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Niall Coffey
Warren B. Hrung
Asani Sarkar

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Abstract

We provide robust evidence of deviations from the covered interest rate parity (CIP) relation since the onset of the financial crisis in August 2007. The CIP deviations exist 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. Following the bankruptcy of Lehman Brothers, uncertainty about counterparty risk became a significant determinant of CIP deviations. The supply of dollars by the Federal Reserve to foreign central banks via reciprocal currency arrangements (swap lines) reduced CIP deviations. In particular, the announcement on October 13, 2008, that the swap lines would become unlimited reduced CIP deviations substantially. These results indicate a breakdown of arbitrage transactions in the international capital markets during the crisis that stems partly from lack of funding and partly from 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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Coffey: Federal Reserve Bank of New York (e-mail: niall.coffey@ny.frb.org). Hrung: Federal Reserve Bank of New York (e-mail: warren.hrung@ny.frb.org). Sarkar: Federal Reserve Bank of New York (e-mail: asani.sarkar@ny.frb.org). The authors thank Viral Acharya, Ron Alquist, Markus Brunnermeier, Emmanuel Farhi, Arvind Krishnamurthy, Richard Levich, Martin Oehmke, Lasse Pedersen, and Dimitri Vayanos for valuable comments. The authors also thank Mark Lueck for data assistance, as well as seminar participants at the National Bureau of Economic Research Summer Institute 2009, the Financial Stability Conference 2009 (Vancouver), and the Federal Reserve System Committee on Financial Structure and Regulation Conference (Boston) for helpful comments. The views expressed in this paper are those of the authors and do not necessarily reflect the position of the Federal Reserve Bank of New York or the Federal Reserve System.

The covered interest rate parity (CIP) relation is a bedrock of international economics. CIP states that, if foreign exchange (FX) risk is fully hedged, then borrowing at home to lend abroad (or vice versa) is not profitable. 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. We measure the deviation from CIP by the US dollar (USD) basis, defined as the difference between the USD 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. 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 (Figure 1).

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 with reference to Libor.[2] However, we continue to find large deviations from CIP when we use the New York Funding

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[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.

Rate (NYFR) and Treasury bill rates (Figure 2).[3] We also find that the USD 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 (Figure 3).

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) show that, given risk-tolerant investors who are margin-constrained and risk-averse investors who are constrained in their derivatives positions, the basis between 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 model of Garleanu and Pedersen (2009) to explain why the CIP deviations turned positive during the crisis. We discuss how a positive basis was indicative of difficulties in borrowing USD in the unsecured funding market, likely due to reduced supply of and increased global demand for USD during the crisis. We then develop empirical measures of margin conditions and the shadow cost of capital and show that they are significant determinants of the basis. These results indicate that arbitrage trades in the international capital markets were limited during the crisis due to funding constraints.

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[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 of increased flow of arbitrage funds associated with lower CIP deviations. In the context of the uncovered interest rate parity, Brunnermeier, Nagel and Pedersen (2008) show that the sudden unwinding of carry trades are attributable to funding illiquidity when speculators near funding constraints.

Another explanation of CIP deviations (also discussed by Keynes (1923)) is that previously riskless cash flows became risky during the crisis.[5] Baba and Packer (2008) show that the basis increases in the difference in CDS prices of European and US firms.[6] We find that uncertainty about counterparty risk became a significant determinant of the basis, particularly in the immediate aftermath of the failure of Lehman Brothers. Taken together, our results therefore indicate a breakdown of arbitrage transactions partly due to lack of funding 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.

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 study changes in the basis on days of Federal Reserve announcements and auctions related to the swap lines. We find that announcement days of the swap lines program are associated with a reduction in the basis by an average of 5 basis points. We further find that the actual auctions of dollars were also effective in bringing down the basis on the days of operations. Shortly after the Lehman bankruptcy, the Fed announced an increase in the size of swap lines to accommodate *any* quantity of USD that might be demanded.[7] We find that this announcement was associated with a substantial reduction in the basis of more than 50 basis points during a single day. These results further establish that funding constraints were key drivers of the basis during the crisis.

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[5] Gorton (2009) discusses how "informationally-insensitive" debt became "informationally-sensitive" during a crisis.

[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] Federal Reserve Press Release, http://federalreserve.gov/newsevents/press/monetary/20081013a.htm. October 13 2008.

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, they 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. They find that central bank swap lines had no statistical effect on the deviations after the Lehman failure (although they do not consider the announcement of unlimited swap lines). Baba and Packer (2008) find a decline in volatility of the basis but no change in its level due to the swap lines. They focus on CDS prices but do not consider arbitrageurs' funding constraints as determinants of CIP deviations.[8]

Our contribution, relative to these papers, lie in using a theoretical framework (based on Garleanu and Pedersen (2009)) to (1) explain why the CIP deviations became positive and (2) derive empirical measures for funding constraints: the overnight repo spread between agency MBS and Treasury collaterals. The short (overnight) maturity and collaterization imply that credit risk is likely to be a small part of the spread. Garleanu and Pedersen (2009) document CIP deviations and comment on its correlation with the TED spread. However, they do not conduct any formal econometric analysis.

[8] 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 McAndrews, Sarkar and Wang (2009).

We extend this framework to develop an empirical measure of uncertainty about counterparty risk and examine the co-evolution of credit risk and liquidity risk during the crisis. Heider, Hoerlova and Holthausen (2009) show theoretically that asymmetric information about counterparty risk can lead to breakdowns in interbank markets. Pritsker (2009) finds that lenders with greater subjective uncertainty about borrowers' default risk charges higher rates. We show that CIP deviations are significantly related to this measure. 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 prior evidence on the efficacy of public liquidity supply from the domestic context to the international markets (also discussed by McGuire and von Peter (2009)).

The remainder of the paper is organized as follows. In Section I, we describe our methodology and data. In Section II, we present estimates of CIP deviation. In sections III and IV, we discuss measures of funding constraints and counterparty risk and present results relating these measures to CIP deviations. In Section V, we assess the impact of the Federal Reserve's announcements and actual operations related to the bilateral currency swap lines on CIP deviations. We conclude in Section VI.

I. Data and Measurement of CIP Deviations

In this section, we discuss our estimates of CIP deviations and describe the data. 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. The CIP relation then states that at each time t:

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

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.

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

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

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

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. A non-zero basis in normal times is likely due to temporary mispricings that are not arbitraged away (Akram et al (2008)).

We obtain tradable quote data on spot and 3-month forward exchange rates from Reuters, Bloomberg and Tullett Prebon, a leading broker in FX markets. Griffoli and Ranaldo (2009) use data from the same source. They argue that the data is representative of the market in that all major participants are included. Further, they show that, although 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 Reuters and Tullett Prebon 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 or the hourly data.

II. Estimates of Deviations from CIP

In this section we present estimates of deviations from CIP during the crisis period. To show robustness of the estimates, we present measures based on alternative dollar interest rates in Section *A* and alternative currency pairs in Section *B*. 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.

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 fluctuated around zero. However, since the crisis started, the euro-USD basis has been consistently large and positive (implying a market-based USD implied funding rate 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 are 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

We re-estimate the basis after replacing the USD Libor rate with the NYFR rate or the Treasury bill rate in equation (3). 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 (see footnote 3). The 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: it is high and positive prior to September 2008 and increases even more sharply 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. This is because the Treasury bill rate closely tracks the policy rate that the Federal Reserve has aggressively reduced over the crisis period. In general, 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 in part due to an excess demand for dollars globally from non-US institutions (McGuire and von Peter (2009)), we expect to see increased USD basis with respect to multiple currencies. We estimate the basis for the US dollar vis-à-vis Australian dollar (AUD), the Swiss franc (CHF), the British pound (GBP), the Japanese yen (JPY) and the New Zealand dollar (NZD). To calculate the USD basis with respect to a currency, we use equation (2) along with the interest rate and exchange rate denominated in the relevant currency. For example, for the GBP-USD currency pair, we back out an implied dollar rate using the GBP Libor rate, and the spot and forward GBP-USD exchange rates.

INSERT FIGURE 3 HERE

From Figure 3, we observe that for five other currency pairs, 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 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 AUD-USD pair for which the basis appears to be high since September 16 2008 compared to the other currency pairs. Overall, the evidence supports the hypothesis of an excess demand for USD worldwide.

In this section we find robust evidence that estimates of the CIP deviation based on different dollar interest rates and currency pairs depict a similar pattern: large and positive deviations after August 2007 followed by even sharper increases following 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 effect of the Federal Reserve's announcements and actual operations related to the bilateral currency swap lines on the CIP deviations.

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 explain why the deviations were positive (section *A*) and to propose empirical proxies for funding constraints (section *B*) and credit risk (section *C*).

The CIP deviation may persist if funding is not available to arbitrageurs. 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 widen price discrepancy.[9] Brunnermeier and Pedersen (2009) study the feedback effects between margins and market conditions.

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 non-zero if investors are heterogeneous and face investment restrictions (typically, leverage constraints on positions in *S* as well as position limits on short positions in *D*). The basis represents differences in risk premia required by different investors. 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 the risk tolerant investor is long *S* and also long *D*, then in equilibrium the basis is:

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

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

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*.[10]

Alternatively, if the risk-tolerant investor has a long position in *S* and a short position in *D*, then in equilibrium the basis is a function of the sum of the two margins:

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

The intuition is that the risk-tolerant investor has to pay margins on both legs of the basis trade.

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*.[11] The swap dealer quotes the forward differential *f*/*s* for the swap transaction. The return to investing \$1 in swaps is $(1+i_f)f/s$ which is equal to the implied rate.

The positive basis means that the situation described by (6) applies---leveraged investors have long positions in *S* (i.e. USD) and short positions in *D* (i.e. FX swaps). Arbitrageurs can earn riskless profits by borrowing USD for 3 months at the Libor rate and investing at the euro Libor rate, while covering the FX risk in the FX swap market. But this arbitrage trade did not occur due to the shortage of USD arising from reduced supply from lenders as well as increased

[10] Equations (5) and (6) are limiting results obtained when the relative wealth of the risk tolerant investor approaches zero. In the general case, the basis also depends on the difference in the covariance of returns of *S* and *D* with the consumption of the risk-tolerant agent.

[11] The investor would swap dollars into euros while simultaneously agreeing to reverse the transaction at the current forward rate and closing the swap in 3 months. Non-US institutions typically obtain dollar funding in the FX swap markets, primarily from US institutions that have a natural dollar deposit base.

demand by global banks during the crisis (Coffey, Hrung, Nguyen and Sarkar (2009)). 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)). On the demand side, McGuire and von Peter (2009) estimate that the USD "funding gap" of European banks had grown to at least $1.1 to $1.3 trillion by mid-2007 and they financed this gap from interbank markets, FX swap markets and central banks. As the first two funding sources dried up during the crisis, global banks had to pay a premium to obtain USD.

INSERT TABLE 2 HERE

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

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

In this section, we propose empirical measures for relative margin constraints and the shadow cost of capital, the two variables in (6).

Our empirical proxy for the tightness of margin conditions is the overnight agency MBS-Treasury repo spread which is the repo rate using agency mortgage-backed securities (MBS) as collateral minus the repo rate using Treasury securities as collateral.[12] Repos have become a primary source of funding for commercial banks, investment banks and securities lenders in recent times. By mid-2008, the gross amount of repos outstanding (including double counting) had exceeded $10 trillion, about the same as the total value of assets in the US banking system

[12] These are general collateral (GC) repo rates that reference non-specific government securities with the lowest level of counterparty risk (Hordahl and King (2008)). In contrast, specific collateral rates reference particular types of collateral, such as an on-the-run bond.

(Hordahl and King (2008)). Since both MBS and Treasury repo loans are collaterized, and given the short (overnight) maturity, the spread between them mainly reflects the relative market illiquidity of the two assets. In particular, agency MBS securities became highly illiquid during the crisis, leading to an increase in the agency MBS-Treasury repo spread.[13] Since margins are expected to increase with market illiquidity (Brunnermeier and Pedersen (2009)), increases in the overnight MBS-Treasury repo spread is as a proxy for increasingly tight margin conditions.[14] Therefore, we expect a positive relation between CIP deviations and the repo spreads.

Our source for overnight repo rate data, previously used by Fleming, Hrung and Keane (2009), is the Federal Reserve Bank of New York's primary dealer survey. The trading desk at the New York Fed collects information each morning from dealers on the average overnight general collateral repo rate at which it has financed its positions in Treasury securities, agency debt securities, and agency MBS, as well as the quantity of securities financed. An overall weighted average is then calculated for each collateral type.

Since we are examining the USD basis at a 3-month maturity, we also use the 3-month agency MBS-Treasury repo rate. The 3-month rate is relevant if banks are concerned about maturity mismatch between funding and investments. A caveat is that counterparty risk may be a larger component of the repo spread for the 3-month maturity (although increases in credit risk may increase the haircut on the loan rather than the repo rate). The data is from Bloomberg who in turn source the data from ICAP North America, a large interdealer broker. Longstaff (2000) uses this data in his analysis of the term structure of repo rates.

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[13] Brunnermeier (2009) uses the repo spread (although not of the overnight maturity) to illustrate liquidity risk during the crisis. Gorton and Metrick (2009) discuss the role of repo markets during the financial 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.

As discussed in Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009), funding liquidity and market liquidity premia are tightly linked. Since the repo spread is intended to capture funding conditions, we also include in our regressions a *market liquidity risk* measure. This is the par-OTR yield spread, defined as the yield of a hypothetical 10-year *off-the-run* par bond minus the *on-the-run* 10-year Treasury yield. The data for the on-the-run 10-year Treasury yield is from Haver Analytics while the par bond yields are from the Federal Reserve Board.[15] The par-OTR spread is a measure of the market liquidity premium in the Treasury market and is taken to be a proxy for systematic market liquidity risk in the economy. Since Treasury yields usually fall when demand for liquid and safe securities rises, systematic liquidity premia is likely to be correlated with Treasury liquidity premia.

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 off-shore dollar markets which should increase the basis. However, increased illiquidity also increases unsecured interest rates in the US, which tends to decrease the basis.

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-Repo spread as proxies for the shadow cost of capital.

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[15] 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. In contrast to our approach, prior literature has used the yield on an actual off-the-run bond to compute the on-off spread. However, the actual yield depends on the specialness of Treasury securities (Duffie (1996)) potentially leading to negative on-off-spreads, as has frequently been the case in recent periods.

C. Empirical measures of counterparty risk

To the extent that arbitrage became risky during the crisis, CIP deviations need not constitute violations of the Law of One Price. Counterparty risk increased substantially during the crisis, which increased unsecured rates. Even secured funding sources such as FX swaps were affected since there was increased probability that the contracts would have to be replaced on unfavorable terms in case of counterparty default (Duffie and Huang (1996)).

Our *credit risk* measures are:

- CDX: The CDX investment grade (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 IG index is from Markit. The index covers 125 names in North America and represents the average credit risk of major global firms.

In addition to its level, uncertainty about credit risk is an important determinant of interest rates (Flannery (1996), Heider et al (2009), Pritsker (2009)). We represent this uncertainty by the quote dispersion among Libor panel banks. 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 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. Our uncertainty measure is consistent with those proposed in Heider et al (2009) and Pritsker (2009) (i.e. the spread in default probabilities assigned by lenders to a borrower's investments). 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. FX volatility determines the cost of hedging FX risk. The equity implied volatility is given by the VIX measure, data for which is pulled from Bloomberg. Since previous work has found VIX to be a significant determinant of asset prices in several markets, we take VIX to stand for the risk aversion of investors in the broader financial markets.[16]

IV. Explaining CIP Deviations: Results

In this section, we explain deviations in CIP using measures of funding constraints and risk measures. We examine whether CIP deviations constitute a breakdown in the Law of One Price due to capital constraints of arbitrageurs---specifically, changes in margin constraints and arbitrageurs' cost of capital (section *A*). In section *B*, we explore the hypothesis that CIP deviations reflect the increased credit risk of arbitrage transactions. In section *C*, we decompose aggregate credit risk into the credit risk of non-US institutions relative to US firms.

A. CIP deviations, margin constraints and shadow cost of capital

INSERT FIGURE 4 HERE

[16] VIX has been found to be a significant determinant of prices of foreign exchange (Brunnermeier, Nagel and Pedersen (2008)), and sovereign CDS (Longstaff, Pan, Pedersen and Singleton (2007)).

Arbitrageurs' funding constraints are determined by the tightness of margin conditions and their shadow cost of capital. Figure 4 plots the Agency MBS-Treasury repo spread (our proxy for margin conditions) for the overnight (MBS-T-ON) and 3 month (MBS-T-M3) maturities along with CIP deviations based on the euro-dollar FX rate and the USD Libor rate. Except for brief periods after the Lehman bankruptcy, the repo spreads are positive, consistent with the greater illiquidity of MBS relative to Treasuries. We observe that the basis and repo spreads co-move for much of the period.

INSERT TABLE 3 HERE

Table 3 shows the correlation of CIP deviations with the MBS-Treasury repo spreads for different crisis periods. Prior to the crisis (Panel A), the basis and the repo spread have a correlation of 0.30 for the overnight spread and 0.22 for the 3-month spread. From August 2007 till September 15 2008 (Panel B), the basis and the repo spreads tend to diverge, and the correlation becomes negative. The negative co-movement generally occurs starting in March 2008 (see Figure 4) when the Federal Reserve initiated the TSLF program designed to provide liquid Treasury collateral in exchange for less liquid collateral (e.g. MBS). This program reduced the illiquidity premium in the repo spread (Fleming, Hrung and Keane, 2009) while the basis was still increasing. After September 15 2008 (Panel C), the correlation becomes positive again (0.50 for the overnight spread and 0.38 for the 3-month spread). Finally, the correlation between the basis and the Par-OTR spread is negative prior to the crisis, positive in the pre-Lehman period and negative again after the Lehman bankruptcy, suggesting that the *relative* liquidity risk of US vis-à-vis non-US firms was changing over the course of the crisis.

INSERT FIGURE 5 HERE

The expected association between the CIP deviation and the TED or the Libor-Repo spread is positive and Figure 5 shows that they generally co-move together, as also shown by Garleanu and Pedersen (2009). However, between August 2007-September 15 2008, the correlation is negative between the basis and the TED spread, which may be attributed to a reduction in the shadow cost of capital after the Fed's TSLF program.

INSERT TABLE 4 HERE

Table 4 shows results from a regression of the USD basis on its own lag, the repo spread, the TED spread and the Par-OTR spread for the pre-crisis period, the pre-Lehman and post-Lehman crisis periods. Panel A shows results when we use the overnight repo spread. For the pre-crisis period, the coefficient on the margin constraint is positive and significant, consistent with tighter margin conditions increasing CIP deviations, as predicted. The coefficient on the TED spread is also positive and significant at the 10% level. From August 2007 to September 15 2008, the basis becomes highly autocorrelated as the coefficient on the lag basis is 0.91. The repo spread is negative and no longer significant, perhaps indicating the effects of the Fed's TSLF program. However, the market liquidity risk measure, Par-OTR becomes a positive and significant determinant of the basis at this time. The TED spread remains positive and significant at the 10% level. In the final crisis period, the repo spread is again positively associated with the basis and the coefficient becomes large in magnitude and highly significant.

Panel B of Table 4 repeats the regressions using the 3-month repo spread. The results are qualitatively similar to those using the overnight spread: the repo spread is generally positively associated with CIP deviations except during the period when TSLF was initiated. The Par-OTR spread becomes negatively and significantly related to CIP deviations in the post-Lehman period, whereas the coefficient is positive and insignificant when using the overnight repo spread. The

difference likely reflects differences in the correlation of Par-OTR with the overnight and 3-month repo spreads in this period (see Panel C of Table 3).

INSERT TABLE 5 HERE

Table 5 repeats these regressions while replacing the TED spread with the Libor-Repo spread. These results generally track those for the TED spread: a positive relationship of CIP deviations with margin conditions (except during the pre-Lehman crisis period) and with the Libor-Repo spread.

B. CIP deviations, credit risk and liquidity risk

Table 3 shows that the correlation of the basis with the CDX index is positive before the Lehman bankruptcy and negative afterwards, suggesting that the *relative* credit risk of US institutions vis-à-vis non-US firms changed during the course of the crisis. In contrast, the correlation of the basis with credit risk dispersion (*Disp*.) is always positive in the crisis period and is more than 60% after the Lehman bankruptcy. Dispersion has relatively low correlation with CDS prices in the pre-crisis period, and higher correlations in the crisis period, consistent with Heider et al (2009) who predict that asymmetry and levels of credit risk are positively associated. 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 6 HERE

In Table 6, we show results from a regression that expands on the previous analysis by adding credit risk measures. Panel A shows results when we use the TED spread as the shadow cost of capital. Dispersion is significantly related to the basis in the pre-crisis and post-Lehman period, with negative and positive signs. The different signs reflect the differential effects of credit risk on the dollar and euro unsecured funding markets. The CDX index is not significantly

related to the basis. VIX and EVOL are positive significant determinants of the basis in the post-Lehman period, although EVOL is only significant at the 10% level. The sign and significance of the repo spread and the TED spread are the same as before, with one exception. In the post-Lehman period, the TED spread has a negative and significant association with the basis, in contrast with a negative and insignificant sign earlier. Therefore, controlling for the effect of credit risk, the increase in the shadow cost of capital had a greater impact on dollar borrowing rates relative to euro rates. Panel B reports results when the Libor-Repo spread is used; the results are similar to those in Panel A. One difference is that the CDX index is now a negative and significant determinant of the basis in the pre-crisis period.

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

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). Therefore, we 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.[17]

INSERT FIGURE 6 HERE

Figure 6 plots the relative default risk measure which was close to zero in the beginning of 2007 and has gradually become more negative, indicating that the default risk of large US

[17] 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.

banks has increased more than large non-US banks during the crisis. Therefore, we expect the relative credit risk measure to be negatively correlated with the basis.

INSERT TABLE 7 HERE

Table 7 shows results from a regression with the CDX index replaced by the relative credit risk of non-US vis-à-vis US banks. For brevity, we only show results for funding constraints and credit risk measures. The results in Panel A, using the TED spread, shows that the relative credit risk measure is significant in the crisis periods. The results in Panel B, using the Libor-Repo spread, shows that it is significant in every period except the pre-Lehman crisis period. In both panels, the sign is positive in the pre-crisis and negative in the crisis period, consistent with expectations. Relative credit risk is another measure of dispersion (between US and non-US firms instead of between Libor banks, as was the case earlier). The results therefore provide further evidence of the significance of this measure, especially after the Lehman failure.

The results indicate that tighter margin conditions associated with higher CIP deviations. An exception is the early period of the crisis when the Fed intervened to relax collateral constraints, at a time when CIP deviations were still increasing. However, market liquidity risk (i.e. the on-off Treasury spread) remains a significant determinant of CIP deviations even during this period. Overall, funding constraints were significant determinants of the basis in all periods. The cost of capital is a significant determinant of the basis, with the sign depending on whether the impact is greater in the euro or the dollar markets. Credit risk--and, in particular, its dispersion---is particularly important in understanding CIP deviations during the post-Lehman crisis period. 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.

V. Central Bank Currency Swaps and CIP Deviations

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

INSERT TABLE 8 HERE

Table 8 shows significant announcement dates for the program. The program was initiated on December 12 2007 with swap lines arranged with the European Central Bank (ECB) and the Swiss National Bank (SNB). As the USD shortage became more acute, the program was expanded in size and scope. After Lehman's bankruptcy, the cap on the amount of funds distributed was removed altogether on October 13 2008, when the Fed promised to accommodate any quantity demanded at the auctions.

To determine the effect of the swap lines program, we define a dummy variable that equals 1 on days when the Fed announces an increase in funds supplied. Correspondingly, the dummy has value -1 on February 1 2008 when the ECB withdrew from the February auctions, and so effectively this constituted a negative supply event. We define a separate dummy variable for the October 13 announcement "uncapping" the swap lines. We also define a dummy variable for days when the Fed conducted TAF auctions where US banks and US branches of foreign banks participated and bid for USD. We do not include dummy variables for ECB auction dates since these dates coincided with TAF auction days leading to a collinearity problem in the regressions. Since auction days are scheduled ahead of time on specific days of the month, we

expect the swap program to have an impact mainly on announcement days, perhaps with the exception of the initial auctions when banks were still learning about the program.

Since the swap lines are expected to reduce liquidity risk, we control for credit risk but not for liquidity risk in estimating their effects. Also, we use the change rather than the level of the basis as the dependent variable. This is necessary to account for persistence in the impact of swap lines on the basis, given that we are using dummy variables to capture the effect of swap lines.[18] We estimate the following regression to examine the effect of swap lines on the basis:

$$\Delta Basis_t = Intercept + \alpha_1 SwapAnn_t + \alpha_2 SwapUncap_t + \alpha_3 \$Auctions_t + \Delta CONTROLS + \varepsilon_t \quad (7)$$

where Δ indicates that the variable is in changes, *SwapAnn* is a dummy variable for announcement days of the swap line program, *SwapUncap* is a dummy variable for October 13 2008 when the size of swap lines became unlimited, *$Auctions* is a dummy variable for TAF auction days, and CONTROL are variables to control for credit risk and market risk. CONTROL includes the CDX index, *Disp*., VIX, and EVOL. In addition, we include the term spread defined as the difference between the 10-year Treasury note and the 3-month bill (both constant maturity). We control for term risk since the loans are for term maturities (mostly for 28 and 84 day maturities) and their effectiveness may depend on the shape of the yield curve.

INSERT TABLE 9 HERE

The results of the regression are in Table 9. The sample period is August 1 2007 till March 30 2009. Since announcement effects may be short-lived, higher frequency of data is likely to improved results. So, 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 repeat

[18] McAndrews et al (2009) make a similar point when estimating the effect of TAF using dummy variables.

the regression using the daily data and report these results in Panel B. The results in Panel A indicate that, from May 23 2008 to September 15 2008, the swap line announcements reduce the basis by an average of more than 5 basis points. In addition, the dollar auctions lower the basis by an additional 1.3 basis point per auction, although this result is only significant at the 10% level. For the period September 16 2008 to March 2009, the announcement uncapping the swap lines had a substantial effect on the basis, which is reduced by almost 80 basis points on the day. The remaining announcement days had no statistically significant effect on the swap lines. This result is intuitive since counterparty risk became a significant determinant of the basis in the post-Lehman period and the Fed's program primarily served to reduce funding liquidity risk.

The results in Panel B, using daily data, are qualitatively similar when considering the same sample period. The swap announcements reduced the basis by an average of 3 basis points from May 23 2008 to September 15 2008, and the uncapping announcement reduced the basis by almost 55 basis points. From August 2007 to May 22 2008, we find that the swap announcements were not statistically significant 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, announcements effects and actual operations related to the Fed's swap lines program appear to have succeeded in reducing the basis when funding constraints were binding. Thus, the swap lines reduced the basis in the pre-Lehman crisis period and again in October 2008 when the swap lines became unlimited in size. This is consistent with enhanced overnight repo spreads at these times (see Figure 4). Announcements after October 2008 had no statistically significant effects on CIP deviations. However, the latter result must be interpreted cautiously since our study does not address the longer-term implications of the Fed's program. For example, CIP deviations decreased substantially from the high of 233 basis points in September

2008 to about 35 basis points at the end of March 2009 but we only examine announcement effects of the swap lines program, rather than the broader impact of the program over time.

VI. Conclusion

In this paper, we document substantial and significant deviations from CIP during the financial crisis, with particularly dramatic deviations following the bankruptcy of Lehman Brothers. This result is robust to the use of alternative benchmark dollar interest rates and different currency pairs. Our results show that funding constraints of arbitrageurs (as measured by our proxies for margin conditions and the cost of capital) are significant determinants of CIP deviations. In addition, we find evidence that uncertainty about counterparty risk became an issue after September 2008, as cash flows previously perceived as riskless became risky. These results indicate limits to arbitrage transactions in the international capital markets during the crisis partly due funding constraints and partly due to counterparty credit risk.

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 a few emerging market countries. We find that announcement days of the swap lines program were associated with a reduction in the basis. We further find that the actual auctions of dollars were also effective in bringing down the basis on the day of the operations. The announcement that swap lines would become uncapped in October 2008 resulted in a reduction of more than 55 basis points in the basis. Although subsequent announcements of swap lines programs did not have a significant effect on the basis, these results appear to point to the success of the Federal Reserve in acting as the international lender of last resort at a time when short-term dollar funding was impaired globally.

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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: Australian dollar (AUS)-USD, Swiss franc (CHF)-USD, British pound (GBP)-USD, Japanese Yen (JPY)-USD and New Zealand dollar (NZD)-USD. The AUS-USD and NZD-USD 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-T ON	Agency MBS repo rate minus Treasury repo rate, both of overnight maturity.
MBS-T M3	Agency MBS repo rate minus Treasury repo rate, both of 3-month maturity.
Libor-Repo	LIBOR rate minus Treasury repo rate, both of 3-month maturity.
TED	LIBOR rate minus Treasury bill rate, both of 3-month maturity.
Par-OTR	Yield on hypothetical off-the-run Treasury trading at par minus on-the-run Treasury yield, both of 10-year maturity
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)
Swap uncap	Dummy variable equal to 1 on day when the Fed announced that the size of the currency swap lines would become unlimited
$ auctions	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-TON	MBS-TM3	TED	LIB-Repo	Par_OTR	Disp.	CDX	VIX	EVOL
Basis	1.000									
MBS-TON	0.297	1.000								
MBS-TM3	0.218	0.402	1.000							
TED	0.244	0.549	0.392	1.000						
Libor-Repo	0.282	0.406	0.855	0.507	1.000					
Par_OTR	-0.138	-0.033	0.143	0.056	0.049	1.000				
Disp.	-0.183	-0.333	-0.431	-0.117	-0.368	-0.267	1.000			
CDX	0.006	0.228	0.628	0.249	0.658	0.505	-0.327	1.000		
VIX	0.010	0.286	0.482	0.349	0.453	0.521	-0.286	0.800	1.000	
EVOL	-0.198	-0.282	-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-TON	MBS-TM3	TED	LIB-Repo	Par_OTR	Disp.	CDX	VIX	EVOL
Basis	1.000									
MBS-TON	-0.289	1.000								
MBS-TM3	-0.400	0.601	1.000							
TED	-0.054	0.300	0.535	1.000						
Libor-Repo	0.114	0.406	0.685	0.732	1.000					
Par_OTR	0.472	0.044	0.109	-0.118	0.258	1.000				
Disp.	0.069	0.110	0.213	0.530	0.369	-0.296	1.000			
CDX	0.196	-0.016	0.071	-0.238	0.034	0.720	-0.514	1.000		
VIX	-0.455	0.370	0.383	0.152	0.014	0.155	-0.205	0.331	1.000	
EVOL	0.498	-0.046	-0.018	-0.053	0.211	0.732	-0.214	0.679	0.101	1.000

Table 3 (continued)

Panel C: September 16 2008 –March 30, 2009

	Basis	MBS-T ON	MBS-T M3	TED	LIB-Repo	Par_ OTR	Disp.	CDX	VIX	EVOL
Basis	1.000									
MBS-T ON	0.497	1.000								
MBS-T M3	0.383	0.040	1.000							
TED	0.605	0.616	0.442	1.000						
Libor-Repo	0.492	0.547	0.483	0.967	1.000					
Par_OTR	-0.380	-0.586	0.315	-0.357	-0.251	1.000				
Disp.	0.611	0.607	0.329	0.898	0.843	-0.469	1.000			
CDX	-0.112	-0.401	0.112	-0.284	-0.256	0.380	-0.405	1.000		
VIX	0.350	-0.099	0.652	0.450	0.504	0.296	0.308	0.355	1.000	
EVOL	-0.124	-0.553	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 TED Spread

Panel A: Repo spread of Overnight Maturity

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
Intercept	-0.847	-1.782	-1.651	-1.539	-0.112	-0.010
Lag Basis	0.015	0.130	0.910**	39.765	0.822**	9.735
MBS-T ON	1.873**	3.652	-0.846	-1.384	24.046**	3.287
TED	0.011	1.809	0.011	1.819	-0.020	-0.478
PAR-OTR	-0.132	-1.689	0.120*	2.081	0.204	0.988
Adj. R^2	0.110		0.891		0.793	
OBS	141		276		135	

Panel B: Repo spread of Three-Month Maturity

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
Intercept	-1.118*	-1.960	-2.550*	-2.085	54.890**	2.467
Lag Basis	0.004	0.038	0.863**	27.052	0.753**	9.028
MBS-T M3	0.054	1.751	-0.047*	-2.374	0.216**	3.368
TED	0.012*	2.307	0.024*	2.570	-0.028	-0.724
PAR-OTR	-0.146	-1.727	0.216**	2.952	-0.865*	-2.257
Adj. R^2	0.080		0.894		0.812	
OBS	137		275		132	

** 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-T (for Treasury) repo spread and the TED spread. Repo spreads of two different maturities are used: the overnight maturity ON (Panel A), and the 3-month maturity M3 (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, Margin Constraints and the Libor-Repo Spread

Panel A: Using Repo spread of Overnight Maturity

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
Intercept	-2.055*	-2.043	-0.734	-0.717	0.949	0.088
Lag Basis	-0.030	-0.278	0.912**	40.101	0.803**	9.249
MBS-T ON	1.968**	4.363	-0.966	-1.666	28.758**	3.181
Libor-Repo	0.073	1.902	0.010	1.098	-0.034	-0.747
PAR-OTR	-0.123	-1.506	0.093	1.556	0.228	1.188
Adj. R^2	0.113		0.893		0.800	
OBS	137		273		133	

Panel B: Using Repo spread of Three-Month Maturity

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
Intercept	-2.409*	-2.002	-1.486	-1.213	54.784**	2.566
Lag Basis	0.009	0.078	0.853**	27.385	0.746**	9.588
MBS-T M3	-0.009	-0.218	-0.058**	-3.267	0.220**	3.582
Libor-Repo	0.108*	2.109	0.041**	2.869	-0.036	-0.927
PAR-OTR	-0.124	-1.350	0.152*	2.237	-0.849*	-2.299
Adj. R^2	0.075		0.896		0.812	
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-T (for Treasury) repo spread and the Libor-Repo spread. Repo spreads of two different maturities are used: the overnight maturity ON (Panel A), and the 3-month maturity M3 (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, Counterparty Risk and Liquidity Risk

Panel A: Interest rate spread = TED spread

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
Intercept	1.007	1.066	0.744	0.300	-49.744*	-1.967
Lag Basis	-0.008	-0.077	0.882**	27.111	0.731**	10.206
Liquidity Risk						
MBS-T ON	1.152**	2.468	-0.676	-1.063	34.233**	4.810
TED	0.012*	1.935	0.009	1.127	-0.207**	-3.107
PAR-OTR	-0.149	-1.468	0.191**	2.347	-0.077	-0.384
Counterparty Risk						
CDX	-0.002	-0.159	0.003	0.236	0.066	0.910
Disp.	-0.523**	-2.573	0.072	0.727	0.516**	3.008
Market Risk						
VIX	-0.023	-0.513	-0.148	-1.464	0.822**	3.918
EVOL	-0.098	-1.155	-0.049	-0.204	1.312	1.855
Adj. R^2	0.128		0.889		0.836	
OBS	139		266		132	

Table 6 (continued)

Panel B: Interest rate spread = Libor-Repo spread

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
Intercept	-1.766	-1.893	2.439	1.046	-48.000*	-2.280
Lag Basis	-0.080	-0.841	0.886**	26.902	0.663**	8.039
Liquidity Risk						
MBS-T ON	1.498**	3.304	-0.667	-0.996	38.055**	4.541
Libor-Repo	0.131**	3.915	0.002	0.140	-0.208**	-3.135
PAR-OTR	-0.046	-0.515	0.217**	2.640	-0.110	-0.563
Credit Risk						
CDX	-0.040**	-2.449	-0.003	-0.309	0.045	0.586
Disp.	-0.363	-1.796	0.050	0.605	0.382*	2.474
Market Risk						
VIX	0.017	0.375	-0.151	-1.535	0.928**	4.064
EVOL	-0.051	-0.767	-0.102	-0.430	1.488*	1.946
Adj. R^2	0.144		0.892		0.844	
OBS	135		263		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, risk measures, the MBS-T (for Treasury) repo spread and the TED spread (Panel A) or the Libor-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 7: 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		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
MBS-T ON	1.123**	2.368	-0.442	-0.698	31.704**	4.350
TED	0.011	1.715	0.010	1.275	-0.208**	-3.759
PAR-OTR	-0.119	-1.158	0.212**	2.808	0.213	1.138
NUS-US CDS	0.035	1.035	-0.028*	-2.267	-0.172**	-2.570
DISP.	-0.562**	-2.591	0.089	1.012	0.492**	3.634
CONTROLS?	YES		YES		YES	
Adj. R^2	0.133		0.890		0.849	
OBS	139		265		131	

Table 7 (continued)

Panel B: Interest rate spread = Libor-Repo spread

	1/1/2007-7/31/2007		8/01/2007 - 9/15/2008		9/16/2008 - 3/31/2009	
Explanatory variable	Estimate	*t*-stats	Estimate	*t*-stats	Estimate	*t*-stats
MBS-T	1.040*	2.391	-0.548	-0.824	35.110**	3.950
Libor-Repo	0.136**	3.467	0.003	0.227	-0.202**	-3.147
PAR-OTR	0.042	0.475	0.208**	2.714	0.142	0.833
NUS-US CDS	0.126**	2.804	-0.012	-1.204	-0.147*	-2.409
DISP.	-0.455*	-2.248	0.072	0.888	0.358**	2.564
CONTROLS?	YES		YES		YES	
Adj. R^2	0.172		0.891		0.854	
OBS	135		262		130	

** 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-T (for Treasury) repo spread and the TED spread (Panel A) or the Libor-Repo spread (Panel B). 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 8: 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	Size of swap lines with ECB, SNB, and BOE to accommodate demand for any quantity of funds at fixed rate.
10/14/2008	Size of swap line sizes with BOJ also uncapped.
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 9: 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	0.073	0.048
Swap ann.	-5.258**	-4.470	16.189	0.905
Swap uncap	---	---	-77.724**	-10.835
$ auctions	-1.279	-1.685	-1.584	-0.574
CONTROLS	YES		YES	
Adj. R^2	0.180		0.193	
OBS	76		130	

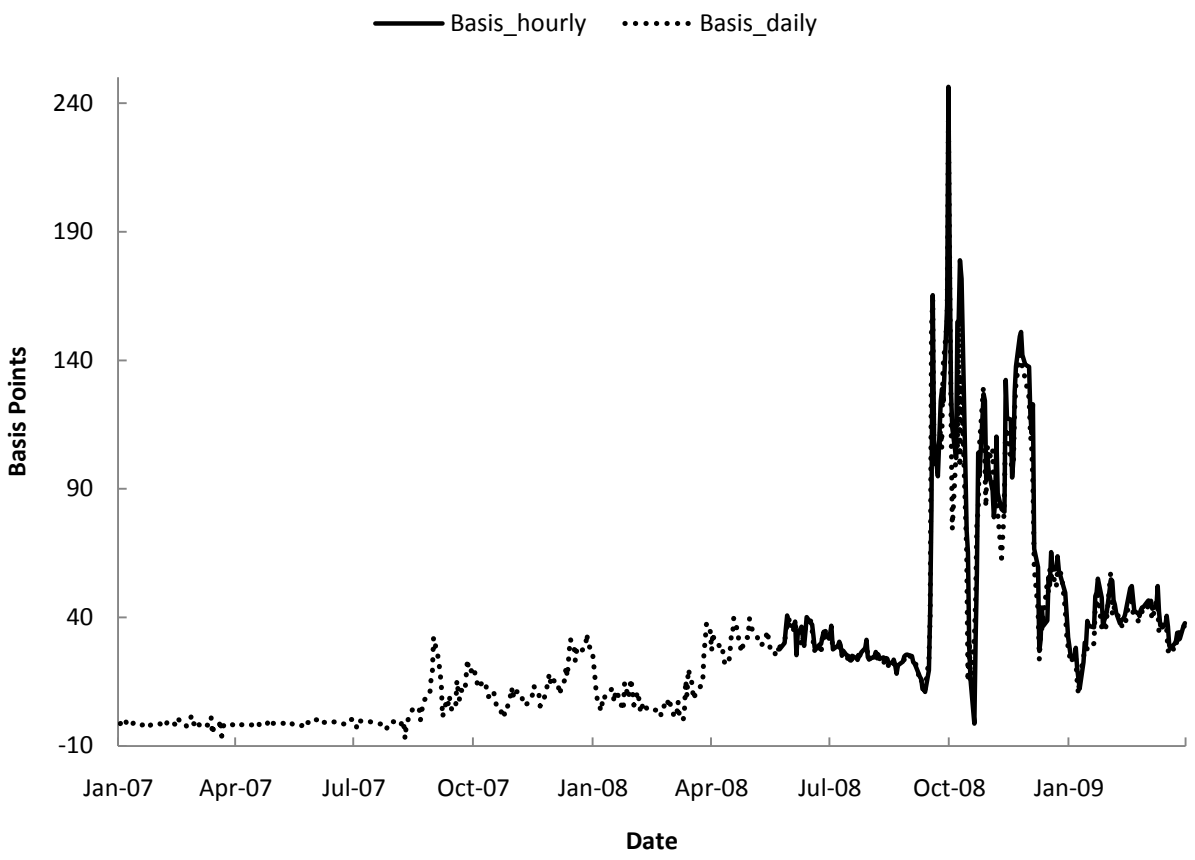
Panel B: Results using euro-dollar data at daily frequency

	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	-0.097	-0.062
Swap ann.	-0.917	-0.466	-2.982**	-4.796	2.152	0.198
Swap uncap	---	---	---	---	-53.528**	-3.633
$ auction	-1.726	-1.630	-1.269	-1.242	3.989	1.027
CONROLS?	YES		YES		YES	
Adj. R^2	-0.018		0.221		0.194	
OBS	85		77		130	

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

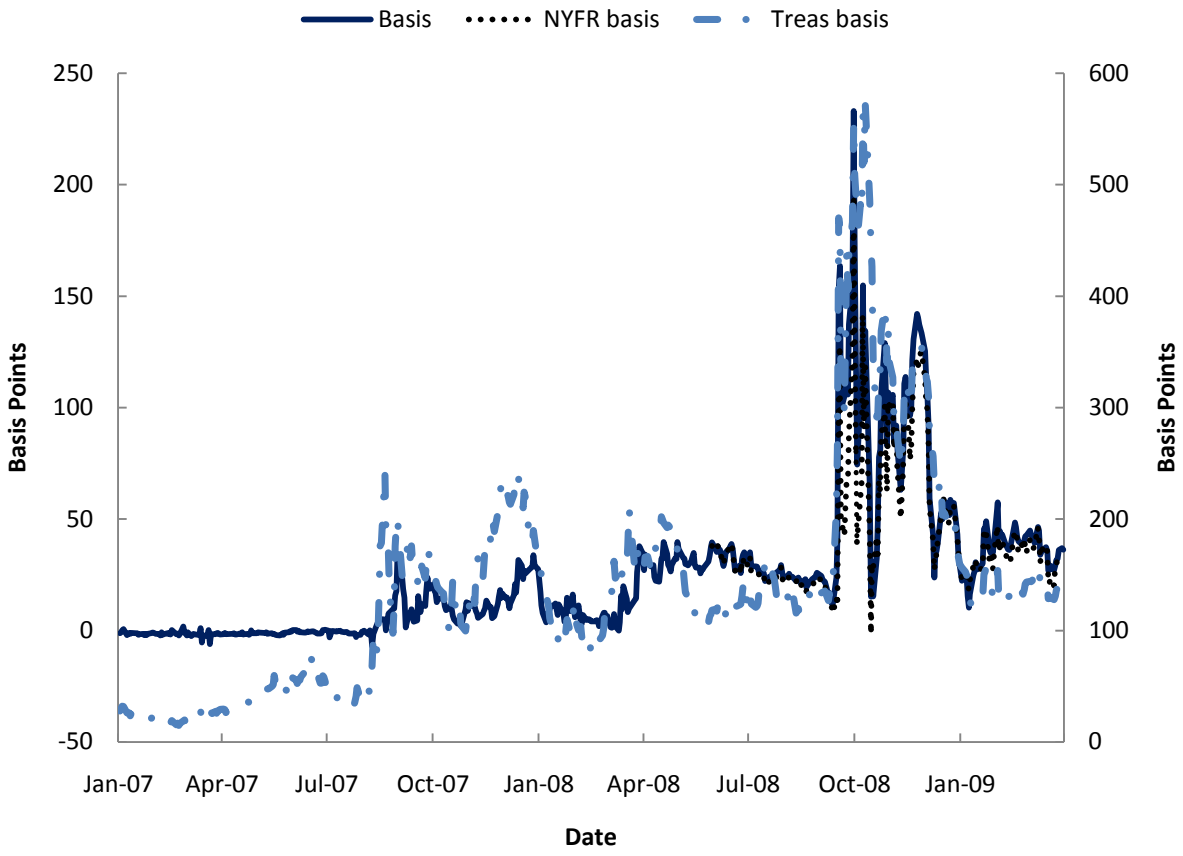
The table shows results from regressions of changes in the 3-month basis on dummy variables for SWAP announcements and dollar auction dates. CONTROLS are changes in Disp., CDX, VIX, EVOL and Y10_3. Variable definitions are in Table 2. The regression is estimated separately for the pre-Lehman period (August 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



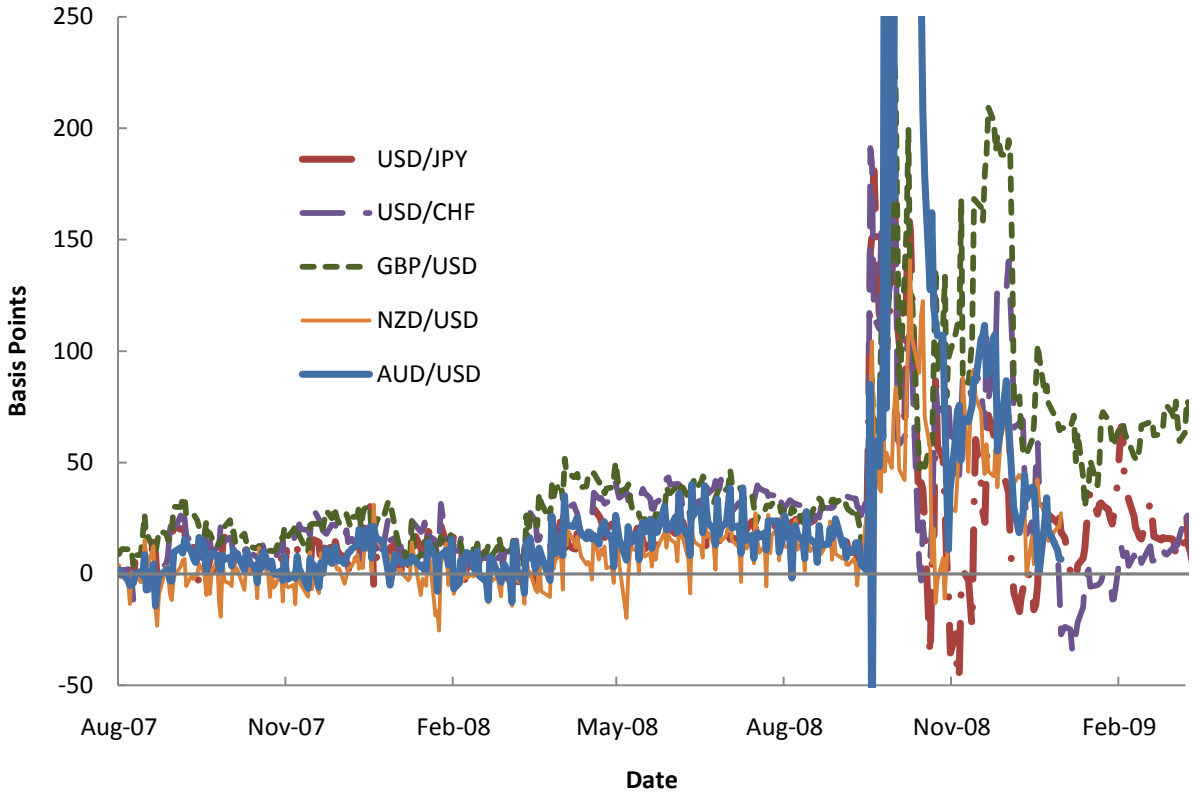
The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD) (i.e. the USD Basis), calculated as the CIP implied USD rate minus the USD LIBOR rate. The CIP implied USD rate is estimated using the euro-dollar exchange rate and the euro LIBOR rate. The dashed line is 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



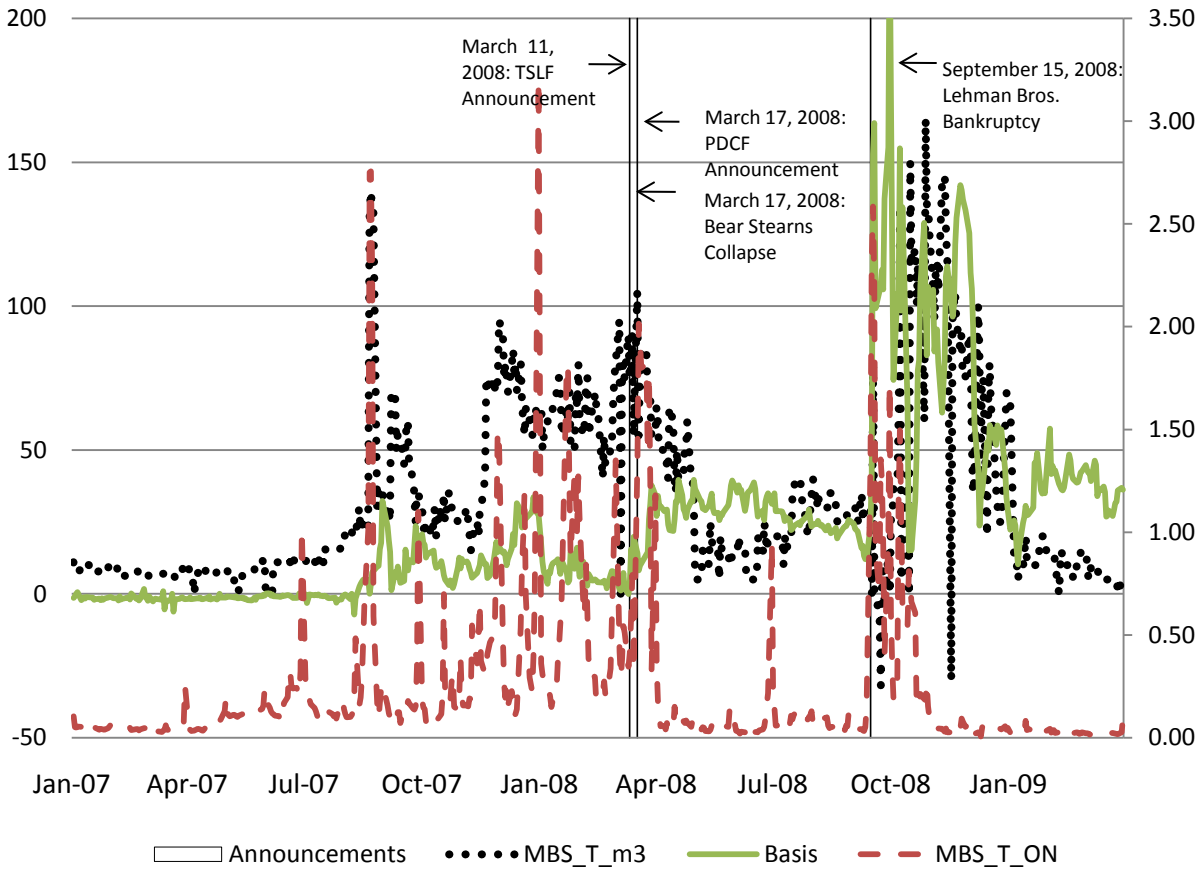
The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD) (i.e. the USD Basis), calculated as the CIP implied USD rate minus several benchmark USD rates. The benchmark USD rates shown are the USD LIBOR rate (left axis), the NYFR rate (left axis) and the Treasury 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: CIP Deviations For Different Currency Pairs, January 2007 –March 2009



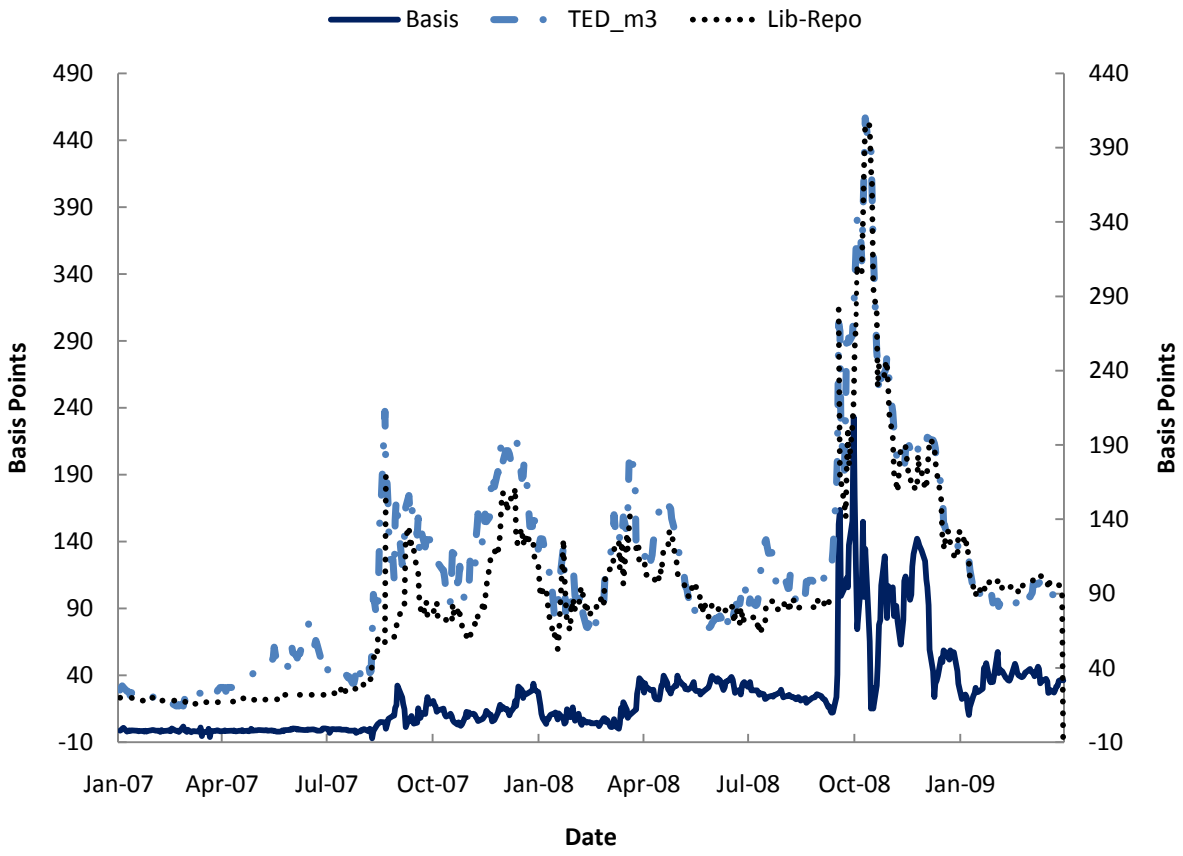
The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD) (i.e. the USD Basis), calculated as the CIP implied USD rate minus the USD LIBOR rate. The CIP implied USD rate is is estimated using exchange rates and interest rates denominated in the following currencies: 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 AUD-USD and the NZD-USD data that are available till December 31 2008.

Figure 4: CIP Deviations, and MBS-Treasury Repo Spread



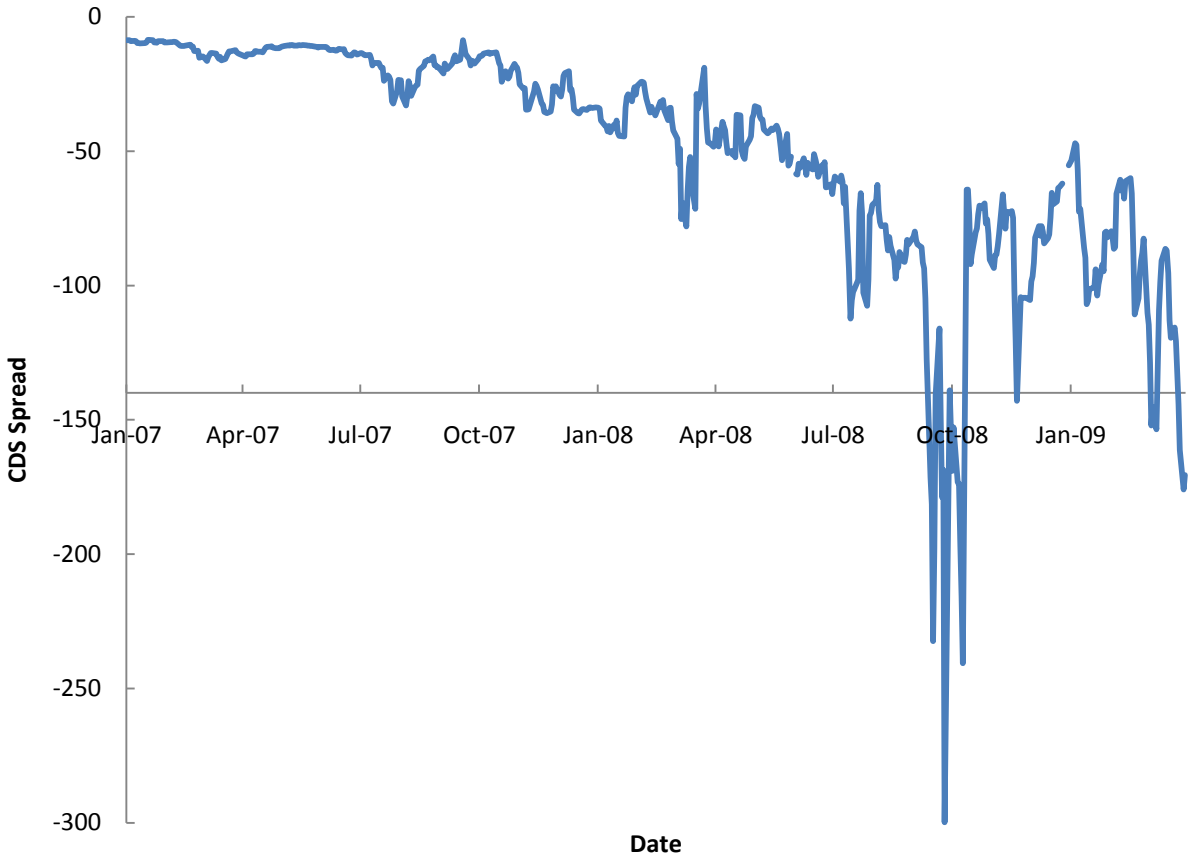
The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD) (i.e. the USD Basis), calculated as the CIP implied USD rate minus the USD LIBOR rate. The CIP implied USD rate is estimated using the euro-dollar exchange rate and the euro LIBOR rate. Also plotted are the agency MBS minus Treasury repo spreads for the overnight (MBS_T_ON), plotted on the right vertical axis, and 3-month (MBS_T_M3) maturities, plotted on the left vertical axis. The sample period is from January 1 2007 till March 30 2009.

Figure 5: CIP Deviations, Libor-Repo Spread and TED Spread



The figure plots estimates of Covered Interest Rate Parity (CIP) deviations in US dollars (USD) (i.e. the USD Basis), 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 Libor minus Treasury repo spread and the 3-month TED spread (i.e. Libor minus the Treasury bill rate). The sample period is from January 1 2007 till March 30 2009.

Figure 6: Difference between CDS Prices of non-US and US Banks



The figure plots the relative default risk of non-US firms relative to US firms. This is estimated as the average CDS prices of 13 non-US banks in the Libor panel minus the average CDS prices of 10 systematically important US banks. 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.The sample period is from January 1 2007 till March 30 2009.