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Dislocations in the won-dollar swap markets during the crisis of 2007–09

Naohiko Baba and Ilhyock Shim[1]

Abstract

Foreign exchange (FX) derivatives markets in the Korean won are comparatively thin and vulnerable to impaired functioning. During the crisis, Korea faced dislocations in its FX swap and cross-currency swap markets, so severe that covered interest parity (CIP) between the Korean won and the US dollar was seriously violated. Using a variation of the EGARCH model, we find that global market uncertainty – as proxied by VIX, the volatility index – was the main factor explaining the movement of deviations from CIP in the three-month FX swap market during the crisis period. The credit risk of Korean banks – as proxied by their credit default swap spread – was also a significant factor explaining deviations from CIP in the three-year cross-currency swap market before the crisis, while the credit risk of US banks was significant during the crisis period. The Bank of Korea's provision of funds using its own foreign reserves was not effective in reducing deviations from CIP, but the Bank of Korea's loans of the US dollar proceeds of swaps with the US Federal Reserve were effective. This is because the loans funded by swaps with the US Federal Reserve effectively added to Korea's foreign reserves and enhanced market confidence.

Keywords: FX swap, cross-currency swap, regime switching, EGARCH model, foreign reserves.

JEL classification: G12, G13, G18.

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Dislocations in the won-dollar swap markets during the crisis of 2007–09

1. Introduction

During the 2007–09 international financial crisis, many countries experienced dislocations in their foreign exchange (FX) swap markets and cross-currency swap markets.[2] When foreign banks' lending to these countries contracted sharply around the fourth quarter of 2008, domestic banks faced difficulties in borrowing in the interbank market as well as much higher costs in obtaining short-term dollar (or euro/Swiss franc in Central Eastern Europe) financing through FX swaps.[3] In particular, many banking systems experienced an abrupt drop in gross international claims, which are the sum of cross-border claims in all currencies and local claims in foreign currencies of international banks.[4] To ameliorate the dislocations in their FX swap and cross-currency swap markets, central banks in Western Europe (Denmark, Sweden, Switzerland, the United Kingdom, and the euro area (for the European Central Bank)), North America (Canada), Asia (India, Japan, Korea and Singapore), Latin America (Brazil, Chile and Mexico), Central and Eastern Europe (Poland and Hungary) and the Pacific (Australia and New Zealand) either used their own foreign reserves or established swap lines with the US Federal Reserve (Fed) or other central banks.

Like many other emerging market economies, Korea relies heavily on US dollar funding through foreign banks and investors, but it does not have deep FX swap and cross-currency swap markets. This turned out to be a major vulnerability during the recent financial crisis, as Korea experienced the most severe dislocations in the FX swap market of any emerging market economy. In response, the Korean authorities took several measures to stabilise their foreign currency funding market. In particular, they drew on Korea's swap line with the Fed and used the country's own foreign reserves to provide foreign currency liquidity to the private sector. Korea's experience thus provides useful lessons on the effectiveness of these two different policies in mitigating foreign currency funding problems.

In this paper, we assess the determinants of deviations from covered interest parity (CIP deviations) in the won-dollar swap markets between January 2005 and December 2009. We are especially interested in whether the aforementioned two policies adopted during the recent crisis were effective in alleviating the CIP deviations. To lay the ground for this analysis, we identify exactly when the won-dollar FX swap market entered into the crisis regime (that is, when CIP conditions collapsed).

Using a regime-switching regression model, we first find that the crisis period in the Korean FX swap market started in early June 2007, which is earlier than the more widely used starting date of the recent crisis, in early August 2007. We view this as mainly because the

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[2] In an FX swap, two parties exchange a set amount in two currencies for the tenor of the contract (which is usually short term). This is equivalent to the combination of an FX spot transaction with an FX forward transaction in the reverse direction. In a cross-currency (basis) swap, one party borrows one currency from another party and simultaneously lends the same value, at current spot rates, of a second currency to that party. Though the structure of cross-currency swaps differs from that of FX swaps, the former basically serve the same economic purpose as the latter, except for the exchange of floating rates during the contract term.

[3] CGFS (2010) provides an overview of global US dollar shortages during the recent crisis.

[4] McGuire and von Peter (2009) use the BIS international banking statistics to identify cross-currency and counterparty funding patterns for the largest banking systems, and to assess the causes of the US dollar shortage during the critical phases of the recent crisis. Their documentation of cross-border banking flows is consistent with the FX swap market dislocations during the crisis period.

Korean authorities began to request that foreign banks in Korea slow down their short-term foreign currency borrowing in early 2007. Combined with an increasing demand for US dollars by Korean exporting companies around that time, this further exacerbated the imbalance of demand and supply in the FX swap market.

Based on the identified starting date of the crisis, we perform a regression analysis using an EGARCH(-in-mean) model for CIP deviations in both the three-month FX swap market and the three-year cross-currency swap market. We consider variables representing global market uncertainty, the counterparty risk of banks and tensions in interbank markets as potential determinants of CIP deviations. We find that during the pre-crisis period, none of these variables had a significant effect on CIP deviations in the three-month won-dollar FX swap market, which implies that the positive and persistent CIP deviations in this market were likely to be driven by transaction costs and structural demand-supply factors not included in the regression. By contrast, we find that during the crisis period, general market uncertainty – as proxied by the Chicago Mercantile Exchange Volatility Index (VIX) – played a significant role in explaining changes in CIP deviations.

Regarding CIP deviations in the three-year cross-currency swap market, we find that during the pre-crisis period, the credit risk of Korean banks – as measured by their CDS spreads – had a significantly positive impact on their level. We believe this is because longer-maturity cross-currency swaps are more sensitive to the credit risk of Korean banks during normal times than shorter-maturity FX swaps. During the crisis period, we find that the credit risk of US banks – as measured by their CDS spreads – had a significant role. This is consistent with the view that US banks suffering from heightened credit risk during the crisis period contributed to widening CIP deviations.

As for the effectiveness of policy responses in reducing CIP deviations in the three-month FX swap market, we find that the Bank of Korea (BOK)'s US dollar loans of the proceeds of swaps with the Fed were effective, whereas the use of the BOK's own foreign reserves was not. Our model does not tell us exactly why this was the case. However, we believe that a major reason was that the BOK's loan auctions funded by the Fed swap line effectively added to Korea's foreign reserves. During the crisis period, Korea's foreign reserves were just enough to cover its short-term foreign currency debt. Providing dollar liquidity from official reserves reduced this coverage. Auctioning off the proceeds from the swap line with the Fed, by contrast, did not result in a reduction of reserves, enhancing market confidence.

In order to assess the importance of foreign reserves and excess demand for US dollars in the FX forward market in explaining CIP deviations in the three-month FX swap market, we examine the monthly data on Korea's foreign reserves adjusted by the outstanding amount of short-term external debt (available foreign reserves), and the net sale of FX forward contracts by Korean companies. We find that, during the pre-crisis period, the net sale of FX forward contracts is strongly correlated with CIP deviations, whereas, during the crisis period, it is available foreign reserves that are strongly correlated. This result suggests that foreign reserves and structural excess demand for US dollars in the FX forward market were also important factors in the determination of CIP deviations in the Korean FX swap market.

In contrast to the three-month FX swap market, we find insignificant effects of policy measures on CIP deviations in the three-year cross-currency swap market. We view this as because most policy measures aimed at alleviating distortions in short-term funding markets.

Section 2 provides a literature review. Section 3 describes dislocations in the won–dollar swap markets during the recent crisis, and summarises policy measures taken by the Korean authorities. In Section 4, we identify the starting date of the crisis from an analysis of the time series of CIP deviations. In Section 5, we analyse the determinants of CIP deviations in the three-month FX swap market and the three-year cross-currency swap market, and investigate the effectiveness of the two main types of policy measures in ameliorating dislocations in these markets. In Section 6, we perform a robustness check and discuss two other factors explaining the movements of CIP deviations. The last section concludes.

2. Literature review

To investigate the determinants of CIP deviations in the won-dollar swap markets and measure the policy effects, this paper draws on the literature on swap market dislocations as well as the literature on methods of assessing policy effectiveness. We also use a regime-switching model to find out when the won-dollar swap markets entered into a crisis state.

Most recent work on dislocations in FX swap and cross-currency swap markets has focused on major currency pairs. By contrast, not much work has been done on emerging market currencies. Baba et al (2008) document the existence of contagion from money market turmoil to swap markets in developed country currency pairs such as US dollar vs euro, sterling and yen. Their evidence suggests that the turmoil in the money market from the summer of 2007 first spilled over to the short-term FX swap market in early August 2007, and then spread further to the longer-term cross-currency swap market by early September. Coffey et al (2009) find that during the crisis period from August 2007 to the Lehman failure, proxies for margin conditions and the cost of capital[5] are significantly correlated with three-month CIP deviations in major currency pairs. They show that, after the bankruptcy of Lehman Brothers, uncertainty about counterparty risk became a significant determinant of deviations from CIP.

Relatively little work has been done on CIP deviations associated with emerging market currencies. Baba and McCauley (2009) document FX swap market dislocations in both advanced and emerging market economies and the policy responses. Several central banks of emerging market economies have also documented CIP deviations in their own currency against the US dollar or euro/Swiss franc (for example, Mak and Pales (2009)).

Several papers, mostly written by researchers at the BOK, investigate CIP deviations in the won-dollar swap markets. Kim et al (2009) provide an overview of the linkage between Korea's external debt, FX forward and swap markets and domestic bond markets. Yang and Lee (2008) show how a structural demand-supply imbalance existed in the FX forward market due to massive selling of FX forwards by Korean shipbuilders, heavy industry companies and Korean investors in foreign stocks. Hwang (2010) considers, as the determinants of CIP deviations, the demand-supply imbalance in the FX forward market and measures of inefficiency in the FX forward market, as well as transaction costs and risk premia. Using quarterly data from 2000 to 2009, he finds that the one-year CIP deviation is larger when the demand-supply imbalance is larger and market efficiency is lower. Yu (2010) analyses CIP deviations in the one-year won-dollar FX swap market from 2005 to 2009. He considers the following three variables to explain CIP deviations: (i) Korean sovereign CDS premium as a proxy for the level of Korea's credit risk, (ii) US TED spread as a proxy for credit and liquidity risks in international financial markets, and (iii) the implied volatility of at-the-money foreign exchange options as a proxy for counterparty risk in the Korean FX swap market. He finds that the Korean sovereign CDS premium is a significant factor in explaining the movement of CIP deviations only during the normal period, while the TED spread and implied volatility are significant factors in both the normal period and the crisis period.

We analyse CIP deviations in the won-dollar swap markets using a fully dynamic GARCH model and also investigate the effectiveness of policy measures taken during the recent crisis. Baba and Shim (2010) examine the policy measures taken to ameliorate dislocations in the three-month won-dollar FX swap market and show that the BOK's use of the Fed swap line was very effective in alleviating dislocations in the won-dollar FX swap market, whereas

[5] Margin conditions are proxied by the spread between the repo rate using agency mortgage-backed securities as collateral (MBS repo) and the repo rate using Treasury securities as collateral (GC repo). The cost of capital is proxied by the spread between Libor and the Treasury bill rate (TED spread).

the provision of funds using its own foreign reserves was not. Our paper is different from Baba and Shim (2010) in that we first identify the starting date of the crisis period using a regime-switching model for CIP deviations, and then consider the determinants of CIP deviations and policy effects in both the three-month FX swap market and the three-year cross-currency swap market. We also conduct a first-pass analysis on the relationship between the CIP deviations and two other factors: available foreign reserves of Korea and the net sale of FX forwards by Korean companies.

A few papers focus on the structural problem of the FX funding market in Korea. According to Kim (2009), foreign bank branches have a monopoly status in supplying US dollar funds to Korean banks. As a result, foreign bank branches were able to enjoy persistent arbitrage profits. Lee (2010) points out that the systemic importance of foreign bank branches and the systemic vulnerability of domestic banks to funding liquidity risk simultaneously increased as Korean domestic banks relied heavily on FX swap transactions with foreign bank branches to raise foreign currency funding until 2008.

Many researchers, including those at the Federal Reserve Bank of New York, have developed a variety of methods to assess the effectiveness of the Fed's policy measures during the recent crisis (for example, Gagnon et al (2010), In et al (2008), Taylor and Williams (2009) and Wu (2008)). In our paper, we closely follow the approach of McAndrews et al (2008), who investigate whether the announcements and operations of the Fed's Term Auction Facility (TAF) are associated with a downward shift in London interbank offered rate (Libor). Such an association is consistent with the TAF's efficacy in mitigating liquidity problems in the interbank funding market. In our paper, we look at the cumulative effects of the BOK's dollar-supplying auctions on the downward shift in CIP deviations.

Several papers specifically analyse the policy effects on CIP deviations in major currency pairs. Baba and Packer (2009b) assess the effectiveness of dollar swap lines established by the Fed and other central banks in ameliorating distortions in FX swap markets. They find that US dollar term funding auctions by the European Central Bank, Swiss National Bank and the Bank of England, as well as the Fed's commitment to provide unlimited US dollar swap lines in October 2008, significantly ameliorated dislocations in the FX swap markets. In terms of the policy effects of the swap lines programme, Coffey et al (2009) find that announcement days are associated with a reduction in the CIP deviation by an average of five basis points, and that the actual auctions were effective in bringing down the CIP deviations on the days of operations. Moreover, the announcement on 13 October 2008 that the swap lines would become unlimited reduced CIP deviations by more than 50 basis points in a single day.

Finally, to identify the starting date of crisis or turmoil in CIP deviations, this paper closely follows the method used in Baba and Sakurai (2011) and identifies the dates of regime switches in the time series of CIP deviations. Along similar lines, González-Hermosillo and Hesse (2009) use a Markov regime-switching technique with three different volatility states (low, medium and high), and show that the euro-dollar FX swap market entered the high volatility state immediately after the collapse of Lehman Brothers in September 2008.

3. Won-dollar swap market dislocations in Korea

In this section, we start by explaining why persistent CIP deviations existed in the FX swap market and the cross-currency swap market in Korea even before the onset of the recent crisis. We then describe the problems faced by Korean banks in obtaining foreign currency funding during the crisis and how they showed up in the won-dollar swap markets. In the next subsection, we summarise policy measures taken by the Korean authorities to mitigate these dislocations during the crisis.

3.1 CIP deviations in the won-dollar FX swap and cross-currency swap markets

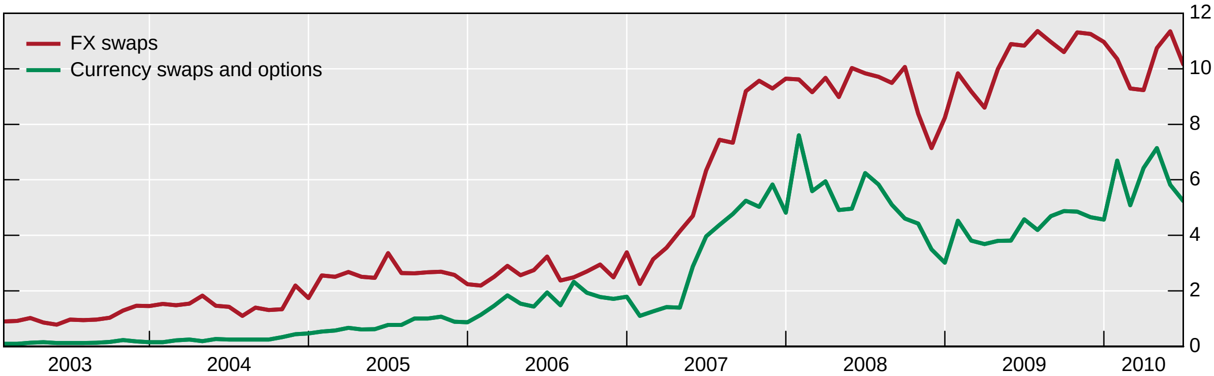
Before we look into Korea-specific circumstances in the swap markets, it is important to point out that, relatively speaking, the short-term FX swap market is best characterised as a funding market, while the long-term cross-currency swap market is best characterised as a bond portfolio investment (or bond arbitrage) market. Thus, the types of participants in these two markets and their motives for trading can be quite different. We look into CIP deviations both in the FX swap market and in the cross-currency swap market.

In Korea, the turnover of the FX swap market is much larger than that of the cross-currency swap market, as shown in the annual data from the BOK cited in Yu (2010). Figure 1 shows the monthly series of the daily transaction volume of won-dollar FX swaps and won-dollar cross-currency swaps and options[6] since 2003. It shows that transaction volumes surged during 2007, mainly because of sharp increases in the orders received by Korean shipbuilders and foreign investment in Korean bonds. Foreign bank branches in Korea and, to a lesser degree, foreign investors such as hedge funds are major players as suppliers of US dollars in both the FX swap market and the cross-currency swap market.

Figure 1

Daily transaction volume of FX swaps and cross-currency swaps and options in Korea

Monthly average; in billions of US dollars



Source: Bank of Korea.

From 2006 to 2007, exporting firms such as the Korean shipbuilders, as well as Korean investors in foreign stocks, sold a large amount of US dollar forwards to domestic banks to hedge their currency exposures (McCauley and Zukunft (2008)). Korean banks sold these US dollar forwards to, and at the same time borrowed US dollars from, Korean branches of foreign banks, in order to hedge currency risk. The Korean branches of foreign banks, in turn, invested the won they had acquired from these FX swap transactions in short-maturity Korean government and BOK paper. The absence of natural buyers of FX forward exposures pushed up the US dollar/Korean won FX forward rate, which drove the forward discount rate above the interest rate differential between the United States and Korea.[7] In effect, US dollars traded at a premium yield in the won-dollar FX swap market, given the strong demand

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6 There is no monthly data available only for currency swaps.

7 The forward discount rate is defined as *ln*(US dollar/Korean won forward rate) minus *ln*(US dollar/Korean won spot rate). The interest rate differential is defined as three-month US dollar Libor minus 91-day Korean won certificate of deposit rate. The CIP deviation is defined as the forward discount rate minus the interest rate differential.

to borrow them. This explains the persistent deviation from CIP in the one- to six-month FX swap markets in Korea from 2006 to early 2007, as shown in Figure 2.

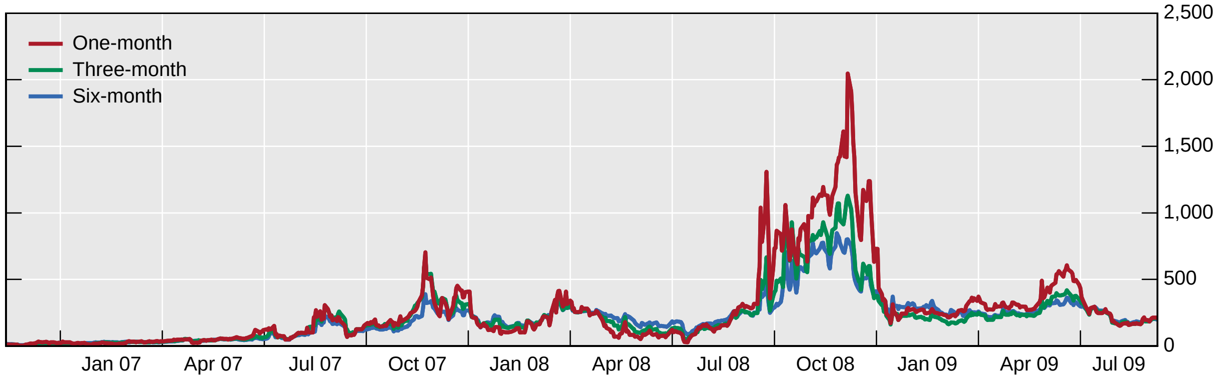
During the same period, arbitrage opportunities were also present in the long-term bond market, as we show in Figure 3. Through the cross-currency swap contracts, foreign banks and foreign investors were able to purchase long-term government bonds and BOK bills, while enjoying arbitrage profits.

CIP deviations widened sharply after the middle of 2007 in both the FX swap and cross-currency swap markets. The interest rate differential turned negative as the Fed cut policy rates by a total of 325 basis points between September 2007 and April 2008, while the BOK held its policy rate at 5%. At the same time, the structurally strong demand for US dollars in the Korean FX forward market and the increasing difficulties experienced by global banks in supplying dollar funding to Korea for more than the shortest periods increased the FX forward rate and, in turn, the forward discount rate, as well as the basis spread. The Korean branches of foreign banks did not take advantage of the enlarged arbitrage opportunities, but began to cut their investments in Korean bonds as funding from their headquarters dried up. Other foreign investors such as hedge funds only partly took their place, as shown by Yang and Lee (2008).

Figure 2

CIP deviations in the won-dollar FX swap market

In basis points

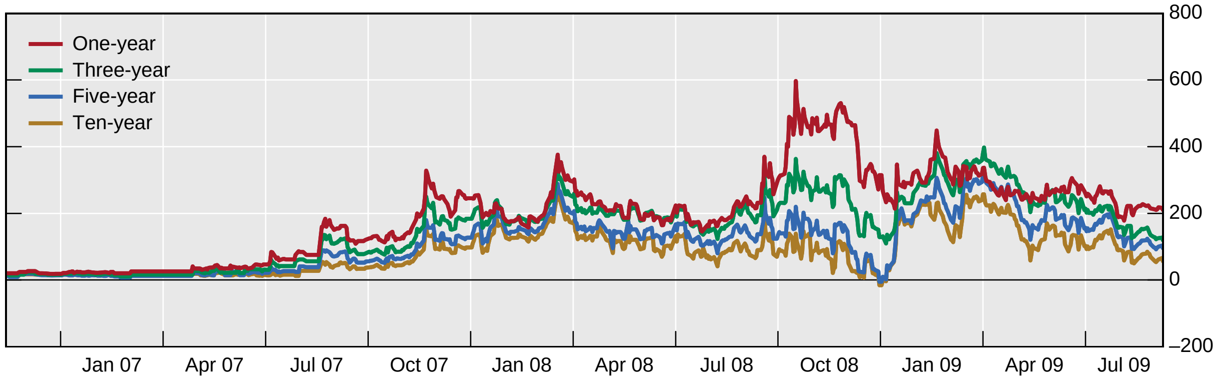


Sources: Datastream; authors' calculations.

Figure 3

CIP deviations in the won-dollar cross-currency swap market

In basis points



Sources: Bloomberg; authors' calculations.

After the failure of Bear Stearns in mid-March 2008, both the FX swap market and cross-currency swap market exhibited severe tensions, as shown by the spikes in the CIP deviations in Figures 2 and 3. However, the market tensions subsequently eased slightly, reflecting the active policy measures taken by major central banks.

Following the bankruptcy of Lehman Brothers in mid-September 2008, the cost of borrowing US dollars by swapping Korean won skyrocketed. Korean banks were now completely shut off from the international market for US dollar funding, and the already strained FX swap market took on the whole burden of supplying US dollars. International banks, deleveraging on a worldwide scale, sharply reduced their exposures to Korea. UK and euro area banks in particular repatriated their large dollar positions.

It should be noted here that the CIP deviations in the short-term FX swap markets reached their peak around December 2008 and then started to decline, partly due to drastic policy responses by the Korean authorities. By contrast, the CIP deviations in the three- to seven-year cross-currency swap markets reached their peak in early April 2009, while the CIP deviation in the 10-year cross-currency market reached its peak after the failure of Bear Stearns in March 2008. Also, Figures 2 and 3 show that the longer the maturity of the FX swap and cross-currency swap markets, the smaller the size of CIP deviations. This is partly because the market participants did not expect the market turmoil to last very long. This confirms that the main problem in the Korean swap markets was more in the short-term funding market than in the long-term investment market.[8]

3.2. Policy responses to dislocations in the won-dollar swap markets

From 2006 onwards, the Korean authorities became worried about the won's appreciation, which was driven partly by the rapid increase in short-term foreign currency borrowing by foreign banks. They therefore announced a set of policy measures to promote domestic banks' investment in foreign securities and reduce short-term borrowing in foreign currency (Table 1). These measures seem to have widened the demand-supply imbalance in the swap markets, contributing to a modest widening of CIP deviations in the first half of 2007.

From the second half of 2007, however, the won-dollar FX swap and cross-currency swap markets started to show signs of greater tension, as deviations from CIP suggested excess demand for US dollars in these markets. In September 2007, the BOK for the first time intervened in the FX swap market by swapping US dollars for Korean won with selected banks. After this intervention, the FX swap market stabilised temporarily, but stress flared up again towards the end of the year. In early 2008, the BOK reacted by partially loosening restrictions on the use of foreign currency loans.

Immediately after the Lehman bankruptcy in September 2008, the Korean Ministry of Strategy and Finance (MOSF) used its foreign reserves to provide US dollar liquidity to small- and medium-sized exporting enterprises and banks. It also guaranteed the external debt issued by Korean banks to enable them to raise funding abroad. The BOK set up a swap auction facility in October 2008 and conducted competitive auctions, swapping its own foreign reserves for won to provide up to $10.27 billion funding to Korean banks. It also entered into a $30 billion swap arrangement with the Fed on 30 October 2008 and conducted competitive US dollar loan auctions using the dollar proceeds of swap transactions with the Fed to provide up to $16.35 billion over the course of a year starting from December 2008. Tables 2 and 3 show the details of US dollar funds auctioned out by the BOK.

[8] It should also be noted that in the Korean FX swap market, transactions were active in the maturity of three months and six months, while in the cross-currency swap market, transactions were active in the one-year and three-year maturities. Transactions on five- to 10-year maturities were not very active due to lack of eligible bonds.

Table 1

Major policy measures taken in Korea to stabilise foreign currency funding markets

Announcement date	Description	Anticipated impact on CIP deviations
15 Dec 2006	From 1 January 2007, the BOK can provide foreign currency loans to domestic banks through currency swap arrangements.	(–)
19 Apr 2007	The Financial Supervisory Service requests 36 foreign banks operating in Korea to slow down short-term foreign currency borrowing.	(+)
12 Jul 2007	The MOSF announces a plan to regulate short-term foreign currency borrowing by lowering the ceiling for tax deductibility of interest expenditure resulting from the borrowing of foreign bank branches from their headquarters, from six times their capital to three times, starting from 1 January 2008.	(+)
10 Aug 2007	The BOK limits foreign currency lending to actual uses overseas by end-users and domestic facilities investment funds for manufacturers.	(+)
11 Sep 2007	The BOK intervenes in the FX swap market for the first time to provide dollars.	(–)
28 Jan 2008	The BOK allows foreign currency lending for domestic facilities investment funds for non-manufacturers.	(–)
14 Jul 2008	The MOSF announces that the tax deductibility ceiling for foreign bank branches will be raised back to its previous level, effective for 2008 business year.	(–)
26 Sep 2008	The MOSF announces a plan to provide the private sector with at least $10 billion by early October.	(–)
17 Oct 2008	The BOK announces a plan to introduce a competitive swap auction facility and to provide banks with $10 billion using the official foreign reserves.	(–)
19 Oct 2008	The MOSF announces a plan to provide foreign currency debt issuance guarantee, and additional $20 billion using the official foreign reserves.	(–)
27 Oct 2008	The BOK allows foreign currency borrowing by domestic exporters for payment of knock-in-knock-out and other currency option transactions.	(–)
30 Oct 2008	The BOK and MOSF announce opening swap lines with the Fed.	(–)
13 Nov 2008	The BOK announces a plan to introduce foreign currency loans secured by export-bills purchased.	(–)
27 Nov 2008	The BOK announces a plan to conduct competitive US dollar loan facility auctions using the proceeds of swap transactions with the Fed.	(–)
1 Dec 2008	The BOK abolishes restrictions on the rollover of foreign currency lending for use as working capital procured before 10 Aug 2007.	(–)
12 Dec 2008	The BOK announces opening swap lines with the People's Bank of China and expanding the existing bilateral swap lines with the Bank of Japan.	(–)

26 Feb 2009	The MOSF announces the removal of withholding tax on bond interest income of non-residents, other tax benefits and relaxation of restrictions on foreign currency deposits by non-residents and foreign currency borrowing by residents.	(–)

Sources: Bank of Korea (BOK); Ministry of Strategy and Finance (MOSF); Financial Supervisory Service.

The tensions in the US dollar funding market peaked in early December 2008, when the BOK started conducting competitive US dollar loan auctions using the dollar proceeds of swap transactions with the Fed. From then on, the difficulty of Korean banks in securing US dollar funds eased quickly. Starting from January 2009, the BOK started to gradually withdraw the funds provided by the swap auctions. The BOK had completely withdrawn funds provided by this type of swap auction by August 2009. From March 2009, the BOK also began to withdraw the funds provided by the loan auctions. By December 2009, all US dollar funds provided by the BOK via this type of loan auction had been withdrawn.

Table 2

List of auctions using the Bank of Korea swap facility funded by foreign reserves

ID	Auction date	Maturity	Total USD amount offered	Total USD amount demanded	Total USD amount allocated	Total USD balance	Note
08 1st	08.10.21	3-month	2.5 bn	2.32 bn	1.52 bn	1.52 bn	First auction
08 2nd	08.10.28	3-month	1.5 bn	2.0 bn	1.2 bn	2.72 bn	
		1-week	1.0 bn	0.4 bn	0.0 bn	2.72 bn	No allocation
08 3rd	08.11.04	3-month	2.0 bn	3.55 bn	2.0 bn	4.72 bn	
08 4th	08.11.11	3-month	2.0 bn	3.45 bn	2.0 bn	6.72 bn	
08 5th	08.11.18	3-month	2.0 bn	3.15 bn	2.0 bn	8.72 bn	
08 6th	08.11.25	3-month	1.5 bn	2.9 bn	1.5 bn	10.22 bn	
08 7th	08.12.16	3-month	1.0 bn	1.85 bn	0.05 bn	10.27 bn	
	09.01.20					8.75 bn	Withdraw 08 1st
	09.01.23					7.55 bn	Withdraw 08 2nd
09 1st	09.02.03	3-month	2.0 bn	3.9 bn	1.3 bn	6.85 bn	Re-auction 08 3rd Withdraw 0.7 bn
09 2nd	09.02.10	3-month	2.0 bn	4.19 bn	2.0 bn	6.85 bn	Re-auction 08 4th
09 3rd	09.02.17	3-month	2.0 bn	3.22 bn	2.0 bn	6.85 bn	Re-auction 08 5th
	09.02.24					5.35 bn	Withdraw 08 6th
	09.03.17					5.3 bn	Withdraw 08 7th
09 4th	09.05.04	3-month	1.3 bn	0.8 bn	0.6 bn	4.6 bn	Re-auction 09 1st Withdraw 0.7 bn
	09.05.12					2.6 bn	Withdraw 09 2nd
	09.05.19					0.6 bn	Withdraw 09 3rd
	09.08.04					0.0 bn	Withdraw 09 4th

Source: Bank of Korea.

Table 3

List of auctions using the Bank of Korea loan facility via the swap line with the Fed

ID	Auction date	Maturity	Total USD amount offered	Total USD amount demanded	Total USD amount allocated	Total USD balance	Note
08 1st	08.12.02	84 days	4.0 bn	7.81 bn	4.0 bn	4.0 bn	First auction
08 2nd	08.12.09	84 days	3.0 bn	4.6 bn	3.0 bn	7.0 bn	
08 3rd	08.12.22	86 days	4.0 bn	3.35 bn	3.35 bn	10.35 bn	
09 1st	09.01.13	84 days	3.0 bn	3.0 bn	3.0 bn	13.35 bn	
09 2nd	09.01.20	84 days	3.0 bn	3.55 bn	3.0 bn	16.35 bn	
09 3rd	09.02.24	84 days	4.0 bn	5.25 bn	4.0 bn	16.35 bn	Re-auction 08 1st
09 4th	09.03.03	84 days	3.0 bn	4.5 bn	3.0 bn	16.35 bn	Re-auction 08 2nd
09 5th	09.03.17	84 days	3.0 bn	4.2 bn	3.0 bn	16.00 bn	Re-auction 08 3rd Withdraw 0.35 bn
09 6th	09.04.07	84 days	2.0 bn	3.6 bn	2.0 bn	15.0 bn	Re-auction 09 1st Withdraw 1.0 bn
09 7th	09.04.14	84 days	2.0 bn	3.7 bn	2.0 bn	14.0 bn	Re-auction 09 2nd Withdraw 1.0 bn
09 8th	09.05.19	84 days	2.5 bn	3.36 bn	2.5 bn	12.5 bn	Re-auction 09 3rd Withdraw 1.5 bn
09 9th	09.05.26	84 days	1.5 bn	2.2 bn	1.5 bn	11.0 bn	Re-auction 09 4th Withdraw 1.5 bn
09 10th	09.06.09	84 days	2.0 bn	2.0 bn	2.0 bn	10.0 bn	Re-auction 09 5th Withdraw 1.0 bn
09 11th	09.06.30	84 days	1.0 bn	1.75 bn	1.0 bn	9.0 bn	Re-auction 09 6th Withdraw 1.0 bn
09 12th	09.07.07	84 days	1.0 bn	1.64 bn	1.0 bn	8.0 bn	Re-auction 09 7th Withdraw 1.0 bn
09 13th	09.08.11	84 days	1.2 bn	1.2 bn	1.2 bn	6.7 bn	Re-auction 09 8th Withdraw 1.3 bn
09 14th	09.08.18	84 days	0.8 bn	0.6 bn	0.6 bn	5.8 bn	Re-auction 09 9th Withdraw 0.9 bn
09 15th	09.09.01	85 days	0.8 bn	0.8 bn	0.8 bn	4.6 bn	Re-auction 09 10th Withdraw 1.2 bn
09 16th	09.09.22	84 days	0.5 bn	0.45 bn	0.45 bn	4.05 bn	Re-auction 09 11th Withdraw 0.55 bn
	09.09.29					3.05 bn	Withdraw 09 12th
	09.11.03					1.85 bn	Withdraw 09 13th
	09.11.10					1.25 bn	Withdraw 09 14th
	09.11.24					0.45 bn	Withdraw 09 15th
	09.12.17					0.0 bn	Withdraw 09 16th

Source: Bank of Korea.

As shown in Table 4, the two facilities were similar in terms of counterparty, maturity, minimum bid amount and auction type. One difference was that the average amount of auctioned funds was larger for the loan auctions funded by the FED swap line than for the swap auctions funded by Korea's foreign reserves. Another difference lay in the method for determining rates: the swap auctions used individual offer rates below the maximum internal swap rate, while the loan auctions using funds from the Fed announced a minimum bid rate for loans one day before each loan auction date. Finally, there was some difference in the collateral requirements between the two types of auctions.

Table 4

Comparison of the two types of US dollar supplying auctions by the Bank of Korea

Terms	Swap auctions using foreign reserves	Loan auctions using funds from the Fed
Method	Competitive auctions	Competitive auctions
Maximum amount available for auctions	USD 10 billion	USD 30 billion
Transaction format	BOK conducts FX swap (sell and buy) or cross-currency swap (CRS pay)	Loan
Counterparties	All foreign exchange banks (commercial banks, foreign bank branches, NACF, NFCF, KDB, IBK and KEXIM)[1]	All foreign exchange banks (commercial banks, foreign bank branches, NACF, NFCF, KDB and IBK)[1]
Maximum maturity	Three months	Maximum 88 days
Actual maturity	Three months, one week	84–86 days
Bid amounts	At least USD 1 million, multiple of USD million, the maximum offer amount is 20% of total bid amount	At least USD 1 million, multiple of USD million, the maximum offer amount is 20% of total bid amount
Determination of rates	Conventional method, variable rate (BOK uses the individual offer rate below the maximum internal swap rate)	Conventional method, variable rate (BOK announces minimum bid rate for loan one day before the auction date)
Collateral	5% margin required against exchange rate fluctuations from swap counterparties	110% of loan amount; every week, impose add-on margin; BOK RP eligible collateral
Average offered amount before withdrawal started	USD 1.98 billion	USD 3.43 billion
Average demanded amount before withdrawal started	USD 2.80 billion	USD 4.58 billion
Average allocated amount before withdrawal started	USD 1.47 billion	USD 3.34 billion

[1] NACF: the National Agricultural Cooperative Federation; NFCF: the National Fisheries Cooperative Federation; KDB: Korea Development Bank; IBK: Industrial Bank of Korea; KEXIM: Korea Export-Import Bank.

Source: Bank of Korea.

4. Structural break analysis

In this section, we estimate the exact dates when the won-dollar FX swap market entered the crisis regime in order to set the stage for a deeper analysis of CIP deviations using an EGARCH(-in-mean) model in the next section. Some papers suggest that the won-dollar swap market started to show signs of stress before the subprime loan problem emerged in early August 2007 on a global basis. But no special events are mentioned in the papers, nor is timing identified. Thus, we attempt to estimate the dates of structural changes using a regime-switching regression model. This model is a natural choice for this purpose, since it does not need any a priori information about the structural break.

We apply the simple regime-switching method proposed by Hamilton (1988, 1989) to the very classic regression model (CIP version of the Fama regression) that tests CIP in the following manner.[9] Estimation is done by maximum likelihood.[10]

$$(\ln F - \ln S)_t = \alpha(s_t) + \beta(s_t)(i^{USD} - i^{KRW})_t + \varepsilon_t \quad \varepsilon_t \sim N(0, \sigma^2(s_t)),$$

where $s_t = j \in \{0,1\}$ denotes the regime. The null hypothesis of perfect CIP is $H_0 : \alpha = 0$ and $\beta = 1$. Here, $\alpha \neq 0$ should capture transaction costs.

The transition probabilities are modelled as

$$\Pr(s_t = 1 | s_{t-1} = 0) = P_{01} = 1 - P_{00} \geq 0,$$

$$\Pr(s_t = 0 | s_{t-1} = 1) = P_{10} = 1 - P_{11} \geq 0 \text{ and}$$

$$P = \begin{pmatrix} P_{00} & 1-P_{11} \\ 1-P_{00} & P_{11} \end{pmatrix} = \begin{pmatrix} \dfrac{1}{1+\exp(a_0 + a_1 \ln(\mathrm{VIX}_{t\text{-}1}))} & 1-\dfrac{1}{1+\exp(b_0 + b_1 \ln(\mathrm{VIX}_{t\text{-}1}))} \\ 1-\dfrac{1}{1+\exp(a_0 + a_1 \ln(\mathrm{VIX}_{t\text{-}1}))} & \dfrac{1}{1+\exp(b_0 + b_1 \ln(\mathrm{VIX}_{t\text{-}1}))} \end{pmatrix},$$

where we test the specifications with and without the lagged logarithm of the VIX[11] as a robustness check. The use of VIX as an explanatory variable is motivated by the literature that emphasises increases in VIX – as a proxy for increases in global market uncertainty – as a trigger for the unwinding of a wide range of trading, including carry trades and emerging market CDS positions (Brunnermeier et al (2008) and Pan and Singleton (2008)).

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[9] We denote by S_t the FX spot rate (US dollar/Korean won) at time *t*, and by $F_{t,t+s}$ the FX forward rate contracted at time *t* for exchange at time *t*+*s*. Covered interest parity in the won-dollar FX swap market states that the interest rate differential ($i^{USD}_{t,t+s} - i^{KRW}_{t,t+s}$) should be perfectly reflected in the forward discount rate ($\ln F_{t,t+s} - \ln S_t$). This condition is equivalent to the equality of the FX swap-implied dollar rate from Korean won and the dollar cash rate, ie, $\frac{F_{t,t+s}}{S_t}(1 + i^{KRW}_{t,t+s}) = 1 + i^{USD}_{t,t+s}$. The difference between these two rates defines the CIP deviations.

[10] Peel and Taylor (2002) provide a survey of estimation methods to test CIP.

[11] The Chicago Mercantile Exchange Volatility Index (VIX) is a 30-day implied volatility index based on S&P 500 index options. A high value of the VIX means investors anticipate the US equity market will move sharply. The VIX can be a proxy for uncertainty in the global market because (i) it is highly correlated with similar volatility indices in other countries (Lustig et al (2009)), and (ii) it tends to jump immediately after the onset of crises and to stay at a very high level for a prolonged period.

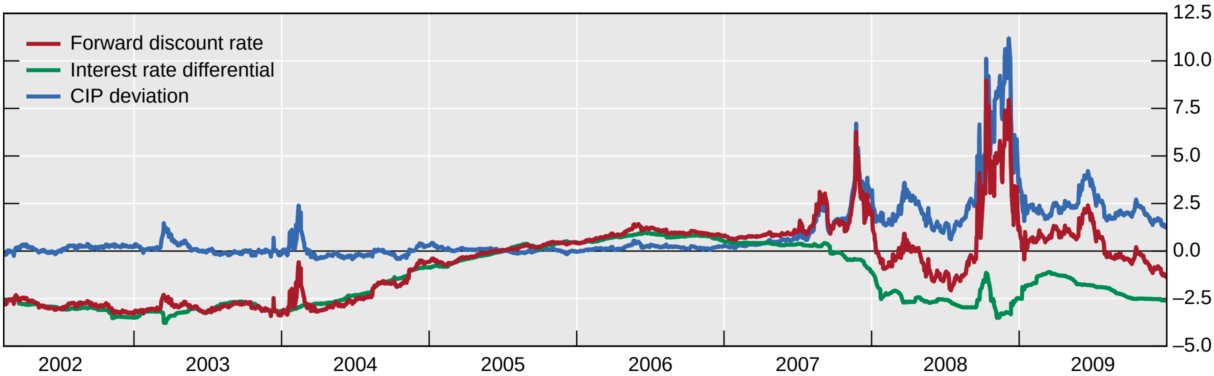
Note that there are several well-known shortcomings in the original regression-based CIP test, which include (i) possible endogeneity of the regressor and (ii) possible structural change in the CIP relationship during market stress. The use of the regime-switching model enables us to directly address the second issue. For the first issue, instrumental variable estimators might conceivably be used rather than OLS estimators, but we see this method as incompatible with the regime-switching model.

We apply the aforementioned method only to the three-month CIP condition, because (i) longer-term cross-currency swaps do not use FX forward contracts, (ii) three months is the most central maturity in the won-dollar swap market, and (iii) the recent turmoil and crisis originated in the short-term money market. We use WM/Reuters spot and forward rates (local closing rates, midrates of interbank bid and offer rates as of 6 am London time) throughout the paper. The forward rates are available from 11 February 2002. We use all the available data for this preliminary analysis through 31 December 2009, as shown in Figure 4.

Figure 4

Three-month forward discount rate, interest rate differential and CIP deviation

In percentage points



The forward discount rate is defined as *ln*(US dollar/Korean won forward rate) minus *ln*(US dollar/Korean won spot rate). The interest rate differential is defined as three-month US dollar Libor minus 91-day Korean won certificate of deposit rate. The CIP deviation is defined as the forward discount rate minus the interest rate differential.

Sources: Datastream; authors' calculations.

Table 5 shows that both specifications (with and without VIX) yield very similar parameter estimates. There are two distinct regimes. Regime 0 (1) is characterised as the combination of low (high) transaction costs, high (low) sensitivity of forward discount rates to interest rate differentials, and low (high) variance. Regime 0 (1) is naturally interpreted as a normal (crisis) regime. Note that although Regime 0 can be regarded as a normal regime, the null hypothesis of perfect CIP $H_0 : \alpha = 0$ and $\beta = 1$ is rejected significantly in Regime 0 as well as Regime 1. This may reflect the existence of structural supply-demand imbalances even under the normal regime in the won-dollar FX swap market.

VIX has a significant coefficient with a correct sign for both transition probabilities (P_{00} and P_{11}). However, the likelihood ratio test shows that inclusion of VIX does not induce a significant increase in predictive power for regime switches. Thus, we rely on the regime-switching dates derived from the model without VIX.

Table 5

The estimation results of regime-switching CIP regressions

$$(\ln F - \ln S)_t = \alpha(s_t) + \beta(s_t)\left(i^{USD} - i^{KRW}\right)_t + \varepsilon_t \qquad \varepsilon_t \sim N\left(0, \sigma^2(s_t)\right)$$

$$P = \begin{pmatrix} P_{00} & 1-P_{11} \\ 1-P_{00} & P_{11} \end{pmatrix} = \begin{pmatrix} \dfrac{1}{1+\exp(a_0 + a_1 \ln(\mathrm{VIX}_{t-1}))} & 1-\dfrac{1}{1+\exp(b_0 + b_1 \ln(\mathrm{VIX}_{t-1}))} \\ 1-\dfrac{1}{1+\exp(a_0 + a_1 \ln(\mathrm{VIX}_{t-1}))} & \dfrac{1}{1+\exp(b_0 + b_1 \ln(\mathrm{VIX}_{t-1}))} \end{pmatrix}$$

(1) Parameter estimates

	Without VIX	**With VIX**
$\alpha(0)$	0.129*** (0.005)	0.129*** (0.005)
$\alpha(1)$	1.716*** (0.064)	1.717*** (0.064)
$\beta(0)$	1.034*** (0.002)	1.034*** (0.002)
$\beta(1)$	0.587*** (0.023)	0.588*** (0.023)
$\sigma(0)$	0.188*** (0.003)	0.188*** (0.003)
$\sigma(1)$	1.780*** (0.025)	1.780*** (0.025)
$P_{00}(a_0)$	–5.834*** (0.631)	–8.244*** (0.607)
$P_{00}(a_1)$		0.855*** (0.202)
$P_{11}(b_0)$	–5.525*** (0.888)	4.948*** (0.868)
$P_{11}(b_1)$		–3.360*** (0.297)
Log likelihood	–1151.667	–1154.103
LR test		3.134

*** indicates significance at the 1% level. The LR test is the likelihood ratio test of the model with VIX against the model without VIX.

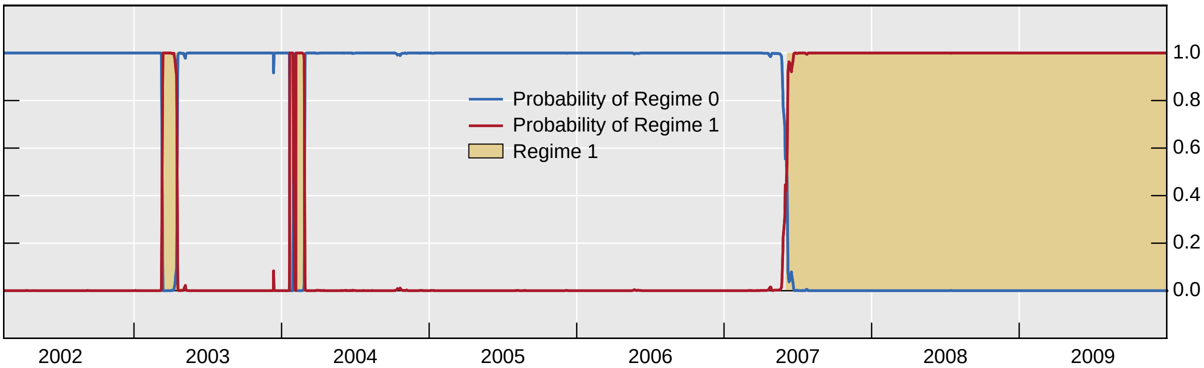
(2) Dates in Regime 1 identified by filtered probability (with the cut-off value 0.5)

Without VIX	**With VIX**
10 March–15 April 2003	10 March–15 April 2003
21–30 January 2004	21–29 January 2004
5–25 February 2004	5–24 February 2004
4 June 2007 –	5 June 2007 –

Across the two specifications, we also identify very similar dates for the crisis regime by filtered probability. If we use 0.5 as a minimum Regime 1 cut-off probability for being in a crisis, periods under the crisis regime estimated from the model without VIX are (i) 10 March 2003–15 April 2003, (ii) 21–30 January 2004, (iii) 5–25 February 2004, and (iv) from 4 June 2007 onwards, as illustrated in Figure 5. Period (i) corresponds to the difficult time for Korean banks to borrow abroad following the accounting scandal of SK Global, a trading firm whose parent was one of the largest conglomerates in Korea. Periods (ii) and (iii) correspond to the turmoil period following the imposition by the Korean government of restrictions on non-deliverable forward positions. Period (iv) corresponds to the recent financial crisis. Thus, the estimation result seems to be robust in terms of its correspondence with real-world events.

Figure 5

CIP regime probabilities[1]



[1] CIP regime probabilities are filtered probabilities based on the estimation result of the regime-switching CIP regression reported in Table 5.

Sources: Datastream; authors' calculations.

It should be noted here that the estimations suggest that the three-month won-dollar FX swap market entered the most recent crisis regime *before* the global financial turmoil started on 9 August 2007. One possible reason for this result is that, as was shown in Section 3.2, the Korean authorities started to request banks in Korea to slow down short-term foreign currency borrowing in early 2007. Combined with the increasing demand for US dollars by exporting companies around that time, this exacerbated the demand-supply imbalance in the FX swap market. In the next section, we use 4 June 2007 as the starting date of the crisis period. In Section 6.1, we will check if the regression results change when we define the starting date of the current crisis as 9 August 2007 instead.

5. The determinants of CIP deviations and policy effects

In this section, we use regression analysis to investigate the determinants of CIP deviations in the three-month won-dollar FX swap market and the three-year won-dollar cross-currency swap market. We also examine the effectiveness of different policy actions in reducing CIP deviations during the crisis period.

5.1 Data and regression models

Following Baba and Packer (2009a, 2009b), we use the EGARCH(1,1) model, but augment it by adding the variance term in the mean equation (EGARCH(1,1)-in-mean model) to test whether volatility risk is properly priced in the won-dollar FX swap and cross-currency swap markets (see Engel et al (1987) and Nelson (1991) for details of the GARCH-in-mean model).[12] If volatility risk is not priced properly, this likely implies the non-existence or inactiveness of risk-averse active arbitragers who typically measure the arbitrage profits against the volatility risk involved.[13]

The maturities for which we run the regressions are three months (short term) and three years (long term). Although their economic function is the same, three-month FX swaps and three-year cross-currency swaps are quite different in terms of their mechanisms. FX swaps are instruments combining spot and forward contracts in the reverse direction. On the other hand, typical cross-currency swaps between the Korean won and the US dollar are contracts in which one party pays a fixed rate in the Korean won and receives a floating leg that is referenced to the six-month US dollar Libor fixing. The cross-currency swap rate is quoted with the interest rate payable on the fixed side (CGFS (2009) and McCauley and Zukunft (2008)). Thus, deviations from three-month CIP are measured as 'FX swap-implied US dollar rate from the Korean won CD rate' minus US dollar Libor, but deviations from three-year CIP as Korean won Treasury Bill rate minus the cross-currency swap rate (Figure 6).

Our choice of explanatory variables is similar to that of Baba and Packer (2009a, 2009b) and Baba (2009) in that variables except for VIX and policy variables – the dates and amounts of BOK auctions supplying US dollars – are included for both the Korean won and the US dollar. Policy variables are also included in the variance equation to test whether these policy measures had stabilising effects in the won-dollar swap markets in the crisis period.

As shown in Table 6, the standard unit root tests suggest that three-month CIP deviations are highly likely to be I(1), while three-year CIP deviations are likely to be I(1) to a lesser degree. The results for other variables are mixed, particularly in the pre-crisis period, but we use the first-differenced form for all the variables throughout the analysis to be on the conservative side except for the policy dummy (auction date dummy) and the lagged level of the dependent variable.

Table 7 in turn shows that the first-differenced value of CIP deviations and their squared values tend to be highly auto-correlated, suggesting the need to control for AR1 effects in the mean equation and GARCH effects in the variance equation. All the variables have large excess kurtosis in both the pre-crisis and crisis periods, suggesting that it is appropriate to use fat-tail distributions. They also have larger standard deviations in the crisis period than in the pre-crisis period.

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12 Risk-averse agents require compensation for holding risky assets, ie a long position in an asset. The key postulate of Engle et al (1987) is that time-varying premia on different term debt instruments can be well modelled as risk premia where the risk is due to unanticipated interest rate movements and is measured by the conditional variance of the one-period holding yield. Specifically, Engle et al (1987) apply the model to six-month treasury bills, two-month treasury bills and 20-year triple-A corporate bonds to determine whether time-varying risk premia are apparent and how large they are. The relationship between the mean and the variance of the returns that will ensure that the asset is fully held in equilibrium will depend upon the utility function of the agents and the supply condition of the assets. In our paper, the deviation from CIP is, in principle, a risk-free arbitrage opportunity under CIP except for transaction costs and risk premium. However, there are still a variety of sources of risk in these seemingly for-arbitrage transactions. Ryu and Park (2008) list risks associated with interest arbitrage transactions as follows. (1) Credit risks: (i) counterparty risk such as default risk of bonds bought and replacement risk; (ii) political risk such as capital controls. (2) Market risks: if investors hold the position until maturity, there is no market risk coming from changes in interest rates; however, investors may be forced to liquidate the position (see Footnote 13 for details). (3) Liquidity risk: (i) market liquidity risk measured by bid-ask spread; (ii) funding liquidity risk stemming from difficulty in funding the arbitrage transactions due to a credit crunch in the international market or reductions in country limits.

13 Value-at-Risk (VaR) – a threshold value such that the probability that loss on the portfolio over a given time horizon exceeds this value is the given probability level – is the most popular method for portfolio investment risk management. Typically, even if investors initially plan to buy and hold bond positions until maturity, hitting the threshold of the VaR risk amount leads to compulsory unwinding of those positions before maturity.

The mean equation and the variance equation are specified as

$$dY_t = a_0 + a_1 Z_{t-1} + a_2 X_{t-1} + \lambda\sigma_t + \varepsilon_t \,,$$

$$\ln\left(\sigma_t^2\right) = \omega + \beta\ln\left(\sigma_{t-1}^2\right) + \gamma\,\frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \eta\left(\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| - \mathrm{E}\left(\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right|\right)\right) + b_1 X_{t-1} \,,$$

where

dY_t CIP deviations

three-month: FX swap-implied US dollar rate from Korean won CD rate – US dollar Libor

three-year: Korean won Treasury Bill rate – cross-currency swap rate

Z_{t-1} *Own dynamics*:

(1) lagged "level" of the dependent variable (Y_{t-1}) to control for the level effect following McAndrews et al (2008),

(2) lagged dependent variable (dY_{t-1}) to control for momentum and AR1 effects,

Global market uncertainty:

(3) VIX (CME),

Counterparty risk:

(4) five-year CDS spread of US banks (JPMorgan),[14]

(5) five-year CDS spread of Korean banks (Markit),[15]

Tensions in the interbank market:

(6) US dollar TED spread defined as Libor –Treasury Bill rate (three month, one year),

(7) Korean won TED spread defined as Koribor – Monetary Stabilisation Bond rate (one year),

X_{t-1} *Bank of Korea Policy*:

(8) FEDSWAP1 = 1 on the dates of competitive US dollar loan facility auctions using US dollar proceeds through the swap lines with the Fed,

(9) FEDSWAP2 = changes in US dollar balance outstanding of US dollar loan auctions,

(10) BOKRES1 = 1 on the dates of competitive swap facility auctions using the Bank of Korea's foreign reserves, and

(11) BOKRES2 = changes in US dollar balance outstanding of US dollar swap auctions.

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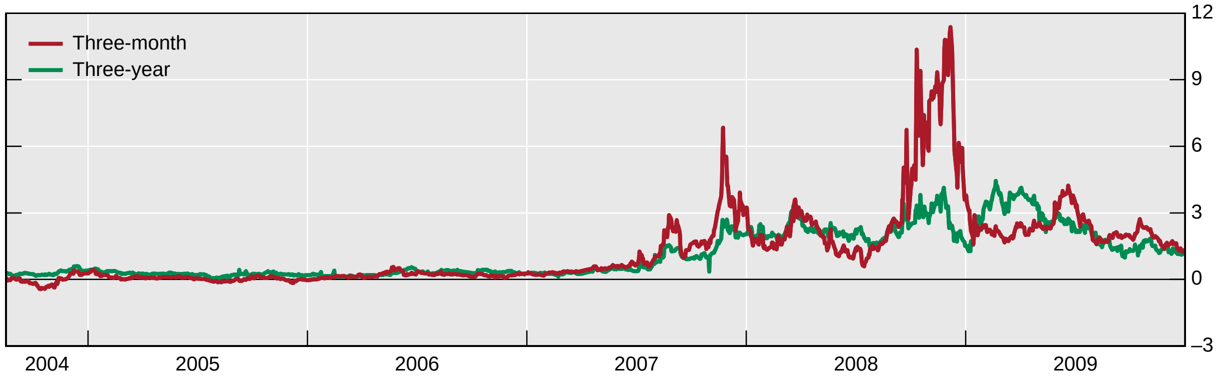
[14] We use the JPMorgan Bank CDS index, which is an equally weighted average of five-year CDS spreads of seven banks (Bank of America, Capital One Bank, Citigroup, JPMorgan Chase, Wachovia Corp, Washington Mutual and Wells Fargo).

[15] An equally weighted average of five-year CDS spreads of six private commercial banks (Kookmin Bank, Woori Bank, Hana Bank, Korea Exchange Bank, National Agricultural Cooperative Federation and Shinhan Bank).

Figure 6

CIP deviations

In percentage points



Sources: Bloomberg; Datastream; authors' calculations.

When $\frac{\varepsilon_{t-1}}{\sigma_{t-1}} > 0$ $\left(\frac{\varepsilon_{t-1}}{\sigma_{t-1}} < 0\right)$, the impact of shocks, $\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right|$, on the logarithm of the conditional variance can be measured by $(\eta+\gamma)\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right|$ $\left((\eta-\gamma)\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right|\right)$. Thus, this asymmetry (the so-called leverage effect) can be tested by the significance of γ. When γ is positive, an unexpected positive shock – larger CIP deviations – have a larger impact on volatility than a negative shock. In other words, widening market dislocations lead to more volatile markets. Also note that volatility persistence or volatility clustering can be measured solely by β, not by $\eta+\beta$.

Technically, the EGARCH model can circumvent a possible non-negativity problem on volatility. To accommodate possible fat-tailness in the data distribution, we use the Student-t distribution. In this case, the log-likelihood contributions can be written as

$$\ln L_t = -\frac{1}{2}\ln\left(\frac{\pi(\nu-2)\Gamma(\nu/2)^2}{\Gamma((\nu+1)/2)^2}\right) - \frac{1}{2}\ln\left(\sigma_{t-1}^2\right) - \frac{(\nu+1)}{2}\ln\left(1+\frac{(Y_t-(a_0+a_1Z_{t-1}+a_2X_{t-1}))^2}{\sigma_t^2(\nu-2)}\right)$$

where the degree of freedom parameter ($\nu > 2$) captures the tail behaviour. The *t*-distribution approaches the normal as $\nu \to \infty$.

Estimation is done using the following two sets of subsamples: pre-crisis period (3 January 2005–1 June 2007); crisis period (4 June 2007–31 December 2009). The start date of pre-crisis periods (3 January 2005) is chosen such that the sample size of the two sub-periods becomes similar. In the next section, we will see if the results differ when we use an alternative and more conventional definition of crisis period: pre-crisis period (3 January 2005–8 August 2007); crisis period (9 August 2007–31 December 2009).

Before we provide the regression results from the above specification, we should note that the results are reasonably robust in terms of alternative GARCH specifications (standard GARCH, PGARCH, TARCH etc), distribution assumptions (normal, GED) and functional form of conditional volatility in the mean equation (standard deviation or variance, with or without logarithm etc). Estimated conditional variance also looks reasonable. Also, both standardised residuals and squared standardised residuals show no evidence of autocorrelation in most cases. In all the models, the Student t's degree of freedom parameter is estimated to be significantly larger than 2, which is the theoretical lower limit.

Table 6

Unit root tests

(1) Pre-crisis period: 3 January 2005–1 June 2007

	Augmented Dicky-Fuller test		**Phillips-Perron test**	
	Level	**1st difference**	**Level**	**1st difference**
CIP deviation (%)				
3M	–1.513	–23.758***	–1.470	–23.774***
3Y	–2.655*	–22.368***	–3.567***	–33.828***
Determinants (%)				
VIX	–5.805***	–21.837***	–5.521***	–32.176***
US bank CDS	–2.235	–5.331***	–1.551	–19.167***
Korean bank CDS	–0.626	–20.447***	–0.711	–20.756***
3M USD TED	–3.957***	–6.943***	–3.709***	–27.484***
1Y USD TED	–3.388**	–23.438***	–9.878***	–63.981***
1Y KRW TED	–3.862***	–18.238***	–7.004***	–30.244***

(2) Crisis period: 4 June 2007–31 December 2009

	Augmented Dicky-Fuller test		**Phillips-Perron test**	
	Level	**1st difference**	**Level**	**1st difference**
CIP deviation (%)				
3M	–2.306	–12.747***	–2.777*	–22.968***
3Y	–2.829*	–28.878***	–2.829*	–28.971***
Determinants (%)				
VIX	–2.124	–23.187***	–2.251	–32.268***
US bank CDS	–2.944**	–22.554***	–2.684*	–22.341***
Korean bank CDS	–1.788	–19.010***	–1.714	–18.571***
3M USD TED	–2.521	–16.438***	–2.191	–20.517***
1Y USD TED	–2.211	–29.850***	–2.467	–29.670***
1Y KRW TED	–2.011	–17.188***	–1.933	–27.240***

Each test is conducted using the specification with a constant term. Lag length for the augmented Dicky-Fuller test is determined by the Schwarz Information criterion. Bartlett Kernel and Newey-West Bandwidth are used for the Phipps-Perron test. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table 7

Summary statistics

(1) Pre-crisis period: 3 January 2005–1 June 2007

	Mean	**Std. dev**	**Skewness**	**Kurtosis**	**Q(10)**	**Q^2(10)**
d(CIP deviation) (%)						
3M	0.0004	0.0265	–0.3250	9.1657	12.4080	18.6624**
3Y	0.0001	0.0315	0.2242	28.2879	56.6392***	134.6944***
Determinants (%)						
d(VIX)	–0.0021	0.8594	1.0196	16.5058	41.7757***	111.8533***
d(US bank CDS)	–0.0001	0.0060	2.5366	21.9001	113.7677***	122.9581***
d(Korean bank CDS)	–0.0004	0.0062	1.0670	10.1401	50.1035***	225.1582***
d(3M USD TED)	0.0005	0.0290	0.7986	10.8844	135.0113***	10.2996
d(1Y USD TED)	0.0002	0.0386	–0.1804	4.3213	121.2650***	19.8489**
d(1Y KRW TED)	0.0000	0.0215	–0.1718	8.0664	59.2504***	116.4398***

(2) Crisis period: 4 June 2007–31 December 2009

	Mean	**Std. dev**	**Skewness**	**Kurtosis**	**Q(10)**	**Q^2(10)**
d(CIP deviation) (%)						
3M	0.0009	0.4165	0.4033	22.1992	143.5209***	614.4484***
3Y	0.0010	0.1744	0.6147	7.3159	17.0594*	67.9967***
Determinants (%)						
d(VIX)	0.0125	2.6658	0.1967	13.3621	53.6914***	611.2789***
d(US bank CDS)	0.0012	0.1365	–4.6551	63.7633	29.1979***	0.1544
d(Korean bank CDS)	0.0013	0.1514	–0.6691	33.1854	136.0715***	660.4222***
d(3M USD TED)	–0.0005	0.1196	0.4664	16.6009	58.6651***	294.1423***
d(1Y USD TED)	0.0001	0.0839	–0.3473	10.7905	38.2916***	84.2698***
d(1Y KRW TED)	0.0007	0.0683	–2.4765	60.3305	23.6346***	117.2558***

Q(10) and Q^2(10) are the Ljung-Box *Q*-statistics of each variable and its squared value, respectively, which test the null hypothesis that there is no autocorrelation up to order 10. ***, ** and * indicate the significant autocorrelation at the 1%, 5% and 10% level, respectively.

5.2 The determinants of CIP deviations

First, Tables 8 and 9 show the estimation results for the three-month FX swap market. In the pre-crisis period, we find (i) no significant pricing of volatility risk, (ii) insignificant level and momentum effects, (iii) insignificant role of VIX, US or Korean banks' CDS spreads, and TED spreads, (iv) strong volatility clustering, and (v) a significant asymmetric impact on volatility dynamics – a stronger impact on volatility when unexpected shocks widen the CIP deviations than when unexpected shocks narrow CIP deviations (Table 8, column (a)). That is, none of the variables measuring global market uncertainty, counterparty risk of banks and tensions in interbank markets has a significant effect on CIP deviations in the pre-crisis period. This result indicates that CIP deviations in this relatively tranquil period are basically noise, but that the positive and persistent deviations from CIP are likely to be driven by transaction costs and some structural demand-supply factors not captured in the regression.

In the crisis period, the estimation results in column (a) of Table 9 suggest (i) no significant pricing of volatility risk, (ii) significant level and momentum effects, (iii) significant role of VIX, (iv) significant effects of BOK loan auctions, (v) strong volatility clustering, and (vi) a significant asymmetric impact on volatility dynamics. Compared to the pre-crisis results, the significant role of VIX is worth noting. Intuitively, increases in the level of overall market uncertainty, as measured by increases in VIX, are associated with significant distortions in US dollar funding activity, and wider deviations from CIP.

Second, Tables 10 and 11 summarise the estimation results for the three-year cross-currency swap market. During the pre-crisis period, the estimation results show (i) no significant pricing of volatility risk, (ii) significant level effect and insignificant momentum effect, (iii) insignificant role of VIX and weakly significant role of Korean banks' CDS spreads, (iv) insignificant effects of TED spreads, (v) significant but relatively weak volatility clustering, and (vi) a weakly significant asymmetric impact on volatility dynamics (Table 10, column (a)). Now, in the pre-crisis period, the CDS spread of Korean banks has weakly significant positive impacts on CIP deviations. This is different from the three-month case. Under normal market conditions, the longer the maturity, the more sensitive CIP deviations are to the credit risk. This is likely to be a natural interpretation of the significant role of the CDS spread of Korean banks in the estimation results.

In the crisis period, we document a consistently significant role of the CDS spread of US banks in driving CIP deviations, as well as strong volatility clustering, in the three-year cross-currency swap market (Table 11, column (a)). These results are consistent with US banks suffering from heightened credit risk during the crisis period and reducing their long Korean won positions, which contributed to widening CIP deviations in the three-year cross-currency swap market.

Table 8

Estimation results of three-month CIP deviation (1)

Pre-crisis period: (a) 3 January 2005–1 June 2007; (b) 3 January 2005–8 August 2007

Sample	**(a)**		**(b)**	
	Mean equation			
GARCH–M (Standard deviation)	–0.058		0.081	
	(0.207)		(0.140)	
Deviation level (–1)	–0.008	–0.009	–0.008	–0.006
	(0.006)	(0.005)	(0.006)	(0.005)
d(Deviation) (–1)	0.050	0.050	0.045	0.046
	(0.037)	(0.037)	(0.037)	(0.037)
d(VIX) (–1)	–0.000	–0.000	–0.000	–0.000
	(0.001)	(0.001)	(0.001)	(0.001)
d(US bank CDS) (–1)	0.155	0.156	0.053	0.058
	(0.156)	(0.157)	(0.133)	(0.131)
d(Korean bank CDS) (–1)	0.136	0.137	0.240**	0.239**
	(0.131)	(0.131)	(0.114)	(0.113)
d(3M USD TED) (–1)	–0.010	–0.010	–0.015	–0.014
	(0.029)	(0.029)	(0.028)	(0.028)
d(1Y KRW TED) (–1)	0.032	0.032	0.032	0.032
	(0.039)	(0.039)	(0.040)	(0.040)
Constant	0.003	0.002	–0.000	0.002
	(0.005)	(0.001)	(0.003)	(0.001)
	Variance equation $\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta(\lvert \varepsilon_{t-1}/\sigma_{t-1} \rvert - \mathrm{E}(\lvert \varepsilon_{t-1}/\sigma_{t-1} \rvert))$			
α	–0.327**	–0.326**	–0.298***	–0.314***
	(0.156)	(0.155)	(0.115)	(0.116)
β	0.966***	0.967***	0.976***	0.974***
	(0.019)	(0.019)	(0.013)	(0.013)
γ	0.067**	0.067**	0.091***	0.090***
	(0.028)	(0.028)	(0.030)	(0.030)
η	0.110**	0.113**	0.181***	0.183***
	(0.046)	(0.047)	(0.048)	(0.048)
Student t parameter	3.950***	3.951***	4.046***	4.038***
Log likelihood	1475.868	1475.833	1523.987	1523.831

The numbers in parentheses are standard errors. ***, ** and * indicate that each parameter estimate is significantly different from zero at the 1%, 5% and 10% level, respectively. The student *t* parameter is tested against the null hypothesis that the degree of freedom parameter is 2 on a one–sided basis.

Table 9

Estimation results of three-month CIP deviation (2)

Crisis period: (a) 4 June 2007–31 December 2009; (b) 9 August 2007–31 December 2009

Sample	(a)		(b)	
	Mean equation			
GARCH–M (Standard deviation)	0.096 (0.075)		0.142* (0.085)	
Deviation level (–1)	–0.026*** (0.008)	–0.020*** (0.006)	–0.044*** (0.011)	–0.035*** (0.008)
d(Deviation) (–1)	0.106*** (0.039)	0.106*** (0.039)	0.121*** (0.040)	0.124*** (0.040)
d(VIX) (–1)	0.007** (0.003)	0.006** (0.003)	0.007** (0.003)	0.008** (0.003)
d(US bank CDS) (–1)	0.060 (0.047)	0.062 (0.047)	0.063 (0.051)	0.068 (0.051)
d(Korean bank CDS) (–1)	–0.148** (0.064)	–0.138** (0.063)	–0.181*** (0.068)	–0.170*** (0.066)
d(3M USD TED) (–1)	–0.003 (0.067)	–0.000 (0.067)	0.007 (0.072)	0.006 (0.073)
d(1Y KRW TED) (–1)	–0.038 (0.104)	–0.036 (0.104)	–0.021 (0.105)	–0.021 (0.105)
FEDSWAP1	–0.092** (0.039)	–0.091** (0.037)	–0.098** (0.040)	–0.098*** (0.037)
FEDSWAP2	–0.060** (0.030)	–0.055* (0.028)	–0.063** (0.031)	–0.058** (0.029)
BOKRES1	–0.014 (0.054)	–0.021 (0.053)	–0.009 (0.055)	–0.031 (0.053)
BOKRES2	–0.002 (0.018)	–0.001 (0.018)	–0.006 (0.018)	–0.005 (0.018)
Constant	0.032*** (0.011)	0.036*** (0.010)	0.066*** (0.017)	0.068*** (0.017)
	Variance equation $\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert - \mathrm{E}(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert))$ $+ \lambda_1 \mathrm{FEDSWAP1}_t + \lambda_2 \mathrm{FEDSWAP2}_t + \lambda_3 \mathrm{BOKRES1}_t + \lambda_4 \mathrm{BOKRES2}_t$			
α	–0.439*** (0.068)	–0.460*** (0.067)	–0.428*** (0.068)	–0.445*** (0.069)
β	0.950*** (0.014)	0.946*** (0.014)	0.952*** (0.014)	0.947*** (0.015)
γ	0.165*** (0.045)	0.154*** (0.046)	0.161*** (0.046)	0.150*** (0.048)
η	0.389*** (0.069)	0.399*** (0.070)	0.381*** (0.069)	0.390*** (0.072)
λ_1 (FEDSWAP1)	0.055 (0.259)	0.022 (0.258)	0.039 (0.257)	0.020 (0.256)
λ_2 (FEDSWAP2)	0.167 (0.139)	0.180 (0.141)	0.137 (0.139)	0.153 (0.141)
λ_3 (BOKRES1)	–0.015 (0.297)	–0.020 (0.297)	–0.024 (0.301)	–0.078 (0.297)
λ_4 (BOKRES2)	0.467** (0.219)	0.495** (0.221)	0.445** (0.221)	0.484** (0.223)
Student t parameter	3.918***	3.878***	3.929***	3.771***
Log likelihood	186.861	186.080	137.527	136.462

The numbers in parentheses are standard errors. ***, ** and * indicate that each parameter estimate is significantly different from zero at the 1%, 5% and 10% level, respectively. The student *t* parameter is tested against the null hypothesis that the degree of freedom parameter is 2 on a one-sided basis.

Table 10

Estimation results of three-year CIP deviation (1)

Pre-crisis period: (a) 3 January 2005–1 June 2007; (b) 3 January 2005–8 August 2007

Sample	**(a)**		**(b)**	
	Mean equation			
GARCH-M (Standard deviation)	–0.223		–0.250	
	(0.181)		(0.164)	
Deviation level (–1)	–0.020***	–0.022***	–0.021***	–0.024***
	(0.007)	(0.007)	(0.006)	(0.006)
d(Deviation) (–1)	0.012	0.003	0.016	0.009
	(0.039)	(0.038)	(0.038)	(0.037)
d(VIX) (–1)	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
d(US bank CDS) (–1)	0.196	0.203	0.320***	0.315***
	(0.139)	(0.138)	(0.060)	(0.060)
d(Korean bank CDS) (–1)	0.230*	0.226*	0.280***	0.280***
	(0.120)	(0.121)	(0.085)	(0.084)
d(1Y USD TED) (–1)	0.022	0.020	0.016	0.014
	(0.018)	(0.017)	(0.017)	(0.017)
d(1Y KRW TED) (–1)	0.034	0.028	0.039	0.032
	(0.033)	(0.033)	(0.033)	(0.033)
Constant	0.011**	0.006***	0.013***	0.007***
	(0.005)	(0.002)	(0.005)	(0.002)
	Variance equation $\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert - \mathrm{E}(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert))$			
α	–5.496***	–5.666***	–4.548***	–4.645***
	(0.974)	(0.963)	(0.721)	(0.756)
β	0.284**	0.263**	0.388***	0.377***
	(0.132)	(0.129)	(0.100)	(0.104)
γ	0.170*	0.181**	0.170*	0.186*
	(0.090)	(0.092)	(0.097)	(0.096)
η	0.469***	0.194***	0.472***	0.494***
	(0.125)	(0.129)	(0.130)	(0.129)
Student t parameter	2.818***	2.834***	2.571***	2.586***
Log likelihood	1541.199	1540.442	1626.310	1624.844

The numbers in parentheses are standard errors. ***, ** and * indicate that each parameter estimate is significantly different from zero at the 1%, 5% and 10% level, respectively. The student *t* parameter is tested against the null hypothesis that the degree of freedom parameter is 2 on a one-sided basis.

Table 11

Estimation results of three-year CIP deviation (2)

Crisis period: (a) 4 June 2007–31 December 2009; (b) 9 August 2007–31 December 2009

Sample	(a)		(b)	
	Mean equation			
GARCH-M (Standard deviation)	0.107 (0.085)		0.069 (0.116)	
Deviation level (–1)	–0.012* (0.007)	–0.004 (0.004)	–0.016** (0.007)	–0.014** (0.006)
d(Deviation) (–1)	0.050 (0.034)	–0.044 (0.034)	–0.036 (0.039)	–0.038 (0.039)
d(VIX) (–1)	0.001 (0.002)	0.001 (0.002)	0.003 (0.003)	0.002 (0.003)
d(US bank CDS) (–1)	0.281*** (0.040)	0.289*** (0.040)	0.275*** (0.039)	0.275*** (0.039)
d(Korean bank CDS) (–1)	–0.073 (0.051)	–0.070 (0.050)	–0.084 (0.048)	–0.084 (0.048)
d(1Y USD TED) (–1)	0.051 (0.053)	0.054 (0.053)	0.076 (0.064)	0.082 (0.064)
d(1Y KRW TED) (–1)	0.022 (0.068)	0.020 (0.066)	–0.024 (0.062)	–0.024 (0.062)
FEDSWAP1	0.013 (0.036)	0.014 (0.033)	0.018 (0.033)	0.017 (0.032)
FEDSWAP2	–0.029 (0.022)	–0.027 (0.021)	–0.031 (0.023)	–0.029 (0.022)
BOKRES1	0.017 (0.079)	0.038 (0.083)	0.019 (0.101)	0.035 (0.097)
BOKRES2	0.033 (0.044)	0.033 (0.046)	0.042 (0.049)	0.038 (0.050)
Constant	–0.002 (0.005)	–0.001 (0.005)	0.017 (0.017)	0.023 (0.013)
	Variance equation $\ln(\sigma_t^2) = \alpha + \beta \ln(\sigma_{t-1}^2) + \gamma\, \varepsilon_{t-1}/\sigma_{t-1} + \eta(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert - \mathrm{E}(\lvert\varepsilon_{t-1}/\sigma_{t-1}\rvert))$ $+ \lambda_1 \mathrm{FEDSWAP1}_t + \lambda_2 \mathrm{FEDSWAP2}_t + \lambda_3 \mathrm{BOKRES1}_t + \lambda_4 \mathrm{BOKRES2}_t$			
α	–0.237*** (0.058)	–0.319*** (0.069)	–0.635*** (0.172)	–0.649*** (0.176)
β	0.969*** (0.012)	0.957*** (0.014)	0.893*** (0.040)	0.889*** (0.041)
γ	0.076 (0.046)	0.066 (0.049)	0.053 (0.055)	0.053 (0.057)
η	0.211*** (0.057)	0.273*** (0.066)	0.362*** (0.080)	0.365*** (0.081)
λ_1 (FEDSWAP1)	–0.029 (0.207)	–0.055 (0.238)	–0.167 (0.324)	–0.186 (0.323)
λ_2 (FEDSWAP2)	0.110 (0.081)	0.149 (0.100)	0.315 (0.163)	0.334 (0.165)
λ_3 (BOKRES1)	0.303 (0.285)	0.361 (0.329)	0.645 (0.544)	0.617 (0.548)
λ_4 (BOKRES2)	–0.048 (0.132)	–0.024 (0.156)	–0.124 (0.238)	–0.094 (0.241)
Student *t* parameter	2.810***	2.861***	3.451***	3.417***
Log likelihood	390.144	389.285	312.994	312.842

The numbers in parentheses are standard errors. ***, ** and * indicate that each parameter estimate is significantly different from zero at the 1%, 5% and 10% level, respectively. The student *t* parameter is tested against the null hypothesis that the degree of freedom parameter is 2 on a one-sided basis.

5.3 Effectiveness of policy responses

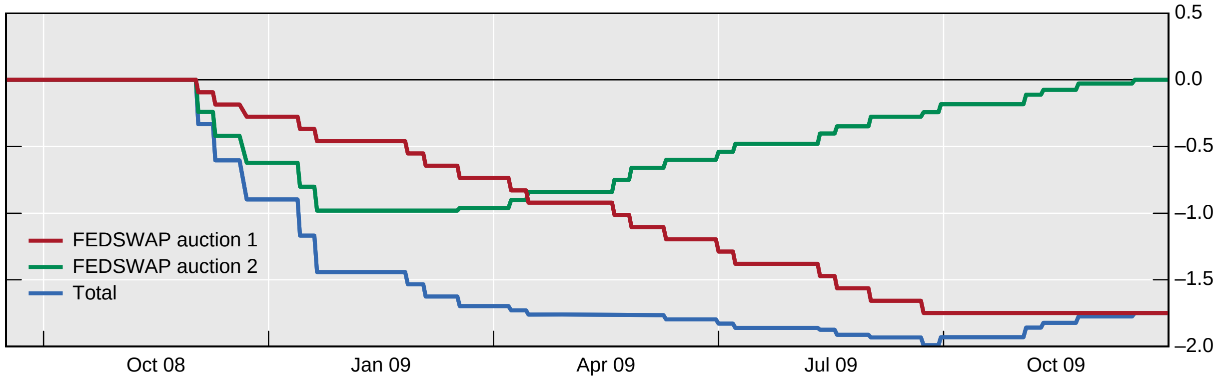
The most interesting result concerns the effectiveness of policy measures. We call BOK loan auctions funded by the Fed swap line FEDSWAP, and BOK swap auctions using its own foreign reserves BOKRES. In the regression, the variables of interest are the following: FEDSWAP1 (BOKRES1) equals 1 on the date of each FEDSWAP (BOKRES) auction; FEDSWAP2 (BOKRES2) denotes the changes in US dollar balance outstanding from FEDSWAP (BOKRES).

In the regression on the three-month CIP deviations, the coefficients on both FEDSWAP1 and FEDSWAP2 are statistically significant, but those on BOKRES1 and BOKRES2 are not. The FEDSWAP auctions were not only statistically but also economically significant: three-month CIP deviations fell by 9.2 basis points on average after each FEDSWAP auction, and every USD 1 billion auctioned out decreased the deviation by a further 6 basis points. The cumulative effects[16] of all FEDSWAP auctions are 1.99 percentage points, which is 20% of the total reduction in the CIP deviation of 9.8 percentage points from the peak in early December 2008 when the first auction was conducted to mid-December 2009 when the last outstanding funds were withdrawn. By contrast, CIP deviations decreased by 1.4 basis points on average after each BOKRES auction, and every USD 1 billion auctioned out further reduced the deviation by a mere 0.2 basis points. Figure 7 illustrates the cumulative effects of FEDSWAP auctions.

Figure 7

Cumulative effects of the Bank of Korea's US dollar loan auctions

In percentage points



Cumulative effects are based on the average of parameter estimates from column (a) in Table 9.

Sources: Datastream; authors' calculations.

By contrast, from the regression analysis on the three-year CIP deviations, we find insignificant policy effects. This is explained by the fact that BOK auctions were aimed at short-term funding markets from one-week to three-month maturities, and not directly meant to address the dislocations in the three-year cross-currency swap market.

There are several possible explanations for the much greater effectiveness of the FEDSWAP auctions than the BOKRES auctions in terms of reducing the CIP deviations in the three-

[16] Cumulative effects are approximated by (1) (point estimate of FEDSWAP1) × (number of auctions) and (2) (point estimate of FEDSWAP2) × (change in US dollar auction balance), as done by McAndrews et al (2008). Thus, the cumulative effects of FEDSWAP1 are monotonically increasing over time, but those of FEDSWAP2 are not (if the amount of US dollar funds in the market decreases, then the cumulative effects should also decrease).

month won-dollar FX swap market. As we have already shown in Table 4, the two facilities were similar in terms of counterparties, maturities, minimum bid amount and auction type. One difference between the two auctions was that the average amount of auctioned funds was larger for FEDSWAP than for BOKRES, but the coefficients for FEDSWAP2 and BOKRES2 already capture this aspect. Another difference is that the BOK announced the minimum bid rate before each FEDSWAP auction, while it used an internal maximum swap rate for each BOKRES auction. This may explain the greater success ratio (that is, the ratio of the allocated amount to the offered amount) for FEDSWAP auctions than for BOKRES auctions. Moreover, the BOKRES auctions required counterparty banks to swap Korean won in cash for US dollars, while the FEDSWAP auctions required Korean government bonds as collateral when providing US dollars. These may be reflected in the difference in the coefficients for FEDSWAP and BOKRES. However, the fact that the BOKRES auctions were conducted earlier than the FEDSWAP auctions cannot account for the difference in their effectiveness because we control for time-varying global factors such as VIX, US banks' credit and US TED spreads as well as Korean banks' credit and Korean TED spreads in our regression analysis.

We believe that the provision of funds by FEDSWAP auctions enhanced market confidence more effectively because they were adding to Korea's foreign reserves, while the provision of funds by BOKRES auctions was not. In Section 6.2, we provide supporting evidence for this conjecture.

6. Robustness check and discussion

6.1. Alternative crisis period

In this subsection, we check if the regression results differ when we use an alternative and widely used definition of crisis period, that is, the pre-crisis period (3 January 2005–8 August 2007) and the crisis period (9 August 2007–31 December 2009).

As shown in column (b) of Table 8, the estimation results from regression analysis on the three-month CIP deviations over the alternative pre-crisis period are quite similar to those from using the pre-crisis period ending on 1 June 2007 in Section 5. The sole difference is the much more significant role of the CDS spread of Korean banks in the alternative and longer pre-crisis period. This is likely to reflect conditions specific to Korea. Some studies suggest that, due to massive FX hedging operations by exporters (especially shipbuilders), the dependence of Korean banks on short-term foreign funds via FX swaps increased at a rapid pace until mid-2007. This negatively affected the credit profile of Korean banks and then in turn affected CIP deviations. The estimation results from regression analysis over the alternative crisis periods are very similar (Table 9, column (b)) with a significant role for VIX and very similar policy effects.

In Table 10, column (b), we see that the estimation results from regression analysis on the three-year CIP deviations over the alternative pre-crisis period are similar to those of the original pre-crisis period, in that the CDS spread of Korean banks plays a significant role. One notable difference between the two pre-crisis periods is the significantly positive role of the CDS spread of US banks in the new pre-crisis period. This may reflect the weakened ability and willingness of US banks to provide US dollar liquidity into the long-term won-dollar cross-currency swap market, when they were facing a gradually heightened concern over counterparty risk in the US dollar cash market in the period between June and August 2007. Over the alternative crisis period, as before, we find the consistently significant role of the CDS spread of US banks as a driver of three-year CIP deviations and insignificant policy effects (Table 11, column (b)).

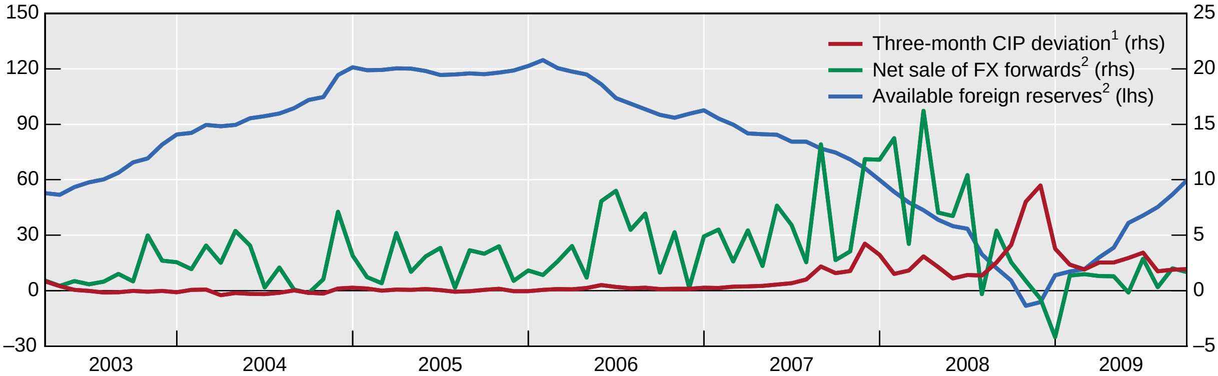
6.2 Discussion of other factors affecting CIP deviations

In our regression analysis, we do not include the (available) amount of official foreign reserves held by Korea and the amount of net sale of FX forwards by Korean companies. These two variables are potentially important in determining the CIP deviation. In particular, the available amount of foreign reserves works as a buffer against liquidity shocks faced by Korean banks borrowing in foreign currency. Here, we define the available foreign reserves as the total amount of reserves minus the sum of the short-term external debt (outstanding debt with original maturity less than one year) and the estimated value of the current debt (long-term debt with remaining time to maturity of less than one year).[17] Also, the net sale of FX forwards by Korean companies[18] can be a measure of excess demand for US dollar funds in the FX swap market.[19]

Figure 8 shows the co-movement of CIP deviations with the available amount of foreign reserves and the net sale of FX forwards by Korean companies. From the figure, it appears that foreign reserves are negatively related to CIP deviations from the time it started to increase in mid-2007, though the relation of the net sale of FX forwards by Korean companies is less clear.

Figure 8

Three-month CIP deviation, net sale of FX forwards, and available foreign reserves



[1] In percentage points. [2] In billions of US dollars.

Sources: Bank of Korea; Datastream; authors' calculations.

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[17] This is based on a rather conservative assumption that all current and short-term external debt is subject to withdrawal at the same time. Considering that the rollover ratio of external debt of Korea dropped below 50% at one point in 2008, we can redefine the available foreign reserves by assuming partial withdrawals. However, we expect the results would be qualitatively the same. Also, we do not know the exact amount of current external debt. Therefore, we use the value of current external debt as of the end of 2008 announced by the Korean authorities and calculate the share of the current external debt out of the total long-term external debt. We use this ratio for other periods, assuming that the maturity composition of long-term external debt did not change over time.

[18] Here, FX forward contracts include both onshore FX forward contracts and offshore FX forward contracts, but do not include FX swaps. Korean companies include both Korean exporting firms and non-bank financial institutions.

[19] When Korean companies sell more FX forwards than they purchase in the FX forward market, the US dollar/ Korean won FX forward rate increases, which in turn increases the forward discount rate in the FX swap market.

Since only monthly data are available for the net sale of FX forwards and foreign reserves and only quarterly data are available for the outstanding amount of Korea's external debt, we cannot include these variables in the regression analysis of the previous sections which were based on daily data. Instead, we run a simple OLS regression using the monthly data to check how these two variables are related to the movements of CIP deviations in both the pre-crisis and crisis periods.[20]

Table 12 suggests that during the pre-crisis period of March 2003 to May 2007, the amount of net sales of FX forwards by Korean companies was positively associated with the movement of the three-month CIP deviations, while the available amount of foreign reserves was not. By contrast, during the crisis period from June 2007 to September 2009, the available amount of foreign reserves was negatively associated with the CIP deviations whereas the amount of net sale of FX forwards no longer had a significant relationship.[21] Although other factors explored in earlier regressions may also be at play, the simple associations documented here suggest that during the crisis period, the loan auctions funded by the Fed, which effectively added to Korea's foreign reserves, contributed to reducing the CIP deviations in the three-month won-dollar FX swap market.

(Table 12)

Additional factors affecting three-month CIP deviations

Sample	**Mar 2003–Sep 2009**		**Mar 2003–May 2007**		**Jun 2007–Sep 2009**	
	No lag	**1-month lag**	**No lag**	**1-month lag**	**No lag**	**1-month lag**
Constant	3.5879***	3.5789***	0.1232	–0.0634	4.3416***	4.2383***
	(0.3261)	(0.3430)	(0.1545)	(0.1512)	(0.5620)	(0.5916)
Available foreign reserves	–0.0354***	–0.0344***	–0.0015	0.0006	–0.0448***	–0.0353**
	(0.004)	(0.0038)	(0.0016)	(0.0015)	(0.0134)	(0.0145)
Net sale of FX forwards	0.0444	0.0278	0.0394***	0.0320**	0.0293	–0.0189
	(0.0364)	(0.0381)	(0.0141)	(0.0138)	(0.0670)	(0.0753)
R squared	0.56	0.52	0.14	0.11	0.34	0.26
Observations	79	78	51	51	28	27

The numbers in parentheses are standard errors. ***, ** and * indicate that each parameter estimate is significantly different from zero at the 1%, 5% and 10% level, respectively.

[20] We use linear interpolation to convert quarterly data on external debt into monthly data.

[21] The estimated parameters are also economically significant: during the pre-crisis period, each USD 1 billion increase in the net sale amount of FX forwards corresponds to an increase in the CIP deviations of 3~4 basis points; during the crisis, each USD 1 billion decrease in the available foreign reserves corresponds to an increase of 3.5~4.5 basis points in CIP deviations.

7. Conclusion

In this paper, we identified the starting date of the crisis period in the won-dollar swap market in Korea using a regime-switching model. Then, we showed that during the crisis period, the level of overall global market uncertainty – as proxied by VIX – was the main factor explaining CIP deviations in the three-month FX swap market. We also find that banks' credit risk was a significant factor explaining the deviations in the three-year cross-currency swap market. The determinants of CIP deviations identified in this paper will help the relevant authorities understand the drivers of the turmoil in these important markets and give guidance on how to strengthen regulation or deepen these markets so as to mitigate these problems going forward.

Regarding the effectiveness of policy measures on reducing CIP deviations, we find that the BOK loans funded by the swap line with the Fed were much more effective than the BOK's swaps using its own foreign reserves. As discussed in CGFS (2010), this result suggests that a country's own foreign reserves and inter-central bank swap arrangements are far from perfectly substitutable. This result has important implications for the current G20 discussion on strengthening the global financial safety net. Even though large foreign reserves have certain merits as self-insurance, once a country faces a foreign liquidity run, swap lines with other central banks can have a very powerful effect in complementing the use of foreign reserves in stopping the run.

The Korean case also points to the dangers of relying on foreign currency borrowing; in particular, the risk of foreign currency maturity mismatch. In response to the crisis, the Korean authorities tightened the foreign currency liquidity regulations for domestic banks in January and July 2010 by fine-tuning the regulation on the foreign currency liquidity ratio, introducing mandatory minimum holdings of safe foreign currency assets and raising the ratio of mid- to long-term borrowing to mid- to long-term lending. Korean financial authorities also introduced limits on net aggregate FX forward positions that were applied to both domestic banks and foreign bank branches starting from October 2010.

It is important to note that foreign currency liquidity risk turned out to be a systemic risk in Korea: all banks faced the same liquidity problem at the same time because they all relied on foreign bank branches for US dollar funding. Moreover, individual Korean banks may have overestimated their ability to hedge foreign exchange risk and secure US dollar funding during the crisis, by relying on relatively thin foreign exchange derivatives markets in the Korean won. This aspect of systemic foreign currency liquidity risk is an extension of the "macroprudential" dimension of aggregate foreign currency mismatches in the banking system identified by Goldstein and Turner (2004). Therefore, it is crucial that foreign currency liquidity regulations and stress testing exercises take this systemic aspect of foreign currency funding liquidity risk into account, and allow for the impairment of foreign exchange derivatives markets in a crisis.

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