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# Capital Constraints, Counterparty Risk, and Deviations from Covered Interest Rate Parity

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**Abstract**

We provide robust evidence of a deviation in the covered interest rate parity (CIP) relation since the onset of the financial crisis in August 2007. The CIP deviation exists with respect to several different dollar-denominated interest rates and exchange rate pairings of the dollar vis-à-vis other currencies. The results show that our proxies for margin conditions and for the cost of capital are significant determinants of the CIP deviations, especially during the crisis period. The supply of dollars by the Federal Reserve to foreign central banks via reciprocal currency arrangements (swap lines) reduced CIP deviations at this time. Following the bankruptcy of Lehman Brothers, uncertainty about counterparty risk became a significant determinant of CIP deviations, and the swap lines program no longer affected the CIP deviations significantly. These results indicate a breakdown of arbitrage transactions in the international capital markets that owes partly to lack of capital and partly to heightened counterparty credit risk. Central bank interventions helped reduce the funding liquidity risk of global institutions.

Key words: covered interest rate parity, funding constraints, counterparty credit risk, central bank currency swap lines, financial crisis, foreign exchange

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The covered interest rate parity (CIP) relation is a bedrock of international economics. CIP states that an investor should be indifferent between borrowing and lending at domestic or foreign interest rates if the foreign exchange (FX) risk is fully hedged. Empirical evidence is generally supportive of the CIP, especially for recent sample periods and for the developed countries, except when exchange controls impede the free flow of capital.[1] Observed CIP deviations tend to be short-lived (11 minutes or less) and are not, on average, profit making (Akram, Rime and Sarno (2008)).

In this paper, we document a substantial and persistent breakdown in the CIP relation since the onset of the crisis in August 2007. Specifically, we measure the deviation from CIP by the US dollar (USD) basis, defined as the difference between the dollar rate implied by the CIP relation (henceforth, the "implied rate") and a benchmark unsecured dollar interest rate (e.g. the USD LIBOR). We show that while the basis is miniscule in normal periods, it has been consistently large and positive since the start of the crisis and increased dramatically after mid-September 2008 following the bankruptcy of Lehman Brothers (Figure 1). For example, the basis estimated using USD LIBOR as the interest rate and the euro-USD currency rate increased from essentially zero in the pre-crisis period to around 25 basis points during the initial periods of the crisis, before shooting up to over 200 basis points by the end of September 2008.

We show that this result is robust to the use of alternative USD interest rates and the use of different currency pairs of USD vis-à-vis other currencies. If banks contributing to LIBOR were strategically under-reporting their true dollar borrowing rates during the crisis, as has been alleged, then we might spuriously observe a deviation from CIP.[2] However, we continue to find

[1] Holmes and Schott (1965) discuss how severe exchange control restrictions resulted in persistent CIP deviations during the early 1930s to the late 1950s. As these controls eased, CIP deviations became less frequent.
[2] See, for example, "Libor Fog," by Carrick Mollenkamp, *The Wall Street Journal*, April 16 2008, page A1.

large deviations from CIP when we use the New York Funding Rate (NYFR) and Treasury bill rates.[3] We also find that the dollar basis estimated with respect to six currency pairs (USD vis-à-vis the Australian dollar, the euro, the Japanese Yen, the British pound, the Swiss franc, and the New Zealand dollar) shows a similar pattern of sharp increases in the crisis period, and especially since September 2008.

We further find that CIP deviations are robust to considerations of transactions costs. We incorporate the bid-ask spread for the four legs of the arbitrage transaction: forward, spot, dollar and the non-dollar rates. As the bid-ask spread in all markets blew up during the crisis the magnitude of CIP deviations is reduced after accounting for the spread. However, we continue to observe a large increase in the basis relative to its pre-crisis level before the Lehman failure, with a more dramatic jump afterwards.

What may have caused this remarkable deviation in the CIP? Keynes (1923) discusses how lack of "floating capital" may impede the CIP relation from holding. In modern parlance, funding constraints during the crisis placed limits to arbitrage (Shleifer and Vishny (1997), Gromb and Vayanos (2002), Geanakoplos (2003), Basak and Croitoru (2006), and Brunnermeier and Pedersen (2009)).[4] Garleanu and Pedersen (2009) develop an asset pricing model where risk-tolerant investors are margin constrained but risk-averse investors are not. They show that, if risk-averse investors are also constrained in their derivatives positions, then the basis between

[3] NYFR, published by ICAP and introduced in June 2008, is a trimmed mean of quotes collected from a panel of contributing US banks. To reduce the incentive to under-report, individual quotes and the composition of the panel are not disclosed. And, while Libor panel banks are asked to provide an estimate of their own borrowing costs, ICAP asks only for an estimate of the rate at which a representative A1/P1 bank would be likely to obtain funding.

[4] Holmes and Schott (1965) provide examples where increases in the flow of arbitrage funds were associated with decreases in CIP deviations. In the context of the uncovered interest rate parity, Brunnermeier, Nagel and Pedersen (2008) document that the sudden unwinding of carry trades are attributable to funding illiquidity when speculators near funding constraints.

a derivative and its asset is non-zero in equilibrium and depends on their relative margins and the leveraged investors' shadow cost of capital.

We use the framework of Garleanu and Pedersen (2009) to explain why the CIP deviations turned positive during the crisis. In particular, the framework implies that a positive basis is an indicator that arbitrageurs would have liked to borrow dollars in the spot market but could not. This is likely due to dollar hoarding by US institutions and a need by non-US institutions to fund their dollar denominated assets.[5] Next, we show that our proxy for margin conditions and the cost of capital are significant determinants of the basis, especially during the crisis period. These results indicate that arbitrage transactions became difficult to implement in the international capital markets during the crisis due to funding constraints.

An alternative explanation (also discussed by Keynes (1923)) is that previously riskless cash flows became risky during the crisis.[6] Baba and Packer (2008) show that the basis increases in the difference in CDS prices of European and US firms indicating heightened counterparty risk in the FX swap markets.[7] We find evidence that uncertainty about counterparty risk became a significant determinant of the basis, particularly after the failure of Lehman Brothers. Taken together, our results therefore indicate a breakdown of arbitrage transactions partly due to lack of capital and partly due to heightened counterparty credit risk, with the relative importance of the two types of risks varying during different stages of the crisis.

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[5] An example of reduced dollar supply is that U.S. money market funds abruptly stopped purchasing bank-issued commercial paper after they faced large redemptions following the bankruptcy of Lehman Brothers (Baba, McCauley, and Ramaswamy (2009)). An example of dollar demand is that European institutions sought out the foreign exchange swap market to finance their special-purpose vehicles that had invested in U.S. mortgage-backed securities (Baba, Packer, and Nagano (2008)).

[6] Holmes (1959) shows how CIP deviations tend to increase when sovereign risk and bank credit risk increases. Frenkel and Levich (1977) find that covered arbitrage profits increase during turbulent times. Taylor (1989) shows that deviations from CIP tend to increase during periods of crisis (e.g. the inception of the European Monetary System in 1979) and they persist for some time. Akram, Rime and Sarno (2008) find that CIP deviations increase with market volatility.

[7] International institutions obtain dollar funding in the FX swap markets, typically from US institutions that have a natural dollar deposit base.

To ease short-term dollar funding constraints, the Federal Reserve agreed to supply dollars to foreign central banks via reciprocal currency arrangements (swap lines) with several developed and emerging market countries. We find that announcements of the swap lines program were successful in bringing down the basis by an average of 5 basis points. The actual auctions of dollars were also effective in bringing down the basis. However, in the post-Lehman period, the swap lines programs did not have a significant effect on the basis possibly because they were not designed to bring down high levels of counterparty risk.[8] These results further establish that funding constraint was a key driver of the basis in the early part of the crisis.

We conduct several robustness checks. We repeat our regressions using changes in the basis (since the basis displays strong autocorrelation). We also repeat our analysis using high frequency (hourly) exchange rate data (this data is only available for part of our sample). Our qualitative results remain the same in all cases.

Of related papers, Griffoli and Ranaldo (2009) also find that funding constraints explain the CIP deviations but, different from us, that counterparty risk does not. The difference may arise because counterparty risk is likely to be less of a factor for the shorter maturity loans they examine (i.e. 1-week maturity compared to our 3-month maturity). Further, Griffoli and Ranaldo (2009) assume that arbitrageurs are able to borrow at secured (i.e. OIS) rates whereas we use unsecured (i.e. LIBOR) funding rates when estimating CIP deviations. Similar to our result, they find that central bank swap lines do not have an effect on the deviations after the Lehman failure. Baba and Packer (2008) find a decline in volatility of the basis but no change in its level due to

[8] The swap lines might also reduce the basis via exchange rates, a mechanism we do not study. Aizenmann and Pasricha (2009) find an affect of the swap lines on the exchange rates of emerging market countries.

the swap lines. They focus on CDS prices as determinants of CIP deviations but do not consider arbitrageurs' funding constraints as determinants of CIP deviations.[9]

Our contribution, relative to these papers, lie in providing a unified framework (based on Garleanu and Pedersen (2009)) to (1) explain why the CIP deviations became positive and (2) derive empirical proxies for funding constraints. Garleanu and Pedersen (2009) also document CIP deviations and comment on its correlation with the TED spread. However, they do not conduct any formal econometric analysis.

We extend this framework to develop an empirical measure of uncertainty about counterparty risk and show that CIP deviations are significantly related to this measure.[10] The extended framework allows us to examine the evolution of credit risk and liquidity risk during the crisis and the interaction between them. For example, Shleifer and Summers (1990) argue that small deviations from fundamentals may not be corrected when cash flows are risky. Our results suggest that even large deviations may not be corrected if cash flows are risky and capital is limited. Finally, we extend the prior evidence on the efficacy of public liquidity supply from the domestic context to the international markets.

The paper is organized as follows. In Section I, we describe our methodology and data. In Section II, we present estimates of the deviation from CIP. In sections III and IV, we discuss the roles of credit risk and liquidity risk in explaining deviations from CIP and present results. In Section V, we assess the impact of the Federal Reserve's bilateral currency swap lines on the CIP deviations. We conclude in Section VI.

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[9] Baba and Packer (2008) use the LIBOR-OIS spread as a proxy for liquidity risk but this proxy includes a substantial component of credit risk, as shown by Taylor and Williams (2008) and McAndrews et al (2008). Second, since they use LIBOR to estimate the basis, LIBOR is effectively on both sides of the regressions.

[10] Heider, Hoerlova and Holthausen (2009) show theoretically that such uncertainty is an important determinant of breakdowns in the interbank markets.

## I. Data and Measurement of Deviations from Covered Interest Parity

The CIP relation is derived from the idea that exchange and international interest rates adjust to equalize the borrowing cost globally. To make the idea concrete, consider the FX swap markets. In an FX swap, two parties engage in a spot currency transaction while simultaneously agreeing to reverse the transaction at the current forward rate at a specified time in the future. In essence, FX swaps allow counterparties to exchange funding at predetermined times in the future, in one currency for another currency, without FX risk. However, Duffie and Huang (1996) show that there exists counterparty credit risk due to the cost of replacing the contract should counterparty default.

A currency arbitrage involving FX swaps works as follows. Let $s$ be the spot rate, $f$ the forward rate, $i^D$ the domestic interest rate and $i^F$ the foreign interest rate at time $t$. Interest rates are in nominal units. Exchange rates are in units of domestic currency per unit of foreign currency. A domestic investor faces a choice between borrowing in the domestic uncollateralized cash market at an interest rate $(1+i^D)$ or, alternatively, converting the domestic currency into foreign currency through an FX swap and borrowing in the foreign uncollateralized cash market at an interest rate $(1+i^F)$. The FX swap dealer quotes the forward differential $(f/s)$. Therefore, if these two ways of borrowing are to be equally costly then the following condition must hold at each time $t$:

$$1 + i_t^D = \frac{f_t}{s_t}\left(1 + i_t^F\right) \tag{1}$$

Equation (1) is the CIP relation. Given data on the forward rate, the spot rate and the foreign interest rate $i^F$, the *implied rate* is the value of $i^D$ that solves (1). The USD basis ($Basis^D$) is the difference between the implied USD rate and a benchmark unsecured USD interest rate.

$$Basis_t^D = \frac{f_t}{s_t}\left(1 + i_t^F\right) - \left(1 + USD \text{ unsecured interest rate}\right) \quad (2)$$

For most of our analysis, we use the euro-USD exchange rate, the euro LIBOR and USD LIBOR fixing rates to estimate the basis:

$$Basis_t^D = \frac{euro\$ \ forward \text{ rate}_t}{euro\$ \ spot \text{ rate}_t}\left(1 + euroLIBOR_t\right) - \left(1 + \$LIBOR_t\right) \quad (3)$$

Arbitrage in international capital markets should ensure that the implied dollar rate is equal to the USD LIBOR rate, so that the basis is zero and CIP holds. If, for example, the basis is positive (say, because LIBOR is lower than the implied rate), institutions should borrow at the LIBOR rate until the basis returns to zero. Non-zero levels of the basis in normal times are likely due to temporary mispricings that are not arbitraged away (Akram et al (2008)).

We obtain tradable quote data on spot and forward exchange rates from Tullet Pebron, a leading broker in FX markets. Griffoli and Ranaldo (2009) use data from the same source. They discuss that the data is representative of the market in that all major participants are included. Further, they show that, although the prices are indicative, they are close to actual trading prices. The 3-month LIBOR rates are pulled from Reuters.

Ideally, data for all legs of the arbitrage transaction should be synchronous. For the early part of our sample, the exchange rate data are only available with close of business day values. Since LIBOR rates are announced at about 7am US Eastern Standard Time (EST), we calculate the day *t* implied rate by matching spot and forward exchange rate data for close of day *t* with LIBOR rates announced on day *t+1* (where all times are US EST). Starting from May 23 2008, we have available hourly data on the euro-USD exchange rate from Tullet Pebron which allows time-matching with LIBOR within the hour. We present results for both sets of data; in general, our results are qualitatively similar whether using the daily and the hourly data.

## II. Estimates of Deviations from Covered Interest Parity

In this section we present estimates of deviations from CIP during the crisis period. To show robustness of the estimates, we present several measures based on alternative dollar interest rates (USD LIBOR, NYFR and Treasury Bills) and alternative currency pairs (US dollar vis-à-vis euro, British pound, Australian dollar, New Zealand dollar, Japanese yen and Swiss franc). In all cases, we estimate the USD basis for a 3-month term loan. The sample period spans January 2007 to March 2009 for a total of 564 daily observations.

Section *A* shows estimates of the basis based on USD LIBOR, NYFR and Treasury bill rates for the daily and hourly euro-USD exchange rates. Section *B* shows estimates of the basis based on different currency pairs.

### *A. Estimates of CIP deviation based on alternative dollar interest rates*

INSERT FIGURE 1 HERE

Figure 1 shows estimates of the USD basis using equation (3) for daily (dashed line) and hourly (solid line) euro-USD exchange rate data. We observe that, prior to August 2007 (the start of the crisis), the basis hovered close to zero with deviations from zero likely due to temporary mispricings that were not arbitraged away. However, since the crisis started, the euro-USD basis has been consistently large and positive (implying a market-based dollar funding rate substantially higher than the USD LIBOR fixing rate). The deviations have been particularly large since the Lehman bankruptcy of September 15 2008. For the period where both hourly and daily exchange rate data is available, we observe that the two estimates track each other closely. Indeed, the correlation between the two basis measures is 0.94. Therefore, our estimates of CIP deviations appear robust to the reporting frequency of the exchange rate data.

INSERT TABLE 1 HERE

Panel A of Table 1 shows the mean and maximum values of the CIP deviations in basis points for different benchmark USD interest rates. The first two rows of Panel A show estimates using the daily and hourly euro-USD exchange rates when USD LIBOR is the reference rate. In the pre-crisis period, the mean and maximum deviations were less than 2 basis points in absolute value. In the crisis period, two regimes may be observable. Prior to September 2008, the basis was large relative to the pre-crisis period, rising to an average of 18 basis points for the daily data, with a maximum of 40 basis points. After September 2008, the basis jumped to an average of 65 basis points using daily data and 70 basis points using hourly data. The corresponding maxima were 233 and 246 basis points.

INSERT FIGURE 2 HERE

Figure 2 displays estimates of the basis when the USD LIBOR rate is replaced by the NYFR rate or the Treasury bill rate in equation (3). As noted in the introduction, the NYFR is a purely domestic US rate unlike LIBOR, which has only 3 US banks among 16 LIBOR panel banks. In addition, the NYFR was designed to minimize the incentives of banks to misreport their borrowing rates. This NYFR data is available from May 30 2008. Figure 2 shows that the behaviour of the NYFR basis is similar to that based on LIBOR: we observe a high and positive rate prior to September 2008 with a further sharp increase in September 2008. Panel A of Table 1 shows that the mean and maximum values of CIP deviations are similar whether based on LIBOR or NYFR. The CIP deviations based on the Treasury bill rate display qualitatively similar dynamics as those based on LIBOR. However, the bill basis is more than 3 times larger than that of the LIBOR basis (see Panel A of Table 1). This is because the Treasury bill rate closely tracks the policy rate and the Federal Reserve has aggressively reduced the latter over the

crisis period. In general, however, these results indicate the robustness of the evidence of CIP deviations with respect to alternative reference dollar interest rates.

*B. Estimates of CIP deviation based on alternative currency pairs*

If increases in the USD basis rate are due to an excess demand for dollars globally from non-US institutions, we would expect to see a widening not just in the USD basis with respect to the euro, but also the USD basis with respect to other currencies. Accordingly, we estimate the basis for the US dollar vis-à-vis Australian dollar, the Swiss franc, the British pound, the Japanese yen and the New Zealand dollar. To calculate the USD basis with respect to a currency different from euro, we use equation (2) along with the interest and exchange rates denominated in the relevant currency. For example, for the USD-GBP currency pair, we back out an implied dollar rate using the GBP LIBOR rate, and the spot and forward USD-GBP exchange rates.

INSERT FIGURE 3 HERE

From Figure 3, we observe that for five other currency pairs (USD-AUD, USD-CHF, USD-GBP, USD-JPY, and USD-NZD), the basis has also widened dramatically since September 15, 2008 and generally followed a path similar to that of the euro-USD basis. Panel B of Table 1 shows the mean and maximum values of the basis estimates for the different currency pairs. We observe that the mean and maximum values are similar for different currency pairs, and moreover they are comparable to those for the USD-euro pair in Panel A of Table 1. One exception is the USD-AUD pair in the period since September 16 2008 when its basis value appears to be high compared to the other currency pairs. Overall, the evidence supports the hypothesis of a structural increase in the demand for dollars worldwide, possibly increasing the implied dollar rate and widening the basis.

In this section we find robust evidence that deviations from CIP have been large and persistent since August 2007. Estimates of the CIP deviation based on a variety of dollar interest rates and a variety of currency pairs all depict similar patterns: large and positive deviations in CIP after August 2007 followed by an even sharper increase following the Lehman bankruptcy in September 2008. In the remainder of the paper, we explain why the arbitrage condition implicit in the CIP relation breaks down during the crisis and we assess the Federal Reserve's success in reducing CIP deviations through the supply of US dollars.

## III. Determinants of CIP Deviations: Discussion and Empirical Methodology

In this section, we discuss a theoretical framework for understanding CIP deviations. We then use the framework to understand why the deviations were positive (section *A*) and to propose empirical proxies for funding constraints (section *B*) and credit risk (section *C*).

Suppose the USD LIBOR is lower than the rate implied by CIP. In theory, arbitrageurs can earn riskless profits by borrowing USD for 3 months at the LIBOR rate, swapping into euros, investing at the euro LIBOR rate, and finally closing the swap in 3 months by converting back into dollars at the forward rate prevailing at the time of the swap. However, if funding is not available to arbitrageurs, then the trade does not occur and the CIP deviation persists. Shleifer and Vishny (1997) show how negative shocks are amplified if investors withdraw money from funds. Gromb and Vayanos (2002) show that when margin-constrained arbitrageurs face capital scarcity, a negative shock induces them to liquidate their own positions and widens price discrepancy.[11] Brunnermeier and Pedersen (2009) study the feedback effects between margins and market conditions.

[11] Geanakoplos (2003) derive margin constraints endogenously and shows the optimality of margin debt contracts.

Basak and Croitoru (2006) and Garleanu and Pedersen (2009) show that, in equilibrium, the basis between an asset *S* and a derivative *D* (i.e. the expected return on *S* minus the expected return on *D*) is not zero if there are leverage constraints on *S* and position limits on *D*. The basis represents differences in risk premia required by heterogeneous groups of investors. For example, Garleanu and Pedersen (2009) show that if risk-averse investors can short only a limited amount of *D*, then in equilibrium the risk tolerant investor is long *S* and also long *D*, and the basis is:

$$Basis_t^{S-D} \approx \psi_t \left( m_t^S - m_t^D \right) \tag{5}$$

where ψ is the margin constrained investor's shadow cost of capital and $m^i$ is the margin on security *i*. A positive basis arises if the margin on *D* is lower than that on *S*, which induces the risk tolerant investor to accept a lower risk premium on *D*.

Alternatively, if the risk-averse investor holds a long position in *D* then, in equilibrium, the risk-tolerant investor goes long in *S* and short in *D*. Since the latter has to pay margins on both legs of the basis trade, the basis is a function of the sum of the two margins:

$$Basis_t^{S-D} \approx \psi_t \left( m_t^S + m_t^D \right) \tag{6}$$

*A. Why were Deviations from Covered Interest Parity Positive?*

In theory, deviations from CIP could be positive or negative. But, as we have seen, they were consistently positive. We use the framework of Garleanu and Pedersen (2009) to understand the sign of the basis after the crisis. In the context of CIP deviations, the implied rate may be viewed as the return from the FX swap position *D* while the LIBOR rate is the return on the spot dollar position *S*. The positive basis means that the situation described by (6) applies and arbitrageurs are long *S* and short *D*. Why are arbitrageurs long dollars? They prefer to borrow dollars at the cheaper dollar rates and lend out at the foreign interest rates. However, as

discussed in Coffey et al (2009), they are unable to do so because of an acute shortage of US dollars (as discussed further in footnote 5).

INSERT TABLE 2 HERE

We now discuss the empirical proxies for margin constraints and the shadow cost of capital. Since arbitrage transactions are not riskless in reality, we also discuss a number of risk measures that we propose as determinants of the basis. A summary of all variable definitions is in Table 2.

*B. Empirical proxy for margin constraint and shadow cost of capital*

Our empirical proxy for the tightness of margin conditions is the 3-month agency MBS-GC repo spread which is the repo rate using agency mortgage-backed securities (MBS) as collateral minus the General Collateral (GC) repo rate using Treasury securities as collateral.[12] Banks rely on the repo market for short term collaterized financing, and so the repo rates should reflect financing stress during the crisis.[13] Since both MBS and GC repo loans are collaterized, the spread between them mainly reflects the liquidity difference between the two assets. In particular, agency MBS securities became highly illiquid during the crisis, leading to an increase in the agency MBS-GC repo spread. Since margins are expected to increase with illiquidity, increases in the MBS-GC repo spread is as a proxy for increasingly tight margin conditions.[14] The data is from Bloomberg.

INSERT FIGURE 4 HERE

[12] General collateral includes: general Treasury collateral; general Federal Agency and GSE collateral; and general MBS collateral. It excludes reverse repurchase agreement activity non-general collateral repurchase agreement activity.
[13] Brunnermeier (2008) uses this spread to illustrate liquidity risk during the crisis.
[14] Garleanu and Pedersen (2009) use the tightness of credit condition variable in the senior officer bank loan survey as a proxy for increasing tightness. This data, however, is only available at the quarterly frequency.

Figure 4 plots the agency-MBS repo spread and the basis based on the euro-dollar FX rate and the USD LIBOR rate. Except for brief periods after the Lehman bankruptcy, the repo spread is positive, consistent with the greater illiquidity of MBS relative to Treasuries. The expected association between the CIP deviation and the repo spread is positive. While this is true for some periods during the crisis, for other periods (especially in 2008), the repo spread and the basis appears to diverge. We will examine the co-movement and the basis in greater detail in the next section.

Garleanu and Pedersen (2009) show that the arbitrageur's shadow cost of capital is the interest rate spread between an uncollaterized and collaterized loan. We use the 3-month TED spread (i.e. the LIBOR minus the Treasury bill rate) and the 3-month LIBOR-GC repo spread as proxies for the shadow cost of capital. Figure 5, which plots the TED spread over the sample period, shows that the basis and the TED spread move together, as also shown by Garleanu and Pedersen (2009). The expected association between the CIP deviation and the TED or the LIBOR-GC repo spread is positive and Figure 5 shows that the basis and the TED spread generally co-move together.

*C. Empirical proxy for credit risk*

If arbitrage was not riskless during the crisis, then CIP deviations need not constitute violations of the Law of One Price. As our discussion of the repo spread indicated, there was market liquidity risk as the MBS market became illiquid before the Fed's TSLF program improved liquidity in the market. In addition, counterparty risk increased substantially during the crisis, which increased the likelihood that the FX swap contract would have to be replaced on unfavorable terms.

The *market liquidity risk* measure is the yield of a hypothetical 10-year off-the-run par bond minus the on-the-run 10-year Treasury yield, called the par-OTR spread. The data for the on-the-run 10-year Treasury yield is from Haver while the par bond yields are from the public website of the Federal Reserve Board of Governors. The hypothetical 10-year Treasury trading at par is derived from a Nelson-Siegel-Svensson zero-coupon curve estimated from off-the-run Treasury coupon securities. The par-OTR spread is a measure of the market liquidity premium of the on-the-run 10-year Treasury, and is likely related to liquidity premia in the Treasury market in general. Since Treasury securities are the most liquid U.S. securities and usually richen when demand for liquid and safe securities rises, the par-OTR spread is taken to be a proxy of systematic market liquidity risk in the economy.[15]

The expected sign of the correlation between illiquidity measures and the basis is ambiguous. Increases in the par-OTR spread have two effects. Increased illiquidity in the US markets makes it less likely that US institutions would be willing to supply dollars in the FX swap market which should increase the basis. However, increased illiquidity also reduces funding in the US market and thereby increases the LIBOR rate, which tends to decrease the basis.

The *credit risk* measures are:

- CDX: The CDX IG index of CDS prices
- Dispersion: The quote dispersion of LIBOR panel banks

CDX represents the average default risk in the economy. Data on the 5-year CDX investment grade (IG) index is from Markit. The index covers 125 names in North America and

[15] Although it represents a liquidity premium, the PAR-OTR spread cannot be taken to represent margin constraints, unlike the MBS-GC spread. First, the PAR-OTR is a spread between yields and not repo rates. Indeed, repo rates for on-the-run Treasuries diverge from GC repo rates (Keane (1995)). Second, changes in the PAR-OTR spread also depend on the specialness of Treasury securities (Duffie (1996)).

represents the average credit risk of major global firms. Counterparty risk is represented by the quote dispersion among LIBOR panel banks. To measure quote dispersion, we obtain from Bloomberg the daily 3-month USD LIBOR quotes of the 16 banks in the LIBOR panel of the British Bankers' Association and then calculate the maximum minus the minimum of the quotes each day. The quote dispersion shows the extent to which some LIBOR panel banks report greater borrowing costs, and therefore more default risk, compared to the typical LIBOR panel bank. In turn, increased quote dispersion of LIBOR banks may reflect a situation where banks in general charge higher interest rates to higher risk counterparties. The expected sign of the correlation of credit risk with the basis depends on whether the credit risk is greater for US or for non-US institutions. If the credit risk increases more for non-US firms then $i^F$ increases more than USD LIBOR and so the basis increases; in the reverse case, the basis decreases.

Finally, we control for *foreign exchange risk* and general *market risk* using:

- EVOL: Options-implied volatility in the euro-USD foreign exchange market.
- VIX: Options-implied volatility in the equity market

The implied volatility for the euro-USD exchange rate is calculated by JP Morgan, and this data is obtained from Bloomberg. Investors are affected by FX volatility if they need to replace the FX swaps contract due to the failure of their counterparty. The equity implied volatility is given by the VIX measure, data for which is pulled from Bloomberg. We use the VIX to measure the risk aversion of investors in the broad financial markets. To the extent that equity investors respond to the same set of risk factors as investors in the money markets, movements in VIX may be informative of variations in funding costs.

## IV. Explaining CIP Deviations: Results

In this section, we explain deviations in CIP as a breakdown in the Law of One Price due to capital constraints of arbitrageurs in the international money and FX markets (section *A*). Specifically, changes in margin constraints and arbitrageurs' cost of capital are expected to determine CIP deviations. In section *B*, we also explore the hypothesis that CIP deviations reflected the increased risk of arbitrage transactions and therefore did not necessarily constitute a breakdown in the Law of One Price. In section C, we examine whether ddeviations from CIP may be expected to increase in the credit risk of non-US institutions relative to US firms.

### *A. CIP deviations, margin constraint and shadow cost of capital*

INSERT TABLE 3 HERE

Table 3 shows the correlation of the basis with the MBS-GC repo spread. Prior to the crisis, the basis and the repo spread moved together, with a correlation of 0.15, consistent with theory. From August 2007 till September 15 2008, the basis and the repo spread tend to diverge, and the correlation becomes negative (-0.40). The negative co-movement generally occurs in 2008 when the Federal Reserve intervened to exchange illiquid MBS collateral for liquid Treasury collateral via the TSLF program (Fleming, Hrung and Keane, 2009). This had the effect of bringing down the illiquidity premium in the repo spread at a time when the basis was still increasing. After September 15 2008, the correlation becomes positive again (0.38). In contrast to the repo spread, the correlation of the basis, TED and the LIBOR-GC spread are positive for all sample periods, as expected.

INSERT TABLE 4 HERE

Table 4 shows results from a regression of the USD basis on its own lag, the repo spread and the shadow cost of capital for the pre-crisis period, the pre-Lehman and post-Lehman crisis

periods. Panel A shows results when the shadow cost of capital is represented by the TED spread. For the pre-crisis period, the margin constraint and the TED spread are both estimated positively, but only the TED spread coefficient is significant. The intercept is negative and significant, implying a higher margin on the uncollaterized LIBOR position, as expected. The adjusted R-squared is only about 6%, indicating that, in the pre-crisis period, changes in the basis are mostly random. For the period August 2007 to September 15 2008, the basis becomes highly autocorrelated and the intercept is no longer significant. Both the repo spread and the TED spread are significant determinants of the basis, with a negative and positive sign, respectively. In the final crisis period, the repo spread and the TED spread are positively associated with the basis, but only the former result is significant. Panel B of Table 4 repeats the regressions using the LIBOR-GC repo spread as the interest rate spread. The results are qualitatively similar to those using the TED spread. Overall, the signs of the coefficients are consistent with the unconditional correlations. The results indicate that the cost of capital is a positive, and generally significant, determinant of the basis, consistent with Garleanu and Pedersen (2009). In addition, the margin constraint is binding during the crisis period, with tighter margins increasing the basis except for the early period of the crisis when the Fed intervened to relax collateral constraints, as discussed earlier.

*B. CIP deviations, credit risk and liquidity risk*

Table 3 shows that the correlation between the basis and the par-OTR spread has changed over the course of the crisis. It is positive prior to the crisis, negative in the pre-Lehman period and positive again after the Lehman bankruptcy. The correlation of the basis with the CDX index is positive before the Lehman bankruptcy and negative afterwards. The changing signs of the correlations suggest that the *relative* credit and liquidity risk of US institutions vis-à-vis non-

US firms were changing over the course of the crisis. The correlation of the basis with dispersion is always positive in the crisis period and is more than 60% after the Lehman bankruptcy. Dispersion has relatively low correlation with CDS prices, indicating that they measure different dimensions of credit risk. EVOL and VIX have a correlation of close to 50% with the basis in the pre-Lehman period and more moderate correlation afterwards.

INSERT TABLE 5 HERE

Table 5 shows results from a regression of the USD basis on its own lag, the repo spread, the interest rate spread and the various risk measures. Panel A shows results when we use the TED spread. The sign and significance of the repo spread and the TED spread are the same as when we did not include the risk measures, with one exception. In the post-Lehman period, the TED spread has a negative and significant association with the basis, in contrast with a positive sign earlier. During this period, the correlation between the TED spread and Dispersion is 0.90 from Table 3, indicating that the TED spread is mainly driven by counterparty risk. Dispersion is positively and significantly with the basis at this time, and it is probably difficult to estimate the separately the effects of the TED spread and counterparty risk. Of the remaining risk measures, PAR-OTR is a significant determinant of the basis during the crisis period. It has a negative association with the basis in the pre-Lehman period and a positive association afterwards. This suggests that US banks may have been hoarding liquidity in the pre-Lehman phase of the crisis, reducing the supply of dollars to the FX swap market, and thereby increasing the basis. The CDX index and EVOL are not significant determinants of the basis, while the VIX is only significant in the pre-Lehman crisis period. Panel B reports results when the LIBOR-GC repo spread is used; the results are similar to those in Panel A.

To what extent are the CIP deviations driven by increases in risk measures during the crisis? Comparing Tables 4 and 5, addition of the risk measures doubles the adjusted R-squared during the pre-crisis period. In the pre-Lehman crisis period, there is no change in the adjusted R-squared; in the post-Lehman period, it increases from about 0.78 to about 0.82. Of the risk measures, the PAR-OTR measure is a significant determinant of the basis during the crisis period but it is not significant during the pre-crisis period. Dispersion is a significant determinant of the basis during the pre-crisis period and the post-Lehman period. This evidence points to a moderate effect of the risk measures during the post-Lehman phase of the crisis.

*C. Relative credit risk of US versus non-US firms*

INSERT FIGURE 5 HERE

The expected sign of the correlation of credit risk with the basis depends on whether the credit risk increases more for US firms (which increases USD LIBOR) or more for non-US institutions (which increases the foreign interest rate $i^F$). Figure 5 shows quotes submitted by firms to the LIBOR panel indicate the dollar funding costs of US and non-US institutions. Throughout the crisis, the average quote submitted by a non-US bank on the USD LIBOR panel has tracked slightly higher than the average quote submitted by a US bank and this difference has become more pronounced since September 2008. This suggests meaningful differences in dollar funding costs between US and non-US institutions over this period.

Given the ambiguity of the effects of the aggregate default risk measure, we also define a measure of relative default risk:

- Relative default risk: The average CDS prices of 13 non-US banks in the LIBOR panel minus the average CDS prices of 10 systematically important US banks.[16]

We expect the relative credit risk measure to be positively correlated with the basis.

INSERT TABLE 6 HERE

Table 6 shows results from a regression with the CDX index replaced by the relative credit risk of non-US versus US banks. For brevity, we do not show results for the other risk measures. The results in Panel A, using the TED spread, shows that the relative credit risk measure is significant in all periods. The results in Panel B, using the LIBOR-GC repo spread, shows that it is significant in every period except the pre-Lehman crisis period. Replacing the CDX index with the relative credit risk measure increases the adjusted R-squared in the pre-crisis period and the post-Lehman period. The relative credit risk is another measure of the dispersion in credit risk (between US and non-US firms). The results therefore provide strong evidence of the significance of this measure, especially after the Lehman failure.

In this section, we have provided evidence that changes in margin constraints and the cost of capital were significant determinants of CIP deviations during the crisis period, consistent with the hypothesis that the CIP deviations represent violations of the Law of One Price as arbitrageurs became capital constrained. Market liquidity risk and the dispersion in credit risk are also significant determinants of CIP deviations, especially after the Lehman bankruptcy. Indeed, the Federal Reserve provided unlimited amounts of dollars to foreign Central Banks after September 20008. In the next section, we examine whether the Fed's dollar liquidity supply eased funding constraints and reduced the basis.

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[16] The 10 systematically important US banks are those defined by the Treasury in its TARP plan. : Bank of America, Bank of NY Mellon, Citigroup, Goldman Sachs, JP Morgan Chase, Morgan Stanley, Merrill Lynch, State Street Corp, Wachovia, Wells Fargo. Bank of America agreed to buy Merrill Lynch on September 15 2008 but the acquisition did not officially close till January 2009. Wells Fargo acquired Wachovia on October 4 2008.

## V. Central Bank Currency Swaps and CIP Deviations

In this section, we investigate the effect of the Central Bank swap lines on deviations of CIP. To the extent that the deviations are due to arbitrageur's capital constraints in the international money markets, the supply of dollars by the Federal Reserve may be expected to alleviate the problem. The Fed supplies dollars to international Central Banks through bilateral currency arrangements whereby it supplies dollars in exchange for foreign currency for a specified period. The foreign Central Bank then supplies dollars to banks in its jurisdictions via auctions.

INSERT TABLE 7 HERE

Table 7 shows significant announcement dates for the program. The program was initiated on December 12 2007 as the Fed arranged swap lines with the European Central Bank (ECB) and the Swiss National Bank (SNB). As the dollar shortage in the international money markets became more acute, the program was expanded in size and scope. After the Lehman bankruptcy in September 2008, the size of the swap lines was greatly expanded and ultimately the cap on the amount distributed was removed altogether.

To determine the effect of the program on the basis, we define a dummy variable that equals 1 on days with swap announcements. The only exception is February 1 2008 when the dummy has value -1 because the ECB withdrew from the auctions in February, which effectively constituted a negative supply of dollars. We also have a dummy variable for days when the Fed conducted TAF auctions where US branches of foreign banks participated and obtained dollars. We do not include dummy variables for auction dates of the ECB since these dates coincided with TAF auction days leading to a collinearity problem in the regressions. While we expect the market impact of the program to be manifested mainly on announcement days, the initial

auctions may be expected to have additional impacts as market participants learnt about the program. As the program progressed, and participants became familiar, the auctions (which fall on specific dates of the month), are expected to have less effect on the basis.

In estimating the effects of the swap lines, we control for credit risk but not for liquidity risk. This is because the swap lines are expected to reduce liquidity risk. In addition, we control for term risk since the loans are for term maturities (mostly for 28 and 84 day maturities) rather than for overnight maturities. We use the difference between the 10-year Treasury note and the 3-month bill (both constant maturity) to capture changes in the slope of the yield curve. Finally, we switch from using the level of the basis to using changes in the basis. This is because the swap dummy is a binary variable. If the effect of the swap lines is persistent, then it is necessary to use the change in the basis to capture this effect, as explained by McAndrews et al (2008) in the context of the Fed's Term Auction Facilities (TAF).

The regression is of the following form:

$$\Delta Basis_t = Intercept + \alpha_1 SwapAnn_t + \alpha_2 \$Auctions_t + \Delta CONTROLS + \varepsilon_t \quad (7)$$

where *SwapAnn* is a dummy variable for announcement days of the swap line program, *$Auctions* is a dummy variable for TAF auction days, CONTROL are the variables to control for credit risk and market risk and Δ indicates that the variable is in changes. The control factors are the CDX index, Dispersion, VIX, EVOL and the term spread.

INSERT TABLE 8 HERE

The results of the regression are in Table 8. The sample period is August 1 2007 till March 30 2009. Since announcement effects may be short-lived, higher data frequency is likely to improved results. Consequently, we initially report results in Panel A for the basis using the hourly euro-dollar FX data which is available from May 23 2008. To check for robustness, we

then repeat the regression using the daily euro-dollar FX data. The results in Panel A indicate that, in the period from May 23 2008 to September 15 2008, the swap line announcements reduced the basis by an average of more than 5 basis points. In addition, the dollar auctions reduced the basis by an additional 1.3 basis point per auction, although this result is only significant at the 10% level. In contrast, for the period after Lehman, there is no statistically significant effect of the swap lines on the basis. This result is intuitive since, from our prior results, counterparty risk was a significant determinant of the basis in the post-Lehman period and the Fed's program was not designed to reduce counterparty risk.

The results in Panel B, using daily data, are qualitatively similar to those in Panel A when considering the same sample period. Thus for the period from May 23 2008 to September 15 2008, the swap announcements reduce the basis by an average of 3 basis points but there is no statistically significant effect in the post-Lehman period. Considering the period from August 2007 to September 15 2008, we find that the swap announcements were not significant but the auctions reduced the basis by almost 1.5 basis points per auction. For the period from December 2007 till May 2008, the swap line announcements had no significant effect on the basis while the auctions reduced the basis by about 2 basis points per auction (although this effect is significant only at the 10% level).

In summary, the Fed's swap lines program appears to have been successful in reducing the basis during periods when capital constraints were binding and less so during periods when counterparty risk was a significant determinant of the basis. In the above analysis, we only looked at the effect of swap lines on the interest rate basis. Aizenman and Pasricha (2009) find that the swap lines significantly impact exchange rates of emerging market countries. Thus, it is

possible that the swap lines affect CIP deviations through exchange rate changes in addition to the interest rate differentials.

## VI. Conclusion

In this paper, we document a substantial and significant breakdown in CIP following the onset of the current crisis. Specifically, we measure the deviation from CIP by the dollar "basis", defined as the difference between the dollar rate implied by the CIP relation (henceforth, the "implied rate") and a benchmark dollar interest rate. We show that, while in normal periods, the basis is miniscule it has been consistently large and positive since the start of the crisis and increased dramatically in mid-September 2008 following the bankruptcy of Lehman Brothers. This result is robust to the use of alternative benchmark dollar interest rates (such as USD LIBOR, NYFR and Treasury Bill rates) and the use of different currency pairs (such as the USD-euro, USD-Japanese Yen, USD - British pound, USD - Swiss franc, and USD - New Zealand dollar) in deriving the basis.

Our results show that capital constraints of arbitrageurs appear to be a key driver of CIP deviations. Our proxy for margin conditions and the cost of capital are significant determinants of the basis, especially during the crisis period. These results are consistent with a deviation of the Law of One Price during the crisis as arbitrage transactions became difficult in the international money markets due to funding constraints. In addition, we find evidence that uncertainty about counterparty risk became an issue following the bankruptcy of Lehman Brothers, so that previously riskless cash flows became risky. These results indicate a breakdown of arbitrage transactions in the international capital markets partly due to lack of capital and partly due to heightened counterparty credit risk.

To ease short-term dollar funding constraints in the international money markets, the Federal Reserve agreed to supply dollars to foreign central banks via reciprocal currency arrangements (swap lines) with several developed and a few emerging market countries. We find that announcements of the swap lines program were successful in bringing down the basis by an average of 5 basis points. The actual auctions of dollars were also effective in bringing down the basis. However, in the post-Lehman period, the swap lines programs did not have a significant effect on the basis possibly because they were not designed to bring down high levels of counterparty risk. In addition, the swap might affect exchange rates as shown by Aizenman and Pasricha (2009) who find an affect of the swap lines on emerging market countries (however, they did not examine exchange rates of developed countries). This is an area for further research.

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## Table 1: Measures of CIP Deviation

**Panel A: Estimates based on euro-dollar exchange rate and alternative dollar interest rates**

| | | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|---|
| Interest rate | FX data frequency | Mean | Max | Mean | Max | Mean | Max |
| LIBOR | Daily | -1.322 | 1.740 | 18.046 | 39.674 | 65.353 | 233.022 |
| Obs. | | 144 | | 279 | | 135 | |
| LIBOR | Hourly | --- | --- | 27.073 | 40.772 | 70.024 | 246.314 |
| Obs. | | --- | | 79 | | 134 | |
| NYFR | Daily | --- | --- | 25.090 | 38.869 | 55.915 | 195.022 |
| Obs. | | --- | | 75 | | 133 | |
| T. Bill | Daily | 35.782 | 79.226 | 141.555 | 242.260 | 247.003 | 572.891 |
| Obs. | | 145 | | 281 | | 135 | |

**Table 1 (continued)**

**Panel B: Estimates based on dollar LIBOR rate and alternative currencies vis-à-vis dollar**

| | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|
| Currency | Mean | Max | Mean | Max |
| AUS | 10.790 | 40.218 | 122.483 | 509.532 |
| Obs | 275 | | 73 | |
| CHF | 20.576 | 43.328 | 41.301 | 191.037 |
| Obs | 275 | | 134 | |
| GBP | 24.342 | 51.676 | 90.038 | 235.752 |
| Obs | 275 | | 133 | |
| JPY | 11.950 | 31.471 | 32.257 | 219.336 |
| Obs | 275 | | 134 | |
| NZD | 4.847 | 37.193 | 49.983 | 140.820 |
| Obs | 275 | | 73 | |

The table shows the mean and maximum values of deviations from Covered Interest Rate Parity (CIP) in basis points for the pre-crisis period (January 1, 2007 – July 31 2007), the pre-Lehman period (August 1 2007 – September 15, 2008) and the post-Lehman period (September 16 2008 – March 30 2009). The deviations are equal to the US dollar (USD) interest rate implied by the CIP relation ("the implied rate") minus the USD interest rate. In Panel A of the table, the implied rate is estimated using the euro-dollar exchange rate and the euro LIBOR rate. The USD interest rates are USD LIBOR, NYFR or Treasury bill rates. The euro-dollar data frequency is either daily or hourly. The hourly dollar-euro data is available from May 23 2008 only. In Panel B of the table, the USD interest rate is USD LIBOR. The implied rate is based on the following exchange rates: USD-Australian dollar (AUS), USD-Swiss franc (CHF), USD - British pound (GBP), USD -Japanese Yen (JPY) and USD -New Zealand dollar (NZD). The USD-AUS and USD-NZD exchange rate data are only available through December 31 2008.

**Table 2: Variable Definitions**

| | |
|---|---|
| Basis | USD interest rate implied by the CIP relation ("the implied rate") minus the USD LIBOR rate. The implied rate is estimated using the euro-dollar spot and forward exchange rates and the euro LIBOR rate. |
| MBS_GC | 3-month agency MBS repo rate minus General Collateral (GC) repo spread |
| LIB_GC | 3-month LIBOR-GC repo spread: LIBOR rate minus GC repo rate |
| TED | 3-month LIBOR rate minus 3-month Treasury bill rate |
| Par-OTR | Yield on hypothetical off-the-run 10-year Treasury trading at par minus yield the on-the-run 10-year Treasury |
| CDX | CDX IG index |
| NUS-US CDS | Average of CDS prices of 13 non-US banks in LIBOR panel minus average of CDS prices of 10 systemically important US banks |
| Disp. | Maximum minus minimum quote of banks in USD LIBOR panel |
| VIX | Equity implied volatility Index |
| EVOL | Euro-US dollar exchange rate implied volatility |
| Swap ann. | Dummy variable equal to 1 on days with announcements of the Fed's currency swap lines program (dates in Table 7) |
| $ auctions | Dates of days when the Fed auctioned dollars to banks |

The table describes the variables used in the regressions.

## Table 3: Correlation of Basis and Its Determinants

**Panel A: January 1, 2007 –July 31, 2007**

| | Basis | MBS_ GC | TED | LIB_ GC | Par_ OTR | Disp. | CDX | VIX | EVOL |
|---|---|---|---|---|---|---|---|---|---|
| Basis | 1.000 | | | | | | | | |
| MBS_GC | 0.218 | 1.000 | | | | | | | |
| TED | 0.244 | 0.392 | 1.000 | | | | | | |
| LIB_GC | 0.282 | 0.855 | 0.507 | 1.000 | | | | | |
| Par_OTR | -0.138 | 0.143 | 0.056 | 0.049 | 1.000 | | | | |
| Disp. | -0.183 | -0.431 | -0.117 | -0.368 | -0.267 | 1.000 | | | |
| CDX | 0.006 | 0.628 | 0.249 | 0.658 | 0.505 | -0.327 | 1.000 | | |
| VIX | 0.010 | 0.482 | 0.349 | 0.453 | 0.521 | -0.286 | 0.800 | 1.000 | |
| EVOL | -0.198 | -0.230 | -0.401 | -0.322 | 0.101 | 0.061 | -0.055 | -0.129 | 1.000 |

**Panel B: August 1, 2007 –September 15, 2008**

| | Basis | MBS_ GC | TED | LIB_ GC | Par_ OTR | Disp. | CDX | VIX | EVOL |
|---|---|---|---|---|---|---|---|---|---|
| Basis | 1.000 | | | | | | | | |
| MBS_GC | -0.400 | 1.000 | | | | | | | |
| TED | -0.054 | 0.535 | 1.000 | | | | | | |
| LIB_GC | 0.114 | 0.685 | 0.732 | 1.000 | | | | | |
| Par_OTR | 0.472 | 0.109 | -0.118 | 0.258 | 1.000 | | | | |
| Disp. | 0.069 | 0.213 | 0.530 | 0.369 | -0.296 | 1.000 | | | |
| CDX | 0.196 | 0.071 | -0.238 | 0.034 | 0.720 | -0.514 | 1.000 | | |
| VIX | -0.455 | 0.383 | 0.152 | 0.014 | 0.155 | -0.205 | 0.331 | 1.000 | |
| EVOL | 0.498 | -0.018 | -0.053 | 0.211 | 0.732 | -0.214 | 0.679 | 0.101 | 1.000 |

**Panel C: September 15, 2008 –March 30, 2009**

| | Basis | MBS_ GC | TED | LIB_ GC | Par_ OTR | Disp. | CDX | VIX | EVOL |
|---|---|---|---|---|---|---|---|---|---|
| Basis | 1.000 | | | | | | | | |
| MBS_GC | 0.383 | 1.000 | | | | | | | |
| TED | 0.605 | 0.442 | 1.000 | | | | | | |
| LIB_GC | 0.492 | 0.483 | 0.967 | 1.000 | | | | | |
| Par_OTR | -0.380 | 0.315 | -0.357 | -0.251 | 1.000 | | | | |
| Disp. | 0.611 | 0.329 | 0.898 | 0.843 | -0.469 | 1.000 | | | |
| CDX | -0.112 | 0.112 | -0.284 | -0.256 | 0.380 | -0.405 | 1.000 | | |
| VIX | 0.350 | 0.652 | 0.450 | 0.504 | 0.296 | 0.308 | 0.355 | 1.000 | |
| EVOL | -0.124 | 0.330 | -0.277 | -0.215 | 0.651 | -0.301 | 0.339 | 0.324 | 1.000 |

The table shows the correlations between the basis and its determinants for the pre-crisis period (January 1, 2007 – July 31 2007; Panel A), the pre-Lehman period (August 1 2007 – September 15, 2008; Panel B) and the post-Lehman period (September 16 2008 – March 30 2009; Panel C). Variable definitions are in Table 2.

## Table 4: CIP Deviations, Margin Constraints and Interest Rate Spreads

**Panel A: Interest rate spread = TED spread**

| | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats | Estimate | *t*-stats |
| Intercept | -2.138** | -4.419 | 0.670 | 0.921 | 5.601 | 1.585 |
| Lag Basis | 0.038 | 0.365 | 0.922** | 43.210 | 0.796** | 9.600 |
| MBS-GC | 0.045 | 1.289 | -0.024* | -1.917 | 0.100* | 1.809 |
| TED | 0.012* | 2.540 | 0.015* | 2.031 | 0.017 | 0.358 |
| Adj. $R^2$ | 0.058 | | 0.890 | | 0.783 | |
| OBS | 137 | | 235 | | 132 | |

**Panel B: Interest rate spread = LIBOR-GC repo spread**

| | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats | Estimate | *t*-stats |
| Intercept | -3.429** | -3.283 | 0.405 | 0.498 | 6.796* | 1.833 |
| Lag Basis | 0.034 | 0.296 | 0.896** | 37.315 | 0.817** | 11.870 |
| MBS-GC | -0.025 | -0.670 | -0.044** | -2.800 | 0.109* | 2.009 |
| LIB-GC | 0.118* | 2.239 | 0.037** | 2.619 | 0.001 | 0.024 |
| Adj. $R^2$ | 0.062 | | 0.893 | | 0.782 | |
| OBS | 137 | | 272 | | 131 | |

** denotes 1% significance and * denotes 5% significance

The table shows results from regressions of the 3-month basis on a lag of the basis, the MBS-GC repo spread and the TED spread (Panel A) or the LIBOR-GC repo spread (Panel B). Variable definitions are in Table 2. The regression is estimated separately for the pre-crisis period (January 1, 2007 – July 31 2007), the pre-Lehman period (August 1 2007 – September 15, 2008) and the post-Lehman period (September 16 2008 – March 30 2009). The standard errors are adjusted for heteroskedasticity and serial correlation using the Newey-West procedure with the number of lags truncated at 5.

## Table 5: CIP Deviations, Credit Risk and Liquidity Risk

**Panel A: Interest rate spread = TED spread**

| | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats | Estimate | *t*-stats |
| Intercept | 0.730 | 0.821 | 0.463 | 0.186 | 34.354 | 1.383 |
| Lag Basis | -0.029 | -0.294 | 0.812** | 19.674 | 0.716** | 9.572 |
| MBS-GC | 0.051 | 1.575 | -0.055** | -2.628 | 0.195* | 2.366 |
| TED | 0.012* | 2.116 | 0.025** | 2.592 | -0.121* | -2.207 |
| **Liquidity Risk** | | | | | | |
| PAR-OTR | -0.137 | -1.431 | 0.330** | 3.342 | -0.736* | -2.106 |
| **Credit Risk** | | | | | | |
| CDX | -0.013 | -0.828 | 0.008 | 0.648 | 0.068 | 0.713 |
| Disp. | -0.541** | -2.607 | 0.113 | 1.142 | 0.370** | 3.102 |
| **Market Risk** | | | | | | |
| VIX | -0.011 | -0.237 | -0.205* | -2.183 | 0.184 | 0.444 |
| EVOL | -0.085 | -1.125 | -0.103 | -0.460 | -0.228 | -0.304 |
| Adj. $R^2$ | 0.109 | | 0.894 | | 0.820 | |
| OBS | 135 | | 265 | | 129 | |

**Table 5 (continued)**

**Panel B: Interest rate spread = LIBOR-GC repo spread**

| | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats | Estimate | *t*-stats |
| Intercept | -1.719 | -1.350 | 1.083 | 0.437 | 34.124 | 1.385 |
| Lag Basis | -0.060 | -0.635 | 0.828** | 20.977 | 0.679** | 9.335 |
| MBS-GC | -0.017 | -0.425 | -0.056** | -2.970 | 0.196* | 2.394 |
| LIB-GC | 0.160** | 3.257 | 0.033* | 1.909 | -0.133* | -2.421 |
| **Liquidity Risk** | | | | | | |
| PAR-OTR | -0.066 | -0.666 | 0.275** | 3.092 | -0.701* | -1.923 |
| **Credit Risk** | | | | | | |
| CDX | -0.044** | -2.637 | 0.002 | 0.131 | 0.052 | 0.516 |
| Disp. | -0.469* | -2.156 | 0.092 | 1.015 | 0.337** | 3.379 |
| **Market Risk** | | | | | | |
| VIX | 0.037 | 0.837 | -0.135 | -1.467 | 0.260 | 0.581 |
| EVOL | -0.069 | -0.888 | -0.159 | -0.680 | -0.195 | -0.252 |
| Adj. $R^2$ | 0.125 | | 0.895 | | 0.823 | |
| OBS | 135 | | 262 | | 129 | |

** denotes 1% significance and * denotes 5% significance

The table shows results from regressions of the 3-month basis on a lag of the basis, risk measures, the MBS-GC repo spread and the TED spread (Panel A) or the LIBOR-GC repo spread (Panel B). Variable definitions are in Table 2. The regression is estimated separately for the pre-crisis period (January 1, 2007 – July 31 2007), the pre-Lehman period (August 1 2007 – September 15, 2008) and the post-Lehman period (September 16 2008 – March 30 2009). The standard errors are adjusted for heteroskedasticity and serial correlation using the Newey-West procedure with the number of lags truncated at 5.

## Table 6: CIP Deviations and Relative Credit Risk of US versus Non-US Firms

**Panel A: Interest rate spread = TED spread**

| | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats | Estimate | *t*-stats |
| MBS-GC | 0.071* | 1.909 | -0.049** | -2.519 | 0.216** | 2.674 |
| TED | 0.007 | 1.321 | 0.024** | 2.603 | -0.133** | -3.583 |
| NUS-US CDS | 0.081* | 1.774 | -0.022* | -2.019 | -0.248** | -4.189 |
| OTHER CONTROLS? | YES | | YES | | YES | |
| Adj. $R^2$ | 0.127 | | 0.894 | | 0.855 | |
| OBS | 135 | | 264 | | 128 | |

**Panel B: Interest rate spread = LIBOR-GC spread**

| | 1/1/2007-7/31/2007 | | 8/01/2007 - 9/15/2008 | | 9/15/2008 - 3/31/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats | Estimate | *t*-stats |
| MBS-GC | -0.008 | -0.193 | -0.055** | -2.999 | 0.215** | 2.675 |
| LIB-GC | 0.155** | 3.191 | 0.034* | 2.012 | -0.132** | -3.270 |
| NUS-US CDS | 0.139** | 3.203 | -0.014 | -1.260 | -0.236** | -3.871 |
| OTHER CONTROLS? | YES | | YES | | YES | |
| Adj. $R^2$ | 0.163 | | 0.894 | | 0.854 | |
| OBS | 135 | | 261 | | 128 | |

** denotes 1% significance and * denotes 5% significance

The table shows results from regressions of the 3-month basis on a lag of the basis, the relative credit risk of non-US versus US firms, the MBS-GC repo spread and the TED spread (Panel A) or the LIBOR-GC repo spread (Panel B). OTHER CONTROLS are Par-OTR, Disp.,VIX and EVOL. Variable definitions are in Table 2. The regression is estimated separately for the pre-crisis period (January 1, 2007 – July 31 2007), the pre-Lehman period (August 1 2007 – September 15, 2008) and the post-Lehman period (September 16 2008 – March 30 2009). The standard errors are adjusted for heteroskedasticity and serial correlation using the Newey-West procedure with the number of lags truncated at 5.

**Table 7: Central Bank Currency Swap Announcements**

| Dates | Announcement |
|---|---|
| 12/12 /2007 | Swap line arrangements with European Central Bank (ECB) and Swiss National Bank (SNB) announced. Agreement for 6 months. |
| 1/10 /2008 | ECB announces two TAF auctions for January 2008. |
| 2/01/2008 | ECB announces it will not participate in February auctions. |
| 3/11/2008 | Size of swap lines with ECB and SNB expanded. |
| 5/2/2008 | Increased size of swap lines with ECB, SNB and extension of program. Program extended till Jan 30 2009. |
| 7/30/2008 | ECB, SNB announce establishment of 84 day TAF auctions. |
| 9/18/2008 | Further expansion of swap lines with ECB and SNB. New swap line arrangements with Bank of Canada (BOC), Bank Of England (BOE), and Bank of Japan (BOJ). |
| 9/24/2008 | New swap line arrangements with Royal Bank of Australia, Danmark Nationalbank, Norges Bank and Sweden Rijksbank. |
| 9/26/2008 | Expanded swap line size with ECB, SNB announced. |
| 9/29/2008 | Increased swap line sizes with ECB, SNB, BOC, BOE, BOJ, and Danmark Nationalbank, Norges Bank and Sweden Rijksbank. Agreements extended till April 30 2009. |
| 10/13/2008 | Expansion of swap line sizes with ECB, SNB and BOE. |
| 10/14/2008 | Expansion of swap line sizes with BOJ. |
| 10/28/2008 | Initiate swap line arrangement with Royal Bank of New Zealand. |
| 10/29/2008 | FED announces swap line arrangements with Banco Central do Brasil, Banco de Mexico, Bank of Korea, and the Monetary Authority of Singapore. |
| 02/03/2009 | FED announces extension of swap line arrangements to October 30 2009 |

The table shows dates of significant announcements of the Federal Reserve's swap line arrangements with various international central banks between December 2007 and March 2009.

## Table 8: Effect of Central Bank Currency Swaps on the Basis

**Panel A: Results using euro-dollar data at hourly frequency**

| | 5/23/2008 - 9/15/2008 | | 9/16/2008 - 3/31/2009 | |
|---|---|---|---|---|
| Explanatory variable | Estimate | *t*-stats | Estimate | *t*-stats |
| Intercept | -0.098 | -0.285 | -0.174 | -0.114 |
| Swap ann. | -5.258** | -4.470 | 4.185 | 0.308 |
| $ auctions | -1.279 | -1.685 | -1.925 | -0.644 |
| CONTROLS | YES | | YES | |
| Adj. $R^2$ | 0.180 | | 0.093 | |
| OBS | 76 | | 130 | |

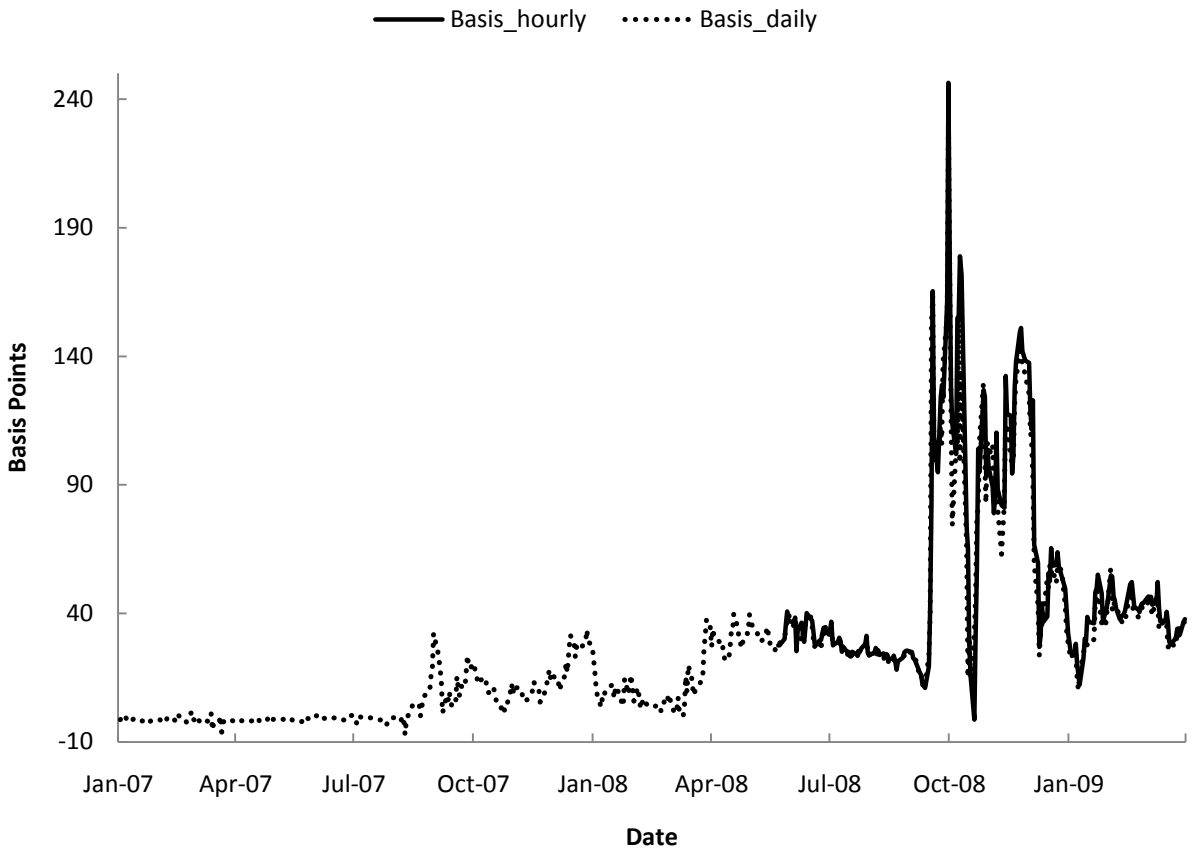
**Panel B: Results using euro-dollar data at daily frequency**

| | 8/1/2007-5/22/2008 | | 5/23/2008-9/15/2008 | | 9/16/2008-3/30/2009 | |
|---|---|---|---|---|---|---|
| Explanatory variable | Est | *t*-stats | Est | *t*-stats | Est | *t*-stats |
| Intercept | 0.225 | 0.680 | 0.057 | 0.203 | -0.168 | -0.106 |
| Swap ann. | -0.917 | -0.466 | -2.982** | -4.796 | -4.335 | -0.506 |
| $ auction | -1.726 | -1.630 | -1.269 | -1.242 | 3.741 | 0.980 |
| CONROLS? | YES | | YES | | YES | |
| Adj. $R^2$ | -0.018 | | 0.221 | | 0.162 | |
| OBS | 85 | | 77 | | 130 | |

** denotes 1% significance and * denotes 5% significance

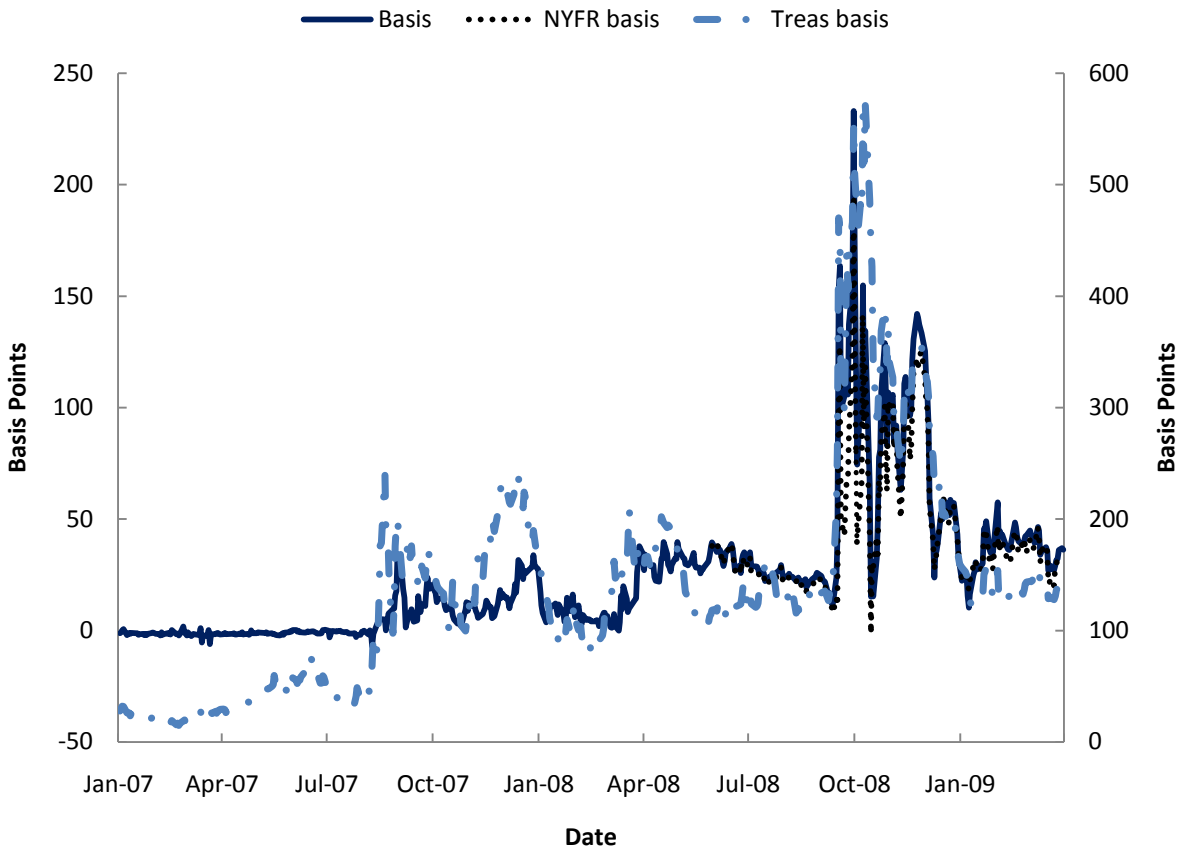
The table shows results from regressions of changes in the 3-month basis on dummy variables for SWAP announcements and dollar auction dates. CONTROLS are changes in Disp., CDX, VIX, EVOL and Y10_3. Variable definitions are in Table 2. The regression is estimated separately for the pre-Lehman period (August 1 2007 – September 15, 2008) and the post-Lehman period (September 16 2008 – March 30 2009). The standard errors are adjusted for heteroskedasticity and serial correlation using the Newey-West procedure with the number of lags truncated at 5.

**Figure 1: CIP Deviations Based on US Dollar LIBOR and Euro-Dollar Exchange Rate January 2007 –March 2009**



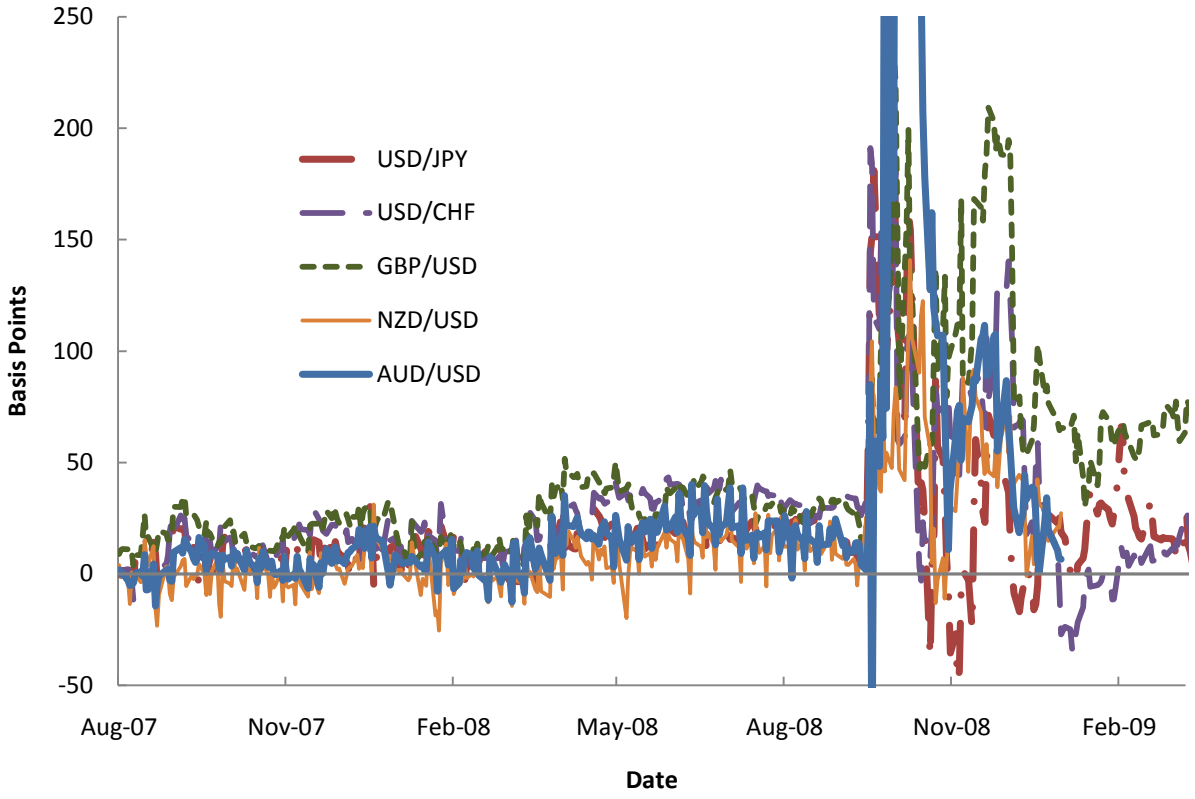

The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD), calculated as the CIP implied USD rate minus the USD LIBOR rate. The CIP implied USD rate is estimated using the euro-dollar exchange rate and the euro LIBOR rate. The dashed line is based on daily exchange rate data and the solid line is based on hourly exchange rate data. The sample period is from January 1 2007 till March 30 2009 except for the hourly data which is available from May 23 2008.

**Figure 2: CIP Deviations Based on Dollar LIBOR, NYFR and Treasury Bill Rates, and the Euro-Dollar Exchange Rate, January 2007 –March 2009**



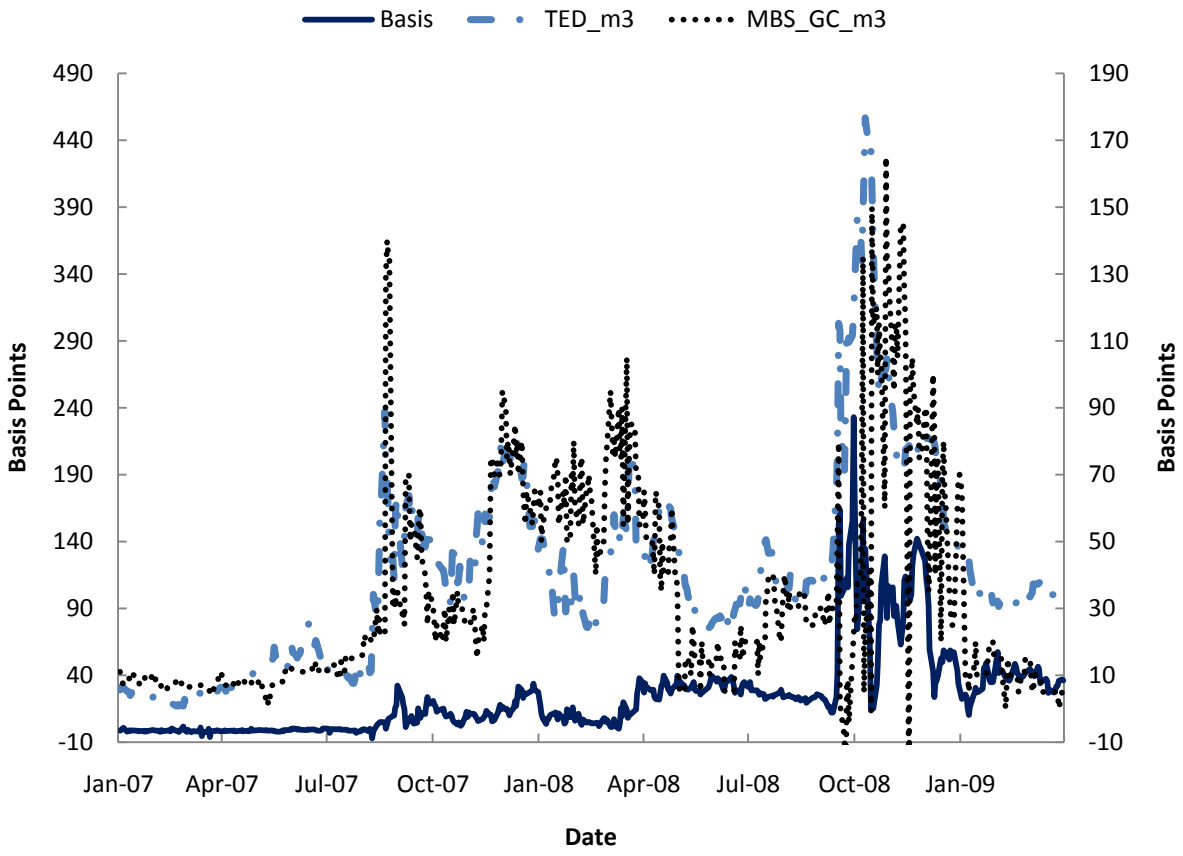

The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD), calculated as the CIP implied USD rate minus several benchmark USD rates. The benchmark USD rates shown are the USD LIBOR rate (left axis), the NYFR rate (left axis) and the Treasury Bill rate (right axis). The CIP implied rate USD is estimated using daily euro-dollar exchange rates and the euro LIBOR rate. The sample period is from January 1 2007 till March 30 2009 except for the NYFR data which is available from May 30 2008.

**Figure 3: FX Basis Calculated For Different Currency Pairs, January 2007 –March 2009**




The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD), calculated as the CIP implied USD rate minus the USD LIBOR rate. The CIP implied USD rate is is estimated using exchange rates and interest rates denominated in the following currencies: the Australian dollar (AUD), the Swiss franc (CHF), the British pound (GBP), the Japanese Yen (JPY) and the New Zealand dollar (NZD). The sample period is from January 1 2007 till March 30 2009 except for the USD-AUD and the USD-NZD data that are available till December 31 2008.

**Figure 4: FX Basis, MBS-GC Repo Spread and TED Spread**




The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD), calculated as the CIP implied USD rate minus the USD LIBOR rate. The CIP implied USD rate is estimated using the euro-dollar exchange rate and the euro LIBOR rate. Also plotted are the 3-month agency MBS minus GC repo spread and the 3-month TED spread (i.e. the LIBOR minus the Treasury bill rate). The sample period is from January 1 2007 till March 30 2009.

**Figure 5: Spread between Average non-US and US USD LIBOR Quotes**