BANK FOR INTERNATIONAL SETTLEMENTS

BIS Working Papers

No 285

From turmoil to crisis: dislocations in the FX swap market before and after the failure of Lehman Brothers

by Naohiko Baba and Frank Packer

Monetary and Economic Department

July 2009

JEL classification: F31, G15

Keywords: FX swap, Covered interest parity, Financial market turmoil, Counterparty risk, US dollar swap lines, Term auction facility, Central bank cooperation, Lehman bankruptcy

BIS Working Papers are written by members of the Monetary and Economic Department of the Bank for International Settlements, and from time to time by other economists, and are published by the Bank. The papers are on subjects of topical interest and are technical in character. The views expressed in them are those of their authors and not necessarily the views of the BIS.

Copies of publications are available from:

Bank for International Settlements
Communications
CH-4002 Basel, Switzerland

E-mail: publications@bis.org

Fax: +41 61 280 9100 and +41 61 280 8100

This publication is available on the BIS website (www.bis.org).

ISSN 1020-0959 (print)

ISBN 1682-7678 (online)

From turmoil to crisis: dislocations in the FX swap market before and after the failure of Lehman Brothers

Naohiko Baba* and Frank Packer†

Abstract

This paper investigates dislocations in the foreign exchange (FX) swap market between the US dollar and three major European currencies. After the failure of Lehman Brothers in September 2008, deviations from covered interest parity (CIP) were negatively associated with the creditworthiness of US financial institutions (as well as that of European institutions), consistent with the deepening of a dollar liquidity problem into a global phenomenon. US dollar term funding auctions by the ECB, SNB, and BoE, as well as the US Federal Reserve commitment to provide unlimited dollar swap lines are found to have ameliorated the FX swap market dislocations.

Key words: FX swap, Covered interest parity, Financial market turmoil, Counterparty risk, US dollar swap lines, Term auction facility, Central bank cooperation, Lehman bankruptcy

JEL classification: F31, G15

---

* Corresponding author. Monetary and Economic Department, Bank for International Settlements and Bank of Japan. Centralbahnplatz 2, CH-4002 Basel Switzerland. e-mail: naohiko.baba@bis.org. Tel: +41 61 280 8819; Fax: +41 61 280 9100.

† Representative Office for Asia and the Pacific, Bank for International Settlements. 78th floor, Two International Finance Centre 8 Finance Street, Central Hong Kong Special Administrative Region of the People's Republic of China. e-mail: frank.packer@bis.org

The authors thank the participants at the Warwick Business School and Journal of International Money and Finance conference on the Global Financial Crisis: Causes, Threats and Opportunities on April 6, 2009, as well as the seminar participants at the Federal Reserve Bank of New York, particularly Jannie Bai, Linda Goldberg, Michael Melvin, Richard Payne (discussant), Asani Sarkar, and Mark Taylor. We also benefitted from discussions with Robert Aliber, Corrinne Ho, and Robert McCauley. All the remaining errors are solely our responsibility. This paper was written when Naohiko Baba is seconded to the Bank for International Settlements from the Bank of Japan in the period of 2007-2009. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Japan or the Bank for International Settlements.

1. Introduction

The functioning of money markets was severely impaired in the summer of 2007, and then even more so following the failure of Lehman Brothers in September 2008. What had begun as a deterioration in a relatively limited segment of the US subprime mortgage sector quickly spread to other markets, especially those of credit and securitized products (BIS, 2008; IMF, 2008). Uncertainty about losses increased the liquidity needs of financial institutions as well as their reluctance to lend to each other in money markets. Reflecting these and possibly other factors, spreads of interbank short-term interest rates over overnight index swap (OIS) and treasury bill rates widened substantially in August 2007, and then, despite some degree of fluctuation, persisted at high levels (Taylor and Williams, 2009), before exploding by a factor of 3-5 times in the wake of the mid-September failure of Lehman Brothers (Fender and Gyntelberg, 2008).

Foreign exchange (FX) swap markets were immune neither to the turmoil nor crisis. Baba et al. (2008) document heightened volatility in the FX swap markets across several G10 currency pairs beginning in the summer of 2007. As noted in that paper, the three-month FX swap-implied dollar rate using euro as a funding currency moved together quite closely with dollar Libor (London interbank offered rate) prior to mid-August 2007. After that, however, the spread between the FX swap-implied dollar rate and dollar Libor widened considerably, reaching more than 40 basis points in September 2007, pointing towards a large and persistent deviation from the short-term covered interest parity (CIP) condition (Figure 1).[3] Just as in the case of Libor-OIS spread, the deviations from CIP then exploded following the bankruptcy of Lehman Brothers.

Baba and Packer (2009) argue that dollar funding shortages of European financial institutions, combined with increased counterparty risks, were largely responsible for dislocations in the FX swap market prior to September 2008. Facing unfavourable demand and supply conditions and the associated impairment of liquidity in interbank markets, many European financial institutions moved to actively convert euros into dollars through FX swaps, creating a one-sided market as US counterparts became more cautious about lending dollars.[4] As documented in Baba and Packer (2009), FX swap prices began to reflect relative counterparty risks after the onset of financial turmoil, indicating that concern over the counterparty risk for European financial institutions relative to that for US financial institutions was an important factor underlying deviations from short-term CIP. However, the study covers a period that ended prior to the bankruptcy of Lehman Brothers, when the turmoil in many markets became much more pronounced, concerns over the counterparty risk of financial institutions expanded well beyond those headquartered in Europe, and the dollar liquidity problem for European institutions deepened into a phenomenon of global dollar shortage.

Central banks undertook coordinated efforts to make dollar funding more readily available to non-US financial institutions, which were redoubled after the Lehman failure. More specifically, on December 12, 2007, the establishment of swap lines between the US Federal Reserve and both the European Central Bank (ECB) and the Swiss National Bank (SNB) was announced. These swap lines allowed the ECB and SNB to conduct US dollar term funding auctions during European trading hours for depository institutions in continental

---

3 An FX swap is a short-term contract in which two parties borrow and lend different currencies simultaneously by combining the FX spot and forward contracts in the reverse direction. The FX swap-implied dollar rate is defined as the total cost, in terms of the dollar rate, from raising euros in the uncollateralised cash market and converting them into dollars through the FX swap market. See Section 2 for more details.

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

Europe in a fashion that complemented the Federal Reserve's own term auction facility (TAF) for US institutions.[5] The size of the transatlantic swap lines was increased several times beginning in March 2008, while alternative maturities were introduced beginning in August. In the immediate aftermath of the Lehman failure in mid-September, not only was the size of the swap lines to support dollar operations increased by a factor of 3-5 times, but new swap lines with other central banks were introduced, including the Bank of England (BoE) and Bank of Japan (BoJ). On October 13, the maximum limits on the swap lines for the ECB, SNB, BoE and BoJ were lifted altogether, permitting these central banks and eligible counterparties unlimited access to US dollar funding in response to market conditions.

In this paper, we empirically investigate the dislocations in the FX swap market both before and after the failure of Lehman brothers under the turmoil across the euro/dollar (EUR/USD), Swiss franc/dollar (CHF/USD), and sterling/dollar (GBP/USD) pairs. We examine the degree to which the common factor underlying deviations from short-term CIP observed in the FX swap market for these currency pairs can be explained by a small number of variables reflecting the ongoing turbulence in global financial markets. Though we control for other relevant factors, we place particular emphasis on the following two issues: (i) the role of the perception of counterparty risk of European and US financial institutions and (ii) the role of the establishment of the dollar swap lines with the Federal Reserve by major central banks in easing tensions in the FX swap market, as well as the take-up of those swap lines through dollar term funding auctions by the ECB, SNB, and BoE.

In the extant literature, a number of studies test the short-term CIP condition, and some identify the specific periods in which such parity conditions collapsed. However, to the best of our knowledge, this paper, in conjunction with the earlier companion piece which covered only the period prior to the failure of Lehman Brothers (Baba and Packer, 2009), is the first one to examine these deviations in the context of the recent financial crisis. Understanding the dislocations in the FX swap market is all the more important given the rapidly growing role of FX swaps in foreign currency funding by financial institutions globally.

The rest of the paper is organized as follows. Section 2 gives an overview of the basic structure of an FX swap and its relationship to the CIP condition. Section 3 describes the evolution of dollar shortage from the beginning of the turmoil in the summer of 2007 into the crisis conditions following the failure of Lehman Brothers. Section 4 presents the empirical strategy, including a conceptual decomposition of possible deviations from CIP in the FX swap market and the main hypotheses to be tested. Section 5 describes the data and construction of the variables, and Section 6 provides the framework and results of the empirical analysis. Section 7 concludes the paper.

2. The FX swap and covered interest parity

An FX swap is a short-term contract in which one party borrows a currency from, and lends another simultaneously to the same party. FX swaps can be viewed as effectively collateralized transactions, though the collateral does not cover the entire counterparty risk. For example, if the counterparty were to default during the contract period, the party would need to reconstruct the position at the current market price, which entails replacement cost. Further, Duffie and Huang (1996) show that FX swaps are subject to significantly more exposure to counterparty risk than are interest rate swaps, due to the exchange of notional amounts.

---

5 See Section 3 for more details. For the coordinated efforts by the central bank community at early stages of the turmoil, see Borio and Nelson (2008) and CGFS (2008).

When non-US financial institutions need short-term dollar funds, they can borrow directly in the dollar cash market, or combine domestic currency borrowing with an FX swap.[6] For example, an institution funding itself in euros but desiring dollar funding could swap the proceeds for dollars, ie in effect sell euros for dollars at the FX spot rate, while contracting to exchange in the reverse direction at maturity at the FX forward rate. In this paper, we call the total cost of raising dollars using euros as a funding currency through the FX swap market "the FX swap-implied dollar rate from the euro". The equality of the FX swap-implied dollar rate and dollar deposit rate defines a condition of indifference as

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

Here, the left-hand side of equation (1) corresponds to the FX swap-implied dollar rate from the euro, where S_t is the FX spot rate at time *t*, $F_{t,t+s}$ is the FX forward rate contracted at time *t* for exchange at time *t+s*, and $r_{t,t+s}^{EUR}$ is the uncollateralized euro interest rate from time *t* to time *t+s*. $F_{t,t+s}/S_t$ corresponds to the forward discount rate conventionally used as the FX swap price. $r_{t,t+s}^{USD}$ is the uncollateralized dollar interest rate. Equation (1) is equivalent to the CIP condition in the traditional international finance literature.

CIP states that interest rate differentials between currencies should be perfectly reflected in the FX forward discount rates, since otherwise an arbitrageur could transact in money and FX markets to make a risk-free profit. A number of studies assess the degree to which short-term CIP is supported by the data. Most of them show that the deviations from the short-term CIP condition have diminished significantly at least among G10 currencies. However, Taylor (1989) finds that, despite increasing efficiency in FX markets, deviations from CIP tend to be evident during periods of uncertainty and turmoil, and persist for some time.[7]

For CIP to hold strictly depends on negligible transaction costs, as well as the lack of political risk, counterparty (credit) risk, liquidity risk, and measurement error (Aliber, 1973). While transaction costs and political risk are largely negligible in today's G10 currency markets, counterparty risk may have increased significantly under the recent turmoil. To the extent that counterparty risk was concentrated on one end of the FX swap market, a deviation from CIP could have emerged. This is particularly the case, when uncollateralized dollar cash markets malfunctioned under the turmoil, and so the only channel of dollar funding was the FX swap market. For example, if European financial institutions typically on the dollar borrowing side of the FX swap market were perceived as risky by US financial institutions on the dollar lending side, then risk premia could have been added to FX swap prices. One historical precedent dates from the late 1990s, when the perceived creditworthiness of Japanese banks raising dollar funds in global cash markets deteriorated significantly, and large deviations from CIP in the dollar/yen FX swap market emerged.[8]

---

6 FX swaps have been employed to fund foreign currencies, both for financial institutions and their customers, including exporters and importers, as well as institutional investors who wish to hedge their positions of foreign bonds against the FX risk. FX swaps are also frequently used as a tool for speculative trading typically by combining two positions with different maturities.

7 According to Taylor (1989), significant deviations were observed on such occasions as the flotation of sterling in 1972 and inception of the European Monetary System in 1979. In addition, Akram et al. (2008) investigate deviations from the CIP condition using tick data that covers several months in 2004 and find some economically significant deviations from the CIP condition, albeit short-lived.

8 See Hanajiri (1999), who suggests that the large deviations from CIP at the time were due chiefly to the deteriorating creditworthiness of Japanese banks, compounded by increased volatility of the FX rate. For an

Liquidity risks may have played a role, as well, particularly if market liquidity was impaired due to outsized or one-sided order flow. This in turn could be due to the realization of funding liquidity risks in the money market. Note, however, that both types of liquidity risk and counterparty risk are most likely intertwined in a complex manner particularly in times of stress, and it is thus quite difficult to distinguish quantitatively between their premia. For example, an illiquid but solvent bank could become insolvent due possibly to inherent maturity mismatch between their assets and liabilities and an inability to roll over short-term funding, combined with an inability to efficiently liquidate positions in certain assets. In the case of dollar funding shortages of European financial institutions, their order flow for dollars in the FX swap market was reported to have surged during the recent financial turmoil. This was due largely to constraints on borrowing in the uncollateralized dollar money market, where US financial institutions appeared less willing to lend dollars to other institutions, resulting from heightened counterparty risk, as well as their own increased demand for dollar liquidity.

Finally, measurement error could have been heightened as well. During the recent turmoil, dollar Libor was reported to have underestimated the dollar funding costs that euro-zone financial institutions actually faced. The non-binding nature of Libor may lead to biased quotes on the part of institutions wary of revealing information that might increase their borrowing costs in times of stress.

3. Global US dollar shortages and central bank policies

3.1 The origins and emergence of US dollar shortages

The origins of the US dollar shortage, as described in a number of recent BIS publications, largely stemmed from a sharp growth in the US dollar assets of European banks over the past decade that sharply outpaced the growth in their retail dollar deposits (McGuire and von Peter, 2008; 2009). As funding from banks and non-banks typically covered only part of this structural shortage of US dollars, European banks were heavily reliant on the FX swap market to obtain such dollar funding.[9] In the summer of 2007, European financial institutions started to increase activity to secure dollar funding to support troubled US conduits to which they had committed backup liquidity facilities, and at the same time interbank funding liquidity deteriorated in line with increased concerns about the creditworthiness of banks. Under these circumstances, an increasing number of European institutions moved to convert European currencies into dollars via FX swaps, resulting in one-sided order flow, and a severe impairment of liquidity in the FX swap markets.

From mid-August to mid-September 2007, market participants indicated that the deteriorating liquidity in underlying term dollar, euro and sterling markets made it very difficult to identify the appropriate interest rates at which to price forward transactions. As a result, FX swap market experienced much wider bid-ask spreads than normal (FRBNY, 2007). Anecdotal evidence also indicated that concerns about counterparty risk were causing on the one hand riskier counterparties to find it more difficult and costly to make transactions, and on the other hand market makers to withdraw from the market. Reflecting these and other factors, as described in Baba et al. (2008), the spreads between the FX swap-implied dollar rates and

analysis of the so-called “Japan premium” at that time for Japanese banks in interbank lending markets, see Covrig et al. (2004) and Peek and Rosengren (2001).

9 European banks’ reliance on dollars was not met by a proportionate need of US banks for European currencies, which implied that a shock to counterparty risk affected the FX swap market disproportionately (Baba et al, 2009).

dollar Libor rose considerably from late August, moving up to levels by close to 45 basis points when funded in the euro, and more than 20 basis points in the Swiss franc and the sterling. It is the determinants of these deviations that we analyze in this paper.

Though there was some alleviation of tensions in FX swap markets in mid-September 2007, from mid-November, trading liquidity in the FX swap market was again impaired, exacerbated by typical year-end funding pressures. Concerns about counterparty risk and one-sided markets again led to wider bid-ask spreads and wider effective dollar costs of funding via the FX swap market than the cash markets.

3.2 The December 2007 policy response: The establishment of US dollar swap lines

In December 2007, the Federal Reserve, the ECB and the SNB responded in a coordinated fashion to address the US dollar shortages of European financial institutions. To improve financial market functioning by providing liquidity in US dollars abroad, the Federal Reserve announced the establishment of swap lines, or “reciprocal currency arrangements”, with the ECB and the SNB on December 12.[10]

In terms of the specifics of the agreement at that time, the ECB could swap euro for up to $20 billion, and the SNB could Swiss francs for up to $4 billion, respectively, through the end of June 2008 (Figure 2). Drawing on these funds, the ECB and SNB were then able to temporarily lend—through auctions conducted in parallel with those of the Federal Reserve’s Term Auction Facility (TAF)—the dollar proceeds of swaps to Eurosystem and Swiss counterparties with eligible collateral in need of term dollar funding. On December 17 and 21, the ECB conducted fixed rate auctions for $10 billion of 28-day and 35-day funds, respectively, where the rate was determined by the marginal rate of the same day Federal Reserve TAF auction (Table 1). On December 17, the SNB held a variable rate tender auction for $ 4 billion (Table 2). All auctions were fully subscribed; thus, by the end of the year, both the ECB and SNB had fully drawn down their swap lines with the Federal Reserve. Similar auctions which essentially rolled over the 28-day swap lines were conducted by the ECB in January 14 and 28, and by the SNB of January 14. However, as term funding pressures declined in February, as well as FX swap market deviations, the auctions were subsequently suspended by the ECB and SNB and not held in February.

3.3 The renewal of term funding pressures and March 2008 increase in swap lines

However, towards the end of February and in March, despite a variety of other measures implemented by the Federal Reserve to ease funding pressures such as the expansion of the size of the TAF, and the implementation of the Term Securities Lending facility, concerns about systemic risk in the financial system resurfaced, and stresses in the FX swap markets again intensified. In response, on March 11 the Federal Reserve authorized further increases in the swap lines with the ECB and the SNB to $30 billion and $6 billion, respectively, and also extended the terms of the swap lines through September 30, 2008. The ECB and SNB both reinstituted their dollar auctions and increased their sizes in line with the increased swap lines. On March 25 and April 7, the ECB held two auctions for $15 billion, while the SNB held one auction for $6 billion on March 25.

---

[10] These were the first established since September 11, 2001, when swap agreements were put into place to assist financial market functioning after the disruptions to infrastructure due to the terrorist attacks.

3.4 The May / July increases in swap lines and additional measures

But even these amounts were insufficient, and to address further pressures in dollar funding markets, on May 2 the Federal Reserve authorized further increases in dollar swap lines with the ECB and the SNB to $50 billion and $12 billion, respectively, and extended their terms again through January 30, 2009. The ECB and SNB were able to increase the size of their dollar auctions to locally eligible institutions which remained fully booked, and by June 30 both lines were completely drawn.

On July 30, in addition to raising the ECB swap line by another $5 billion to $55 billion, the Federal Reserve announced that it would auction 84-day funds via the TAF (while continuing with the 28-day fund auctions), to counteract the perceived increasing shortages of dollar funds at a longer maturity. It was also announced that, in coordination with the lengthening of the maturity of the TAF loans of the Federal Reserve, the ECB and SNB also would make available funds of 84 day maturity in their dollar auctions. The increase in the ECB's swap line was authorized in order to accommodate a shift of some of its auctions to 84-day terms. Auctions of 84-day dollar funds for local institutions were then held by the ECB and SNB on August 11 and 12, respectively.

3.5 From turmoil to crisis: The failure of Lehman Brothers

Concerns over the health of the financial sector—and related counterparty risks— increased sharply after the bankruptcy of the investment bank Lehman Brothers on September 15. The sharp rise in counterparty credit concerns—which were also damaged by the Federal Reserve's announcement of a bailout package for AIG the next day—led to even more intense pressures in global funding markets. Greater demand for funding coinciding with heightened precautionary hoarding by many institutions hit both secured and unsecured term lending markets. Many financial institutions increasingly funded themselves at very short maturities, raising rollover risks (FRBNY, 2008).

Global funding market pressures were evident in the virtual shut-down of the FX swap market. Dealers reported that bid-ask spreads on FX swaps increased to as much as 10 times the levels that had prevailed before August 2007.[11] They also reported a widespread decline in interbank market making and exceptionally limited trading activity in term maturity tenors. The price action was reportedly driven by demand for dollar funding from global financial institutions, particularly European financial institutions. As many of these institutions increasingly struggled to obtain funding in the unsecured cash markets, they turned to the effectively collateralized FX swap market as a primary channel for raising dollar funding. This extreme demand for dollar funding led a sizable shift in FX forward prices, with the implied dollar funding rate observed in FX swaps on many major currencies rising sharply above that suggested by the other relative interest measures such as the dollar OIS (overnight index swap) rate and the dollar Libor. During the quarter, the spread of the three month FX swap-implied dollar rate from euro and sterling—US dollar FX forward points—over the dollar Libor fixing rate widened to around 330 and 260 basis points, respectively, in early October after the Lehman failure (Figure 1).

Once again, the central banking community was galvanized into action. To further address the problems in funding markets which had worsened in the wake of the Lehman failure, on September 18, the US Federal Reserve authorized a more than two-fold increase in the swap lines to the ECB and SNB of $110 and $27 billion, respectively. At the same time, new dollar swap lines were opened to the BoJ, BoE and Bank of Canada (BoC) of $60, $40 and $10 billion, respectively. The new swap lines to the BoE were in response to dislocations in

[11] For some examples of indicative bid-ask spreads, see Melvin and Taylor (2009).

the GBP/USD FX swap market which is one of the FX swap currency pairs under investigation in this paper (Figure 2, Table 3).

As the financial crisis continued, there followed rapid-fire increase in the amount of the dollar swap lines over the next few weeks. The swap lines with the ECB and SNB were increased to $120 and $30 billion on September 26, and the ECB, SNB, BoJ, BoE and BoC's swap lines were increased to $240, $60, $120, $80 and $30 billion on September 29. Finally, on October 13, the swap lines were announced to be unlimited with the ECB, SNB, BoE, with the BoJ following the day after.

In a signal of how the crisis had taken on global dimensions, and how seriously the Federal Reserve viewed its role as a provider of global dollar liquidity, new central banks in addition those from Japan, England, and Canada were brought into the swap lines, including many from emerging market economies. The Federal Reserve established swap lines with the Reserve Bank of Australia, the Sveriges Riksbank, the Denmarks Nationalbank and the Norges Bank on 24 September, while the Reserve Bank of New Zealand (RBNZ) was signed up on October 28. On October 29, the Banco Central do Brasil, the Banco de Mexico, the Bank of Korea and the Monetary Authority of Singapore were added to the list of countries with dollar swap lines established with the Federal Reserve. As of the end of October, the authorized swap line amounts were $30 billion for the central banks of Canada, Australia, Sweden, Brazil, Mexico, Korea and Singapore, and $15 billion for the Norges Bank, Denmarks Nationalbank and the RBNZ.[12] As mentioned above, the ECB, the SNB, BoE, and BoJ had unlimited swap line amounts. In late 2008, all swap lines had been authorized through April 30, 2009, though on February 3, 2009, the Federal Reserve extended the swap lines to October 30, 2009.

Financial markets reacted well to the announcements of both the increases in the absolute amounts of the swap lines and the increase in numbers. In particular, the approval of unlimited dollar swap facilities for selected central banks on October 13 was greatly welcomed. Many market participants reported that the expended swap facilities improved term funding conditions: indeed, from the time of the dramatic moves on October 13 to the end of the year, the three-month dollar Libor-OIS declined by approximately 230 basis points to 120 basis points. Meanwhile, over the same time period, the FX swap market deviations from the CIP condition fell sharply, particularly for the EUR/USD and CHF/USD pairs (by more than 60 and 80 basis points, respectively), to the levels which were still above those traced before the Lehman failure, but not by very much (Figure 1).

4. Empirical strategy and main hypotheses

4.1 Overall empirical strategy

In this paper, we analyze three FX swap pairs between the US dollar and each of the three major European currencies (EUR, CHF and GBP). Our sample period covers the period from August 9, 2007 through January 30, 2009 and is divided into subperiods of before and after the Lehman Brothers bankruptcy filing on September 15, 2008.[13] This is because the failure

---

[12] Interestingly, as of December 31, the BoC, the RBNZ, Banco Central do Brasil, Banco de Mexico, and the Monetary Authority of Singapore had not drawn down on their swap lines, though it was thought that the mere announcement of the swap lines had had an announcement effect on FX swap market dislocations.

[13] Baba and Packer (2009) cover the period from September 1, 2006 through September 12, 2008, putting emphasis on the comparison of the EUR/USD pair deviations from CIP between pre-turmoil and turmoil periods.

of Lehman Brothers ushered in a new period of global US dollar shortages characterized by much higher volatility in financial markets, as discussed above. Specifically, the first period covers from August 9, 2007 through September 12, 2008,[14] and the second period covers from September 15, 2008 through January 30, 2009.

We first attempt to extract a common factor from the FX swap deviations for these three currency pairs, using principal component analysis.[15,16] This common factor should reflect the general supply/demand imbalances for US dollars vis-à-vis European currencies emanating from the whole range of financial institutions operating in the FX swap market of these different currency pairs. The use of the common factor analysis is chiefly motivated by the fact that European financial institutions choose the funding currencies in a very flexible manner depending on the relative funding costs of different options for raising dollars through FX swaps. For example, banks in the euro area often use other European currencies, typically Swiss franc and/or pound sterling, as a funding currency to raise dollars when the dollar-raising cost using these currencies is low compared with the cost using euros. Thus, FX swap-implied dollar rates should be very closely related each other even in the turmoil and crisis periods, particularly among these three currency pairs.

Then, we apply the EGARCH (exponential generalized autoregressive conditional heteroskedasticity) model to the common factor, to estimate the impacts of counterparty risk measures for European and US financial institutions on the level of the common factor, as well as measure the effectiveness of central bank policy initiatives on both the level and volatility of the common factor.

4.2 Decomposition of FX swap deviations

We basically follow the conceptual decomposition formula of FX swap deviations from short-term CIP, as proposed in Baba and Packer (2009), using the OIS rates as a benchmark interest rate. The OIS is an interest rate swap in which the floating leg is linked to a publicly available index of daily overnight rates. The two parties agree to exchange at maturity the difference between interest accrued at the agreed fixed rate and interest accrued through the geometric average of the floating index rate. We regard the OIS rates as a proxy for expected future overnight rates for the following two reasons. First, the counterparty risk associated with the OIS contracts is relatively small because no principal is exchanged.[17] Second, the liquidity risk premia contained in OIS rates should be very small because of the lack of any initial cash flows.

The use of OIS rates as a benchmark enables us to decompose the FX swap deviation measured by Libor rates as follows:

---

14 We follow Taylor and Williams (2009) in the choice of August 9 as a starting date of the turmoil, which is when BNP Paribas, in announcing the freeze of redemptions for three of its investment funds, cited an inability to value them. Subsequently, the risk premia embedded in short-term money market rates, as represented by the Libor-OIS spreads, widened substantially in major currencies.

15 The aim of the principal component analysis is to reduce the dimensionality of the data with minimum loss of information. This method has recently seen renewed interest to evaluate the common factor across various financial asset classes. See Longstaff et al. (2008) and Pérignon et al. (2007), among others. Furthermore, Baba (2009) utilize the principal component analysis to analyze the common factor between the short-term FX swap and the longer-term cross-currency basis swap markets.

16 By contrast, Baba and Packer (2009) use the FX swap deviation for the EUR/USD pair as a dependent variable.

17 Moreover, the residual risk is mitigated by collateral and netting arrangements.

$$F/S\left(1+Libor^{i}\right)-\left(1+Libor^{USD}\right)$$
$$\approx\left[\left(\ln F^{i,USD}-\ln S^{i,USD}\right)-\left(OIS^{USD}-OIS^{i}\right)\right]+\left[\left(Libor^{i}-OIS^{i}\right)-\left(Libor^{USD}-OIS^{USD}\right)\right] \quad (2)$$

i=EUR, CHF, and GBP

Here, the right-hand side of equation (2) can be obtained by first separating the term involving the FX forward discount rate from that involving Libor rates, and then log-approximating the FX forward discount term.[18] This decomposition is useful in choosing explanatory variables for the common factor regressions that follow.

4.3 Two sets of main hypotheses

The following two sets of main hypotheses are tested. The first hypothesis concerns the counterparty risk of European and US financial institutions perceived in the markets. We observe that under normal circumstances European financial institutions are on the US dollar borrowing side of FX swaps, and US financial institutions are on the US dollar lending side. Thus an asymmetry of counterparty risk between European and US financial institutions could potentially show up in the FX swap deviations from CIP. We call this the counterparty risk hypothesis.

The counterparty risk hypothesis is directly related to the first term on the right-hand side of equation (2), which denotes the deviation of the interest rate differential implied in the FX forward discount rate from the differential in the OIS rates of the same currency pair.[19] If European financial institutions facing US dollar shortages are perceived as riskier by US counterparts, then a risk premium may be added to the forward discount rate relative to pure expectations about the interest rate differential between the dollar and the European currency that are reflected in the OIS rates. Thus, an increase in counterparty risk for European financial institutions should always work to raise the FX swap deviations, as we have measured them, while increased counterparty risk for US financial institutions should work in the opposite direction.[20]

On the other hand, when the dollar shortages localized among European financial institutions became a global shortage after the Lehman failure as discussed above, the impact of increasing counterparty risk for US financial institutions may have changed. US financial institutions also suddenly faced considerable difficulty raising US dollar funds in the short-term cash markets, due chiefly to greatly increased concerns over counterparty risk, and these needs could not be entirely met by scheduled TAF auctions of the Federal Reserve. Under such circumstances, US financial institutions would have much less ability to provide dollar funds in the FX swap markets, and many market participants even suggested that some US financial institutions in fact turned to FX swap markets to raise US dollars using

---

18 We abstract from the term $\left(F/S-1\right)Libor^{i}$ because it is at least an order of magnitude smaller than the other terms.

19 The Libor-OIS spreads in the second term on the right-hand side of the same equation may also capture counterparty risk, as argued in Taylor and Williams (2009). However, Libor-OIS spreads should reflect average counterparty risk for Libor panel banks and not necessarily the counterparty risk of European financial institutions relative to US institutions. See Section 5 for more details.

20 As alluded to earlier, counterparty risk is closely associated with market liquidity risk particularly in times of stress, and thus conceptually speaking, it would be appropriate to control for transactions costs when estimating the effect of counterparty risk. Due to the difficulty in finding reliable time-series measures of market liquidity in the FX swaps market that we could apply to our empirical framework, though, we can control only for funding liquidity conditions. To the extent that market liquidity independently might affect FX swap deviations, and also be correlated to counterparty risks while being relatively uncorrelated to funding liquidity risks (for which we control), the measured effects of counterparty risk may be overstated.

European currencies as funding sources. If US institutions in fact undertook such actions extensively, then we might expect counterparty risk for US institutions to be *positively* related to the level of FX swap deviations during the second period under investigation.

The second set of hypotheses concerns the effects of central bank measures to address the US dollar shortage problem, as discussed in Section 3. Specifically, we test the following two types of measures. The first type is the US dollar auctions conducted by the ECB, SNB and BoE, which are supported by the swap lines with the Federal Reserve. What we call the USD auction hypothesis posits that, because of their associated provision of US dollar funds to European financial institutions, US dollar funding auctions significantly lowered FX swap deviations from CIP. A related hypothesis is that implementation of US dollar auctions also served to stabilize the FX swap market by lowering the volatility of deviations from CIP. We measure the effects of these US dollar auctions on the level and volatility of the common factor. We also estimate the effect of coordinated US dollar auctions across the three central banks on its level and volatility.

The second type of measures is actual commitments by the Federal Reserve to establish and increase dollar swap lines with other central banks. As discussed above, there were eight such announcements that related to Federal Reserve Swap lines with the ECB, SNB and BoE during the sample period. To the extent that these announcements were anticipated to diminish the dollar shortage-related dislocations in FX swap markets, we might expect significantly lower FX swap deviations to be associated with the announcements. In this paper, we focus on two of the announcements identified as significant by market participants: first, when in addition to raising the swap lines with the ECB, the introduction of longer maturity (84-day) TAF auctions by the Federal Reserve, ECB, and SNB were simultaneously announced, and second, when unlimited dollar swap lines were announced between the Federal Reserve and the ECB, SNB and BoE.

5. Data and variables

5.1 FX swap deviation

The common factor estimated from spreads between each of the FX swap-implied three month dollar rates (using Libor in each currency as the funding cost) and the three-month dollar Libor rate is the dependent variable in all the regression analyses that follow.[21] We focus on rates of three-month maturity because it is considered the most representative of all the short-term maturities.[22]

The Libor fixings are released every business day by the British Bankers' Association (BBA). The Libor fixing is meant to capture the rates paid on unsecured interbank deposits at large,

[21] Another possibility is to use more market-based interest rates instead of Libor rates. A natural candidate would be the eurodollar deposit rate released by the US Federal Reserve for the dollar rate, and the rates reported by a major brokerage company such as the ICAP for the European currency rates. When using these rates to calculate the FX swap deviations, they become much lower than those based on Libor rates, even negative on many occasions, particularly after the failure of Lehman Brothers (this tendency is most evident for the CHF/USD pair, for which the FX swap deviation is negative for most of the post-Lehman period). This characteristic is at odds with market observations that the cost of raising dollar funds via the FX swap market was well above dollar cash rates following the Lehman failure and stayed at very high levels for a prolonged period of time. Further, because the Federal Reserve reports only the US dollar rate in this format, the use of the Federal Reserve's eurodollar rate raises a mismatch problem with the European rates (ICAP) particularly in terms of coverage of reporting institutions and calculation methods.

[22] For the analysis using data of other maturities, see Baba and Packer (2009).

globally active banks. Just prior to 11:00 GMT, the BBA surveys a panel of banks, asking them to provide the rates at which they believe they could borrow reasonable amounts in a particular currency and maturity. However, the banks are under no obligation to prove that they can actually borrow at those rates.[23] The dollar Libor panel consists of 16 banks from 7 nations. The BBA excludes the highest and lowest quartile of rates and takes a simple average.

For the FX forward discount rate, we use the New York composite FX spot and forward rates taken from Bloomberg, where the composite bid rate is equal to the highest bid rate of more than 30 contributing financial institutions (as of end-February 2009), and the composite ask rate is the lowest ask rate offered by the same institutions. The average of the bid and ask rates is used.

5.2 Determinants of common factor

Counterparty risk measures

To test the counterparty risk hypothesis, we use the following measures of counterparty risk perceptions for European and US financial institutions: the (senior) CDS spread index for European financial institutions with investment grade ratings included in the iTraxx Europe series, and the CDS sectoral spread index for brokers/dealers and other US financial institutions with investment grade ratings.[24] Both indices are taken from the Data Query web site managed by JPMorgan Chase. We label each CDS spread index CDS (European) and CDS (US), respectively. The counterparty risk hypothesis posits that before the Lehman failure, CDS (European) and CDS (US) should have significantly positive and negative impacts on the common factor, respectively, and after the Lehman failure, both CDS (European) and CDS (US) should have significantly positive impacts.

Central bank measures

To test the effectiveness of central bank measures, we create the following two sets of indicator variables. The first set attempts to capture the effect of the US dollar auctions conducted by ECB, SNB and BoE. For each date of the bid submissions for the US dollar auction by each central bank, the indicator variable takes the value of 1; and 0 otherwise.[25] We use four such indicator variables depending on the auction maturities. Take the ECB case for example, ECB 1 includes all the US dollar auctions conducted by the ECB from overnight maturity, ECB 2 includes those at maturities of 5 days or longer, ECB 3 includes maturities of 28 days or longer, and ECB 4 includes maturities of 80 days or longer. Together with the use of indicator variables independently for each central bank, we also use the indicator variables labelled ECB&SNB (before the Lehman failure) and ECB&SNB&BOE (after the Lehman failure) in the same maturity zones that take the value of 1 if all the central banks with US dollar auction facilities conducted the auctions on the same day.[26]

---

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

[24] Baba and Packer (2009) also use average CDS spreads for dollar Libor panel banks headquartered in the Eurozone and those headquartered in the United States, in addition to the broader indices we use in this paper. They report that the use of the CDS indices covering a broader set of financial institutions than the dollar Libor panel banks provides supporting evidence for the counterparty risk hypothesis.

[25] Baba and Packer (2009) also test a similar dummy for the announcement dates of the US dollar auctions, and find slightly weaker evidence for the effectiveness of the auctions than when using a dummy for the bid submission dates.

[26] BoE did not conduct US dollar auctions before the failure of Lehman Brothers. See Section 3 for details.

The second set of indicator variables labelled Commitment 1 and Commitment 2 takes the value of 1 from July 30, and October 13, 2008 onwards, respectively, when the commitment to address the US dollar shortage problem was reinforced by the central bank community. In particular, Commitment 2 is expected to have a large impact because on that day, a strong joint announcement was made by major central banks, that the dollar swap lines between the Federal Reserves and the ECB, SNB and BoE would be unlimited.

To the extent that these central bank measures were effective in ameliorating the dollar shortage problem, the corresponding indicator variables should have a significantly negative effect on the level and volatility (in the case of US dollar auctions) of the common factor.

Broad-based cash rate-OIS spread

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

To control for this factor, we utilize the three-month eurodollar deposit rate released by the US Federal Reserve. The eurodollar rate is based on rates actually observed in the eurodollar interbank cash market and reflects a much broader array of financial institutions than the Libor panel banks, which are meant to be only large, globally active banks. To maintain consistency with equation (2), we use the spread of the broad-based dollar cash rate over the dollar OIS rate, which is labelled Broad-OIS spread in the analysis that follows. To the extent that the FX swap market price is moved by the demand for US dollar funds of financial institutions outside the Libor universe—institutions that may face different costs of funds—we expect the effects of the Broad-OIS spread on the common factor to be positive. The OIS rate is taken from Bloomberg.

Libor-OIS spread

Under the normal circumstances prior to the financial turmoil that started in the summer of 2007, OIS rates tended to move just below the corresponding currency Libor in a very stable manner. After the onset of the financial turmoil, however, the Libor-OIS spreads widened substantially, particularly for the dollar spread.

Market observers posited several possible drivers for the widened Libor-OIS spreads. One commonly cited factor was a deterioration in funding liquidity for banks, ie a decline in their ability to service or roll-over their short-term liabilities as they fell due (IMF, 2008). This in turn was closely related to greater concerns about banks' ability to liquidate positions in certain assets, ie increased market liquidity risk. Another potential factor was a rise in counterparty risk for the Libor panel banks, as argued in Taylor and Williams (2009), among others. Uncertainty about the potential losses from subprime mortgage-related structured products is reported to have added concerns about counterparty risk among financial institutions in the early stages of the turmoil.

In this paper, we include the dollar Libor-OIS spread in the regression analysis, maintaining consistency with equation (2). The expected sign for this variable is negative. Including this variable is basically meant to control for the funding liquidity conditions in the US dollar cash market (vis-à-vis European counterparts). Namely, using the Libor-OIS spread in our regression reduces the likelihood that we are confounding counterparty risk with funding liquidity risk conditions that may be highly correlated with our CDS-based measures. While there may be a counterparty risk component in Libor-OIS spreads, several studies suggest that liquidity factors have been the more important (Michaud and Upper, 2008; Schwarz, 2008). Further, since counterparty risk possibly embedded in the Libor-OIS spread is the counterparty risk averaged over the Libor-panel banks, it does not necessarily reflect the risk for the categories such as European and US financial institutions for which our counterparty hypothesis is tested.[27]

6 Empirical analysis

6.1 Framework

We test the above-mentioned two sets of main hypotheses after controlling for relevant factors discussed above. To account for stochastic volatility, as well as to measure the effect of central bank policy measures on it, we employ the EGARCH (1,1) model proposed by Nelson (1991).[28] The EGARCH (1,1) model for the common factor can be written as

Mean (level) equation:

$$\begin{aligned}\text{Common factor}_t &= a + b_1\text{CDS(European)}_t + b_2\text{CDS(US)}_t \\ &+ b_3\text{USD auction}_t + b_4\text{Commitment}_t \\ &+ b_5\text{Broad - OIS spread}_t + b_6\text{Libor - OIS spread}_t + \varepsilon_t \quad \varepsilon_t \sim N\left(0, \sigma_t^2\right)\end{aligned} \tag{3}$$

Variance (volatility) equation:

$$\ln\left(\sigma_t^2\right) = \alpha + \beta\ln\left(\sigma_{t-1}^2\right) + \gamma\,\varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\left|\varepsilon_{t-1}/\sigma_{t-1}\right| - \sqrt{2/\pi}\right) + \lambda\text{USD auction}_t \tag{4}$$

In the mean equation, b_1 and b_2 are the coefficients reflecting the effect of the counterparty risk for European and US financial institutions, respectively, on the level of the common factor, and b_3 and b_4 are those capturing the effect of the central bank policy measures. In the variance equation, λ measures the effect of the dollar auctions by each central bank on the volatility of the common factor.[29]

The major advantage of the EGARCH model over other GARCH models is that the conditional variance is specified in the log-form and thus we do not need to impose any non-negativity constraints on the variance equation. We can also test the asymmetric leverage effects by the coefficient of γ such that when ε_{t-1} is positive, the total effect of ε_{t-1} on the log of the conditional variance can be measured by $(\eta+\gamma)\left|\varepsilon_{t-1}/\sigma_{t-1}\right|$, and when ε_{t-1} is negative, it can be measured by $(\eta-\gamma)\left|\varepsilon_{t-1}/\sigma_{t-1}\right|$. The expected signs of each determinant in the regression are summarized in Table 4.

6.2 Summary statistics and principal component analysis

Table 5 reports summary statistics of each variable under study before and after the Lehman failure. Almost all the variables are found to experience a large increase in mean and

---

27 In fact, as 14 of 16 Libor panel banks are the same between the dollar and the euro, the difference in Libor-OIS spreads between this currency pair is not likely to capture fully the changing perceptions of the difference in counterparty risks between European and US financial institutions.

28 EGARCH is widely used in analyzing the effects of central bank communications on financial asset prices. See Beine et al. (2009) and Ehrmann and Fratzscher (2007), for example.

29 Volatility persistence can be measured by β in the EGARCH model.

standard deviation after the Lehman failure. Before the Lehman failure, the FX swap deviations are about 0.16 percentage points on average, but they increased to the range of 0.5-1.0 percentage points afterwards. The standard deviation of the FX swap deviation also surged to about five times its level in the preceding period. Meanwhile, the CDS spread variables increased quite a bit in the later period, particularly for US financial institutions. While both the Broad-OIS spread and Libor-OIS spread increased significantly after the Lehman failure, the former spread jumped by considerably more, from 0.8 to 2.7 percentage points on average. The broad-based eurodollar deposit rate reached around 6 percent at the height of market stress in October 2008, more than 1 percentage point higher than the dollar Libor at that time, as shown in Figure 3.[30] This result suggests an increasing importance of including the Broad-OIS spread as an explanatory variable in the regressions, so as to control for the limited representativeness of dollar Libor.

Table 6 shows the results of principal component analysis for the three FX swap deviations.[31] 82 and 88 percent of the total variance of the FX swap deviations are explained by just the first principal component before and after the Lehman failure, respectively. Factor loadings of the first principal component take on very similar values across the three FX swap pairs in both periods. This suggests that we can safely regard the first principal component as a common factor to the FX swap deviations of the three currency pairs (also note here that correlation between the first principal component and each FX swap deviation is very high).

Table 7 reports the results of two standard unit root tests (Augmented Dickey-Fuller test and Phillips-Perron test) for all the variables. In both periods, the principal component, as well as each original series of FX swap deviations, are significantly found to be I(0). Based on this test result, in the analysis that follows, we use the level of the common factor of the FX swap deviations as a dependent variable, not the changes in that variable, since taking the first difference in the common factor is likely to lead to a serious loss of information without corresponding benefit.[32] Thus, our presumption is that US dollar liquidity provision by central banks is aimed at mitigating the US dollar shortage problem that shows up in the level of the common factor of FX swap deviations.

By contrast, the results are mixed for the determinants of the common factor. Before the Lehman failure, both CDS spread indices are found to be I(1), and after the Lehman failure, CDS (US) and both Broad-OIS and Libor-OIS spreads are found to be I(1). Since our dependent variable is the level of the common factor as mentioned above and we follow the decomposition formula (2), we choose to use the level of each determinant in the analysis below. That said, we will report the results of complete robustness checks in this regard later in this Section.

---

[30] It should be noted, however, that the broad-based spread and the Libor-OIS spread are very highly correlated, where coefficients of correlation are 0.92 and 0.95 before and after the Lehman failure, respectively. We will conduct a robustness check concerning these issues later in this Section.

[31] The principal component is a standardized series with zero mean and one standard error.

[32] By contrast, McAndews et al. (2008) use the change of the US dollar Libor-OIS spread as the dependent variables when investigating the effects of the TAF conducted by the Federal Reserve on it. One major stated reason for their approach is that the level of the Libor-OIS spread has a unit root in their sample period.

6.3 Estimation results

Table 8 reports the estimation results of EGARCH analysis of the common factor (first principal component) for the period before the Lehman failure.

First of all, the counterparty risk hypothesis is found to hold during this period in all cases. The coefficient on CDS (European) is always significantly positive, and that on CDS (US) is always significantly negative. This result is consistent with Baba and Packer (2009), who find that the difference in CDS spreads between broad-based European and US financial institutions has a significantly positive association with the EUR/USD swap deviation during the same period.

Second, while none of the dummy variables of the USD auctions nor the included swap lines commitment variable (commitment 1)[33] have significantly negative coefficients on the level of the common factor, by contrast, the USD auction dummies do have a significantly negative impact on the volatility of the common factor in all cases. Estimates of the variance coefficient are more negative and statistically significant when the variable is limited to auctions conducted at maturities of 80 days or longer. For example, the estimates of λ=-2.634 and -2.232 for ECB 4 and SNB 4 in Table 8 suggest that volatility drops by 92 and 89 percent on average on the day of the auctions, respectively.[34]

Third, both control variables, the Broad-OIS and Libor-OIS spreads, have significantly positive and negative coefficients, respectively, in all cases, which is consistent with equation (3).[35] The results also support the view that higher demand for US dollar funds by a wider range of financial institutions than the dollar Libor panel banks should have a significantly positive effect on the level of the common factor of FX swap deviations.

Fourth, the variance equation is well estimated in all specifications.[36] The ARCH (η) and GARCH (β) effects are significantly positive in all cases. The estimated high coefficients of the GARCH term indicates the existence of volatility clustering, such that large changes tend to be followed by large changes. The asymmetric ARCH leverage effect (γ) is found to be significant such that a negative shock tends to have a larger impact on volatility than a positive shock.

Next, Tables 9-12 report the results of EGARCH analysis after the Lehman failure.[37] First, in all cases, CDS (European) has a significantly positive coefficient on the level of the common

---

33 As discussed earlier, we included an indicator variable that takes the value of 1 after the July 30 announcement of an increase in the ECB's swap lines as well as an increase in term of the dollar funds that would be made available by both the ECB and SNB, supported by the swap lines. In other regressions (not reported), other dates in which swap lines were increased during the period were also found to be insignificant.

34 The instantaneous drop rate is calculated as $\exp(\lambda)-1$.

35 The coefficients on the Broad-OIS and Libor-OIS spreads, always of the opposite sign, are often found to be roughly of the same magnitude. This suggests that information of both spreads for the FX swap deviation might be captured more efficiently by the spread between the broad-based dollar rate and dollar Libor. We conduct a robustness check for this specification later in this Section.

36 The Ljung-Box Q statistics for the autocorrelation of the squared standardized residuals from the EGARCH model (not reported) are found to be insignificant for various lag lengths. This turns out to be always the case throughout the analysis that follows.

37 In comparing the size of coefficients between the two periods, it should be noted that our dependent variables (first principal component) in both periods are standardized variables with 0 mean and 1 standard deviation. Based on regression results of the original FX swap deviation series on the principal component in each period, we find that, in terms of the impact on the original FX swap deviation series, an estimated coefficient of 1 in the pre-Lehman period roughly corresponds to a coefficient of 0.2 in the post-Lehman period. Thus, a smaller coefficient in the latter period can still correspond to a larger impact on the original FX swap deviation.

factor, consistent with the results before the Lehman failure. CDS (US) also has a significantly positive coefficient in all cases except one. This result is in marked contrast to that for the earlier period, but consistent with our counterparty risk hypothesis, as posited for after the Lehman failure. As discussed above, after this event, US financial institutions also faced difficulty raising US dollar funding in cash markets, due to greatly increased concerns over counterparty risk. Under such circumstances, US financial institutions had much less ability to provide dollar funds in the FX swap markets, and many market observers even suggested that some US financial institutions turned to FX swap markets to raise dollars chiefly using European currencies as funding sources.

Second, USD auction dummies at maturities of 28 days or longer have significantly negative coefficients on the level of the common factor in all cases for the ECB (Table 9), SNB (Table 10) and BoE (Table 11), including the case of the same-day coordinated auction dummy (Table 12). These results suggest that US dollar auctions conducted by each of the central banks, particularly at maturities of 28 days or longer, successfully alleviated the dollar shortage problem to the extent it showed up in FX swap deviations from the CIP condition. In the case of the ECB's auctions, the auction dummy at maturities of 5 days or longer also have a significantly negative coefficient.

How can these impacts be evaluated in economic terms? Based on the results of regressions that measure the association between the common factor and each original series of FX swap deviation, we can approximate the impacts of the US dollar auctions in terms of the original series of FX swap deviations: the estimated coefficient on the USD auction dummy of -0.2 roughly corresponds to a reduction of the FX swap deviation of 6.0 (EUR/USD), 6.9 (CHF/USD), and 6.5 (GBP/USD) basis points, respectively. The US dollar auctions with relatively long maturities also exert a significantly stabilizing effect on the volatility of the common factor. Specifically, US dollar auctions at maturities of 28 days or longer have a significantly negative impact on volatility in all cases, corresponding to the reduction in volatility of 69 (ECB 3), 61 (SNB 3), and 65 (BoE 3) percentage points on average. Results for maturities of 80 days or longer are very similar except for the case of SNB 4 (Table 10).[38]

Third, the shift by the Federal Reserve to unlimited dollar swap lines for the ECB, SNB and BoE, as captured by the "commitment 2" dummy variable, always has a significantly negative effect on the level of the common factor. As discussed above, on October 13, 2008, major central banks jointly announced measures to improve short-term US dollar liquidity conditions including the unlimited dollar swap lines. In terms of the original series of FX swap deviations, the estimated coefficient on this commitment dummy of -1 corresponds to reductions in the FX swap deviations of 30.2 (EUR/USD), 34.6 (CHF/USD), and 32.6 (GBP/USD) basis points, respectively. The results are consistent with the view expressed by many market observers that the moves by the central banking community to address the US dollar shortage problem in the FX swap markets were especially effective from mid-October.[39]

Fourth, as is the case with the estimation results before the Lehman failure, Broad-OIS and Libor-OIS spreads have significantly positive and negative coefficients, respectively, in all cases, which is consistent with equation (3).[40]

---

[38] We further tested the hypothesis that joint USD auctions by three central banks are more effective than the auctions conducted by a single central bank by including both the same-day dummy and a dummy variable that takes the value of 1 if each central bank conduct auctions alone. We were not able to find significant evidence supporting this hypothesis, though.

[39] We also tested whether indicator variables for other dates when swap line increases were announced, but they were not found to be significant.

[40] The coefficients on both spreads drop in magnitude by 90 percent from the pre to post-Lehman regressions. Even when considering the (above-mentioned) fact that a coefficient of 1 pre-Lehmann would correspond to

6.4 Robustness checks

As mentioned earlier, some of the determinants of the common factor are found to be I(1) and there is very high correlation between the Broad-OIS spread and the Libor-OIS spread, so we report the summary of a complete set of robustness checks based on the following specifications.

First, in both periods, we use the spread of the eurodollar rate reported by the Federal Reserve over dollar Libor, which is found to be I(0) in both periods, instead of using the Broad-OIS and Libor-OIS spreads, separately. This is to cope with the high correlation between these spreads and potential non-stationarity problems, as well as the point mentioned earlier that the information of both spreads for the FX swap deviation might be captured more efficiently by the single variable, given the rough equivalence of the absolute value of the coefficients on the variables estimated separately.

Second, at the same time, we use the changes in both CDS (European) and CDS (US) in the pre-Lehman regressions, and the change in CDS (US) in the post-Lehman regressions. This is based on the unit root test results, as reported in Table 7, in which the level of those variables are found to be I(1), which might potentially pose non-stationarity problems for the estimation.

The EGARCH analysis based on the above specifications shows that our main results remain almost intact in both periods.[41] More specifically, in the pre-Lehman regressions, the CDS (European) and CDS (US) have a significantly positive and negative coefficients, respectively, for determining the level of the common factor, respectively, and USD auction dummies at 28 days or longer have a significantly negative coefficients for determining its volatility in most cases. In the post-Lehman regressions, both the CDS (European) and CDS (US) have significantly positive coefficients for determining the level of the common factor, while the same USD auction dummies have a significantly negative impact on its level and volatility in most cases, and the commitment dummy 2, which takes the value of 1 from October 13, 2008 onwards, has a significantly negative impact on its level.

6.5 Discussion: Assessing policy effectiveness

As documented above, the policy measures to ensure that adequate term dollar funding was available to European banks intensified in the wake of Lehman bankruptcy. That the renewed efforts met with more success is indicated by the significance of the dollar auction variable in reducing both the level and volatility of the common factor in the post-Lehman regression, as opposed to the more limited results of reduced volatility in the earlier pre-Lehman period. At the same time, it should be remembered that perhaps the objectives of policy had changed after September 15, when interbank rates and measures of dislocation in FX swap markets spiked by many times their previously elevated values. Central banks may have been determined to get out “ahead of the curve” and took back the clock on dislocations, as opposed to merely stabilize their movements. The pronounced impact of the move to unlimited dollar swap lines by the Federal Reserve with the central banks under study may also reflect the increased aggressiveness of central bank intent.

---

the same impact on the original FX swap deviation as a coefficient of one-fifth that size post-Lehmann, coefficients on the Broad-OIS and Libor-OIS spreads in the post-Lehman period still appear to be relatively small compared with those of the preceding period. We would lean towards ascribing this outcome to simple increased measurement error in the later, more volatile period, for reasons such as the deterioration of market liquidity after the Lehman failure, for which we find it difficult to control as described above.

[41] Detailed results are available upon request.

Policymakers post-Lehman were also dealing with dollar shortages that were now global in nature, as underscored in the results by our findings suggestive that even US financial institutions found themselves short of term funding and some turned to FX swap markets to raise dollars. Swap lines were extended to central banks across many continents and time zones. Though not explicitly addressed in our empirical exercise, the fact that central banks undertook a shift to a "full court press" in their defensive strategies, with swap lines increases announced simultaneously with an increase in the number of countries receiving term dollar funds, may also have increased the effectiveness of the policy measures post-Lehman.

Of course, the increase in dollar swap lines among central banks after the Lehman failure cannot take sole credit for the alleviation of dislocations in the FX swap market around that time. To be sure, these measures were widely welcomed by market participants and credited with alleviating funding pressures in term funding markets. However, the increase in the dollar swap lines to unlimited amounts occurred shortly after the adoption of many other measures by the authorities to stabilize the financial system by reducing counterparty credit and liquidity risks. In particular, the US Treasury's guarantee for money market funds' net asset value which sought to stop a run on money market funds, as well as the Federal's Reserve's ABCP money market fund liquidity facility (AMLF) which granted money market funds indirect access to Federal Reserve funding was announced on September 19. Further, the Federal Reserve announced a Commercial Paper Funding Facility (CPFF) on October 7, which financed repayments to money market funds of maturing CP that money market funds did not roll over, as well as reduced the risk of CP on money market fund portfolio balance sheet. The combination of the above measures was likely important in alleviating funding pressures on non-US banks in particular, since money market funds had been the largest suppliers of dollar funding to non-US banks (Baba et al, 2009). It is quite possible that the shift to unlimited dollar swap lines was more effective in the wake of these other measures.

7. Concluding remarks

Financial markets shifted from turmoil to crisis mode following the failure of Lehman Brothers on September 15, 2008. This paper has empirically investigated dislocations in the FX swap market around this seismic event. As documented in Baba and Packer (2009), well before the Lehman failure, there had already been a striking change in the relationship between perceptions of counterparty risk and FX swap prices. That is, after the onset of financial turmoil the summer of 2007, CDS spread differences between European and US financial institutions were positively related to deviations from CIP observed in the FX swap market. The findings suggested that concern over the counterparty risk of European financial institutions was one of the important drivers of the deviation from covered interest parity in the FX swap market.

However, after the bankruptcy of Lehman Brothers, the turmoil in many markets became much more pronounced. In FX and money markets, what had principally been a dollar liquidity problem for European financial institutions deepened into a phenomenon of global dollar shortage. The empirical results spanning the failure of Lehman are consistent with this globalization of the dollar shortage problem. US financial institutions after the failure faced difficulty raising US dollar funding possibly as much as European institutions, and in striking contrast to the pre-Lehman period of turmoil, declining credit worthiness of US institutions provided an independent source of imbalances in the FX swap markets to the decline in creditworthiness of European institutions.

Central bank measures to counter the dollar shortage were redoubled after the Lehman failure. In December 2007, the Federal Reserve had initiated dollar swap lines with the ECB and SNB so as to facilitate the provision of US dollar term funds to Eurosystem and Swiss counterparties. These amounts were increased two to three times over the following nine months. But in response to the greatly increased pressure following the failure of Lehman Brothers, the central banks ramped up at an unprecedented pace their transatlantic dollar funding of non-US banks, culminating in the establishment of unlimited swap lines by the Federal Reserve with the ECB, SNB and the BoE on October 13. 2008.

While the establishment of dollar swap lines had not had a significant impact on the level of the FX swap deviation before the failure of Lehman Brothers, if anything, indicating that central banks had fallen behind the curve, our empirical evidence suggests that they became effective in diminishing the level of FX swap market deviation in the later period. The impacts of the moves on the FX swap market deviations were such that the deviations were at least 30 basis points less than those otherwise might have been after the introduction of the unlimited swap lines. Since we are controlling for the effects of funding liquidity problems in the interbank markets, this is likely a lower bound estimate on the effectiveness of the measures.

We also test whether the actual provision of funds by the ECB, SNB and BoE in auctions, designed to occur on the same day as those of the Federal Reserve's Term Auction Facility, had an impact on the FX swap market deviations. In contrast to the results before the failure of Lehman Brothers, dollar auction dummies have a significantly negative effect on the level of the common factor for EUR/USD, CHF/USD and GBP/USD FX swap deviations, as long as the auction dummies include maturities of 28 days or longer. The result suggests that US dollar auctions at longer maturities conducted by the European central banks successfully ameliorated the problem of US dollar shortage in the FX swap markets. In addition, both prior to and after the Lehman failure, the US dollar liquidity-providing operations by the central banks under study appear to have lowered the volatility (and thus the associated uncertainty) of the FX swap deviations. Our estimation results thus support the view that the dollar term funding auctions conducted by the ECB, SNB and BoE, supported by dollar swap lines with the Federal Reserve, played a positive role in stabilizing the FX swap market for the euro/dollar, Swiss franc/dollar and sterling/dollar currency pairs.

This study focuses on the degree to which FX swap markets for European currencies vis-à-vis the US dollar were shaken by the failure of Lehman Brothers, as well as the effectiveness of concerted policy measures to overcome dollar shortages in the major currency areas of industrialized Europe. After the Lehman failure, as dislocations in FX swap markets reflected dollar shortages that were global in nature, the provision of dollar funds in coordination with the Federal Reserve expanded greatly to include central banks in five continents including many emerging market economies. Future researchers might focus on the degree to which the heterogeneity of institutions and financial systems influenced the effectiveness of the provision of dollar funds during the crisis.

References

Akram, F., Rime, D., Sarno, L., 2008. Arbitrage in the Foreign Exchange Market: Turning on the Microscope. Journal of International Economics 76 (2), 237-253.

Aliber, R. Z., 1973. The Interest Rate Parity Theorem: A Reinterpretation. Journal of Political Economy 81 (6), 1451-1459.

Baba, N., 2009. Dynamic Spillover of Money Market Turmoil from FX Swap to Cross-Currency Swap Markets: Evidence from the 2007-2008 Turmoil. Journal of Fixed Income 18 (4), 24-38.

Baba, N., McCauley R. N., Ramaswamy S., 2009. US Dollar Money Market Funds and Non-US Banks. BIS Quarterly Review (March), 65-81.

Baba, N., Packer, F., Nagano, T., 2008. The Spillover of Money Market Turbulence to FX Swap and Cross-Currency Swap Markets. BIS Quarterly Review (March), 73-86.

Baba, N., Packer F., 2009. Interpreting Deviations from Covered Interest Parity During the Financial Market Turmoil of 2007-08. Journal of Banking and Finance, forthcoming.

Bank for International Settlements (BIS), 2008. Annual Report.

Beine, M., Janssen, G., Lecourt, C., 2009. Should Central Bankers Talk to the Foreign Exchange Markets? Journal of International Money and Finance 28 (5), 776-803.

Borio, C., Nelson, W., 2008. Monetary Operations and the Financial Turmoil. BIS Quarterly Review (March), 31-46.

Brunnermeier, M. K., 2009. Deciphering the Liquidity and Credit Crunch 2007-08. Journal of Economic Perspectives 23 (1), 77-100.

Committee on the Global Financial System (CGFS)., 2008. Central Bank Operations in Response to the Turmoil. CGFS Working Paper No. 31, Bank for International Settlements, Basel Switzerland.

Covrig, V., Low, B. S., Melvin M., 2004. A Yen is not a Yen: TIBOR/LIBOR and the Determinants of the Japan Premium. Journal of Financial and Quantitative Analysis 39 (1), 193-208.

Duffie, D., Huang, M., 1996. Swap Rates and Credit Quality. Journal of Finance 51 (2), 921-950.

Ehrmann, M., Fratzscher, M., 2007. Communication by Central Bank Committee Members: Difference Strategies, Same Effectiveness? Journal of Money, Credit and Banking 39 (2-3), 509-541.

European Central Bank (ECB)., 2007. Financial Stability Review (December).

Federal Reserve Bank of New York (FRBNY), 2007. Treasury and Federal Reserve exchange operations: July-September 2007 (November).

Federal Reserve Bank of New York (FRBNY), 2008. Treasury and Federal Reserve exchange operations: July-September 2008 (November).

Fender, I., Gyntelberg, J., 2008. Overview: Global Financial Crisis Spurs Unprecedented Policy Actions. BIS Quarterly Review (December), 1-24.

Gyntelberg, J., Wooldridge, P., 2008. Interbank Rate Fixings during the Recent Turmoil. BIS Quarterly Review (March), 59-72.

Hanajiri, T., 1999. Three Japan Premiums in Autumn 1997 and Autumn 1998: Why did Premiums Differ between Markets? Bank of Japan Financial Market Working Paper Series 99-E-1, Tokyo Japan.

International Monetary Fund (IMF)., 2008. Market and Funding Illiquidity: When Private Risk Becomes Public. Global Financial Stability Report (April), 86-117.

Longstaff, F. A., Pan, J., Pedersen, L. H., Singleton, K. J., 2008. How Sovereign is Sovereign Credit Risk? manuscript.

McAndews, J., Sarkar, A., Wang, Z., 2008. The Effects of the Term Auction Facility on the London Interbank Offered Rate. Federal Reserve Bank of New York Staff Report No. 335, New York USA.

McGuire, P., von Peter, G., 2008. International Banking Activity amidst the Turmoil. BIS Quarterly Review (June), 31-43.

McGuire, P., von Peter, G., 2009. The US Dollar Shortage in Global Banking. BIS Quarterly Review (March), 47-63.

Melvin, M., Taylor, M. P., 2009. The Crisis in the Foreign Exchange Market. Journal of International Money and Finance, forthcoming.

Michaud, F-L., Upper, C., 2008. What Drives Interbank Rates? Evidence from the Libor Panel. BIS Quarterly Review (March), 47-58.

Nelson, B., 1991. Conditional Heteroskedasticity in Asset Returns: A New Approach. Econometrica 59 (2), 347-370.

Peek, J., Rosengren, E. S., 2001. Determinants of the Japan premium: Action Speak Louder than Words. Journal of International Economics 53 (2), 283-305.

Pérignon, C., Smith D. R., Villa C., 2007. Why Common Factors in International Bond Returns are not so Common? Journal of International Money and Finance 26 (2), 284-304.

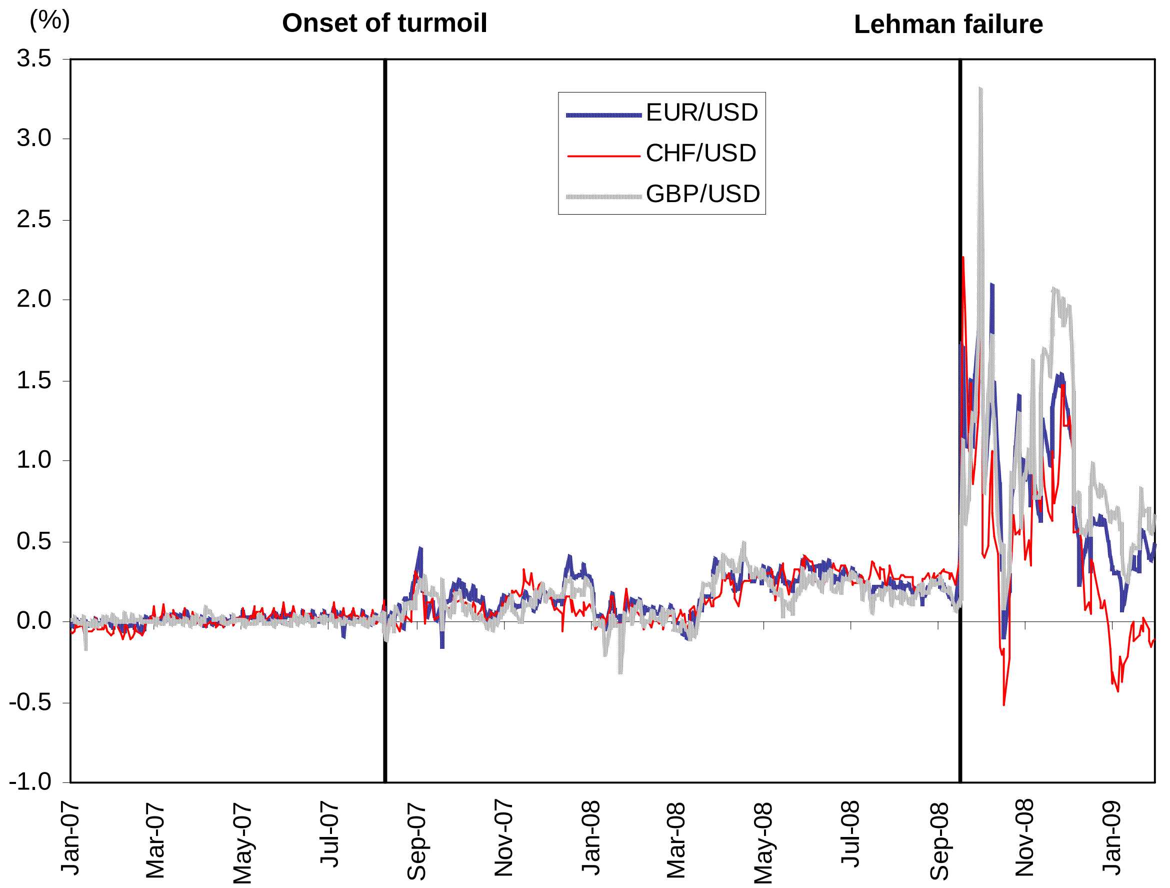
Schwarz, K., 2008. Mind the Gap: Disentangling Credit and Liquidity in Risk Spreads, manuscript.

Taylor, J. B., Williams, J. C., 2009. A Black Swan in the Money Market. American Economic Journal: Macroeconomics 1 (1), 58–83.

Taylor, M. P., 1989. Covered Interest Arbitrage and Market Turbulence. Economic Journal 99 (396), 376-391.

Figure 1

FX swap deviations from the covered interest parity condition

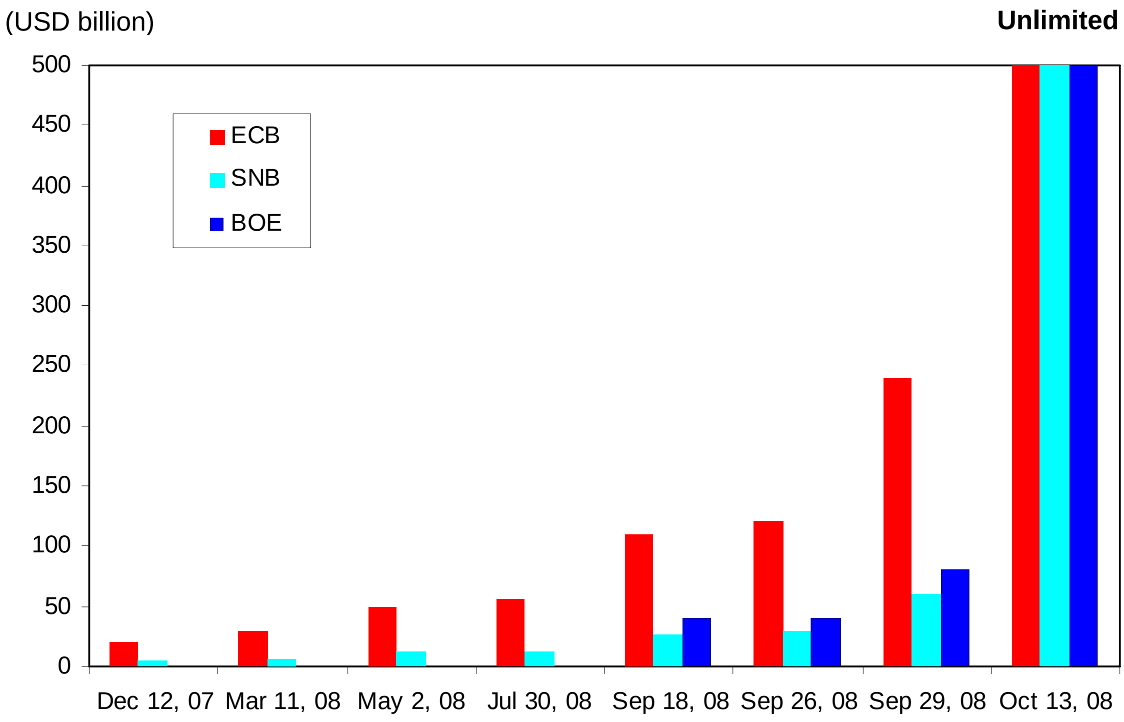


Note: FX swap deviations are calculated as the difference between the FX swap-implied dollar rate and uncollateralized dollar cash rate, where the FX swap-implied dollar rate is defined as a total cost, in terms of a dollar rate, from raising each of European currencies in the uncollateralized cash market and converting them into dollars through the FX swap market. Libor rates are used as the uncollateralized cash rates for all currencies involved.

Source: Bloomberg; Authors' calculations.

Figure 2

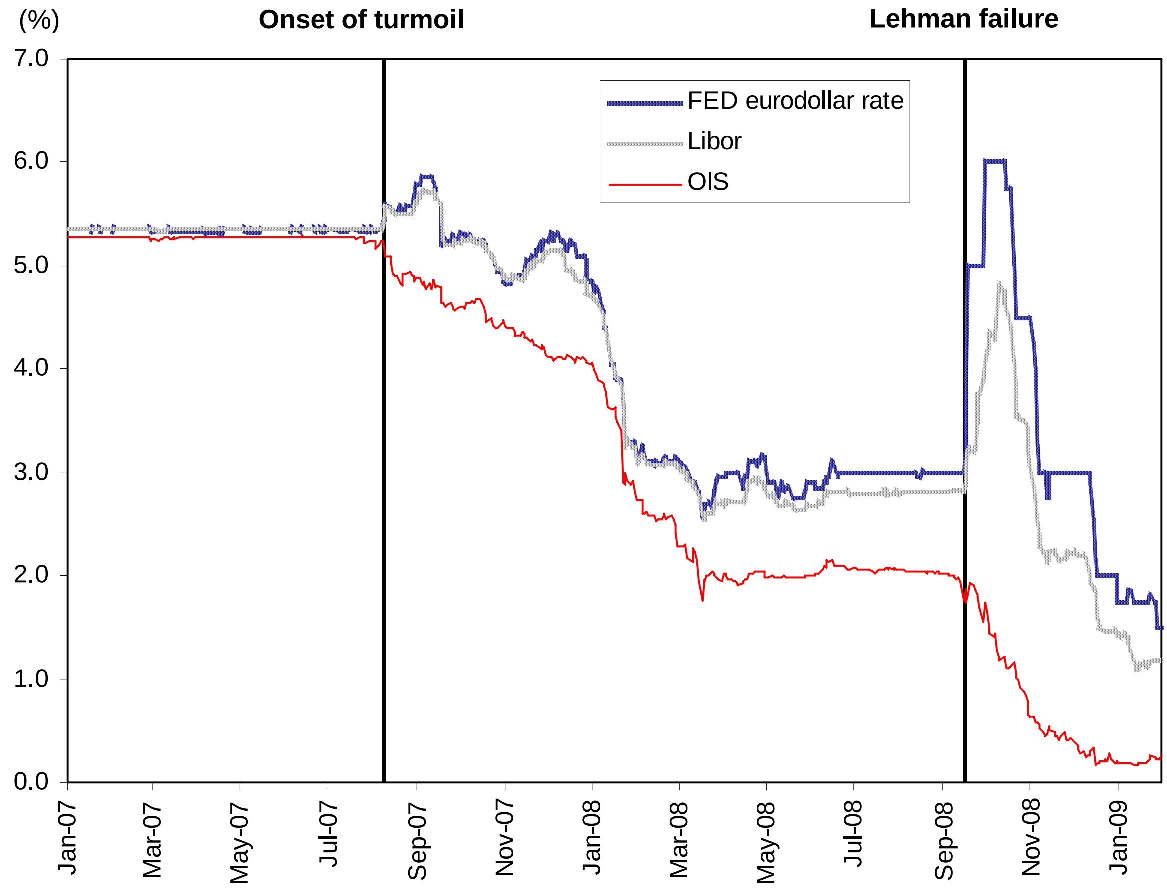
US dollar swap lines with US Federal Reserve



Source: Central banks.

Figure 3

US dollar interest rates



Source: Federal Reserve; Bloomberg.

Table 1

US dollar auctions by European Central Bank

Allotment date	Allotment/Bid amount (USD billion)	Maturity (days)	Allotment date	Allotment/Bid amount (USD billion)	Maturity (days)
12/17/07	10/22	28	10/03/08	50/83	3
12/21/07	10/14	35	10/06/08	20/89	85
01/14/08	10/15	28		50/91	1
01/28/08	10/12	28	10/07/08	50/109	1
03/25/08	15/31	28	10/08/08	70/122	1
04/07/08	15/31	28	10/09/08	100/116	1
04/21/08	15/30	28	10/10/08	94/94	4
05/05/08	25/40	28	10/14/08	98/98	1
05/19/08	25/59	28	10/15/08	100/120	1
06/02/08	25/65	28		171/171	7
06/16/08	25/78	28	10/21/08	102/102	28
06/30/08	25/85	28		23/23	28
07/14/08	25/90	28	10/22/08	68/68	7
07/28/08	25/102	28	10/29/08	92/92	7
08/11/08	10/39	84	11/04/08	71/71	84
08/12/08	20/91	28	11/05/08	59/59	7
08/25/08	20/89	28	11/12/08	61/61	7
09/08/08	10/32	84	11/18/08	52/52	28
09/09/08	10/43	28	11/19/08	72/72	8
09/18/08	40/102	1	11/26/08	85/85	6
09/19/08	40/97	3	12/02/08	67/67	84
09/22/08	25/110	28	12/03/08	75/75	7
	40/82	1	12/10/08	57/57	7
09/23/08	40/78	1	12/16/08	48/48	28
09/24/08	40/62	1	12/17/08	42/42	5
09/25/08	40/73	1	12/23/08	52/52	16
09/26/08	30/41	3	12/30/08	11/11	83
	35/82	7	01/07/09	41/41	7
09/29/08	30/57	1	01/13/09	21/21	28
09/30/08	30/77	1	01/14/09	58/58	7
	31/31	1	01/21/09	60/60	7
10/01/08	50/71	1	01/27/09	24/24	84
10/02/08	50/67	1	01/28/09	61/61	7

Source: European Central Bank.

Table 2

US dollar auctions by Swiss National Bank

Allotment date	Allotment/Bid amount (USD billion)	Maturity (days)	Allotment date	Allotment/Bid amount (USD billion)	Maturity (days)
12/17/07	4/17	28	10/16/08	4/4	1
01/14/08	4/11	28	10/17/08	1/1	1
03/25/08	6/15	28	10/20/08	1/1	1
04/22/08	6/15	28	10/21/08	1/1	1
05/06/08	6/10	28		13/13	28
05/20/08	6/8	28	10/22/08	1/1	1
06/03/08	6/11	28		3/3	7
06/17/08	6/18	28	10/23/08	2/2	1
07/01/08	6/16	28	10/24/08	6/6	1
07/15/08	6/16	28	10/27/08	7/7	1
07/29/08	6/11	28	10/28/08	7/7	1
08/12/08	2/10	84	10/29/08	2/2	1
08/13/08	4/12	28		6/6	7
08/26/08	6/11	28	10/30/08	1/1	1
09/09/08	2/8	84	10/31/08	1/1	1
09/10/08	2/6	28	11/03/08	0.3/0.3	1
09/18/08	10/10	1	11/04/08	1/1	1
09/19/08	10/21	1		2/2	84
09/22/08	10/16	1	11/05/08	1/1	1
09/23/08	10/15	1		2/2	7
	8/23	28	11/12/08	1/1	7
09/24/08	10/14	1	11/18/08	7/7	28
09/25/08	10/11	1	11/19/08	1/1	8
09/26/08	7/8	1	11/26/08	6/6	6
	5/5	7	12/02/08	3/3	84
09/29/08	8/8	1	12/03/08	0.3/0.3	7
09/30/08	10/13	1	12/10/08	0.3/0.3	7
10/01/08	10/12	1	12/16/08	2/2	28
10/02/08	9/9	1	12/17/08	0.2/0.2	5
10/03/08	6/6	1	12/23/08	0.2/0.2	16
10/06/08	7/7	1	12/30/08	2/2	80
10/07/08	10/12	1	01/07/09	1/1	7
	4/9	88	01/13/09	0/0	28
10/09/08	10/11	1	01/14/09	1/1	7
10/10/08	10/12	1	01/21/09	1/1	7
10/14/08	8/8	1	01/27/09	0/0	84
10/15/08	9/9	1	01/25/09	1/1	7
	7/7	7			

Source: Swiss National Bank.

Table 3

US dollar auctions by Bank of England

Allotment date	Allotment/Bid amount (USD billion)	Maturity (days)	Allotment date	Allotment/Bid amount (USD billion)	Maturity (days)
09/18/08	14/14	1	10/23/08	4/4	1
09/19/08	21/21	3	10/24/08	3/3	3
09/22/08	26/26	1	10/27/08	3/3	1
09/23/08	30/30	1	10/28/08	3/3	1
09/24/08	30/30	1	10/29/08	3/3	1
09/25/08	35/35	1		46/46	7
09/26/08	10/12	3	10/30/08	1/1	1
	30/32	7	10/31/08	1/1	3
09/29/08	10/13	1	11/03/08	0.4/0.4	1
09/30/08	10/14	1	11/04/08	0.4/0.4	1
10/01/08	7/7	1		12/12	84
	13/13	6	11/05/08	0.3/0.3	1
10/02/08	9/9	1		21/21	7
10/03/08	8/8	3	11/06/08	0.3/0.3	1
	30/35	7	11/07/08	0.3/0.3	3
10/06/08	10/11	1	11/12/08	15/15	7
10/07/08	8/8	1	11/18/08	23/23	28
10/07/08	18/18	7	11/19/08	10/10	7
10/08/08	9/9	1	11/26/08	19/19	7
	12/13	6	12/02/08	11/11	84
10/09/08	10/10	1	12/03/08	4/4	7
10/10/08	8/8	4	12/10/08	0.1/0.1	7
	30/39	7	12/16/08	10/10	28
10/14/08	9/9	1	12/17/08	0.1/0.1	10
	30/36	3	12/24/08	0.1/0.1	4
10/15/08	10/12	1	12/30/08	0.5/0.5	84
	76/76	7	12/31/08	0/0	7
10/16/08	9/9	1	01/07/09	0/0	7
10/17/08	9/9	3	01/13/09	9/9	28
10/20/08	9/9	1	01/14/09	0/0	7
10/21/08	6/6	1	01/21/09	0/0	7
	26/26	28	01/27/09	2/2	84
10/22/08	4/4	1	01/28/09	0/0	7
	45/45	7			

Source: Bank of England.

Table 4

Expected signs of determinants

	CDS (European)	CDS (US)	USD auction	Commitment 1 (30 Jul 08)	Commitment 2 (13 Oct 08)	Broad-OIS spread	Libor-OIS spread
	Level	Level	Level & Vol	Level	Level	Level	Level
Before Lehman	+	–	–		–	+	–
After Lehman	+	+	–	–		+	–

Table 5

Summary statistics

(1) Before Lehman failure

Sample: 9 August 2007 – 12 September 2008

	Mean	**Maximum**	**Minimum**	**Std. dev**	**Skewness**	**Kurtosis**
FX swap deviation (%)						
EUR/USD	0.171	0.446	-0.272	0.115	-0.344	3.060
CHF/USD	0.166	0.406	-0.290	0.123	-0.186	2.241
GBP/USD	0.138	0.481	-0.313	0.120	-0.232	3.252
Determinants of common factor (%)						
CDS (European)	0.703	1.610	0.205	0.288	0.670	3.404
CDS (US)	2.263	4.695	0.846	0.784	0.310	2.992
Broad-OIS spread	0.806	1.201	0.250	0.207	-0.384	2.232
Libor-OIS spread	0.690	1.635	0.243	0.142	-0.176	3.336

(2) After Lehman failure

Sample: 15 September 2008 – 30 January 2009

	Mean	**Maximum**	**Minimum**	**Std. dev**	**Skewness**	**Kurtosis**
FX swap deviation (%)						
EUR/USD	0.831	2.602	-0.093	0.511	0.734	3.246
CHF/USD	0.478	2.386	-0.512	0.609	0.798	3.617
GBP/USD	0.987	3.302	0.082	0.577	1.097	4.304
Determinants of common factor (%)						
CDS (European)	1.182	1.560	0.920	0.136	0.565	3.250
CDS (US)	5.079	8.542	3.571	1.064	1.247	4.377
Broad-OIS spread	2.679	4.826	1.234	1.059	0.583	2.244
Libor-OIS spread	1.803	3.644	0.893	0.738	0.819	2.812

Source: Federal Reserve; Bloomberg; JPMorgan.

Table 6

Principal component analysis

(1) Before Lehman failure
Sample: 9 August 2007 – 12 September 2008

	Factor loadings (correlations)	
	1st component	**2nd component**
FX swap deviation (EUR/USD)	0.597 (0.938)	-0.253 (-0.154)
FX swap deviation (CHF/USD)	0.551 (0.865)	0.819 (0.497)
FX swap deviation (GBP/USD)	0.582 (0.914)	-0.515 (-0.313)
Eigenvalues	2.465	0.368
Cumulative variance explained	0.822	0.944

(2) After Lehman failure
Sample: 15 September 2008 – 30 January 2009

	Factor loadings (correlations)	
	1st component	**2nd component**
FX swap deviation (EUR/USD)	0.594 (0.963)	-0.033 (-0.017)
FX swap deviation (CHF/USD)	0.570 (0.924)	-0.687 (-0.351)
FX swap deviation (GBP/USD)	0.567 (0.920)	0.726 (0.370)
Eigenvalues	2.623	0.261
Cumulative variance explained	0.876	0.963

Note: Principal component analysis is done based on the correlation matrix.

Table 7

Unit root test

(1) Before Lehman failure

Sample: 9 August 2007 – 12 September 2008

	Augmented Dickey-Fuller Test		**Phillips-Perron Test**	
	Level	1st difference	Level	1st difference
FX swap deviations				
EUR/USD	-4.392***	-19.578***	-4.251***	-22.786***
CHF/USD	-3.415**	-13.337***	-3.542***	-34.728***
GBP/USD	-3.018**	-15.799***	-3.763***	-21.888***
Principal component	-3.804***	-18.459***	-3.451***	-21.150***
Determinants of common factor				
CDS (European)	0.013	-16.742***	0.020	-16.741***
CDS (US)	0.409	-11.576***	0.586	-11.451***
Broad-OIS spread	-3.546***	-18.282***	-3.525***	-18.289***
Libor-OIS spread	-4.691***	-19.298***	-4.799***	-19.322***

(2) After Lehman failure

Sample: 15 September 2008 – 30 January 2009

	Augmented Dickey-Fuller Test		**Phillips-Perron Test**	
	Level	1st difference	Level	1st difference
FX swap deviations				
EUR/USD	-2.877*	-8.428***	-3.046**	-9.556***
CHF/USD	-1.767**	-9.210***	-2.035*	-14.875***
GBP/USD	-3.100**	-8.083***	-3.197**	-9.913***
Principal component	-3.218***	-8.781***	-2.767***	-11.061***
Determinants of common factor				
CDS (European)	-4.201***	-8.252***	-3.734***	-8.647***
CDS (US)	-2.057	-9.859***	-2.009	-9.931***
Broad-OIS spread	-0.544	-6.712***	-0.492	-6.713***
Libor-OIS spread	-0.473	-6.219***	-0.518	-6.313***

Note: Unit root test is done with a specification including a constant term. When the constant term is not significant at the 5% level, the test is redone without it.

Table 8

EGARCH analysis before Lehman failure

Sample: August 9, 2007-September 12, 2008

Mean equation

CDS (European)	2.912*** (0.283)	2.939*** (0.299)	2.920*** (0.300)	2.885*** (0.297)	2.680*** (0.303)
CDS (US)	-1.169*** (0.099)	-1.134*** (0.107)	-1.181*** (0.107)	-1.131*** (0.106)	-1.102*** (0.110)
USD auction (ECB 3)	0.144 (0.101)				
USD auction (ECB 4)		-0.052 (0.111)			
USD auction (SNB 3)			0.168* (0.089)		
USD auction (SNB 4)				0.080 (0.117)	
USD auction (ECB&SNB 3)					-0.059 (0.144)
Commitment 1	0.039 (0.078)	0.020 (0.081)	0.023 (0.083)	-0.001 (0.083)	0.052 (0.081)
Broad spread (USD)	10.678*** (0.515)	10.580*** (0.495)	10.841*** (0.513)	10.765*** (0.504)	10.908*** (0.513)
Libor-OIS (USD)	-9.684*** (0.795)	-9.733*** (0.299)	-9.982*** (0.801)	-9.968*** (0.787)	-10.223*** (0.809)
Constant	-1.085*** (0.236)	-1.047*** (0.229)	-0.988*** (0.236)	-1.009*** (0.229)	-0.890*** (0.238)
Variance equation					
α	-0.678*** (0.154)	-0.677*** (0.153)	-0.708*** (0.159)	-0.697*** (0.154)	-0.655*** (0.157)
β	0.770*** (0.053)	0.788*** (0.052)	0.761*** (0.059)	0.775*** (0.055)	0.794*** (0.056)
γ	-0.178** (0.009)	-0.193** (0.088)	-0.188** (0.093)	-0.204** (0.090)	-0.191** (0.087)
η	0.739*** (0.177)	0.690** (0.177)	0.737*** (0.177)	0.706*** (0.176)	0.676*** (0.180)
λ (USD auction ECB 3)	-0.854*** (0.236)				
λ (USD auction ECB 4)		-2.634*** (0.282)			
λ (USD auction SNB 3)			-0.615*** (0.257)		
λ (USD auction SNB 4)				-2.232*** (0.243)	
λ (USD auction ECB&SNB 3)					-1.057** (0.452)
Log likelihood	-342.6	-342.9	-343.9	-344.0	-344.7

Variance equation: $$\ln\left(\sigma_t^2\right)=\alpha+\beta\ln\left(\sigma_{t-1}^2\right)+\gamma\,\varepsilon_{t-1}/\sigma_{t-1}+\eta\left(\left|\varepsilon_{t-1}/\sigma_{t-1}\right|-\sqrt{2/\pi}\right)+\lambda \text{USD auction}_t$$

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ***, ** and * denote the 1%, 5%, and 10% significance level, respectively.

Table 9

EGARCH analysis after Lehman failure (1)

Sample: September 15, 2008 – January 30, 2009

Mean equation

CDS (European)	1.014*** (0.186)	3.705*** (0.493)	1.569*** (0.205)	0.698*** (0.178)	2.680*** (0.303)
CDS (US)	0.104** (0.053)	-0.043 (0.112)	0.207*** (0.046)	0.248*** (0.037)	
USD auction (ECB 1)	0.132*** (0.040)				
USD auction (ECB 2)		-0.301*** (0.057)			
USD auction (ECB 3)			-0.249*** (0.034)		
USD auction (ECB 4)				-0.247*** (0.024)	-0.059 (0.144)
Commitment 2	-1.019*** (0.072)	-1.108*** (0.087)	-0.959*** (0.084)	-1.166*** (0.045)	0.052 (0.081)
Broad-OIS spread	1.322*** (0.080)	1.410*** (0.091)	1.390*** (0.069)	1.205*** (0.063)	10.908*** (0.513)
Libor-OIS spread	-0.973*** (0.092)	-0.628*** (0.148)	-1.234*** (0.085)	-1.090*** (0.077)	-10.223*** (0.809)
Constant	-3.091*** (0.181)	-5.992*** (0.423)	-3.985*** (0.235)	-2.762*** (0.190)	-0.890*** (0.238)

Variance equation

$$\ln\left(\sigma_t^2\right) = \alpha + \beta \ln\left(\sigma_{t-1}^2\right) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\left|\varepsilon_{t-1}/\sigma_{t-1}\right| - \sqrt{2/\pi}\right) + \lambda \text{USD auction}_t$$

α	-2.184*** (0.206)	-1.611*** (0.173)	-1.794*** (0.127)	-2.185*** (0.151)	-0.655*** (0.157)
β	0.742*** (0.065)	0.799*** (0.062)	0.770*** (0.063)	0.825*** (0.063)	0.794*** (0.056)
γ	0.269 (0.171)	0.156 (0.208)	0.321* (0.175)	0.274 (0.205)	-0.191** (0.087)
η	2.217*** (0.220)	1.748*** (0.205)	2.041*** (0.178)	2.477*** (0.249)	
λ (USD auction ECB 1)	0.266 (0.194)				
λ (USD auction ECB 2)		0.283 (0.275)			
λ (USD auction ECB 3)			-1.182*** (0.289)		
λ (USD auction ECB 4)				-1.299*** (0.354)	-1.057** (0.452)
Log likelihood	-119.0	-124.3	-117.6	-116.9	-344.7

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ***, ** and * denote the 1%, 5%, and 10% significance level, respectively.

Table 10

EGARCH analysis after Lehman failure (2)

Sample: September 15, 2008-January 30, 2009

		Mean equation			
CDS (European)	1.067*** (0.193)	1.471*** (0.193)	1.465*** (0.218)	1.128*** (0.180)	2.680*** (0.303)
CDS (US)	0.083* (0.047)	0.237*** (0.040)	0.165*** (0.049)	0.140*** (0.048)	
USD auction (SNB 1)	0.081* (0.043)				
USD auction (SNB 2)		0.021 (0.040)			
USD auction (SNB 3)			-0.178*** (0.032)		
USD auction (SNB 4)				-0.218*** (0.020)	-0.059 (0.144)
Commitment 2	-1.042*** (0.065)	-1.031*** (0.102)	-1.130*** (0.117)	-1.220*** (0.056)	0.052 (0.081)
Broad-OIS spread	1.448*** (0.100)	1.309*** (0.075)	1.312*** (0.087)	1.201*** (0.070)	10.908*** (0.513)
Libor-OIS spread	-1.165*** (0.099)	-1.188*** (0.088)	-1.100*** (0.113)	-0.960*** (0.083)	-10.223*** (0.809)
Constant	-3.016*** (0.185)	-3.934*** (0.223)	-3.586*** (0.283)	-2.906*** (0.224)	-0.890*** (0.238)
		Variance equation $\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert - \sqrt{2/\pi}\right) + \lambda \text{USD auction}_t$			
α	-2.069*** (0.206)	-1.864*** (0.157)	-1.646*** (0.139)	-2.141*** (0.169)	-0.655*** (0.157)
β	0.706*** (0.069)	0.773*** (0.088)	0.737*** (0.071)	0.838*** (0.054)	0.794*** (0.056)
γ	0.198 (0.193)	0.253 (0.196)	0.246 (0.158)	0.315* (0.183)	-0.191** (0.087)
η	2.081*** (0.213)	1.962*** (0.164)	1.867*** (0.177)	2.361*** (0.242)	
λ (USD auction SNB 1)	0.293 (0.209)				
λ (USD auction SNB 2)		0.223 (0.247)			
λ (USD auction SNB 3)			-0.951*** (0.322)		
λ (USD auction SNB 4)				0.439 (0.376)	-1.057** (0.452)
Log likelihood	-119.9	-123.0	-119.8	-118.6	-344.7

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ***, ** and * denote the 1%, 5%, and 10% significance level, respectively.

Table 11

EGARCH analysis after Lehman failure (3)

Sample: September 15, 2008-January 30, 2009

Mean equation

CDS (European)	1.249*** (0.182)	1.346*** (0.179)	1.488*** (0.234)	0.581*** (0.152)	2.680*** (0.303)
CDS (US)	0.244*** (0.044)	0.180*** (0.035)	0.193*** (0.062)	0.283*** (0.032)	
USD auction (BOE 1)	0.087*** (0.026)				
USD auction (BOE 2)		-0.031 (0.038)			
USD auction (BOE 3)			-0.192*** (0.033)		
USD auction (BOE 4)				-0.241*** (0.022)	-0.059 (0.144)
Commitment 2	-1.166*** (0.090)	-1.093*** (0.081)	-1.050*** (0.105)	-1.166*** (0.038)	0.052 (0.081)
Broad-OIS spread	1.207*** (0.077)	1.288*** (0.066)	1.287*** (0.090)	1.158*** (0.052)	10.908*** (0.513)
Libor-OIS spread	-1.150*** (0.079)	-1.104*** (0.092)	-1.094*** (0.096)	-1.049*** (0.064)	-10.223*** (0.809)
Constant	-3.477*** (0.198)	-3.499*** (0.226)	-3.758*** (0.274)	-2.747*** (0.163)	-0.890*** (0.238)

Variance equation

$$\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\left|\varepsilon_{t-1}/\sigma_{t-1}\right| - \sqrt{2/\pi}\right) + \lambda \text{USD auction}_t$$

α	-2.300*** (0.189)	-2.066*** (0.195)	-1.705*** (0.136)	-2.314*** (0.133)	-0.655*** (0.157)
β	0.820*** (0.052)	0.727*** (0.069)	0.768*** (0.063)	0.821*** (0.057)	0.794*** (0.056)
γ	0.300** (0.153)	0.339 (0.215)	0.318** (0.161)	0.237 (0.194)	-0.191** (0.087)
η	2.189*** (0.199)	2.070*** (0.201)	1.890*** (0.181)	2.600*** (0.219)	
λ (USD auction BOE 1)	0.477** (0.196)				
λ (USD auction BOE 2)		0.499** (0.243)			
λ (USD auction BOE 3)			-1.056*** (0.325)		
λ (USD auction BOE 4)				-1.174*** (0.351)	-1.057** (0.452)
Log likelihood	-120.5	-121.4	-118.7	-117.0	-344.7

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ***, ** and * denote the 1%, 5%, and 10% significance level, respectively.

Table 12

EGARCH analysis after Lehman failure (4)

Sample: September 15, 2008-January 30, 2009

Mean equation

CDS (European)	1.020*** (0.237)	1.164*** (0.216)	1.345*** (0.218)	1.336*** (0.199)	2.680*** (0.303)
CDS (US)	0.247*** (0.055)	0.226*** (0.043)	0.313*** (0.057)	0.235*** (0.050)	
USD auction (ECB&SNB&BOE 1)	0.028 (0.037)				
USD auction (ECB&SNB&BOE 2)		-0.037 (0.041)			
USD auction (ECB&SNB&BOE 3)			-0.227*** (0.046)		
USD auction (ECB&SNB&BOE 4)				-0.236*** (0.036)	-0.059 (0.144)
Commitment 2	-1.145*** (0.109)	-1.170*** (0.093)	-0.924*** (0.105)	-0.966*** (0.081)	0.052 (0.081)
Broad-OIS spread	1.261*** (0.095)	1.237*** (0.086)	1.360*** (0.077)	1.356*** (0.067)	10.908*** (0.513)
Libor-OIS spread	-1.161*** (0.103)	-1.120*** (0.103)	-1.353*** (0.109)	-1.221*** (0.081)	-10.223*** (0.809)
Constant	-3.283*** (0.240)	-3.301*** (0.239)	-3.981*** (0.284)	-3.791*** (0.219)	-0.890*** (0.238)

Variance equation

$$\ln\left(\sigma_t^2\right) = \alpha + \beta \ln\left(\sigma_{t-1}^2\right) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta\left(\left|\varepsilon_{t-1}/\sigma_{t-1}\right| - \sqrt{2/\pi}\right) + \lambda \text{USD auction}_t$$

α	-1.994*** (0.156)	-1.884*** (0.185)	-1.697*** (0.135)	-1.936*** (0.152)	-0.655*** (0.157)
β	0.737*** (0.092)	0.758*** (0.076)	0.762*** (0.062)	0.754*** (0.069)	0.794*** (0.056)
γ	0.264 (0.192)	0.291 (0.209)	0.355** (0.179)	0.386** (0.192)	-0.191** (0.087)
η	1.926*** (0.182)	1.958*** (0.193)	1.910*** (0.180)	2.121*** (0.214)	
λ (USD auction ECB&SNB&BOE 1)	0.465** (0.226)				
λ (USD auction ECB&SNB&BOE 2)		0.337 (0.273)			
λ (USD auction ECB&SNB&BOE 3)			-1.162*** (0.328)		
λ (USD auction ECB&SNB 4&BOE 4)				-1.165*** (0.460)	-1.057** (0.452)
Log likelihood	-121.3	-121.9	-119.7	-120.1	-344.7

Note: Numbers in parentheses are Bollerslev-Wooldrige robust standard errors. ***, ** and * denote the 1%, 5%, and 10% significance level, respectively.