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Abstract

During the global financial crisis, there were substantial deviations from covered interest parity (CIP) condition. In particular, in the post Lehman period, the US dollar interest rate became very low on the forward market. However, the deviations from the CIP condition varied across markets. After presenting a simple model, the following analysis examines how the CIP condition between the Japanese yen and the US dollar was violated in Tokyo, London, and New York markets. We show that the CIP deviations became largest in the New York market soon after the Lehman shock but were largest in the Tokyo market in the rest of the turmoil period. The regressions suggest that market-specific credit risks and central banks' liquidity provisions explained the difference across the markets. In particular, they indicate that larger dollar-specific risk and smaller yen-specific risk caused larger deviations in the Tokyo market.

JEL codes: G15, G12, F36

Keywords: covered interest parity, credit risk, liquidity risk, interbank market, global financial crisis

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1. Introduction

In a well-integrated money market, covered interest parity (CIP) condition was perceived to be solidly anchored in riskless arbitrage for international asset pricing. However, reflecting various risk characteristics, deviations from the CIP condition became substantial during previous crises (see, for example, Taylor, 1989; Rhee and Chang, 1992 for earlier contributions in literature). For unsecured rates such as LIBOR, deviations were widened reflecting creditworthiness of financial institutions. However, even for secured rates such as overnight index swap (OIS) rates, deviations were still substantial during the global financial crisis. From June 1, 2006 to December 30, 2010, Figure 1 depicts daily deviations from the CIP condition between the US dollar and each of the six non-US dollar currencies: Euro, UK pound, Danish krone, Swiss franc, Japanese yen, and Singapore dollar. We calculated deviations from the CIP condition by the annualized value of $(1+i^{us}_t) - (1+i^{n}_t)(F_{t+1}/S_t)$, where i^{us}_t is three-month US dollar OIS rate, i^{n}_t is three-month non-US dollar OIS rate, S_t is the spot exchange rate between the two currencies, and F_{t+1} is its three-month forward exchange rate. For all combinations, deviations from the CIP condition had been negligible until the beginning of August 2007. But significant downward deviations had occurred since mid-August 2007. In particular, there were large downward deviations after the Lehman shock on September 15 in 2008. The downward deviations were stabilized around the end of 2008 but had been significant until summer of 2009.[1]

Among the six non-US dollar currencies, the deviations were largest in the Danish krone and smallest in the Singapore dollar. But the choice of the currencies did not make substantial difference for the deviations. The OIS rates are secured rates that measure market participants' expected average policy rate over the relevant term. Since secured arbitrage, as opposed to unsecured, removes many of the counter-party credit risks, this may imply that potential liquidity risk in the US dollar was the dominant source in violating the CIP condition. However, during the global financial crisis, liquidity risk might have differed not only across currencies but also across markets. In particular, it is likely

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[1] The figure shows another significant downward deviations after spring in 2010 because of the Euro crisis. But the effect of the Euro crisis is out of scope of this paper.

that the US dollar funding was tighter when the London and the New York markets were closed, while the Japanese yen funding was tighter when the Tokyo market was closed.

The purpose of this paper is to examine how deviations from the CIP condition varied across the markets during the global financial crisis. During the crisis, financial sectors expanded their prudential hoarding in the face of growing internal funding and liquidity needs, as well as limited capital to pledge in exchange for liquid funds. Because of its role as dominant international currency, the US dollar interest rate was likely to be low on the forward market in the global financial crisis. After presenting a simple model that describes such an economy, we calculate the CIP condition between the Japanese yen and the US dollar and examine how it was violated in 2007-2009 in the three markets: Tokyo, London, and New York. We show that when we use the Japanese yen as a benchmark, the US dollar interest rate, which had temporarily became lowest in the New York market soon after the Lehman shock, was lowest in the Tokyo market during the rest of the post Lehman turmoil. The regression results suggest that credit risk in interbank markets and central banks' liquidity provisions explained the difference across the markets. We observe that the market-specific CIP deviations were attributable to asymmetric risks across the markets. In particular, larger dollar-specific risk and smaller yen-specific risk explained larger deviations in the Tokyo market. We also find that some coordinated central bank liquidity provision was asymmetrically useful in reducing market-specific liquidity risk.

In previous literature, several studies have explored sources of deviations from the CIP condition under the global financial crisis. Baba and Packer (2009a,b) are one of the first attempts and find that deviations from covered interest parity were negatively associated with the creditworthiness of European and US financial institutions. The authors such as Coffey, Hrung, and Sarkar (2009) and Fong, Valente, and Fung (2010) show that in addition to credit risk, liquidity and market risk played important roles in explaining the deviations.[2] There are also several studies on the effects of central bank liquidity

[2] Grioli and Ranaldo (2010) find that the results were essentially the same even if we used secured rates such as OIS. Fukuda (2015) shows that the UK pound became equally low as the US dollar in the Euro

provisions during the global financial crisis in recent literature. Taylor and Williams (2009) show how TAF affected risk premiums in the US interbank market. Goldberg, Kennedy, and Miu (2011) show the contribution of foreign exchange swap lines among central banks to reducing dollar funding pressures and limiting stresses in money markets (see also Genberg, Hui, Wong and Chung, 2009; Aizenman and Pasricha, 2010; Hui, Genberg, and Chung, 2011 for their recent contribution to the same topic).

The following analysis confirms some of their findings, especially those based on secured rates. However, unlike previous studies, our analysis pays a special attention to how the CIP condition was violated in three alternative markets: Tokyo, London, and New York. We show that deviations from the CIP condition showed different features across the markets soon after the Lehman shock. We find that market-specific risk premiums discussed in Fukuda (2012), especially lager dollar-specific risk and smaller yen-specific risk in the Tokyo market, explained the difference across the markets.[3] We also find that central bank liquidity provisions had varieties of asymmetric effects across the markets.

In investigating market-specific features in Tokyo and New York markets by intra-daily data, our analysis has motivations that are similar to those in Ito and Roley (1987) and Tsutsui and Hirayama (2010). However, these studies neither analyzed the CIP condition nor explored market-specific features during the global financial crisis. Investigating what happened during the global financial crisis is worthwhile to be noted because large shocks reveal market-specific features more clearly than small shocks.

The rest of the paper is organized as follows. After exploring a simple model of our analysis in Section 2, Section 3 investigates deviations from the CIP condition in the three markets. After explaining a basic framework of our econometric tests in Section 4, Section 5 explains how to measure counter-party credit risks and liquidity risks. Section 6 and 7 report the results of our regressions. Section 8 concludes and refers to the implications.

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crisis.

[3] Fukunaga and Kato (2015) investigate the relationship between the Japanese general collateral (GC) repurchase agreement (repo) and uncollateralized call rates in Japan during the recent financial crisis.

2. A Theoretical Model

To see how international liquidity risk is reflected in the CIP condition, we consider a representative agent model in a small open economy. In the economy, there are two liquid assets. The two liquid assets which mitigate losses from liquidity shocks are domestic liquid asset and foreign liquid asset. The domestic liquid asset is denominated in the local (non-US dollar) currency, whereas the foreign liquid asset is denominated in the international currency (that is, the US dollar). The representative consumer chooses his or her stream of real consumption and asset holdings so as to maximize the following expected utility:

$$(1) \qquad \sum_{j=0}^{\infty} \beta^{i} E_t u(C_{t+j}),$$

where β is discount factor such that $0 < \beta < 1$ and E_t is conditional expectation operator based on the information at period t. In the following analysis, we denote nominal values of domestic and foreign liquid assets at the end of period t by A_t and A^*_t respectively. Then, for all t, the consumer's budget constraint is written as:

$$(2) \quad A_t + S_t A^*_t = (1+i_{t-1}) A_{t-1} + (1+i^*_{t-1}) F_t A^*_{t-1} + P_t (Y_t - L_t - C_t),$$

where P_t = domestic price, i_{t-1} = nominal interest rate of domestic liquid asset, i^*_{t-1} = nominal interest rate of foreign liquid asset, S_t = spot exchange rate, F_t = forward exchange rate, and L_t = real loss from liquidity shocks. For all variables, subscript denotes time period. Y_t is real output in period t.

Because of nominal contract, the consumer cannot hedge domestic inflation risk for the two liquid assets under the budget constraint (2). However, since F_t is forward exchange rate contracted in period t-1, the consumer covers the foreign asset's exchange risk by the forward contract. Thus, even if the spot exchange rate is volatile, the consumer faces no uncertainty on the one-period nominal return from holding the foreign liquid asset.

In our economy, both local and international liquidity shocks, L_t^D and L_t^F, hit the economy and deteriorate the output Y_t at the beginning of each period. The size of the production loss L_t ($\equiv L_t^D + L_t^F$), however, depends on real values of the liquid assets the consumer holds in period t. Following a shopping time model of money in literature, we assume that the loss from the local liquidity shock $L^D{}_t(A_t/P_t)$ is decreasing and convex function of A_t/P_t, whereas the loss from the international liquidity shock $L^F{}_t\,(A^*_t/P^*_t)$ is decreasing and convex function of A^*_t/P^*_t where P^*_t is foreign price in period t. We can thus denote the total loss from the liquidity shocks as follows

$$(3) \quad L_t = L^D{}_t\,(A_t/P_t) + (S_t P^*_t\,/P_t) L^F{}_t\,(A^*_t/P^*_t),$$

where $L^{D\prime}{}_t\,(\cdot) < 0$, $L^{D\prime\prime}{}_t\,(\cdot) > 0$, $L^{F\prime}{}_t\,(\cdot) < 0$, and $L^{F\prime\prime}{}_t\,(\cdot) > 0$. Since the loss from the international shock is denominated in the international currency, it is multiplied by $(S_t P^*_t\,/P_t)$ to adjust the real exchange rate.

The representative consumer maximizes (1) subject to (2) and (3). The first-order conditions of the constrained maximization lead to

$$(4) \quad u'\,(C_t) = \beta\,[(1+i_t)/\{1+L^{D\prime}{}_t\,(A_t/P_t)\}]\,E_t\{(P_t/P_{t+1})u'\,(C_{t+1})\},$$

$$= \beta\,[(1+i^*_t)(F_{t+1}/S_t)/\{1+L^{F\prime}{}_t\,(A^*_t/P^*_t)\}]\,E_t\{(P_t/P_{t+1})u'\,(C_{t+1})\}.$$

Rearranging the second equality of the first-order conditions, we obtain the following modified CIP condition:

$$(5) \quad (1+i_t)/\{1+L^{D\prime}{}_t\,(A_t/P_t)\} = (1+i^*_t)(F_{t+1}/S_t)/\{1+L^{F\prime}{}_t\,(A'^*_t/P^*_t)\}.$$

Since no liquidity shock implies that $L^{D'}_t(A_t/P_t) = L^{F'}_t(A*_t/P_t) = 0$, equation (5) is degenerated into the standard CIP condition when there is no liquidity shock. However, to the extent that the two liquid assets have different marginal contributions in mitigating the liquidity shocks, the condition (5) implies that the standard CIP condition does not hold when there are liquidity shocks. Taking logarithm of both sides of equation (5), we approximately obtain

$$(6) \quad i_t - (i*_t + f_{t+1} - s_t) = L^{D'}_t(A_t/P_t) - L^{F'}_t(A'*_t/P*_t),$$

where $f_{t+1} \equiv log(F_{t+1})$ and $s_t \equiv log(S_t)$.

Equation (6) indicates that the deviations from the CIP condition depend on the difference between $L^{D'}_t(A_t/P_t)$ and $L^{F'}_t(A*_t/P*_t)$. It is easy to see that $i_t > i*_t + f_{t+1} - s_t$ when $L^{F'}_t(A*_t/P*_t) < L^{D'}_t(A_t/P_t) \leq 0$ and that $i_t < i*_t + f_{t+1} - s_t$ when $L^{D'}_t(A_t/P_t) < L^{F'}_t(A*_t/P*_t) \leq 0$. During the global financial crisis, the shortage of international liquidity increased marginal benefits of holding the US dollar large in many countries. To the extent that $A*_t$ is foreign liquid assets denominated in the US dollar, this implies that the absolute value of $L^{F'}_t(A^F_t/P*_t)$ became large during the crisis. The condition (6) thus explains why the US dollar interest rate became lower on the forward market during the crisis.

However, we need to note that the loss from the shortage of international liquidity may differ across different markets. More specifically, the London and the New York markets are thicker than the Tokyo market in the US dollar transactions, while the Tokyo market is thicker than the other two markets in the Japanese yen transactions. This implies that the Tokyo market may have smaller absolute value of $L^{D'}_t(A_t/P_t)$ and larger absolute value of $L^{F'}_t(A*_t/P*_t)$ than the other two markets. Comparing deviations from the CIP condition in the Tokyo market with those in the London and New York markets, the following sections explore the validity of this conjecture.

3. Deviations from CIP in the Three Markets

In the following analysis, we examine how the degree of deviations from the CIP condition differed in the three markets before and after the global financial crisis. Using daily data of three-month OIS rates, we calculate the CIP condition between the Japanese yen and the US dollar and examine how it was violated in the three markets during the global financial crisis in 2007-2009. The spot exchange rates and three-month forward exchange rates used for each market are their interbank middle rates at 5pm in Tokyo time, at 4pm in London time, and at 5pm in New York time respectively.

Unfortunately, yen-denominated OIS rates are available only in Tokyo time, whereas dollar-denominated OIS rates are available only in NY time. We thus use date *t* dollar-denominated OIS rate in NY time as a proxy for date *t*+1 rate in Tokyo time and date *t*+1 rate in London time respectively. We also use date *t* yen-denominated OIS rate in Tokyo time as a proxy for date *t* rates in London and NY times respectively. The approximations are based on the assumption that market participants expect no policy change of FRB when the NY market is closed and no policy change of the BOJ when the Tokyo market is closed. Since the daily changes of the OIS rates are very small, the measurement errors from the approximation will be negligible.

For the three markets, we calculate deviations from the CIP condition by the annualized value of $(1+i^{us}_{t}) - (1+i^{jp}_{t})(F_{t+1}/S_{t})$, where i^{us}_{t} is three-month US dollar OIS rate, i^{jp}_{t} is three-month Japanese yen OIS rate, S_t is the yen-dollar spot exchange rate, and F_{t+1} is its three-month forward exchange rate. The units of the interest rates are basis points. The spot and forward exchange rates in London time and the dollar-denominated OIS rates are downloaded from the Datastream, whereas the spot and forward exchange rates in Tokyo and NY times are downloaded from the Nikkei Quick database. The yen-denominated OIS rates are from Tokyo Tanshi Co. Ltd.

Table 1 summarizes biannual average of the deviations from the CIP condition in the three markets from 2007 to 2009. It indicates that the absolute value of the deviations from the CIP condition were less than 10 basis points in all of the markets in the first half of 2007. But after the latter half of 2007, the negative deviations were more than quadruplicated in the three markets. In particular, the absolute value of the deviations exceeded 130 basis points in the latter half of 2008. In the latter half of 2009, the deviations were almost stabilized but their absolute values were larger than those in the first half of 2007. The absolute values of the deviations were similar across the three markets. But except in the first half of 2008, the Tokyo market had the largest deviations. The Tokyo market had larger deviations than the other two markets especially after the second half of 2008.

Table 2 reports monthly average of the deviations from the CIP condition in the three markets from July 2008 to March 2009. To see the changes before and after the Lehman shock, it also reports average deviations in the three markets in the first-half and the second-half of September 2008. The New York market had the largest deviations in September 2008. In particular, the difference between the New York and the other two markets became substantial in the second half of September 2008. This suggests that reflecting a series of unexpected shocks originated in New York or in Washington D.C., the New York market faced more serious liquidity shortage soon after the Lehman shock. However, except in September 2008 and in November 2008, the Tokyo market still had the largest deviations. This implies that the Tokyo market faced either the largest liquidity shortage in the US dollar or the smallest liquidity shortage in the Japanese yen during most of the turmoil period.

To test whether the deviations from the CIP condition in the Tokyo market are significantly different from those in the other two markets, Table 3 reports mean value of the difference between the markets and its t-statistics for three alternative sample periods: from January 2, 2007 to August 31, 2008, from September 1, 2008 to September 30, 2008, and from October 1, 2008 to December 31, 2009. In the table, “Tokyo-London” indicates the difference between the Tokyo and London markets and “Tokyo-NY” indicates the difference between the Tokyo and New York markets. Each mean value indicates that the Tokyo market had larger deviations than the other two markets from January 2, 2007 to August 31, 2008 and had smaller deviations from September 1, 2008 to September 30, 2008. But its t-value implies that the differences across the markets were not statistically significant before September 2008. In contrast, the Tokyo market had significantly larger deviations from October 1, 2008 to December 31, 2009. Each t-value suggests that when the Japanese yen is used as a benchmark, the Tokyo market had significantly lower US dollar interest rate than the other two markets during the post-Lehman turmoil period.

4. Empirical Specification

The purpose of the following sections is to examine how market-specific risks caused substantial deviations from the CIP condition during the global financial crisis. Our main interest is to explore what determines the size of deviations in different markets. Equation (6) in section 2 implies that the degree of the deviations depends on $L^{F'}_{t}$ (A^*_t/P^*_t) and $L^{D'}_{t}$ (A_t/P_t). We will investigate whether these liquidity shocks had market-specific features during the global financial crisis. Unfortunately, we cannot observe such notional variables directly. For the proxies, we thus use market-specific credit risk measures and market-specific liquidity risk measures. As mentioned in previous studies, even secured rate deviations from the CIP condition might depend on credit risk in interbank markets. This is because liquidity risk may increase as credit risk increases in interbank markets (see, for example, Afonso, Kovner, and Schoar (2011)). The following analysis follows this idea and explores how credit and liquidity risk measures in interbank markets affected deviations from the CIP condition during the global financial crisis.

For h = Tokyo, London, or New York, we define the degree of deviations from the CIP condition in market h in period t by

$$(7) \qquad Dev_t(h) \equiv \{1 + i^{us}_t(h)\} - \{1 + i^{jp}_t(h)\}\{F_{t+1}(h)/S_t(h)\},$$

where $i^{us}_t(h)$ is three-month US dollar OIS rate, $i^{jp}_t(h)$ is three-month yen OIS rate, $S_t(h)$ is yen-dollar spot exchange rate in market h, and $F_{t+1}(h)$ is its three-month forward exchange rate. The unit of $Dev_t(h)$ is basis point. We then estimate the following EGARCH(1,1) model with lag dependent variables as explanatory variables:[4]

[4] The EGARCH model was proposed by Nelson (1991). While the GARCH model imposes the nonnegative constraints on the parameters, there are no restrictions on these parameters in the EGARCH model.

(8a) $Dev_t(h) = const. + \sum_j a_j Dev_{t\text{-}j}(h) + \sum_k b_k Credit_t(h,k) + \sum_m c_m Policy_{m,t}$,

(8b) $Log\ \sigma_t^2 = const. + d_1\ |\varepsilon_{t-1}/\sigma_{t-1}\ | + d_2\varepsilon_{t-1}/\sigma_{t-1} + d_3 Log\ \sigma_{t-1}^{\ 2} + d_4 Market_t + d_5 Market_{t-1}$,

where k = the US dollar or the Japanese yen, ε_t in (8b) is the error term (residual) in (8a), and σ_t^2 is its GARCH conditional variance.

In (8a), we include $Credit_t(h,k)$ as an explanatory variable to capture credit risk measure in currency k in period t in market h. In the financial turmoil, some traders are not given as much "balance sheet" to invest, which is perceived as a shortage of liquidity to them. Under this situation, the traders at one bank are reluctant to expose their bank's funds during a period of time where the funds might be needed to cover the bank's own shortfalls. Consequently, term loan markets come under stress, and term interest rates may be disconnected from overnight interest rates in each market. The explanatory variable $Credit_t(h,k)$ in (8a) explores the impact of such market-specific credit risk on $Dev_t(h)$.

In (8a), we also include central bank's policy dummy $Policy_{m,t}$ as an explanatory variable. In the global financial crisis, several central banks made attempts to improve liquidity premiums in each money market. To the extent that each central bank has the ability to reduce the liquidity risk premium effectively, measuring the effects of these attempts is a first step toward understanding the nature of the liquidity risk premium. The explanatory variable $Policy_{m,t}$ in (8a) explores the impact of such central bank's attempt on $Dev_t(h)$.

In (8b), we include the Chicago Board Options Exchange Volatility Index (VIX) for $Market_t$. The VIX is a popular measure of the implied volatility of S&P 500 index options. A high value corresponds to a more volatile market and therefore, more costly options. Often referred to as the fear index, the VIX represents a measure of the market's expectation of volatility over the next 30-day period. We use this measure as a proxy of market risk in the US market. To allow the lagged effects, we use the current and lagged value of VIX for $Market_t$ and $Market_{t-1}$ respectively.

5. “Credit Risk Measures” and “Policy Dummies”

5.1. Credit risk measures: $Credit_t(h,k)$

To measure credit risk in each market, the following analysis uses the spreads between LIBOR and OIS rate and those between TIBOR and OIS rate. LIBOR (London Interbank Offered Rate) is a daily reference rate in the London interbank market, while TIBOR (Tokyo Interbank Offered Rate) is a daily reference rate in the Tokyo offshore market. Both dollar-denominated and yen-denominated rates are available for LIBOR and TIBOR. Since LIBOR and TIBOR are based on the interest rates at which banks borrow unsecured funds from other banks in each interbank market, each spread reflects a counterparty credit risk in each currency in each interbank market. That is, the US dollar-denominated LIBOR–OIS spread reflects US dollar-specific credit risk in the London market, while the yen-denominated LIBOR–OIS spread reflects yen-specific credit risk in the London market. Similarly, the US dollar-denominated TIBOR–OIS spread reflects US dollar-specific credit risk in the Tokyo market, while the yen-denominated TIBOR–OIS spread reflects yen-specific credit risk in the Tokyo market.

Both dollar-denominated and yen-denominated LIBORs are published by the British Bankers’ Association, after 11:00 a.m. each day (Greenwich Mean Time). Yen-denominated TIBOR is published by Japanese Bankers Association after 11:00 a.m. each business day (Tokyo time), while dollar-denominated TIBOR is the data collected by Bloomberg and Nikkei Quick News Inc. at the Tokyo close. In calculating the spreads, we use daily data of their three-month rates. The data of yen-denominated TIBOR was downloaded from the Nikkei Quick data base, while the data of dollar-denominated LIBOR was downloaded from DataStream. The data sources of OIS rates are the same as those in section 3.

In the sample period, the spreads may have measurement errors because some panel banks acted strategically when quoting rates to the LIBOR survey during the global financial crisis (see, for example, Mollenkamp and Whitehouse [2008]). How to deal with the measurement errors is outside the scope of this paper. But when the measurement errors exist, the estimated coefficient would be less significant. Thus, to the extent that it is statistically significant, we may conclude that the sign of the estimated coefficients is reliable.

Unfortunately corresponding credit risk measure is not available in New York market. Given the integration between London and New York markets, we thus use the LIBOR–OIS spreads as credit risk measure for the New York market. We also use daily cross-sectional standard deviation of Federal Funds (FF) rates as a proxy of dollar-denominated credit risk in the New York market. To the extent that credit risk is heterogeneous, the standard deviation will increase as credit risk increases in the New York interbank market.

Table 4 summarizes basic test statistics for these daily credit risk measures for the whole sample period from the beginning of January 2007 to the end of December 2009. It also reports those for the two subsample periods: from September 2008 to October 2008 and from November 2008 to December 2009. Concerning the currency-specific spreads, the dollar-denominated spreads have larger mean, larger standard deviation, and larger skewness than the yen-denominated spreads. This indicates that the dollar-denominated spreads are not only larger but also are more volatile and more skewed in the distribution. The feature was especially conspicuous from September 2008 to October 2008 when the Lehman shock hit the global financial markets. During the most turbulent period, the dollar-denominated spreads were more than tripled, while the yen-denominated spreads were widened only modestly. This implies that currency-specific risk rose mainly in the US dollar soon after the Lehman shock. However, the difference between the two currency-specific spreads became smaller from November 2008 to December 2009. In the post Lehman period, the dollar-denominated spreads decreased substantially, while the yen-denominated spreads still remained large.

Regarding the market-specific spreads, it is worthwhile to note that TIBOR-OIS spreads are larger than LIBOR-OIS spreads when denominated in the US dollar but smaller when denominated in the Japanese yen. This was especially true from September 2008 to October 2008; TIBOR-OIS spreads are larger than LIBOR-OIS spreads by 23.66 basis points in mean, 27.1 basis points in median, and 24.85 in maximum. This implies that reflecting less thick dollar transactions, dollar-specific risk went up more in the Tokyo market than in the London market soon after the Lehman shock.

In contrast, TIBOR-OIS spreads are smaller than LIBOR-OIS spreads when denominated in the Japanese yen. This was especially true from September 2008 to October 2008; TIBOR-OIS spreads are smaller than LIBOR-OIS spreads by 10.66 basis points in mean, 14.86 basis points in median, and 7.11 in maximum. Reflecting better credit quality of Japanese banks and thick yen transactions, the yen specific risk went up more in the London market than in the Tokyo market. Thus, unlike the dollar specific risk, the yen-denominated TIBOR-OIS spreads was smaller than the yen-denominated LIBOR-OIS spreads soon after the Lehman shock.

The statistics for standard deviation of FF rates indicates that the volatility of the FF rates changed substantially during the turmoil period. The standard deviation of FF rates increased dramatically soon after the Lehman shock, although they were stabilized substantially after November 2008.

5.2. Policy dummies: $Policy_{m,t}$

In the global financial crisis, the Federal Reserve Bank (FRB)'s Foreign Exchange (FX) swap facilities are designed to improve liquidity conditions in global money markets by providing foreign central banks with the capacity to deliver U.S. dollar funding to institutions in their jurisdictions. Using funds accessed through the swaps, several central banks such as the Bank of Japan (BOJ) and the Bank of England (BOE) provided dollar liquidity to institutions in the regions.

Using the FRB's FX Swap Lines with the BOJ and the BOE, the following analysis use the US dollar liquidity provisions by BOJ and BOE as central bank's policy dummies. We also use the FRB's Term Auction Facility (TAF) to estimate the effect of US dollar liquidity provisions by FRB.[5] The swaps credit of the US dollar was available only to depositories outside the U.S. in the countries in which the central bank participated in the swaps program, while the TAF credit of the US dollar was only directly available to depository institutions located in the U.S. Thus, these US dollar liquidity

[5] Under the Term Auction Facility (TAF), the FRB auctions term funds to depository institutions in the United States. All depository institutions that are eligible to borrow under the primary credit program is eligible to participate in TAF auctions.

provisions could have different effects on deviations from CIP condition in each market. For each FX swap line and TAF, we include the dummy variable which equals to the amount allocated on the dates for the operations and zero otherwise. The unit of the amount for each dummy variable is thousand US dollar.

In addition, to measure the effects of Japanese yen liquidity provisions by BOJ, we use a dummy for BOJ's yen liquidity provisions, that is, "special funds-supplying operations to facilitate corporate financing".[6] We include the dummy variable which equals to the amount allocated on the dates for the operations and zero otherwise. The unit of the amount is thousand Japanese yen. The BOJ's "special funds-supplying operations to facilitate corporate financing" increase availability of the Japanese yen only for financial institutions located in Japan. But since no yen liquidity was provided by other central banks, we use the dummy variable not only for the Tokyo market but also for the London and NY markets. We constructed the BOJ's liquidity provision dummy based on the same calendar day for all of the markets.

6. Estimation Results

This section reports our basic empirical results concerning the effects of various credit risk measures and policy dummies on the deviations from the CIP condition in the three markets. In each regression we use daily data during the sample period from January 2, 2006 through December 30, 2009, a span of time that includes both the market turmoil period and a comparable period of time before and after the turmoil. The units of the interest rates are basis points. To avoid simultaneous biases, explanatory variables expect for the OIS rates are the latest values before 5pm in Tokyo time, 4pm in London time, and 5pm in New York time respectively.

We estimate the EGARCH(1,1) model with two lagged dependent variables in (8a). Table 5 reports the estimated results. They are very similar across the three markets; Most of the credit and policy

[6] "Special funds-supplying operations to facilitate corporate financing" is operations by which the BOJ extends loans to its counterparties for an unlimited amount against the value of corporate debt submitted to the BOJ as collateral.

dummies had significant symmetric effects on the CIP condition in each market. The table reports the estimations with and without including insignificant yen liquidity provisions.

6.1. The effects of local credit risk measures

In all of the three markets, each local credit risk measure has a significantly positive effect when denominated in the US dollar, while it has a significantly negative effect when denominated in the Japanese yen. That is, in the Tokyo market, the dollar-denominated TIBOR–OIS spread (i.e., “Local Dollar spread”) had a significantly negative effect, while the yen-denominated TIBOR–OIS spread (i.e., “Local Yen spread”) had a significantly positive effect. Similarly, in the London and NY markets, the dollar-denominated LIBOR–OIS spread (i.e., “Local Dollar spread”) had a significantly negative effect, while the yen-denominated LIBOR–OIS spread (i.e., “Local Yen spread”) had a significantly positive effect. The Tokyo market had a larger negative effect of “Local Dollar spread” and a smaller positive effect of “Local Yen spread” than the other two markets. But the coefficients were similar in the London and New York markets. The results do not depend on whether we include some liquidity risk measures as explanatory variables or not.

This indicates that an increase in US dollar-specific credit risk in each local market exacerbated the negative deviations in $Dev_t(h)$, while an increase in yen-specific credit risk in each local market reduced the deviations. To the extent that yen-specific credit risk increases $L^{D\,'}_t\,(A_t/P_t)$ and that US dollar-specific credit risk increases $L^{F\,'}_t\,(A^*_t/P^*_t)$, the result is consistent with equation (6) where the deviations from the CIP condition depends on the difference between $L^{D\,'}_t\,(A_t/P_t)$ and $L^{F\,'}_t\,(A^*_t/P^*_t)$. In particular, recalling that the Tokyo market had larger US dollar-specific credit risk and smaller yen-specific credit risk than the other two markets, this may help to explain why the Tokyo market had greater CIP deviations in the post Lehman period.

As did the other dollar-denominated credit risk measures, the standard deviation of FF rates also had a negative effect in the NY market. That is, the increased standard deviation of FF rates exacerbates the negative deviations from CIP condition in the New York market. This was true even if we include the dollar-denominated LIBOR–OIS spread as an explanatory variable. This indicates that the standard deviation of FF rates may reflect different types of credit risks which are not captured by the LIBOR spread. Noting that standard deviation of FF rates soared up dramatically in September 2008 but was stabilized after November 2008, the market-specific feature may explain why the CIP deviations were largest in the New York market soon after the Lehman shock.

6.2. The effects of policy dummies

Among various policy dummies, the dummy for the BOJ's FX swap line has a significantly positive effect in the Tokyo market. The BOJ's US dollar liquidity provisions were effective in reducing US dollar liquidity risk mostly in the Tokyo market. However, the dummy for the BOE's FX swap line and the dummy for the FRB's TAF credit had a negative effect in the London and NY markets respectively. The effect of the BOE's FX swap line was not significant but the effect of the FRB's TAF credit was significant. This indicates that US dollar liquidity provisions outside Japan were not effective in reducing yen-dollar liquidity risk and might have exacerbated the deviations from the yen-dollar CIP condition.

In contrast, the dummy variable of the BOJ's yen liquidity provisions, that is, the dummy for "special funds-supplying operations to facilitate corporate financing", took a positive sign but it was not statistically significant in any market. The BOJ's yen liquidity provisions were not effective in reducing the deviations from the CIP condition during the global financial crisis. This may reflect the fact that shortage of yen liquidity was not serious even during the post Lehman period. This is in marked contrast with the fact that the BOJ's US dollar liquidity provisions were effective in reducing the deviations in the Tokyo market. However, their effects were market-specific in that US dollar liquidity provisions did not reduce the deviations in the London and New York markets.

6.3. GARCH conditional variance equation

When estimating the GARCH conditional variance equation (8b), most of the parameters were statistically significant. In particular, the coefficient of $|\varepsilon_{t-1}/\sigma_{t-1}|$ was always significantly positive, implying that there was asymmetry in the GARCH conditional variance.

Regarding the effects of the market risk on the conditional variance, the estimated coefficient of $Market_t$ was positive, while that of $Market_{t-1}$ was negative. This indicates that a rise of the market risk increased the conditional variance temporarily but reduced it in the next business day. Their absolute value was largest in the Tokyo market and was smallest in the New York market. But the estimated coefficients of $Market_t$ and $Market_{t-1}$ were always statistically significant in all of the markets.

7. The Effects of Foreign Credit Risk Measures

7.1. The purpose of this section

In the last section, we examined what caused substantial deviations from the CIP condition during the global financial crisis and showed that an increase in US dollar-specific credit risk in each local market exacerbated the deviations in the forward contract market, while an increase in yen-specific credit risk in each local market reduced the deviations. We also showed that the BOJ's US dollar liquidity provisions were effective in reducing the deviations in the Tokyo market. However, the analysis in the last section mainly focused on the effects of local shocks on the local market and rarely examined how foreign shocks were transmitted across the markets. The purpose of this section is to examine what additional impacts foreign shocks had on the CIP deviations in local market. For h = Tokyo, London, or New York, we estimate the following EGARCH(1,1) model:

$$(9a) \quad Dev_t(h) = const. + \sum_j a_j\, Dev_{t-j}(h) + \sum_k b_{1,k}\, Credit_t(h,k) + b_2\, STD(FF\ rate_t) + \sum_k c_{1,m}\, Policy_{m,t} + \sum_k c_{2,m^*}\, Policy_{m^*,t},$$

$$(9b) \quad Log\ \sigma_t^2 = const. + d_1 |\varepsilon_{t-1}/\sigma_{t-1}| + d_2 \varepsilon_{t-1}/\sigma_{t-1} + d_3 Log\ \sigma_{t-1}^2 + d_4 Market_t + d_5 Market_{t-1} + \sum_k d_{6,k}\, Credit_t(h^*,k),$$

In estimating the EGARCH(1,1) model, we include $Credit_t(h^*,k)$ and $Policy_{m^*,t}$ as additional variables, where h^* ($\neq h$) denotes a foreign market and m^* ($\neq m$) denotes a foreign policymaker. $Credit_t(h^*,k)$ is credit risk measure in currency k in the foreign market h^*, while $Policy_{m^*,t}$ is policy dummy for a foreign policymaker m^*. We include $Policy_{m^*,t}$ and the standard deviation of FF rates ($STD(FF\ rate_t)$) as explanatory variables in (9a). However, since most of the other foreign credit risk measures did not have a significant effect in (9a), we include $Credit_t(h^*,k)$ not in (9a) but in (9b).

To allow the time differences across the markets, we constructed the BOE's swap line dummy variable based on the same calendar day for the London and the New York markets but based on the last business day for the Tokyo market. We also constructed the FRB's TAF dummy variable based on the same calendar day for the New York market but based on the last business day for the Tokyo and the London markets. We also used the LIBOR–OIS spreads on the same calendar day for the London and the New York markets but those on the last business day for the Tokyo market and used the standard deviation of FF rates on the same calendar day for the New York market but those on the last business day for the Tokyo and the London markets. In contrast, we used the TIBOR–OIS spreads on the same calendar day for all of the markets.

7.2. The estimation results

Table 6 reports the estimated results. Even if we include various foreign shocks as additional explanatory variables, the effects of local credit risk measures and local policy dummies on the deviations did not change in the EGARCH model. In particular, as in Table 5, the estimation results are very similar across the three markets in Table 6. That is, even if we control the effects of foreign shocks, an increase in US dollar-specific credit risk in each local market exacerbated the negative deviations, while an increase in yen-specific credit risk in each local market reduced the deviations. The BOJ's yen liquidity provisions to local financial institutions were not effective in reducing the deviations from the CIP condition during the global financial crisis.

However, unlike the other credit risk measures, the standard deviation of FF rates always took significantly negative sign in all of the three markets. This indicates that the standard deviation of FF rates may reflect different types of credit risks which are captured neither by the LIBOR spreads nor by TIBOR spreads. Noting that standard deviation of FF rates soared up dramatically in September 2008, the result implies that the Lehman shock had world-wide transmissions and caused large scale CIP deviations not only in the New York market but also in the Tokyo and London markets.

In addition, when we include various foreign shocks as additional explanatory variables, the effects of several US dollar liquidity provisions showed different features. The dummy for the BOJ's FX swap line was not significant in the London market. But it had a positive effect not only in the Tokyo market but also in the New York market. The BOJ's US dollar liquidity provisions were effective in reducing US dollar liquidity risk both in the Tokyo market and in the New York market.

In contrast, the dummy for the BOE's FX swap line and the dummy for the FRB's TAF credit had a negative effect in all markets. In particular, the FRB's TAF dummy was statistically significant not only in the New York market but also in the Tokyo market. This indicates that US dollar liquidity provisions outside Japan might have exacerbated world-wide deviations from the yen-dollar CIP condition.

7.3. GARCH conditional variance equation

When estimating the GARCH conditional variance equation (9b), most of the parameters did not change even if we include foreign shocks as additional explanatory variables. In particular, the estimated coefficient of $Market_t$ was positive, while that of $Market_{t-1}$ was negative. However, foreign credit risk measures had additional significant effects in the GARCH conditional variance equation. That is, in the London and NY markets, the dollar-denominated TIBOR–OIS spread (i.e., "Foreign Dollar spread") had a significantly positive effect, while the yen-denominated TIBOR–OIS spread (i.e., "Foreign Yen spread") had a significantly negative effect. In the Tokyo market, the dollar-denominated LIBOR–OIS spread (i.e., "Foreign Dollar spread") had a significantly positive effect, while the yen-denominated LIBOR–OIS spread (i.e., "Foreign Yen spread") had a negative effect.

The result implies that the volatility of the CIP deviations increased when US dollar-specific credit risk had increased in the other market and decreased when yen-specific credit risk had increased in the other market. Noting that US dollar-specific credit risk exacerbated the negative deviations and that yen-specific credit risk stabilized the deviations, the above result indicates that the market-specific credit risk that had increased the deviations increased the volatility in the other market, while the market-specific credit risk that had decreased the deviations decreased the volatility in the other market. In violating the CIP condition, credit risk in each market might affect the volatility of the deviations rather than the level of the deviations in the other markets.

8. Concluding Remarks

The global financial crisis increased various risk premiums in national and regional financial markets. But unlike medium- or long-term financial markets, shortage of the US dollar as liquidity became vital in the international money markets during financial crisis. In this paper, we examined how the CIP condition between the Japanese yen and the US dollar was violated in the Tokyo, London, and New York markets. During the global financial crisis, there were substantial deviations from the CIP condition. We found that the CIP deviations temporarily became largest in the New York market soon after the Lehman shock but was largest in the Tokyo market during most of the turmoil period.

One of the major findings in the paper is that such liquidity shortage of the US dollar was more serious in Tokyo market when the other markets are closed, while that of the Japanese yen was more serious in the other two markets when the Tokyo market is closed. In particular, we find that larger dollar-specific risk and smaller yen-specific risk explained why the CIP deviations were larger in the Tokyo market. Coordinated central banks' liquidity provisions can be an important tool in reducing liquidity risk in the US dollar transactions. However, we observe varieties of asymmetric effects across the markets. This suggests that some regional specific policy prescriptions might be desirable in stabilizing the international financial market.

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Table 1. Biannual average of the deviations from the CIP condition

Unit: basis points

	Tokyo 5pm	London 4pm	New York 5pm
Jan. 2007 - June 2007	-9.53	-9.45	-9.53
July 2007 - Dec. 2007	-46.65	-46.51	-46.15
Jan. 2008 - June 2008	-42.36	-42.36	-42.18
July 2008 - Dec. 2008	-135.79	-134.50	-135.38
Jan. 2009 - June 2009	-50.42	-49.11	-49.29
July 2009 - Dec. 2009	-21.02	-20.62	-20.46

This table summarizes biannual average of the deviations from the CIP condition in the three markets from 2007 to 2009.

Table 2. Monthly average of the deviations from the CIP condition

Unit: basis points

	Tokyo 5pm	London 4pm	New York 5pm
Average July 2008	-60.11	-59.57	-59.88
Average August 2008	-67.61	-66.68	-66.33
Average September 2008	-150.61	-159.10	-169.30
2008/9/1-9/15	-57.62	-61.72	-62.01
2008/9/16-9/30	-243.59	-256.48	-266.84
Average October 2008	-304.92	-293.74	-293.49
Average November 2008	-135.00	-134.99	-135.46
Average December 2008	-92.63	-88.14	-86.23
Average January 2009	-56.05	-53.68	-54.57
Average February 2009	-71.23	-69.97	-69.65
Average March 2009	-60.52	-57.08	-57.88

This table reports monthly average of the deviations from the CIP condition in the three markets from July 2008 to March 2009.

Table 3. **Mean value of the difference between the markets and its t-statistics**

	Tokyo-London			Tokyo-NY		
Sample period	sample mean	t-statistic		sample mean	t-statistic	
January 2, 2007 to December 31, 2009	-0.604	-1.632		-0.548	-1.262	
January 2, 2007 to August 31, 2008	-0.118	-0.385		-0.245	-0.760	
September 1, 2008 to September 30, 2008	7.752	0.958		13.969	1.318	
October 1, 2008 to December 31, 2009	-1.852	-2.981	**	-1.901	-2.951	**

In the table, “Tokyo-London” indicates the difference of the deviations from the CIP condition between the Tokyo and London markets and “Tokyo-NY” indicates the difference between the Tokyo and New York markets. The negative sign in the sample mean implies that the negative deviations are bigger in the Tokyo market.

** Statistical significance at the 5% level.

Table 4. **Basic test statistics for credit risk measures**

(1) January 2 in 2007 to December 31 in 2009

				Unit = basis points	
	Eurodollar		Euroyen		FF rate
	LIBOR-OIS	TIBOR-OIS	LIBOR-OIS	TIBOR-OIS	Std Dev.
Mean	64.89	71.81	36.37	35.40	16.51
Median	61.48	64.30	39.50	35.25	8.00
Maximum	363.75	388.60	80.50	79.23	195.00
Minimum	4.13	4.50	10.25	2.80	2.00
Std. Dev.	61.31	65.64	15.85	15.20	22.12
Skewness	2.02	2.10	0.17	−0.06	3.58
Kurtosis	8.64	8.81	2.45	2.53	20.29
Observations	783	733	759	733	755

(2) September 1 in 2008 to October 31 in 2008

				Unit = basis points	
	Eurodollar		Euroyen		FF rate
	LIBOR-OIS	TIBOR-OIS	LIBOR-OIS	TIBOR-OIS	Std Dev.
Mean	216.51	240.17	50.48	39.82	59.47
Median	252.65	279.75	54.25	39.39	44.00
Maximum	363.75	388.60	66.50	59.39	195.00
Minimum	78.20	84.40	38.06	34.09	7.00
Std. Dev.	99.04	105.51	10.14	5.93	46.68
Skewness	−0.13	−0.34	0.03	1.73	1.21
Kurtosis	1.54	1.66	1.33	6.10	3.85
Observations	45	42	45	42	43

(3) November 1 in 2008 to December 31 in 2009

				Unit = basis points	
	Eurodollar		Euroyen		FF rate
	LIBOR-OIS	TIBOR-OIS	LIBOR-OIS	TIBOR-OIS	Std Dev.
Mean	66.13	77.67	41.05	49.58	7.07
Median	43.11	52.45	40.25	46.12	5.00
Maximum	226.38	233.90	80.50	79.23	56.00
Minimum	7.46	18.30	17.94	36.45	3.00
Std. Dev.	54.81	55.00	0.17	8.80	5.89
Skewness	0.79	0.91	0.36	0.67	3.26
Kurtosis	2.67	2.92	2.03	2.73	19.89
Observations	304	282	293	282	292

Table 5. The estimated results of Equation (8)

			Tokyo Market		London Market		New York Market	
		Constant term	−0.042	−0.039	−0.041	−0.041	−0.038	−0.038
			(−9.837)	(−8.265)***	(−5.907)***	(−5.938)***	(−9.804)***	(−9.836)***
	Lagged	Dependent var. (-1)	0.746	0.759	0.760	0.761	0.735	0.733
	dependent		(20.885)***	(22.388)***	(18.565)***	(18.456)***	(24.870)***	(25.031)***
	var.	Dependent var. (-2)	0.060	0.047	0.096	0.094	0.126	0.128
			(1.543)	(1.259)	(2.415)**	(2.364)**	(4.142)***	(4.268)***
	Local	Local Dollar spread	−0.128	−0.118	−0.108	−0.108	−0.096	−0.097
eq.	credit risk		(−9.800)***	(−8.371)***	(−6.193)***	(−6.293)***	(−6.233)***	(−6.334)***
(8a)	measures	Local Yen spread	0.098	0.086	0.122	0.123	0.116	0.120
			(7.664))***	(6.235)***	(3.810)***	(3.870)***	(5.353)***	(5.572)***
		Std Dev. of FF rate					−0.045	−0.047
							(−4.739)***	(−4.890)***
	Central	US dollar provisions	0.252	0.230	−0.002	−0.002	−0.201	−0.203
	banks'		(3.085)***	(2.748)***	(−0.810)	(−0.802)	(−2.424)**	(−2.459)**
	liquidity	Jap. yen provisions	0.051		0.014		0.042	
	provisions		(0.655)		(0.380)		(0.436)	
	EGARCH	Constant term	−0.284	−0.253	−0.334	−0.337	−0.319	−0.316
	conditional		(−10.504)***	(−11.056)***	(−3.378)***	(−3.391)***	(−8.697)***	(−8.774)***
	variance	$\lvert\varepsilon(t-1)/\sigma(t-1)\rvert$	0.311	0.272	0.350	0.352	0.357	0.356
	equation		(17.538)***	(17.385)***	(4.204)***	(4.240)***	(16.974)***	(17.129)***
		$\varepsilon(t-1)/\sigma(t-1)$	−0.012	−0.012	−0.029	−0.030	−0.035	−0.034
eq.			(−0.761)	(−0.811)	(−0.645)	(−0.656)	(−2.161)**	(−2.139)**
(8b)		Log $\sigma(t-1)^2$	0.986	0.986	0.982	0.982	0.985	0.986
			(269.7)***	(341.4)***	(151.80)***	(150.29)***	(185.07)***	(188.140)***
	Market	VIX	0.064	0.078	0.058	0.059	0.032	0.033
	risk		(7.907)***	(11.944)***	(2.643)***	(2.671)***	(2.835)***	(2.918)***
		VIX(-1)	−0.065	−0.079	−0.058	−0.059	−0.033	−0.034
			(−7.997)***	(−12.129)***	(−2.668)***	(−2.696)***	(−2.925)***	(−3.011)***
		Adjusted R-squared	0.946	0.946	0.942	0.942	0.935	0.936

This table gives the estimation results of the EGARCH model testing the impact of various credit risk measures, several types of US dollar liquidity provisions, and Japanese yen liquidity provisions on deviations from CIP condition in the three markets.

* Statistical significance at the 10% level.

** Statistical significance at the 5% level.

*** Statistical significance at the 1% level.

Table 6. The estimated results of equation (9)

		Tokyo Market		London Market		New York Market	
	Constant term	−0.032	−0.027	−0.034	−0.035	−0.036	−0.033
		(−5.312)***	(−5.383)***	(−7.651)***	(−8.162)***	(−6.359)***	(−7.509)***
Lagged dependent var.	Dependent var. (-1)	0.840	0.735	0.791	0.771	0.834	0.742
		(19.880)***	(20.146)***	(20.267)***	(20.064)***	(21.858)***	(22.302)***
	Dependent var. (-2)	−0.016	0.095	0.083	0.096	0.048	0.135
		(−0.358)	(2.387)**	(2.026)**	(2.380)**	(1.237)	(3.787)***
Local credit risk measures	Local Dollar spread	−0.095	−0.090	−0.088	−0.092	−0.085	−0.085
		(−6.601)***	(−6.626)***	(−6.132)***	(−6.538)***	(−4.907)***	(−5.246)***
	Local Yen spread	0.165	0.055	0.102	0.102	0.112	0.101
		(3.944)***	(3.726)***	(4.381)***	(4.572)***	(3.448)***	(4.160)***
	Std Dev. of FF rate	−0.186	−0.060	−0.024	−0.024	−0.038	−0.046
		(−3.171)***	(−4.474)***	(−1.924)*	(−1.950)*	(−3.206)***	(−4.232)***
Central banks' liquidity provisions	BOJ US$ provisions	0.276	2.930	−0.006		0.295	2.930
		(2.914)***	(3.177)***	(−0.052)		(2.853)***	(2.867)***
	BOE US$ provisions	−0.004		−0.002	−0.002	−0.003	
		(−1.466)		(−0.660)	(−1.003)	(−1.170)	
	FRB US$ provisions	−0.176	−0.188	−0.0454		−0.181	−0.188
		(−2.051)**	(−1.991)**	(−0.501)		(−1.938)*	(−1.894)*
	Jap. yen provisions	0.051		−0.003		0.037	
		(0.692)		(−0.035)		(0.386)	
EGARCH conditional variance equation	Constant term	−0.397	−0.351	−0.702	−0.632	−0.481	−0.540
		(−7.888)***	(−10.50)***	(−7.468)***	(−7.639)***	(−6.264)***	(−7.708)***
	$\lvert\varepsilon(t-1)/\sigma(t-1)\rvert$	0.356	0.293	0.397	0.391	0.414	0.362
		(12.702)***	(17.538)***	(13.319)***	(14.003)***	(11.588)***	(14.616)***
	$\varepsilon(t-1)/\sigma(t-1)$	−0.012	−0.019	−0.090	−0.070	−0.081	−0.074
		(−0.511)	(−1.168)	(−4.768)***	(−3.932)***	(−3.686)***	(−4.157)***
	Log $\sigma(t-1)^2$	0.964	0.961	0.914	0.927	0.958	0.940
		(126.98)***	(165.09)***	(56.313)***	(65.006)***	(80.433)***	(80.173)***
Market risk	VIX	0.042	0.049	0.044	0.055	0.017	0.022
		(3.290)***	(4.524)***	(3.593)***	(4.470)***	(1.217)	(1.764)*
	VIX(-1)	−0.046	−0.053	−0.040	−0.052	−0.017	−0.021
		(−3.641)***	(−5.014)***	(−3.413)***	(−4.405)***	(−1.186)	(−1.630)
Foreign credit risk measures	Foreign $ spread	0.139	0.155	0.141	0.120	0.076	0.111
		(4.080)***	(5.627)***	(3.280)***	(3.049)***	(2.088)***	(3.358)***
	Foreign Yen spread	−0.073	−0.134	−0.766	−0.622	−0.313	−0.490
		(−0.919)	(−2.216)**	(−4.387)***	(−3.949)**	(−2.747)***	(−4.637)***
	Adjusted R-squared	0.951	0.948	0.942	0.942	0.935	0.935

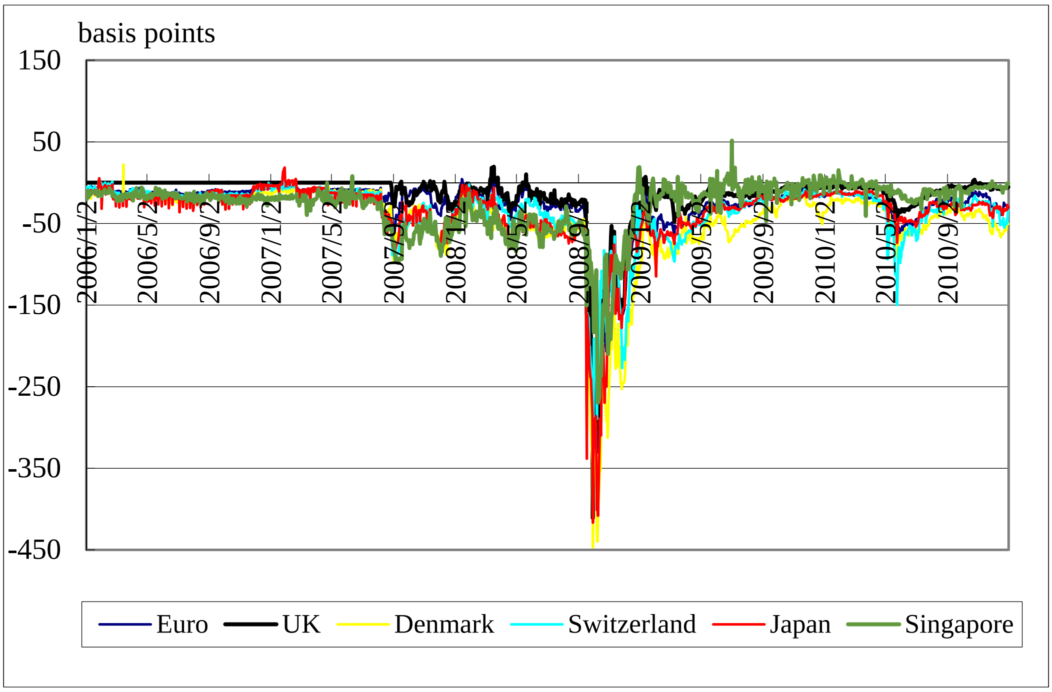
This table gives the estimation results of the EGARCH model testing the impact of various credit risk measures, several types of US dollar liquidity provisions, and Japanese yen liquidity provisions on deviations from CIP condition in the three markets.

* Statistical significance at the 10% level.

** Statistical significance at the 5% level.

*** Statistical significance at the 1% level.

Figure 1. Deviations from the CIP condition between the US dollar and six currencies



This figure depicts daily deviations from CIP condition between the US dollar and each of the six non-US dollar currencies. The downward deviations imply that the US dollar had lower interest rate than the other currencies on the forward market in the global financial crisis.