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Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08

Naohiko Baba[1] and Frank Packer

Abstract

This paper investigates the spillover effects of money market turbulence in 2007–08 on the short-term covered interest parity (CIP) condition between the US dollar and the euro through the foreign exchange (FX) swap market. Sharp and persistent deviations from the CIP condition observed during the turmoil are found to be significantly associated with differences in the counterparty risk between European and US financial institutions. Furthermore, evidence is found that dollar term funding auctions by the ECB, supported by dollar swap lines with the Federal Reserve, have stabilized the FX swap market by lowering the volatility of deviations from CIP.

Key words: FX swap; covered interest parity; financial market turmoil; counterparty risk; dollar swap lines, dollar term auction facility

JEL classification: F31; G15

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1. Introduction

The functioning of money markets was severely impaired in the summer of 2007. What began as a deterioration in a relatively limited segment of the US subprime mortgage sector quickly spread to other markets, especially those of credit and securitised products (BIS 2008, IMF 2008). Uncertainty about losses increased the liquidity needs of financial institutions as well as their reluctance to lend to each other in money markets, particularly at maturities longer than one month. Reflecting these and possibly other factors, spreads of interbank short-term interest rates over overnight index swap (OIS) and treasury bill rates widened substantially in August 2007, and then, despite some degree of fluctuation, persisted at high levels (Taylor and Williams, 2008a,b).

A much less well documented aspect of the turmoil is how the turbulence in money markets spilled over to foreign exchange (FX) swap markets. One of the few works to address the question is Baba, Packer, and Nagano (2008), which documents heightened volatility in the FX swap markets across several G10 currency pairs soon after the financial market turmoil erupted. As noted in that paper, the three-month FX swap-implied dollar rate using euro as a funding currency moved together quite closely with dollar Libor (London interbank offered rate) prior to the summer turmoil in money markets (Figure 1).[2] From mid-August 2007, however, the spread between the FX swap-implied dollar rate and dollar Libor widened considerably, reaching 40 basis points in September 2007, pointing towards a large and persistent deviation from the short-term covered interest parity (CIP) condition. Though the spread narrowed substantially after the beginning of 2008, it widened again from early March.[3]

Baba, Packer, and Nagano (2008) argue that dollar funding shortages of non-US financial institutions were largely responsible for these developments. More specifically, soon after the turmoil began, European financial institutions increased activity to secure dollar funding to support US conduits for which they had committed backup liquidity facilities.[4] At the same time, US financial institutions appeared to become much more cautious about lending dollars to other institutions because of heightened counterparty risk and their own need to preserve funds on hand. Facing unfavourable demand and supply conditions and the associated impairment of liquidity in interbank markets, many European institutions moved to actively convert euros into dollars through FX swaps.[5] Deteriorating liquidity in the FX swap market likely contributed to further deviations of the FX swap market from the short-term CIP condition,[6] despite coordinated efforts by central banks to make dollar funding more readily available to non-US financial institutions. More specifically, as part of a series of coordinated measures to provide term dollar funding, on December 12, 2007, the establishment of swap

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2 An FX swap is a contract in which two parties borrow and lend different currencies by combining the FX spot and forward contracts in the reverse direction. The most liquid maturities for the FX swap are for less than one year. The FX swap-implied dollar rate is defined as the total cost, in terms of the dollar rate, from raising euros in the uncollateralised cash market and converting them into dollars through the FX swap market. See section 2 for more details.

3 A similar tendency was apparent in some other currency pairs, particularly the sterling/dollar pair.

4 Using the BIS international banking statistics, McGuire and von Peter (2008) show that European banks have faced relatively large dollar funding requirements, especially since mid-2007.

5 ECB (2007) stated that many non-US financial institutions moved to actively convert euros into dollars through FX swaps after the turmoil began in early August 2007.

6 This is consistent with FRBNY (2007), which stated that the impairment of trading liquidity in the FX swap market was particularly severe from mid-August to mid-September 2007.

lines between the Federal Reserve and both the European Central Bank (ECB) and the Swiss National Bank (SNB) was announced. These swap lines allowed the ECB and SNB to conduct US dollar term funding auctions during European trading hours for depository institutions in continental Europe in a fashion that complemented the Federal Reserve's own term auction facility (TAF) for US institutions.[7]

In this paper, we empirically investigate the above-mentioned spillover effects of the money market turmoil of 2007–08 on the FX swap market. We examine the degree to which the deviations from short-term CIP observed in the three-month FX euro/dollar swap market are associated with factors reflecting the turbulence in global financial markets. Although we control for other relevant factors, we place particular emphasis on the following two issues: (i) the role of the perception of relative counterparty risk between European and US financial institutions, and (ii) the role of the ECB's dollar term funding auctions in easing tensions in the FX swap market.

In the extant literature, a number of studies test the short-term CIP condition, and some identify the specific periods in which such parity conditions collapsed. However, to the best of our knowledge, no study analyzes explicitly the relationship between money market tensions and CIP. This paper intends to fill that gap, both in the context of the financial market turmoil and in light of the rapidly growing role of FX swaps in foreign currency funding by financial institutions globally.

The rest of the paper is organized as follows. Section 2 gives an overview of the basic structure of an FX swap and its relationship to the CIP condition. Section 3 conceptually decomposes possible deviations from CIP and presents two major hypotheses. Section 4 describes the data and construction of the variables, and Section 5 provides the framework and results of the empirical analysis. Section 6 concludes the paper.

2. The FX swap and covered interest parity

An FX swap is a contract in which one party borrows a currency from, and simultaneously lends a second currency to, another party. Although FX swaps can be viewed as effectively collateralised transactions, the collateral does not cover the entire counterparty risk. For example, if one party to the swap defaults during the contract period, the counterparty needs to reconstruct the position at the current market price, which entails replacement cost. Furthermore, Duffie and Huang (1996) show that FX swaps are subject to greater counterparty risk than are interest rate swaps because, unlike interest rate swaps, FX swaps entail the exchange of notional amounts at the start of the contract.[8]

A financial institution or other entity needing foreign currency funding can either (1) borrow directly in that currency's uncollateralised cash market or (2) borrow in another (typically the domestic) currency's uncollateralised cash market and convert the proceeds into an obligation in the desired currency through an FX swap.[9]

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[7] The size of the transatlantic swap lines were increased several times beginning in March 2008, while the total amount of the term US dollar offers by the ECB were increased several times starting in May. Alternative maturities were introduced beginning in August. For more details of the coordinated efforts by the central bank community, see Borio and Nelson (2008) and CGFS (2008)

[8] In addition, the volatility of FX rates tends to be greater than that of interest rates, another factor likely to elevate counterparty risk in FX swaps above that of interest rate swaps.

[9] Financial institutions use FX swaps both for themselves and for their customers, including exporters and importers. Institutional investors use them to hedge their positions in foreign bonds against FX risk. FX swaps, which are also frequently used for speculative trading, are most liquid at terms shorter than one year.

In this paper, we call the total funding cost of the second alternative the "FX swap-implied rate". For example, when a financial institution raises dollars via an FX swap with euros, it exchanges euros for dollars at the FX spot rate while contracting to exchange in the reverse direction at maturity at the FX forward rate (Figure 2). The FX swap-implied dollar rate from the euro in gross terms can be written as

$$\frac{F_{t,t+s}}{S_t}\left(1+r_{t,t+s}^{EUR}\right) \tag{1}$$

where S_t is the FX spot rate between the euro and dollar at time *t*, $F_{t,t+s}$ is the FX forward rate contracted at time *t* for exchange at time *t*+*s*, and $r_{t,t+s}^{EUR}$ is the uncollateralised euro cash fixed interest rate from time *t* to time *t*+*s*. $F_{t,t+s}/S_t$ corresponds to the euro/dollar forward discount rate that is used for the FX swap price quotation.[10]

The use of FX swaps to raise dollars should depend on relative costs. That is, whether an institution would be encouraged to borrow domestic currency funds in the uncollateralised cash market and use the FX swap to raise dollars should depend on whether the FX swap-implied dollar rate is lower than the rate of uncollateralised dollar funds.[11] The equality of dollar rates and of FX swap-implied dollar rates (from the euro) defines a condition of indifference as

$$1+r_{t,t+s}^{USD}=\frac{F_{t,t+s}}{S_t}\left(1+r_{t,t+s}^{EUR}\right) \tag{2}$$

where $r_{t,t+s}^{USD}$ is the uncollateralised dollar cash fixed interest rate. Equation (2) is equivalent to the covered interest parity (CIP) condition in the international finance literature, applied to the euro/dollar currency pair.

CIP postulates that interest rate differentials between currencies should be perfectly reflected in the FX forward discount rates because, otherwise, an arbitrageur could transact in interest and exchange markets to make a risk-free profit. A number of studies assess the degree to which short-term CIP – ie CIP in short-term interest rate markets - is supported by the data. Most of them show that the deviations from the short-term CIP condition have diminished significantly, at least among G10 currencies. However, one notable study, by Taylor (1989), finds that, despite increasing efficiency in FX markets in the decade preceding his study, deviations from CIP tend to rise during periods of uncertainty and turmoil and persist for some time before they are arbitraged away.[12]

For CIP to hold strictly depends on minimal transaction costs as well as on the lack of political risk, credit (counterparty) risk, liquidity risk, and measurement error. Transaction costs and political risk are largely negligible in today's G10 currency markets, but counterparty risk could well have increased significantly in the recent turmoil. To the extent that counterparty risk was concentrated on one end of the FX swap market, a deviation from

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10 More precisely, the price of FX swap is conventionally quoted as $F_{t,t+s}-S_t$.

11 While one interpretation is to view the choice as between collateralised (FX swap) vs uncollateralised dollar funding (deposit), the perspective of covered interest parity implies a comparison of one uncollateralised rate (eg dollar) versus another uncollateralised rate (eg euro) combined with an FX swap (euro for dollar).

12 According to Taylor (1989), significant deviations were observed on such occasions as the flotation of sterling in 1972 and the inception of the European Monetary System in 1979. Akram, Rime, and Sarno (2008) investigate deviations from the CIP condition using tick data that cover seven months in 2004 and find some short-lived but economically significant deviations from the CIP condition.

CIP could have emerged. This is particularly the case in the recent period, when uncollateralised dollar cash markets were dysfunctional and so the FX swap market emerged as an important source of dollar funding for many institutions. For example, if European financial institutions on the dollar borrowing side of the FX swap market were perceived as risky by US financial institutions on the dollar lending side, then risk premia could have been added to the dollar funding rates through FX swaps. Even if the counterparty risk of European financial institutions included in the dollar Libor panel of banks was not perceived as high, that of smaller, less prominent European institutions active in the FX swap market may have been. That would have raised the FX swap-implied dollar rates above dollar cash rates like dollar Libor.

Liquidity risk also may have played a role, particularly if market liquidity was impaired because of outsized or one-sided order flow, with effects compounded by perceptions of increased counterparty risk. In the case of European financial institutions, their order flow for dollars in the FX swap market surged during the financial turmoil. That surge was reportedly due largely to the difficulty of borrowing in the uncollateralised dollar interbank market, where US financial institutions appeared less willing to lend dollars to other institutions because of a perceived heightening of counterparty risk and because of their own increased demand for dollar liquidity.

Finally, measurement error in gauging true dollar funding costs over the period could have increased. During the turmoil, dollar Libor has been reported to have underestimated the funding costs that European financial institutions actually faced. The non-binding nature of Libor may lead to biased quotes on the part of institutions wary of revealing information that might increase their borrowing costs in times of stress.

3. Decomposition of deviations from CIP and two main hypotheses

a. Decomposition exercise

To fully understand the empirical analysis that follows, it helps to decompose deviations from short-term CIP, using overnight-index swap (OIS) rates as a benchmark interest rate. The OIS is an interest rate swap in which the floating leg is linked to a publicly available index of daily overnight rates. The two parties agree to exchange at maturity the difference between interest accrued at the agreed fixed rate and interest accrued through the geometric average of the floating index rate. As in Michaud and Upper (2008), we regard the OIS rates as a proxy for expected future overnight rates, for the following two reasons. First, the counterparty risk associated with the OIS contracts is relatively small because no principal is exchanged.[13] Second, the liquidity risk premia contained in OIS rates should be very small because of the lack of any initial cash flows.

The use of OIS rates as a benchmark enables us to decompose the short-term CIP deviation based on Libor as follows:

$$
\begin{aligned}
&F/S\left(1+Libor^{EUR}\right)-\left(1+Libor^{USD}\right)\\
&\approx\left[\left(\ln F-\ln S\right)-\left(OIS^{USD}-OIS^{EUR}\right)\right]+\left[\left(Libor^{EUR}-OIS^{EUR}\right)-\left(Libor^{USD}-OIS^{USD}\right)\right]
\end{aligned}
\tag{3}
$$

Here, the right-hand side of equation (3) can be obtained by first separating the term involving the FX forward discount rate from that involving both Libor rates and then log-

[13] Moreover, the residual risk is mitigated by collateral and netting arrangements.

approximating the FX forward discount term.[14] This decomposition enables us to distinguish conceptually between the distortions of the FX swap market and the Libor market.

b. Two main hypotheses

Two main hypotheses are tested in the following empirical analysis. The first concerns the difference between European and US financial institutions with regards to counterparty risk: ie the larger the perceived counterparty risk difference between the two types of institutions, the larger should be the FX swap deviations from the short-term CIP condition. This hypothesis is based on the observation that European financial institutions are largely on the dollar borrowing side of the euro/dollar FX swap market, and thus an asymmetry of counterparty risk between European and US financial institutions could potentially show up in deviations from CIP. We call this the counterparty risk hypothesis.

The counterparty risk hypothesis is directly related to the first term in the right-hand side of equation (3), which denotes the deviation of the interest rate differential implied in the euro/dollar forward discount rate from the differential in the OIS rates of the same currency pair. If European financial institutions facing dollar shortages are perceived as riskier than US counterparts, then a risk premium may be added to the forward discount rate relative to the pure expectations about the interest rate differential between the dollar and the euro that are reflected in the OIS rates. The Libor-OIS spreads in the second term in the right-hand side of the same equation may also capture counterparty risk, as argued in Taylor and Williams (2008a,b). However, Libor-OIS spreads should reflect average counterparty risk for Libor panel banks and not necessarily the counterparty risk of European financial institutions relative to US institutions. In fact, 14 of 16 Libor panel banks are the same between the dollar and the euro, so the difference in Libor-OIS spreads between this currency pair is not likely to capture fully the changing perceptions of the difference in counterparty risk between European and US financial institutions.

The second hypothesis concerns the effects of a US dollar term funding auction launched by the ECB in December 2007, supported by dollar swap lines with the Federal Reserve, through which the ECB was able to lend dollars to Eurosystem banks against ECB-eligible collateral. What we call the dollar auction hypothesis posits that, because of their associated provision of dollar funds to Eurozone banks, dollar term funding auctions significantly lower FX swap deviations from CIP. A related hypothesis is that implementation of dollar auctions has served to stabilize the FX swap market by lowering the volatility of deviations from CIP.

4. Data and variables

a. Sample periods

In the following empirical exercise, we split the sample into two periods: one of relative tranquillity, which runs from September 1, 2006, through August 8, 2007; and one of turmoil, which runs from August 9, 2007, through September 12, 2008. Although one might choose other dates to mark the inception of the turmoil of 2007–08, we follow Taylor and Williams (2008a,b) in the choice of August 9, which is when BNP Paribas, in announcing the freeze of redemptions for three of its investment funds, cited an inability to value them. Following that

[14] We abstract from the term $(F/S-1)Libor^{EUR}$ because it is at least an order of magnitude smaller than the other terms.

announcement, the ECB on August 9 and 10 injected overnight liquidity totalling 95 billion euros into the interbank market, signalling the beginning of a set of extraordinary moves throughout the central bank community. At the same time, the risk premia embedded in short-term money market rates, as represented by the Libor-OIS spreads, widened substantially in major currencies. Our sample period ends on September 12, 2008, three days before the failure of Lehman Brothers, which ushered in a new period of global dollar shortages characterised by even greater volatility in financial markets.

b. Variables

FX swap deviation

The difference between the FX swap-implied three month dollar rate (from the euro) and the three-month dollar Libor rate is the dependent variable in all the regression analyses that follow. We focus on rates of three-month maturity because it is considered the most representative of all the short-term maturities. To calculate the FX swap-implied dollar rate, we use euro Libor for the euro funding rate. For the euro/dollar forward discount rate, we use the New York composite FX spot and forward rates taken from Bloomberg, where the composite bid rate is equal to the highest bid rate of all 34 contributing financial institutions (as of September 2008), and the composite ask rate is the lowest ask rate offered by the same institutions. We take the average of the bid and ask rates as of 17:00 New York time.

The Libor fixings are released every business day by the British Bankers' Association (BBA). The Libor fixing is meant to capture the rates paid on unsecured interbank deposits at large, globally active banks. Just prior to 11:00 GMT, the BBA surveys a panel of banks, asking them to provide the rates at which they believe they could borrow reasonable amounts in a particular currency and maturity. However, the banks are under no obligation to prove that they can actually borrow at those rates.[15] The dollar Libor panel consists of 16 banks from seven nations. The BBA excludes the highest and lowest quartile of rates and takes a simple average.

CDS spread difference between European and US financial institutions

To test the counterparty risk hypothesis, we use the following two measures of the difference in counterparty risk perceptions between European and US financial institutions. The first one is the difference in CDS spreads between the dollar Libor panel banks headquartered in the Eurozone and those headquartered in the United States, which we label "CDS (Libor)". More specifically, we use the simple average of five-year CDS spreads for three Eurozone banks and the same average for three US banks included in the dollar Libor panel.[16] The data are taken from Bloomberg.

The other measure is the difference in CDS spreads between two aggregate sectoral CDS spread indices that captures a broader array of financial institutions in each region. Specifically, we use the CDS spread for European financials with investment grade ratings included in the iTraxx Europe series and the CDS spread for US financials with investment grade ratings.[17] We label the difference between these two indices "CDS (IG)". The data are provided by JP Morgan Chase, which compiles the indices from quotes on more than 20 financial institutions. Both CDS (Libor) and CDS (IG) are measured as of 17:00 New York

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[15] See Gyntelberg and Wooldridge (2008) for details.

[16] Eurozone financial institutions are Deutsche Bank AG, Rabobank, and West LB AG. US financial institutions are Bank of America, Citibank NA, and JP Morgan Chase.

[17] We use indices calculated as the simple average of the CDS spreads for included institutions.

time. The counterparty risk hypothesis posits that these measures should have a positive and statistically significant impact on the FX swap deviation.

US dollar term funding auctions conducted by the ECB

In December 2007, the ECB began to conduct US dollar term funding auctions supported by swap lines with the Federal Reserve. The aim of the auctions, timed so as to occur on the same day as those of the Federal Reserve's Term Auction Facility,[18] was to facilitate the provision of US dollar term funds to Eurosystem counterparties against ECB-eligible collateral. The first tender bid submission was on December 17, 2007, and was followed by 18 more provisions through September 12, 2008. At first, the maturity of the funds was 28 days; but 84-day auctions were introduced in August. Originally conducted for $20 billion, the size of the auctions was increased three times in 2008 (in March to $30 billion, in May to $50 billion, and in July to $55 billion).

To test the dollar auction hypothesis, we create two indicator variables, labelled "dollar auction 1" and "dollar auction 2". For each date of the bid submissions for the ECB dollar term funding auction, dollar auction 1 takes the value of 1; it is zero otherwise. Dollar auction 2 takes the value of 1 for each of the dollar term funding announcement dates. Dollar auction 1 basically follows Taylor and Williams (2008a), who analyze the effects of the TAF established by the Federal Reserve for US-based depository institutions on the dollar Libor-OIS spread. Dollar auction 2 follows McAndrews, Sarkar, and Wang (2008), who use a similar indicator variable for TAF announcement dates, in addition to that for submission dates, to investigate the TAF effects on the dollar Libor-OIS spread.

If the dollar term funding auctions by the ECB were able to alleviate purported dollar shortages on the part of Eurozone banks, we might expect to see a negative and statistically significant impact of the FX swap deviation at the time of the announcement or bid submission of those auctions. We are also interested in whether these auctions had a stabilising effect on the FX swap market, where we expect a negative and significant impact on the volatility of the FX swap deviation.

Broad-based cash rate-OIS spread difference between the US dollar and the euro

In contrast to Libor that reflects the funding costs of only Libor panel banks, FX swap-implied dollar rates may well reflect the funding costs of a wider range of financial institutions, as discussed above. Thus, the FX swap deviations from CIP may stem from the difference in the financial institutions involved in the FX swap and Libor markets.

To control for this factor, we utilize the three-month eurodollar deposit rate released by the Federal Reserve, as well as Euribor (Euro interbank offered rate). The eurodollar rate is based on rates actually observed in the eurodollar interbank cash market as of around 9:30 New York time and reflects a much wider array of financial institutions than the Libor panel banks, which are meant to be only large, globally active banks. As for the Euribor, which is fixed around 11:00 CET, its contributing panel consists of about 45 financial institutions, most of which are Eurozone banks.[19] In the estimation, we use the difference between the spread of the eurodollar over the dollar OIS rate on the one hand and the spread of Euribor over the euro OIS rate on the other to maintain consistency with equation (3). That difference is labelled "broad spread (dollar-euro)". To the extent that the FX swap market price is moved

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[18] However, Federal Reserve TAF auctions were not always accompanied by the provision of liquidity through dollar auctions by the ECB. For example, the ECB's dollar term funding auctions were suspended in February when the dollar liquidity situation improved (they resumed in March).

[19] Because Euribor is calculated on a 365-days basis, we convert it into a 360-days basis for consistency with other data.

by the demand for funds of banks outside the Libor universe (banks that may face different costs of funds), we expect the effects of the broad spread (dollar-euro) on the FX swap deviation to be positive.

Libor-OIS spread difference between the euro and US dollar

Under the normal circumstances prior to the financial turmoil of 2007–08, OIS rates tended to move below the corresponding currency Libor with almost constant small margins. After the onset of the financial turbulence in August 2007, however, the Libor-OIS spreads widened substantially, particularly for the dollar and the euro.

Market observers posited several possible drivers for these widened spreads. One commonly cited factor was a deterioration in funding liquidity for banks, ie a decline in their ability to service or roll-over their short-term liabilities as they fell due (IMF 2008).[20] This in turn was closely related to greater concerns about banks' ability to liquidate positions in certain assets, ie increased market liquidity risk. A third potential factor was a rise in counterparty risk for the Libor panel banks. Uncertainty about the potential losses from subprime mortgage-related structured products is reported to have added concerns about counterparty risk among financial institutions.

In this paper, we use the difference between euro and dollar Libor-OIS spreads, labelled "Libor-OIS (euro-dollar)", as a control variable in the estimation. Including this variable reduces the likelihood that we are confounding counterparty risk with funding or market liquidity risk in the CDS-based measures. We use the OIS rates as of 17:00 New York time, taken from Bloomberg. The expected sign for this variable is positive, as shown in equation (3).

5. Empirical analysis

a. Framework

We test whether counterparty risk differences as well as the ECB's dollar term funding auctions had effects on the levels and volatility of FX swap deviations. To account for stochastic volatility, we employ throughout the analysis below the EGARCH(1,1) model proposed by Nelson (1991)[21]. The EGARCH(1,1) model we use can be written as

Mean equation:

$$\begin{aligned}\text{FX swap deviation}_t &= a + b_1\text{CDS(Libor or IG)}_t + b_2\text{Dollar Auction (1 or 2)}_t \\ &+ b_3\text{Broad spread}_t + b_4\text{Libor - OIS}_t + \varepsilon_t \quad \varepsilon_t \sim N\left(0, \sigma_t^2\right)\end{aligned} \tag{4}$$

Variance equation:

$$\begin{aligned}\ln\left(\sigma_t^2\right) &= \alpha + \beta\ln\left(\sigma_{t-1}^2\right) + \gamma\,\varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\left|\varepsilon_{t-1}/\sigma_{t-1}\right| - \sqrt{2/\pi}\right) \\ &+ \lambda\text{Dollar Auction (1 or 2)}_t\end{aligned} \tag{5}$$

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20 Dudley (2008), in a speech given in May, ascribed the increases in Libor-OIS spreads to that point to increased bank balance sheet pressures as a consequence of the reintermediation process.

21 EGARCH (exponential generalized autoregressive conditional heteroskedasticity) is widely used in analyzing the effects of monetary policy, particularly the effects of central bank communications, on financial asset prices. See Ehrmann and Fratzscher (2008), for example.

where b_1 and b_2 are the coefficients reflecting the influence of the counterparty risk differences and the ECB's dollar term funding auctions, respectively, on the mean of FX swap deviations, and λ is the coefficient of the dollar auctions on the volatility of FX swap deviations. In this specification, the effect of the dollar auctions decreases over time when $\beta < 1$. The effect can be measured by λ on the bid submission or the announcement date, $\lambda\beta$ on the next date, $\lambda\beta^2$ on the third date, and so on.

The left-hand side of the variance equation (5) is the log of the conditional variance, and thus we do not need to impose any non-negativity constraints on the variance equation. When ε_{t-1} is positive, the total effect of ε_{t-1} on the log of the conditional variance can be measured by $(\eta+\gamma)|\varepsilon_{t-1}/\sigma_{t-1}|$, and when ε_{t-1} is negative, it can be measured by $(\eta-\gamma)|\varepsilon_{t-1}/\sigma_{t-1}|$. Thus, the asymmetric leverage effects can be tested by the coefficient of γ. Further, volatility persistence can be measured by β in the EGARCH model.

b. Summary statistics and equality tests

Table 1 shows the means, and Table 2 the standard deviations, of the variables under study as well as the results from tests of the null hypothesis that those values were unchanged between the two periods. The mean and the standard deviation of every variable are found to be significantly different (at the 1% level) across the two periods.

More specifically, before the turmoil, the FX swap deviation was only 1 basis point on average but increased to more than 17 basis points on average during the period of turmoil. And in the period of turmoil, the standard deviation of the FX swap deviation surged to four times its level in the preceding period. As for the counterparty risk difference between European and US financial institutions, both measures – CDS (Libor) and CDS (IG) – became significantly more negative, suggesting that, on average, higher counterparty risk was perceived for US banks during the turmoil. However, during some subperiods of the turmoil, these measures increased substantially, consistent with a heightened counterparty risk of European institutions on a relative basis during those subperiods. As for the control variables, the mean difference between the euro and dollar Libor-OIS spreads became much more negative across periods; while the average difference between the more broadly based cash-OIS spreads (dollar-euro) widened significantly. Both these control variables become much more volatile under the turmoil.

Differences in variable means and standard deviations do not necessarily portend a change in the structural relationship between the dependent variable and regressors. Table 3 reports the results of the sequential Chow tests of the hypotheses that no structural change occurred across periods in the relation between the dependent variable (FX swap deviation) and each of the regressors. The hypothesis of no structural break after August 8, 2007, is decisively rejected in every case, providing us with statistical grounds for conducting the analysis separately for the two periods.

c. Estimation results

The estimation results of the EGARCH mean equation are reported in the top panel of Table 4 (for the first period) and of Table 5 (for the second period). First, the counterparty risk hypothesis appears to hold during the turmoil when CDS (IG) is used. Before the turmoil, the coefficients for both CDS (Libor) and CDS (IG) have a negative sign, contradicting the hypothesis (Table 4). Under the turmoil, however, the coefficients are significantly positive in the case of CDS (IG), though not for CDS (Libor), as shown in Table 5. This suggests that the wider sample of bank CDS spreads is more likely to properly capture the influence of counterparty risk differences between European and US financial institutions on FX swap pricing during the period of turmoil.

The above results indicate that under the turmoil, FX swap deviations tended to significantly widen when counterparty risk was heightened for a wide range of European financial institutions relative to US counterparts. This supports the counterparty risk hypothesis and is consistent with the view of many market participants that US financial institutions became more sensitive to the counterparty risk of European financial institutions that faced the need to raise dollars. Further, the fact that the results were significant only when using the proxy measure that captures the risk of a wide array of financial institutions is consistent with the view that large banks like the Libor panel banks tended to have much easier access to the provision of dollar liquidity from the Federal Reserve.

Our finding bears similarities with the Japan premium episode in the late 1990s. At that time, due to a substantial deterioration of their creditworthiness relative to that of other financial institutions in advanced nations, Japanese banks found it extremely difficult to raise dollars in global money markets, and a so-called Japan premium arose between dollar cash rates paid by Japanese banks and by other banks (Covrig, Low, and Melvin 2004; and Peek and Rosengren 2001). As suggested in Nishioka and Baba (2004) and Baba and Amatatsu (2008), Japanese banks then turned to the FX swap and longer-term cross-currency markets for dollar funding, which resulted in substantial deviations from the CIP condition in its traditional sense. The dislocations in the FX swap market that have been triggered by the turmoil may be understood in a similar context.

By contrast, as shown in the top panel of Table 5, virtually no evidence is found for the dollar auction hypothesis in terms of its impact on the level of the FX swap deviation. The coefficient is positive or negative, depending on the specification, and not significant. This result parallels those of Taylor and Williams (2008a,b); those two studies, published in April and May, respectively, found little effect of the Federal Reserve TAF on the dollar Libor-OIS spread.[22]

Further, significant changes can be found in the estimated coefficients on the control variables between the two periods. In particular, the coefficients on broad spread (dollar-euro) are significantly positive in all cases under the turmoil, while they are not necessarily so before the turmoil. The estimated coefficients under the turmoil are also much higher than those before the turmoil. In combination with the results discussed above, this finding is consistent with the view that the demand for dollar liquidity in FX swap markets under the turmoil came from a wider array of financial institutions than just dollar Libor panel banks. A similar observation can be made for the Libor-OIS (euro-dollar) variable: it always has a significantly positive effect on the FX swap deviation under the turmoil but not so in all cases before the turmoil. The estimated coefficients during the period of turmoil are larger, more significant, and closer to the value of 1 suggested by the earlier decomposition (equation (3)). This is consistent with the view that relative liquidity conditions in the Libor funding markets mattered more to FX swap markets during the turmoil than before.

As for the variance equation, the bottom panels of Tables 4 and 5 show that the ARCH (η) and GARCH (β) effects are significantly positive in both periods. Also, although not reported, the Ljung-Box *Q* statistics for the autocorrelation of the squared standardized residuals from the EGARCH model are found to be insignificant for various lag lengths in all cases. This implies that the EGARCH model does a good job in fitting the time-varying volatility of the FX swap deviation. The estimated coefficients on the GARCH term are large

22 Taylor and Williams (2008b) shift the Libor data back one day to adjust for the time difference between Libor set at around 11:00 GMT and other variables set at New York time. They make the shift because the Libor fixings occur before the TAF events that may drive other variables, including the CDS and OIS data. In our case, actual bid submissions are conducted before the Libor fixings, so we do not adopt that adjustment. Nonetheless, for an additional robustness check, we made the same adjustment as in Taylor and Williams (2008b) and found that the estimation results were virtually unchanged.

(larger than 0.9 before the turmoil and during the turmoil when CDS (IG) is used). This result shows the existence of volatility clustering, such that large changes tend to be followed by large changes. On the other hand, the asymmetric leverage effects are found to be insignificant in all cases.

The dollar auction hypothesis largely holds in the case of volatility: the coefficients on the dollar auction 1 (bid submission date) variable are found to be significantly negative in all cases, while those on the dollar auction 2 (announcement date) variable are significantly negative when CDS (IG) is used as an explanatory variable. This result supports the view that the dollar term funding auctions by the ECB have significantly lowered the volatility of the FX swap deviations from CIP under the turmoil, particularly on the bid submission dates. The coefficients on the dollar auctions also suggest a large impact in economic terms. On the dollar auction bid submission dates, for example, the estimated volatility of FX swap deviations decreases by 65.4% when CDS(IG) is used, which exerts a relatively long-lasting dynamic effect given the high value of the estimated coefficient of β =0.906. The dollar term funding auctions of the ECB, supported by dollar swap lines with the Federal Reserve, appear to have contributed to the stabilization of the FX swap market.

6. Concluding remarks

This paper has empirically investigated spillovers to the FX swap market from the money market turbulence that began in the summer of 2007. As documented in Baba, Packer, and Nagano (2008), an important aspect of the turmoil was a shortage of dollar funding for many financial institutions, particularly European institutions that needed to support US conduits for which they had committed backup liquidity facilities. At the same time, financial institutions on the dollar-lending side became more cautious because of their own growing needs for dollar funds and increased concerns over counterparty risk. Facing these unfavourable conditions in interbank markets, non-US institutions turned to the FX swap market to convert euros into dollars.

Our empirical results show a striking change in the relationship between perceptions of counterparty risk and FX swap prices after the onset of financial turmoil. That is, CDS spread differences between European and US financial institutions have a positive and statistically significant relationship with the deviations from CIP observed in the FX swap market. The result holds when we consider the CDS spreads of a range of financial institutions wider than that of the Libor panel. Our findings suggest that concern over the counterparty risk of European financial institutions was one of the important drivers of the deviation from covered interest parity in the FX swap market.

The results hark back to the Japan premium episode in the late 1990s, when the creditworthiness of Japanese banks had substantially deteriorated. Faced with the extreme difficulty of raising dollars in global interbank markets, Japanese banks turned to FX swap markets, which resulted in substantial deviations from CIP.

While not significantly reducing the level of FX swap deviations over the period, the ECB's US dollar liquidity-providing operations to Eurosystem counterparties do appear to have lowered the volatility (and thus the associated uncertainty) of the FX swap deviations. Our estimation results thus support the view that the dollar term funding auctions conducted by the ECB, supported by dollar swap lines with the Federal Reserve, played a positive role in stabilizing the euro/dollar FX swap market.

This study covers a period that ends in September 2008 shortly before the bankruptcy of Lehman Brothers. After the Lehman failure, the turmoil in many markets become much more pronounced. In currency and money markets, what had principally been a dollar liquidity problem for European banks deepened into a phenomenon of global dollar shortage. The provision of dollar funds by central banks, supported in some cases by unlimited dollar swap lines with the Federal Reserve, expanded greatly. One promising line of research would focus on the effectiveness of the diverse array of policy measures taken in this recent, more severe stage of the financial crisis.

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Table 1

Means of variables

(% points)

Mean of	Before turmoil (a) (Sep 1, 06–Aug 8, 07)	Under turmoil (b) (Aug 9, 07–Sep 12, 08)	Equality test on difference ((b) – (a))
FX swap deviation	0.012	0.171	0.159**
CDS (Libor)	–0.045	–0.189	–0.144**
CDS (IG)	–0.259	–1.560	–1.301**
Broad spread (dollar-euro)	0.020	0.174	0.154**
Libor-OIS (euro-dollar)	–0.029	–0.059	–0.030**

Note: Equality test is based on the *t*-test using Welch's approximation for unequal variance. ** denotes the 1% significance level.

Table 2

Standard deviations of variables

(% points)

Standard deviation of	Before turmoil (a) (Sep 1, 06–Aug 8, 07)	Under turmoil (b) (Aug 9, 07–Sep 12, 08)	Equality test on difference ((b) – (a))
FX swap deviation	0.027	0.115	0.088**
CDS (Libor)	0.023	0.197	0.174**
CDS (IG)	0.160	0.542	0.382**
Broad spread (dollar-euro)	0.020	0.174	0.154**
Libor-OIS (euro-dollar)	0.010	0.112	0.102**

Note: Equality test is based on Levene's robust statistics. ** denotes the 1% significance level.

Table 3

Chow test for each regressor (F-statistics)

Sample: September 1, 2006–September 12, 2008

CDS (Libor)	138.95**
CDS (IG)	75.63**
Broad spread (dollar-euro)	121.85**
Libor-OIS (euro-dollar)	327.93**

Note: The breakpoint is August 9, 2007. The Chow test is based on the regression models with each variable and constant as regressors. ** denotes the 1% significance level.

Table 4

EGARCH analysis before turmoil

Sample: September 1, 2006–August 8, 2007

	Mean equation	
CDS (Libor)	–0.211**	
	(0.078)	
CDS (IG)		–0.061**
		(0.013)
Broad spread (dollar-euro)	0.244	0.280*
	(0.128)	(0.115)
Libor-OIS (euro-dollar)	0.175	0.402*
	(0.212)	(0.187)
Constant	–0.001	–0.001
	(0.005)	(0.004)
	Variance equation	
	$\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert - \sqrt{2/\pi}\right)$	
α	–0.926**	–0.878**
	(0.036)	(0.308)
β	0.903**	0.911**
	(0.047)	(0.039)
γ	0.062	0.072
	(0.049)	(0.053)
η	0.284**	0.289**
	(0.098)	(0.095)
Adj R-squared	–0.034	–0.028

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ** and * denote the 1% and 5% significance levels, respectively.

Table 5

EGARCH analysis under turmoil

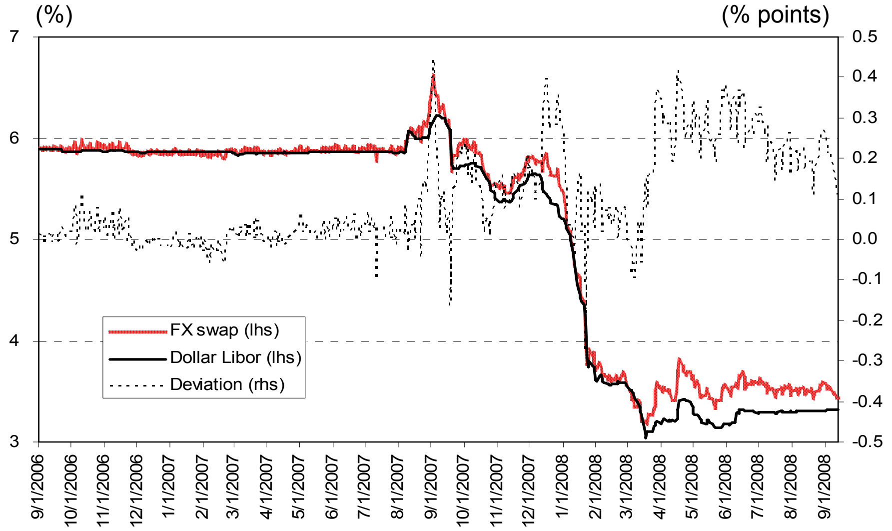
Sample: August 9, 2007–September 12, 2008

	Mean equation			
CDS (Libor)	–0.060**	–0.064**		
	(0.016)	(0.018)		
CDS (IG)			0.032**	0.035**
			(0.007)	(0.007)
Dollar Auction 1	–0.004		0.001	
	(0.007)		(0.008)	
Dollar Auction 2		0.001		0.010
		(0.009)		(0.010)
Broad spread (dollar-euro)	0.733**	0.736**	0.901**	0.921**
	(0.037)	(0.039)	(0.035)	(0.037)
Libor-OIS (euro-dollar)	1.302**	1.307**	1.301**	1.312**
	(0.041)	(0.043)	(0.051)	(0.050)
Constant	0.105**	0.104**	0.145**	0.147**
	(0.004)	(0.004)	(0.011)	(0.010)
	Variance equation			
	$\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\lvert \varepsilon_{t-1}/\sigma_{t-1} \rvert - \sqrt{2/\pi}\right) + \lambda \text{Dollar Auction}$			
α	–2.405**	–2.334**	–0.783	–0.607
	(0.557)	(0.503)	(0.477)	(0.356)
β	0.680**	0.692**	0.906**	0.930**
	(0.092)	(0.082)	(0.070)	(0.053)
γ	0.089	0.103	–0.026	–0.029
	(0.091)	(0.088)	(0.046)	(0.039)
η	0.704**	0.679**	0.342**	0.289**
	(0.118)	(0.123)	(0.110)	(0.088)
λ (Dollar Auction 1)	–0.697*		–0.654**	
	(0.283)		(0.196)	
λ (Dollar Auction 2)		–0.362		–0.532*
		(0.268)		(0.209)
Adj R-squared	0.703	0.703	0.741	0.742

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ** and * denote the 1% and 5% significance levels, respectively.

Figure 1

Three-month FX swap-implied US dollar rate from euro



Note: The FX swap-implied US dollar rate is defined as the total cost, in terms of the dollar rate, from raising euros in the uncollateralised cash market and converting them into dollars through the FX swap market. Euro Libor is used as the uncollateralised euro cash rate.

Figure 2

Flow of funds in FX swap