D^{**}]$	0.009	0.005	0.0135	0.012
	$\lambda^{*}\,[= D^{*}]$	0.011	0.025	0.0155	0.014
	F_b^*	1008.82	995.17	1004.39	1005.86
	F_a^*	1010.80	1014.78	1006.35	1007.83
	F^*	1009.81	1004.97	1005.37	1006.84
	f^*	0.00981	0.00497	0.00537	0.00684
	$Y_{s/b}\left[= Y_{b/s}\right]$	0.45	0.1667	0.3375	0.3

Table 3. Alternative methods to hedge short customer-related FX position.

This table demonstrates detailed transactions and cash flows of the two methods for the j-th FX bank to hedge its short customer-related FX position. Refer to Table 1 for the other explanations.

Current time		Maturity time	
Transaction	Cash flow	Transaction	Cash flow
Method (i)			
a. Buy fc	+\$1		
	-ĐS		
b. Lend fc	-\$1	b. Receive fc	\$$(1+i_f)$
c. Borrow dc	+ĐS	c. Repay dc	-Đ$S\,(1+i_d)$
		d. Settle ct	-\$$(1+i_f)$
			+Đ$F_a\,(1+i_f)$
Total	0		Đ$[F_a\,(1+i_f) - S\,(1+i_d)]$
Method (ii)			
a. Sell/buy FX swap	-\$1	a. Settle FX swap	+\$1
	+ĐS		-ĐF_a
b. Buy fc	+\$1		
	-ĐS		
		c. Settle ct	-\$1
			+ĐF_a
Total	0		0

Table 4. Summary statistics of the data.

This table shows summary statistics of the data. All numbers are annualized basis points. λ^* indicates the threshold borrowing spread, τ the transaction costs measured by half of the bid-ask spread of FX forward exchange rate quotations, D the deviation from the standard CIP, and $\widetilde{D}$ the deviation from the modified CIP.

	Daily				Weekly			
	Mean	S.d.	Min	Max	Mean	S.d.	Min	Max
	A. Whole period							
λ^*	50.8	62.6	3.5	450.2	49.5	59.4	11.7	348.2
$\lambda^* - \tau$	19.9	46.0	0.0	365.9	18.5	42.0	0.0	263.0
$\|D\|$	134.1	191.3	0.2	2869.5	98.4	127.7	0.0	1071.4
$\widetilde{D}$	93.0	160.9	0.0	2706.0	56.7	92.5	0.0	849.1
	B. Sub-period 1: Pre-crisis							
λ^*	25.7	9.8	3.5	110.5	24.9	6.4	11.7	47.4
$\lambda^* - \tau$	4.3	7.2	0.0	36.5	3.5	6.2	0.0	27.5
$\|D\|$	59.2	66.4	0.2	599.3	39.2	36.0	0.2	245.9
$\widetilde{D}$	39.7	63.2	0.0	572.9	21.1	31.9	0.0	218.6
	C. Sub-period 2: Post-crisis							
λ^*	70.7	77.9	7.9	450.2	68.8	73.6	12.1	348.2
$\lambda^* - \tau$	32.2	58.4	0.0	365.9	30.3	53.0	0.0	263.0
$\|D\|$	193.3	232.7	0.4	2869.5	144.8	152.3	0.0	1071.4
$\widetilde{D}$	135.2	198.0	0.0	2706.0	84.8	112.7	0.0	849.1

Table 5. Estimation results for the new model.

This table shows the estimation results for the new model which is specified as (23) and (24).

	Whole period		Sub-period 1		Sub-period 2	
Variable	Estimate	S.e.	Estimate	S.e.	Estimate	S.e.
	A. Daily					
constant	0.1137	0.0316	0.0579	0.0803	0.4634	0.0496
λ^*_{t1}	-0.3721	0.0062	-0.2356	0.1976	-0.4173	0.0774
$\widetilde{D}_{t-1}$	0.0874	0.0183	-0.0101	0.0317	0.0873	0.0232
λ^*_{t-1}	0.2950	0.0103	0.2833	0.0390	0.1856	0.1278
$\widetilde{D}_{t-2}$	0.0703	0.0218	-0.0266	0.0291	0.0589	0.0252
λ^*_{t-2}	0.0013	0.0068	-0.1052	0.1313	0.0188	0.0602
$\widetilde{D}_{t-3}$	0.1008	0.0188	0.0447	0.0323	0.0774	0.0221
λ^*_{t-3}	0.3302	0.0028	0.2575	0.1202	0.3270	0.1189
$\widetilde{D}_{t-4}$	0.0911	0.0244	-0.0290	0.0323	0.0763	0.0287
λ^*_{t-4}	0.2130	0.0042	0.1969	0.0466	0.2152	0.0950
Variance:						
constant	1.7206	0.0025	0.6920	0.0370	2.5313	0.0858
$\widetilde{D}_{t-1}$	0.9281	0.0174	0.1473	0.0476	0.9172	0.1006
	B. Weekly					
constant	0.0569	0.0416	-0.0784	0.1651	0.0556	0.0673
λ^*_{t}	-0.4236	0.1481	-0.0840	0.5047	-0.3428	0.1067
$\widetilde{D}_{t-1}$	0.0694	0.0310	-0.0908	0.0574	0.0711	0.0395
λ^*_{t-1}	-0.6176	0.2189	0.1837	0.5278	-0.6423	0.1693
$\widetilde{D}_{t-2}$	0.0758	0.0377	-0.0089	0.0597	0.0894	0.0447
λ^*_{t-2}	-0.2521	0.2678	-1.5063	0.7386	-0.2051	0.1407
$\widetilde{D}_{t-3}$	0.2293	0.0413	-0.0654	0.0595	0.2764	0.0521
λ^*_{t-3}	0.4331	0.2569	0.7492	0.5280	0.4360	0.1033
$\widetilde{D}_{t-4}$	0.1327	0.0347	-0.0173	0.0552	0.1687	0.0496
λ^*_{t-4}	0.0762	0.2144	0.5662	0.6006	0.0178	0.0528
$\widetilde{D}_{t-5}$	0.1005	0.0471	0.0401	0.0855	0.0910	0.0534
λ^*_{t-5}	0.6200	0.2190	0.5991	0.5821	0.4317	0.0966
Variance:						
constant	0.3454	0.0376	0.0999	0.0162	0.5173	0.0561
$\widetilde{D}_{t-1}$	0.7389	0.1106	0.5345	0.1526	0.6693	0.0928

Table 6. Estimation results for the conventional model.

This table shows the estimation results for the conventional model which is specified as (27) and (28).

	Whole period		Sub-period 1		Sub-period 2	
Parameter	Estimate	S.e.	Estimate	S.e.	Estimate	S.e.
	A. Daily					
α	-0.3163	0.0015	0.0219	0.0792	-0.0361	0.0538
β	1.0610	0.0041	-0.2841	0.2088	1.6730	0.0935
$\widehat{D}_{t-1}$	0.0866	0.0045	-0.0097	0.0294	0.0930	0.0206
τ_{t-1}	-0.4383	0.0022	0.3668	0.1738	-1.0854	0.0667
$\widehat{D}_{t-2}$	0.0602	0.0029	-0.0208	0.0299	0.0504	0.0170
τ_{t-2}	0.3620	0.0035	0.0168	0.1330	0.3710	0.0356
$\widehat{D}_{t-3}$	0.1072	0.0038	0.0452	0.0295	0.0868	0.0186
τ_{t-3}	0.9793	0.0025	0.4475	0.2090	0.8666	0.0310
$\widehat{D}_{t-4}$	0.1093	0.0027	-0.0168	0.0294	0.0987	0.0218
τ_{t-4}	0.8627	0.0039	0.4280	0.2407	0.7924	0.0220
Variance:						
constant	1.4611	0.0021	0.5945	0.0345	2.2272	0.0764
$\widehat{D}_{t-1}$	0.8085	0.0009	0.1527	0.0524	0.7597	0.0491
	B. Weekly					
α	-0.1672	0.0606	0.0277	0.1218	-0.1370	0.0923
β	1.0104	0.4499	-0.3910	0.5560	1.8313	0.6336
$\widehat{D}_{t-1}$	0.1468	0.0334	-0.0741	0.0623	0.1756	0.0431
τ_{t-1}	-0.1519	0.4260	0.2743	0.5269	-0.5777	0.5976
$\widehat{D}_{t-2}$	0.1871	0.0325	-0.0145	0.0573	0.2094	0.0423
τ_{t-2}	0.3868	0.3707	0.4156	0.5443	0.2887	0.5958
$\widehat{D}_{t-3}$	0.1979	0.0442	0.0765	0.0779	0.2022	0.0524
τ_{t-3}	-0.0821	0.4083	-0.0798	0.5550	-0.4908	0.6218
Variance:						
constant	0.2346	0.0281	0.0962	0.0146	0.3810	0.0576
$\widehat{D}_{t-1}$	0.6730	0.0824	0.5239	0.1390	0.5701	0.0820

Table 7. Probability of equilibrium and conditional disequilibrium size.

This table shows the predicted probability of equilibrium (‘$\Pr[\widetilde{D}=0]$’)which is specified as (29) and the conditional disequilibrium size (‘$\mathrm{E}[\widetilde{D}|\widetilde{D}>0]$’) expressed as (30). Not only the estimates from the model (Model) but also sample counterparts (Data) are provided.

	Daily			Weekly		
	Whole	Sub-prd 1	Sub-prd 2	Whole	Sub-prd 1	Sub-prd 2
	A. New model					
$\Pr[\widetilde{D}=0]$: Model	0.3553	0.4263	0.2889	0.3221	0.4517	0.2381
$\Pr[\widetilde{D}=0]$: Data	0.2514	0.3581	0.1674	0.2844	0.4070	0.1923
$\mathrm{E}[\widetilde{D}\|\widetilde{D}>0]$: Model	1.5248	0.7529	2.0146	0.8664	0.3848	1.1637
$\mathrm{E}[\widetilde{D}\|\widetilde{D}>0]$: Data	1.2415	0.6149	1.6249	0.7923	0.3430	1.0432
	B. Conventional model					
$\Pr[\widetilde{D}=0]$: Model	0.2505	0.3937	0.1478	0.1854	0.4458	0.0571
$\Pr[\widetilde{D}=0]$: Data	0.1988	0.3003	0.1189	0.2409	0.3763	0.1366
$\mathrm{E}[\widetilde{D}\|\widetilde{D}>0]$: Model	1.6710	0.7330	2.4369	1.0313	0.3890	1.7051
$\mathrm{E}[\widetilde{D}\|\widetilde{D}>0]$: Data	1.3231	0.5853	1.7879	0.9314	0.3486	1.2641

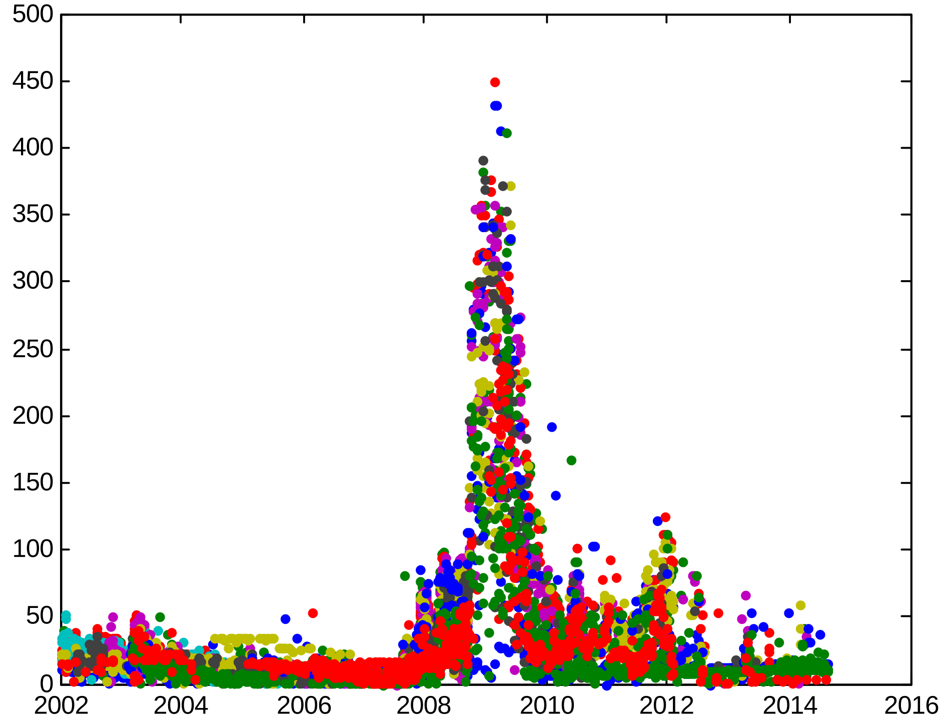

Figure 1. Short-term U.S. dollar borrowing spreads of individual Korean domestic banks.

This figure plots the time trend of short-term (i.e., maturity up to one year) U.S. dollar borrowing spreads of individual Korean domestic banks from January 1, 2002 to August 15, 2014.

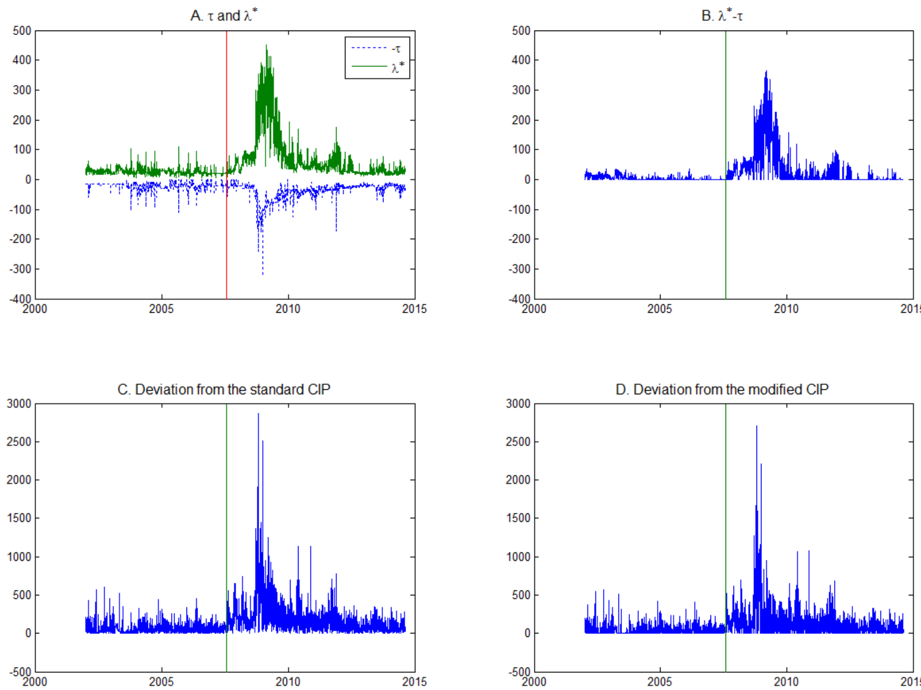

Figure 2. Threshold borrowing spreads, transaction costs, and deviations from the CIP: Daily frequency.

This figure plots the daily time trend of the threshold borrowing spreads λ^* and transaction costs τ (Panel A), the difference between the both λ^*-τ (Panel B), the absolute deviations from the standard CIP (Panel C), and the deviations from the modified CIP (Panel D) in the short-term Korean markets from January 1, 2002 to August 15, 2014. The vertical line indicates July 31, 2007 to differentiate two periods: pre-crisis and post-crisis.

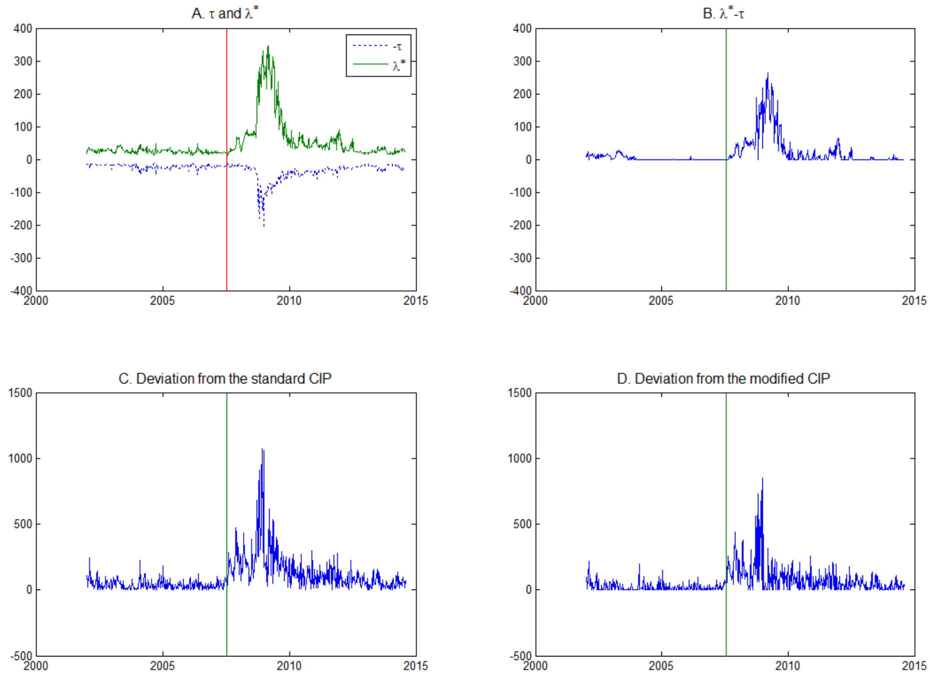

Figure 3. Threshold borrowing spreads, transaction costs, and deviations from the CIP: Weekly frequency.

This figure plots the weekly time trend of the threshold borrowing spreads λ^* and transaction costs τ (Panel A), the difference between the both λ^*-τ (Panel B), the absolute deviations from the standard CIP (Panel C), and the deviations from the modified CIP (Panel D) in the short-term Korean markets from January 1, 2002 to August 15, 2014. The vertical line indicates July 31, 2007 to differentiate two periods: pre-crisis and post-crisis.