Covered Interest Parity Deviation and Counterparty Default Risk: US Dollar / Korean Won FX Swap Market

Hanbok Choi
Woori Investment & Securities

Young Ho Eom
Yonsei School of Business, Yonsei University

Woon Wook Jang*
College of Government and Business, Yonsei University

Don H. Kim
Board of Governors of the Federal Reserve System

ABSTRACT

We investigate how much of the CIP (covered interest parity) deviation observed in FX swap markets during the financial crisis can be explained by credit risk. To this end, we develop a structural model of defaultable FX swaps, applying the approach of Coval et al. (2009a, b) to the FX setting. Calibrating the model to Korean banks and US banks, we find that significant portions of the CIP deviation in the US Dollar / Korean Won FX swaps can be explained by counterparty risk; most of this effect is due to the counterparty risk of Korean banks (as opposed to US banks). The influence of counterparty default risk is pronounced especially for the period after the default of Lehman Brothers.

JEL classification: E44, F31, G24.

Keywords: Arrow-Debreu State Price, Counterparty Default Risk, Covered Interest Parity, Foreign Exchange Risk, FX Swap.

March 27, 2015

* Corresponding author. Address: College of Government and Business, Yonsei University, 1 Yonseidae-gil, Wonju, Gangwon-Do, 220-710, S. Korea; E-mail: zara2k@yonsei.ac.kr; Tel.: 033-760-2338; Fax: 033-760-2918.

Covered Interest Parity Deviation and Counterparty Default Risk: US Dollar / Korean Won FX Swap Market

ABSTRACT

We investigate how much of the CIP (covered interest parity) deviation observed in FX swap markets during the financial crisis can be explained by credit risk. To this end, we develop a structural model of defaultable FX swaps, applying the approach of Coval et al. (2009a, b) to the FX setting. Calibrating the model to Korean banks and US banks, we find that significant portions of the CIP deviation in the US Dollar / Korean Won FX swaps can be explained by counterparty risk; most of this effect is due to the counterparty risk of Korean banks (as opposed to US banks). The influence of counterparty default risk is pronounced especially for the period after the default of Lehman Brothers.

JEL classification: E44, F31, G24.

Keywords: Arrow-Debreu State Price, Counterparty Default Risk, Covered Interest Parity, Foreign Exchange Risk, FX Swap.

1. Introduction

One of many remarkable things that occurred during the recent financial crisis is the large and persistent deviation from the covered interest parity (CIP) relation in the FX swap markets. This effect has been extensively studied first by Baba and Packer (2009a, b), who found that the deviations are significantly associated with the differences in counterparty risk and that the reduction in funding liquidity has also played a role.

In this paper, we build on Baba and Packer (2009a, b) and explore how much the CIP deviation in the FX swap market can be explained by credit risk. Whereas Baba and Packer (2009a, b) examined the relationship between the CIP deviation and the CDS spread differential between domestic and foreign institutions in a statistical approach, we take a structural setup and investigate whether the credit risk implied by domestic and foreign institutions' financial asset price can produce the CIP deviation of the magnitude seen in the financial crisis. This question is interesting at least for two reasons: First, although credit risk in swap contracts have been studied for long, most of earlier studies have found only a small quantitative effect of counterparty risk on swap valuation.[1] It is thus interesting to investigate how (and whether) this conclusion changes in "crisis situation". Second, credit risk channel is not the only source of the CIP deviation. Indeed, Coffey et al. (2009) and Buraschi et al. (2011) have emphasized the problems with funding liquidity (limits to arbitrage) as the key factor in the CIP deviation. Therefore, an in-depth analysis of the credit risk contribution may help sort out the relative importance of these channels.

For concreteness, we focus on the US Dollar / Korean Won (USD/KRW) FX swap market, which (like many other FX swaps) showed a notable CIP deviation during the financial crisis period. We proceed in the bilateral defaultable swap pricing framework of Sorensen and Bollier (1994) and Hübner (2001, 2004). The default probabilities are modeled in a structural approach (a la Merton). To this end, we apply the novel approach of Coval, Jurek, and Stafford (2009a, b) to our setting: we take the Won-Dollar exchange rate as the relevant systematic risk factor, and

[1] See Duffie and Huang (1996), He (2000), Collin-Dufresne and Solnik (2001), Liu, Longstaff, and Mandell (2006), Feldhutter and Lando (2008).

compute the default probability given the realization of the systematic risk factor. This probability, along with the state price density computed from Won-Dollar FX options (analogously to Coval et al.), is used to compute the value of the FX swap.

We find that the counterparty risk of local banks (Korean banks) plays a major role in accounting for the CIP deviation. We also find that the influence of this counterparty risk is especially pronounced for the period after the default of Lehman Brothers. On the other hand, the risk coming from foreign banks (US banks)' creditworthiness has trivial effect. Regression analysis of residual errors shows that, during the periods after Lehman bankruptcy, global market uncertainty (CBOE VIX) and capital constraints of arbitrageurs (TED spread) could explain a portion of the remaining CIP deviations unexplained by the counterparty credit risk model of this paper.

The rest of this paper is organized as follows. In Section 2, we discuss the recent developments in the USD/KRW FX swap market and review the related literature. Section 3 describes our model, and Section 4 is devoted to the calibration of the model, including the discussion of the extraction of the Arrow-Debreu state price density. Section 5 discusses the empirical results and Section 6 concludes.

2. Background and Literature Survey

FX swaps are contracts in which one party borrows a currency from, and simultaneously lends a second currency to, another party. An FX swap can be viewed as two transactions: a spot foreign exchange transaction, and a forward foreign exchange transaction. Under no-arbitrage (and ignoring counterparty risk), one can easily derive the fair forward FX rate

$$F_{t,\tau} = S_t \exp\left\{\left(r_d - r_f\right)\tau\right\},$$

assuming continuous compounding, where $F_{t,\tau}$ denotes the time t fair forward FX rate with time-to-maturity of τ (i.e., maturity date $T = t + \tau$), S_t the spot FX rate, and r_d and r_f the domestic and foreign τ period zero-coupon yields, respectively. This equation is the celebrated covered interest parity (CIP) relation. The so-called swap point is the forward FX rate minus the spot FX rate, i.e., $F_{t,\tau} - S_t$.

A closely related swap contract is the currency swap contract. Currency swaps differ from FX swaps in that exchanges of cash flows in different currencies occur on a regular basis until the maturity. Because both FX swaps and currency swaps involve the exchange of principals, counterparty risk can play a greater role than in the case of interest rate swaps (IRS).[2] For example, Duffie and Huang (1996) notes that under plausible parameter settings, the effect of counterparty risk is about 10 times stronger in currency swaps than in IRS (though during normal times the effect could still be viewed as quantitatively small).

During the financial crisis, the FX swap markets displayed a notable deviation from the CIP, and it stands to reason that counterparty credit risk played a major role. Indeed, recent empirical studies such as Baba, Packer, and Nagano (2008), Baba and Packer (2009a, b), and Coffey et al. (2009) present evidence of the association between the CIP deviations and counterparty default possibilities in the FX swap market of major currency pairs. Figure 1 and Figure 2 show that a large CIP deviation occurred also in the USD/KRW FX swap market, and that the deviation had strong associations with the relative deterioration in local banks' creditworthiness measured by differences in 5 year CDS premium.

[Insert FIGURE 1 here]

[Insert FIGURE 2 here]

In Figure 1, the panel denoted as ‘Swap Point’ shows time series of the market-quoted mid closes for each Friday of the USD/KRW FX swap points for the 3 month maturity over the sample period. One can observe that, a majority of the time, the swap points show negative values. Actually, the USD/KRW FX swap points have on average been negative and the negative swap points are increasing in absolute values with maturities (-1.97, -3.09, -4.43, and -5.16 for

[2] The effect of counterparty risk in IRS is very small; see, e.g., Duffie and Huang (1996), He (2000), Collin-Dufresne and Solnik (2001), Liu, Longstaff, and Mandell (2006), Feldhutter and Lando (2007).

the maturities of 3, 6, 9, and 12 months, respectively). This implies that the USD/KRW FX swap point-implied USD interest rates have on average been larger than their KRW counterparts. In addition, the negative swap points mean that typical USD-funding parties in the USD/KRW FX swap, generally local Korean financial institutions, have on average had to pay a cost in terms of the KRW amount receivable at maturity, say, of 1.97 KRW per USD for securing USD at the effective date in a 3m USD/KRW FX swap.

A caution, however, is in order. Note that the ‘cost’ mentioned in the preceding paragraph is not, and should not be, interpreted literally as an irrevocable realized ‘loss’ because if the USD/KRW FX swap market had been arbitrage free and the market had worked right, the cost of 1.97 KRW per USD should have definitely been compensated by the rate differentials between the two currencies. That is, if the rate differentials between then-prevailing, actual USD and KRW interest rates had stood at the very levels implied by the market quoted USD/KRW FX swap points, then the USD-funding party in the USD/KRW FX swap could have perfectly hedged her position by investing the USD principal at the then-prevailing USD interest rate while having her rate of funding the KRW principal locked in at the then-prevailing KRW rate. Indeed, this is what CIP is all about. Remember, however, that as shown in the ‘IRS rates’ panel of Figure 1 and Figure 2 it was not the case for the USD/KRW FX swap market for some extended period of time and it have strong relation with the local banks' creditworthiness.

Note, however, that the credit risk (counterparty risk) in FX swaps is not the only explanation for the large and persistent CIP deviation. Baba and Packer (2009b), Coffey et al. (2009), and Buraschi et al. (2011) have stressed that the drying up of liquidity (limits to arbitrage) may have also played a major role. Thus, a careful assessment of counterparty default possibilities in FX swaps is needed to better understand the recent phenomenon of strong CIP deviation. Beyond this "positive" perspective, counterparty risk modeling in FX swap contracts takes on practical importance as a necessary part of an effective risk management by financial and other institutions with international funding needs.

Unfortunately, defaultable swap modeling is quite involved. As noted in Hübner (2001, 2004), the difficulties are well reflected in those assumptions frequently encountered in existing literature on defaultable swap pricing models. One simplifying assumption is that only one party is defaultable in a swap (Cooper and Mello, 1991; Baz, 1995; Li, 1998). However, the structural approaches taken by Cooper and Mello (1991) and Li (1998) with only one defaultable counterparty do not allow closed form solutions. Bilateral, though symmetric, default risks are accounted for in Duffie and Singleton (1997), who takes the reduced-form approach explained in detail in Duffie and Singleton (1999). Duffie and Huang (1996), again following the framework of Duffie and Singleton (1999), present a full-blown version of swap pricing model with the assumption of asymmetric bilateral default risks, which is in reality more in line with the industry practice of 'Full Two-Way Payment Rule' applied in the case of a counterparty default. But under Duffie and Huang (1996) there is no analytical solution, due to the recursive nature of the discounting scheme similar to that of pricing an American option. Note that by nature option pricing features slip in when pricing a defaultable swap (Sorensen and Bollier, 1994; Nandi, 1998). Following a reduced-form approach corresponding to that of Duffie and Singleton (1999), Hübner (2001, 2004) provides closed-form solutions to pricing interest rate swaps and currency swaps with asymmetric bilateral default risks, which are just a summation of terms similar to the option pricing formula by Longstaff (1990) and Black and Scholes (1973), respectively.

Most of the aforementioned literature on defaultable swap pricing models, including Cooper and Mello (1991), Li (1998), Duffie and Huang (1996), Hübner (2001, 2004) are focused on pricing, and do not go into empirical analysis with real data. Furthermore, their main focus is on interest rate swaps and currency swaps; the case of FX swaps is not explicitly discussed. Thus, not surprisingly, issues like the implication of counterparty risk for FX swap market CIP deviation have not been addressed in the extant literature on defaultable swap pricing.

In the present study, we follow the approach of Hübner (2001, 2004) to derive an expression for the value of bilateral-defaultable FX swap, and cast our model in the framework of Coval et al. (2009a, b) who made a novel use of state price density in S&P 500 index options to price credit risk in tranche CDO (Collateralized Debt Obligation). While Coval et al. (2009a, b) used stock index as the state variable, we use the exchange rate as the state variable, utilizing the state price density information in FX options.

3. Model for Pricing Defaultable USD/KRW FX Swap

In this section we develop a structural model of defaultable FX swaps, applying the approach of Coval et al. (2009a, b) to the FX setting.

A. The Economy

Analogous to Coval et al (2009a,b), let us assume a one-factor economy in which the log returns of the USD/KRW exchange rate and the individual firm value have the following dynamics under the physical measure (P-measure):

$$\ln\frac{S_T}{S_t} = \left(r_d - r_f + \lambda_S - \frac{\sigma_S^2}{2} \right)\tau + \sigma_S \sqrt{\tau} Z_S, \tag{1}$$

$$\ln\frac{A_{i,T}}{A_{i,t}} = \left(r_d + \lambda_i - \frac{\sigma_i^2}{2} \right)\tau + \beta_i \sigma_S \sqrt{\tau} Z_S + \sigma_i \sqrt{\tau} Z_i, \tag{2}$$

where S_t is the USD/KRW exchange rate, r_d denotes the KRW risk-free rate, r_f is the USD risk-free rate, λ_S is the USD/KRW FX risk premium, σ_S is the USD/KRW FX return volatility, and $\tau\left(=T-t\right)$ is the time to maturity. And $A_{i,t}$ denotes firm i's asset value at time t, λ_i is the asset risk premium, σ_i is the idiosyncratic volatility of firm i, and β_i is the loading of firm i's asset return on the USD/KRW FX return, which is analogous to the CAPM beta.

An important assumption we make is that, between the asset value and the market factor (i.e., USD/KRW exchange rate) there is a CAPM-like restriction on the excess returns. That is, we assume the following restriction holds:

$$\lambda_i - \frac{\sigma_i^2}{2} = \beta_i \left(\lambda_S - \frac{\sigma_S^2}{2} \right). \tag{3}$$

If we define

$$s_\tau \equiv \ln\frac{S_T}{S_t} - \left(r_d - r_f \right)\tau, \qquad (4),$$

then from equation (1) we have

$$\sigma_S \sqrt{\tau} Z_S = s_\tau - \left(\lambda_S - \frac{\sigma_S^2}{2} \right) \tau. \tag{5}$$

Furthermore, from (2) and (3),

$$\begin{aligned} A_{i,T}\left(s_\tau\right) &= A_{i,t} \exp\left\{ \left(r_d + \lambda_i - \frac{\sigma_i^2}{2} \right) \tau + \beta_i \sigma_S \sqrt{\tau} Z_S + \sigma_i \sqrt{\tau} Z_i \right\} \\ &= A_{i,t} \exp\left\{ \left(r_d + \lambda_i - \frac{\sigma_i^2}{2} \right) \tau + \beta_i \left[s_\tau - \left(\lambda_S - \frac{\sigma_S^2}{2} \right) \tau \right] + \sigma_i \sqrt{\tau} Z_i \right\} \\ &= A_{i,t} \exp\left\{ r_d \tau + \beta_i s_\tau + \sigma_i \sqrt{\tau} Z_i \right\}. \end{aligned} \tag{6}$$

Thus, assuming that firm i is allowed to go bankrupt only at time of maturity T, one can derive the following conditional probability of default given s_τ for firm i at maturity, $p_i^{Default}\left(s_\tau\right)$, using equation (6):

$$\begin{aligned} p_i^{Default}\left(s_\tau\right) &= \mathrm{Prob}\left[A_{i,T}\left(s_\tau\right) < D_i \right] \\ &= \mathrm{Prob}\left[A_{i,t} \exp\left\{ r_d \tau + \beta_i s_\tau + \sigma_i \sqrt{\tau} Z_i \right\} < D_i \right] \\ &= \mathrm{Prob}\left[Z_i < \frac{\ln\left(D_i / A_{i,t}\right) - \left(r_d \tau + \beta_i s_\tau\right)}{\sigma_i \sqrt{\tau}} \right], \end{aligned} \tag{7}$$

where $D_i / A_{i,t}$ is firm i's initial debt-to-asset ratio.

B. Defaultable FX swap pricing

We now turn to the valuation of the USD/KRW FX swap in conjunction with the setup of the economy described above.

According to Sorensen and Bollier (1994) and Hübner (2001, 2004), the formula for valuing a swap with counterparty default risks can be represented as a combination of call/put options depending on the signs of expected cash flows receivable; Hübner, in particular, derived explicit formulae for the valuation of interest rate swaps and currency swaps.

When it comes to valuing an FX swap, things get simpler, as there is only one future cash flow that can occur in an FX swap. For example, a ‘Buy-and-Sell’ USD/KRW FX swap is an

OTC contract, under which the 'Buying' party agrees with the counterparty to buy at the effective date of the swap a specific amount of USD at the then-prevailing USD/KRW foreign exchange rate with the promise that at maturity she will sell the USD at the predetermined exchange rate, or the strike price.[3] Thus, when it comes to valuing a USD/KRW FX swap, only the final exchange of cash flows matters and the predetermined exchange rate is the very rate at which the present value of the promised final exchange of cash flows is set to equal zero. Consequently, by convention the last and only cash flows exchanged at maturity are the ones that are affected by the possibility of counterparty default.

Let T, A, and B denote respectively the maturity, party A, and party B of a given USD/KRW FX swap. Assuming that defaults can occur only at the maturity of the swap, we can formulate in the spirit of Hübner (2001, 2004) that from the perspective of party A the value of the FX swap (vulnerable to the risk of B's default), $V(t)$, is given by:

$$V(t) = V_+(t) - V_-(t), \tag{8}$$

where

$$\begin{aligned} V_+(t) = & \int_{-\infty}^{\infty} (1-\xi_B) p_B^{Default}(s_\tau) \cdot \max\left\{ D_T^A(s_\tau) - D_T^B(s_\tau), 0 \right\} q(s_\tau) ds_\tau \\ & + \int_{-\infty}^{\infty} \left(1 - p_B^{Default}(s_\tau)\right) \cdot \max\left\{ D_T^A(s_\tau) - D_T^B(s_\tau), 0 \right\} q(s_\tau) ds_\tau \end{aligned} \tag{9}$$

and

$$\begin{aligned} V_-(t) = & \int_{-\infty}^{\infty} (1-\xi_A) p_A^{Default}(s_\tau) \cdot \max\left\{ D_T^B(s_\tau) - D_T^A(s_\tau), 0 \right\} q(s_\tau) ds_\tau \\ & + \int_{-\infty}^{\infty} \left(1 - p_A^{Default}(s_\tau)\right) \cdot \max\left\{ D_T^B(s_\tau) - D_T^A(s_\tau), 0 \right\} q(s_\tau) ds_\tau . \end{aligned} \tag{10}$$

Here $D_T^i(s_\tau)$ for $i = A, B$, denotes the cash flow entitled to party i at time T, ξ_i for $i = A, B$, is the fractional loss given default, and $q(s_\tau)$ is the Arrow-Debreu state prices implied by the OTC USD/KRW FX options.

To be more concrete, let the FX swap strike be denoted by K. And assume that in the swap, party A is the USD seller at maturity. Then, equation (9) and (10) can be rewritten as follows:

[3] In a 'Sell-and-Buy' swap, the opposite holds.

$$V_+(t) = \int_{-\infty}^{\infty}(1-\xi_B)p_B^{Default}(s_\tau)\cdot \max\{K - S_T(s_\tau), 0\} q(s_\tau) ds_\tau \\ + \int_{-\infty}^{\infty}\left(1 - p_B^{Default}(s_\tau)\right)\cdot \max\{K - S_T(s_\tau), 0\} q(s_\tau) ds_\tau \tag{11}$$

and

$$V_-(t) = \int_{-\infty}^{\infty}(1-\xi_A)p_A^{Default}(s_\tau)\cdot \max\{S_T(s_\tau) - K, 0\} q(s_\tau) ds_\tau \\ + \int_{-\infty}^{\infty}\left(1 - p_A^{Default}(s_\tau)\right)\cdot \max\{S_T(s_\tau) - K, 0\} q(s_\tau) ds_\tau. \tag{12}$$

In summary equation (8), (11), and (12) can be reduced to

$$V(t) = \int_{-\infty}^{\infty}\left(1-\xi_B p_B^{Default}(s_\tau)\right)\cdot \max\{K - S_T(s_\tau), 0\} q(s_\tau) ds_\tau \\ - \int_{-\infty}^{\infty}\left(1 - \xi_A p_A^{Default}(s_\tau)\right)\cdot \max\{S_T(s_\tau) - K, 0\} q(s_\tau) ds_\tau. \tag{13}$$

The forward exchange rate $F_{t,\tau}$ is the value of K that makes $V(t)$ zero.

Remember that in our model the state of nature is completely determined by the single market factor, namely the USD/KRW exchange rate. Thus, in order to value a defaultable USD/KRW FX swap using equation (13) we need to be first equipped with a set of state price densities, $q(s_\tau)$, and firm i's default probabilities conditional on the market state represented by s_τ, developed in equation (7). Then, with those two ingredients in hand, our strategy is just to integrate equation (13) with respect to s_τ to reach $V(t)$.

C. State Price Densities

For extracting the state price density $q(s_\tau)$ implied by USD/KRW FX options, we follow the method of Coval et al. (2009a, b), who show how one could get a complete set of Arrow-Debreu state price densities analogous to that of Breeden and Litzenberger (1978) taking into account the implied volatility skew observed in the options market, which is as follows:

$$q(s_\tau) = \left.\frac{\partial^2 C^{BS}\left(K, \sigma(K,\tau), \tau\right)}{\partial K^2}\right|_{K = x\cdot F_{t,\tau}} \\ = \left.\frac{\partial^2 C^{BS}}{\partial K^2} + \left(\frac{\partial \sigma}{\partial K}\right)\left[2\frac{\partial^2 C^{BS}}{\partial K \partial \sigma} + \frac{\partial^2 C^{BS}}{\partial \sigma^2}\cdot\frac{\partial \sigma}{\partial K}\right] + \left(\frac{\partial^2 \sigma}{\partial K^2}\right)\frac{\partial C^{BS}}{\partial \sigma}\right|_{K = x\cdot F_{t,\tau}}, \tag{14}$$

where $x=\exp\{s_\tau\}$ denotes the moneyness level and $F_{t,\tau}=S_t\exp\left\{\left(r_d-r_f\right)\tau\right\}$, is the forward price. In equation (14) C^{BS} represents the USD/KRW FX option prices using the Black-Scholes formula and $\sigma\left(x,\tau\right)$ is a specification for the implied volatility function to capture the volatility smirk. Note that the Arrow-Debreu state price density in equation (14) is a function of the slope and curvature of the USD/KRW FX option implied volatility smile, the co-variation effect of changes in the option strike and implied volatility on C^{BS}, and their products with the option vega and vega of vega. Of course, if the option volatility is flat across all strike levels, only the first term remains, implying a normal distribution for the option underlying returns.

For the specification of the implied volatility function, Coval et al. (2009a, b) applied the one based on the hyperbolic tangent function ('tanH' model, hereafter) which takes the form:

$$\sigma\left(x,\tau\right)=a+b\cdot\tanh\left(-c\ln x\right),\ \ \left(a>b>0\right). \tag{15}$$

One of attractive features of tanH model is that this function is bounded above and below, allowing us to control the magnitude of the implied volatility outside of the domain of strike prices for which we observe option prices. However, this functional form has a characteristic which rather meets the stylized facts for long-dated options.[4] Note that we are interested in the FX options and of which maturities are less than one year. Therefore, in addition to the tanH model, we also apply the stochastic volatility inspired model ('SVI' model, hereafter) proposed by Gatheral (2004) to have a more flexible form for the volatility smile:

$$\sigma^2\left(x,\tau\right)=a+b\left\{\rho\left(x-m\right)+\sqrt{\left(x-m\right)^2+s^2}\right\}, \tag{16}$$

here a gives the overall level of variance, b gives the angle between the left and right asymptotes, s determines how smooth the vertex is, ρ determines the orientation of the graph, and changing m translates the graph.

[4] The tanh model generates an approximately linear skew for options close to at-the-money strike prices and linear skew is the stylized facts for long-dated options.

4. Calibration of the Model

For the pricing of the defaultable USD/KRW FX swap summarized in the equation (13) we calculate Arrow-Debreu state price densities applying the tanH and SVI implied volatility models to the equation (14). We also need to calculate firm's default probabilities conditional on the market state. This section details each calibration procedure.

A. Extraction of the Arrow-Debreu State Price Density

Fitting of Implied Volatility Functions

In foreign exchange markets, options are quoted using the Black-Scholes implied volatility with their corresponding option delta(Δ) as a measure for exercise price. The most liquid option markets are those for at-the-money forward and for 25- and 10-delta calls and puts.[5]

In this paper we use Bloomberg FX option quotes. Table 1 shows the descriptive statistics for market quoted USD/KRW FX option-implied volatilities on each day for the 5 moneyness levels of 10Δ Put, 25Δ Put, ATM, 25Δ Call and 10Δ Call during the sample period from January 3, 2006 to December 30, 2010.

[Insert TABLE 1 here]

[Insert TABLE 2 here]

With the market quoted volatility for maturities of 3, 6, 9 and 12 month for each 5 moneyness levels (10Δ Put, 25Δ Put, ATM, 25Δ Call and 10Δ Call), we estimate 3 parameters of the tanH model and 5 parameters of the SVI model by minimizing the square root of mean squared pricing errors, respectively. Out of a total of 1,245 days during the sample period, 1,238

[5] In FX options market a delta is represented without the "%" notation, so that a 25Δ call means a call option whose delta is 0.25. Similarly, a 25Δ put is a put option whose delta is -0.25.

observation days for 3m, 1,239 for 6m, 1,160 for 9m and 1,231 for 12m are used in estimation. The difference in the number of observations is due to discrepancies in the number days for which all the 5 implied volatility quotes are available for each maturity.

Table 1 shows the descriptive statistics for the tanH and SVI model-fitted implied volatilities and the root mean square error (RMSE) of each model and the estimated parameters of each model are reported in Table 2. As can be seen in the RMSE columns for each implied volatility model in Table 1, the performance of SVI model is better than that of the tanH model in all maturities and moneynesses.. The relatively poor fit of the tanH model compared to the good fit of the SVI model is attributable in part to the inflexible shape of the hyperbolic tangent function as an implied volatility model for the maturity less than 1 year. However, we also applied it to the following analyses to show robustness of our results.

Extraction of State Price Density

With the fitted parameters of equations (15) and (16), we obtain a complete set of USD/KRW FX option-implied Arrow-Debreu state price densities for each day and for each maturity using equation (14).

Figure 3 shows typical shapes of extracted state price densities for two days, before and after the financial crisis. These densities are nothing but an overall summarization of market participants' views, or market consensus, on the state of nature implied by USD/KRW FX option premiums. As we can notice in Figure 3 the shapes of densities have been changed from a rather symmetric one to the extremely skewed one. Actually, just after the signing of a merger agreement under which JP Morgan acquired Bear Stearns (March 16, 2008) the shape have been started to skew to the right, and far more skewed after the Chapter 11 bankruptcy petition filed for by Lehman Brothers in less than half a year. It is exactly at around that time the unprecedentedly large CIP deviations began to be observed in major currency pairs.

[Insert FIGURE 3 here]

What the figures in the right columns of Figure 3 reveal is that at around that time, USD/KRW FX options market participants began to take quite an asymmetric stance in their assessment on the direction of the future USD/KRW FX rates, witnessed by the highly flattened, positively-skewed densities. This in turn means that the market participants began to set remarkably higher-than-before prices in the Arrow-Debreu sense to the states of nature associated with higher USD/KRW FX rates. It is not a mere coincidence that the Arrow-Debreu state price densities implied by the USD/KRW FX options market went through the notable changes at the same time that the USD/KRW FX swap market began to suffer from unprecedented dislocations as shown by Figure 1 and Figure 2 in the introduction. This is exactly what we purpose to examine in this paper via a defaultable FX swap pricing model, which can hopefully provide some clues to understanding the interaction between the rapid changes in the USD/KRW FX market participants' assessment of the future state of nature and the USD/KRW FX swap value.

B. Firm Value Dynamics

Given state price densities, we compute firm i's conditional probability of default at time T given s_τ. To this end, we need to calibrate 3 firm-specific parameters appearing in equation (7): firm i's asset volatility, σ_i, the sensitivity of asset value to the USD/KRW FX rate, β_i, and debt-to-asset ratio, $D_i / A_{i,t}$.

As individual firms to be applied to the calibrations, we select 3 Korean local banks (KB financial group (KB); Shinhan financial group ltd. (SH); and Woori finance holdings co. (WR)) and 3 global banks (JP Morgan Chase & Co (JPM); Bank of America Corp (BOA); and Deutsche bank AG (DB)) which are known as major players in the USD/KRW FX markets.

For the calibrations of σ_i and β_i we use two different approaches. First one is to use firm i's equity values as a proxy for its asset values. We estimate asset volatility using 120 days (and 252 days) of historical equity return data and regress it on the changes of FX rates to calculate β_i. However, since equity volatility is generally larger than that of asset, this can overstate the asset volatility, so the default probability of the firm might be also overstated. Second way is to filter out asset value processes and its return volatilities using Merton's (1974) bond pricing model (Crosbie and Bohn, 2003; Bharath and Shumway, 2008). Then, β_i is obtained by regressing filtered asset value processes on the changes of FX rates. We briefly summarize this method.

Merton (1974) assumes that a firm value follows geometric Brownian motion and only one bond with maturity T and face value K_i has been issued by the firm. Then, by put-call parity and Ito's lemma, the unobservable firm i's asset value, A_i, and the volatility of asset returns, σ_i, have the following relation with its observable equity price, E_i, and the volatility of equity returns, $\sigma_{E,i}$:

$$E_i = A_i N(d_1) - e^{-rT} N(d_2) \tag{17}$$

$$\sigma_{E,i} = \frac{A_i}{E_i} \sigma_i N(d_1) \tag{18}$$

where $N(\cdot)$ denotes the cumulative standard normal distribution function; r is the risk-free rate, $d_1 = \left\{ \ln(A_i / K_i) + (r + 0.5\sigma_i^2)T \right\} / (\sigma_i \sqrt{T})$ and $d_2 = d_1 - \sigma_i \sqrt{T}$.

Following Crosbie and Bohn (2003) and Bharath and Shumway (2008), we assume 1 year maturity of the bond ($T = 1$); estimate $\sigma_{E,i}$ from historical 1 year of equity returns; and take the face value of the debt as the sum of the book values of current liabilities and a half of the long-term liabilities (we denote this case as 'CL' hereafter). We also estimate the case when all book values of debt account are used as the face value of the only debt ('All' hereafter). Then we can solve equation (17) and (18), simultaneously, to find A_i and σ_i.[6]

Given book values of debt (CL or All) and filtered asset values, we can directly calculate the debt-to-asset ratio at date t, $D_i / A_{i,t}$. In this paper we also apply an alternative procedure for

[6] Alternatively, we could have calculated asset value and its return volatility following the more complicated iterative procedure introduced in Bharath and Shumway (2008). However, Bharath and Shumway (2008) report that the simultaneously solved one has better performance in the out-of-sample prediction test than the iteratively solved one.

the calibration of the debt-to-asset ratio: given σ_i and β_i, the debt-to-asset ratio, $D_i / A_{i,t}$, is extracted from firm i's 1 year market CDS (Credit Default Swap) premium quotes.[7] [8]

Figure 4 shows time series behaviors of the filtered asset value and the 3 firm value parameter estimates for KB financial groups (local Korean bank) and JP Morgan Chase (US bank). Figure 4 is the results when σ_i is obtained by applying Merton (1974) model, β_i is estimated with 120 days of filtered asset value, and $D_i / A_{i,t}$ is calculated from the debt value (CL) with filtered asset value.

[Insert FIGURE 4 here]

In panel (a) of Figure 4 the asset values of KB show decreasing pattern from the beginning of the recent crisis, and then plummet near the time of Lehman failure. At that time the asset volatility of KB increase with a greater fluctuation than before and this pattern continue till the end of third-quarter of the year 2009.

The panel (b) of Figure 4 shows the estimates of the asset beta proxy and the initial debt-to-asset ratio, respectively. As for the asset beta proxies we find that the loadings of KB financial

---

7 To this end, we make the following simplifying assumptions regarding the terms of the relevant CDS: 1) during the 1 year life of the CDS, the specified credit events of the reference entity could fall only on each quarterly premium payment date; 2) the LGD (Loss Given Default) is assumed to be constant and set to equal 60% of the CDS notional amount; 3) the LGD is paid in cash at the same time of the default; 4) the relevant parties entering into the CDS is default-free. With these assumptions, the 1 year fair CDS premium, $CDS_{1\text{year}}$, can be written as follows:

$$CDS_{1\text{year}} = \frac{0.6\sum_{\tau}\int_{-\infty}^{\infty}\left[Q\left(s_{\tau-0.25}\right)-Q\left(s_{\tau}\right)\right]q\left(s_{\tau}\right)ds_{\tau}}{0.25\sum_{\tau}\int_{-\infty}^{\infty}Q\left(s_{\tau}\right)q\left(s_{\tau}\right)ds_{\tau}}, \qquad \text{where} \qquad Q\left(s_{\tau}\right)=1-N\left[\frac{\ln\left(D_i / A_{i,t}\right)-\left(r_d\tau+\beta_i s_{\tau}\right)}{\sigma_i\sqrt{\tau}}\right],$$

and where $\tau \in \{0.25, 0.5, 0.75, 1\}$. Here $Q\left(s_{\tau}\right)$ denotes 1 minus firm i 's conditional probability of default at time T given s_{τ}, or conditional survival probability, with $Q\left(s_0\right)=1$.

8 With regard to the use of CDS premium in the estimation one may argue that, if counterparty risk is important for the pricing of the FX swaps, it would be also relevant in the setting of CDS. Actually Arora et al. (2012) reports that there is a significant relation between the credit risk of dealer and dealer's selling prices of credit protection. However they also show that the effect on CDS spreads is negligible. In particular, an increase in the dealer's credit spread of 645 basis points only translates into a one basis point decline on average in the dealer's spread for selling credit protection. We also note that FX swap contracts involve the exchange of principals while it is not the case for the CDS contracts, so a probable counterparty credit risk in the CDS contracts is incomparable to that of the FX swap contracts. Based on these reasons we assumed the relevant parties entering the CDS are default-free.

group with respect to the USD/KRW FX rates are negative for the whole sample period, which means that at least for the sample period of this study the asset value of KB financial group on average goes downward when the USD/KRW FX rate moves upward. This characteristic of estimated betas for the other local banks (SH and WR) are qualitatively similar to that of KB. And in fact this is what has been normally observed in the Korean stock market. On the other hand, the asset value sensitivities of 3 global banks with the USD/KRW FX rates do not show any specific sign, and an example for the JPM case can be found in the panel (d) of Figure 4. Lastly, the debt-to-asset ratio shows increasing and then decreasing pattern for both local and global banks as can be seen in the panel (b) and (d) for the KB and JPM case, respectively.

Now that we are equipped with all the relevant parts, i.e., Arrow-Debreu state price densities and the 3 parameter estimates governing firms' asset dynamics, in Section 5 we price USD/KRW FX swaps explicitly accounting for counterparty default possibilities, and investigate the relationship between counterparty creditworthiness and the USD/KRW FX swap point term structure.

5. Empirical Results

A. Defaultable FX Swap Implied USD Interest rates

In this section, we report 3 versions of defaultable FX swap implied USD interest rates for the 4 maturities of 3m, 6m, 9m, and 12m using the set of Arrow-Debreu state price densities extracted in Section 4. In the valuation of FX swap several combinations of calibration methods for 3 firm-specific parameters and implied volatility models (SVI or tanH) are applied to equation (13) and (14), and all 20 cases of combinations used in this paper are summarized in Table 3.

Figure 5 shows the time series of market quoted FX swap implied USD rates and model-implied ones for the case of KB as a local bank and JPM as a global bank. Here we applied the 1st calibration method in Table 3 and the results for the other combinations of calibration methods are reported in Table 4 as a root-mean-square-error (RMSE). For the other combinations of banks we only report averages of the RMSEs of the 20 combinations of calibration methods in Table 5 to save space.

[Insert FIGURE 5 here]

[Insert TALBE 4 here]

[Insert TALBE 5 here]

‘Market’ in Figure 5 is the market FX swap points implied USD interest rate and ‘Libor’ is the market quoted USD Libor, which the USD/KRW FX swap market participants conventionally use as the reference for the USD interest rates. If the CIP condition holds, then the differences between the ‘Market’ interest rate and ‘Libor’ should be close to, or ideally equal to, zero. Figure 5 shows that this is not the case and the RMSEs in the ‘Libor’ columns in Table 4 and Table 5 also show that FX swap implied rate is way far from the actual Libor for the whole sample period; this indicates that the violations of CIP in the USD/KRW FX swap market are quite severe.

In Figure 5, ‘L1G0’, ‘L0G1’, and ‘L1G1’ are theoretical USD/KRW FX swap points implied USD interest rates obtained by substituting into equation (13) the USD/KRW FX options market-implied Arrow-Debreu state price densities and the 3 parameter estimates governing each firm’s asset dynamics. In Table 4 and Table 5 the numbers in the columns of L1G0, L0G1, and L1G1 are the RMSEs between the market FX swap points implied USD interest rate and each model rate.

L1G0[9] is calculated incorporating the state dependent default possibilities of the USD paying party at maturity (i.e. local Korean banks), while L0G1 is calculated assuming default possibilities of the KRW paying party at maturity (i.e. global banks). Lastly, L1G1 is computed assuming that both parties of the USD/KRW FX swap are defaultable at maturity but with

[9] Here the letters ‘L’ and ‘G’ denote a local Korean bank and global US bank, respectively.

asymmetric degrees of creditworthiness. So, in calculating L1G1 both the USD paying party and KRW paying party at maturity are assumed to be defaultable as well.

From the Figure 5 and from the columns of L1G0 in Table 4 and Table 5 it can be seen that a sizable portion of CIP violations observed in the USD/KRW FX swap market is attributable to the possibilities of counterparty defaults, especially the creditworthiness of the USD paying party (local Korean bank). In Figure 5, what's more intriguing is that the influences of counterparty creditworthiness on the USD/KRW FX swap points are concentrated on the period since the collapse of Lehman. On the other hand, the columns of L0G1 in Table 4 and Table 5 show that the influence of creditworthiness of the KRW paying (global bank) party is comparatively smaller than that of USD paying party. To be specific, in the 3m USD/KRW FX swap, the RMSE of L1G0 for the sample period since Lehman failure stays at 1.81%, while that of L0G1 is 3.15% which is close to the RMSE of Libor, 3.08%. This suggests that out of the total CIP deviations the default possibilities of local banks take a substantial amount of portion.

Figure 5 also shows that L1G1 implied rate follows closely the path of L1G0 implied rate and for some period these two are indistinguishable. Nevertheless, we can find that the L1G1 implied rates are rather lower than L1G0 implied rates. This is due to the fact that if we consider the default possibilities of both banks then default risks of each bank make a netting effect on the FX swap price, so the counterparty default risk effect to the FX swap is diminished. This characteristic also explains why, for some period time, L0G1 implied rates are lower than the market quoted labor. The relationship among model implied rates also can be seen in Table 4 and Table 5 as a number: generally, the RMSEs of L1G0 is smallest among them, followed by RMSEs of L1G1; and almost all combinations, RMSEs of L0G1 is larger than that of market quoted Libor.

In summary, we find that at least for the sample period after Lehman failure, the counterparty creditworthiness did work as a major factor influencing the USD/KRW FX swap points, serving to exacerbate the violations of the CIP condition observed during the recent financial crisis to an unprecedented extent. This is in line with the regression-based findings by existing researches such as Baba, Packer, and Nagano (2008) and Baba and Packer (2009a, b).

B. Regression Analysis

Examining Figure 6, Table 4, and Table 5, it can be seen that still a substantial portion of the total CIP violations remains unexplained. Thus, we perform a set of regressions to understand better what the pricing errors are composed of.

We use the unexplained CIP deviation as a dependent variable, which is the difference between the market basis and the model implied basis:

$$\text{Market Basis} = \left(\text{KRW Libor} - \frac{1}{\tau} \ln \frac{F_{t,\tau}}{S_t} \right) - \text{USD Libor}. \tag{16}$$

$$\text{Model Implied Basis} = \left(\text{KRW Libor} - \frac{1}{\tau} \ln \frac{F_{t,\tau}^*}{S_t} \right) - \text{USD Libor}. \tag{17}$$

Here $F_{t,\tau}$ is the market quoted forward rate and $F_{t,\tau}^*$ is the L1G0 model-implied forward rate.

The explanatory variables are selected based on the findings of existing literatures (see Baba et al., 2008; Baba and Packer, 2009a, b; Baba and Shim, 2014; Buraschi et al., 2011; Coffey et al., 2009). The previous studies have tried to explain the CIP deviation by broadly two categories of variables. One class of variables is proxies for capital constraints of arbitrageurs to exploit arbitrage opportunities and the other class consists of proxies for heightened counterparty credit risk in the crisis period. In our regression analysis the MBS-GC repo spread and the TED spread are used as proxies for capital constraints of arbitrageurs. Here MBS-GC spread is defined as 3-month agency MBS repo rate minus General Collateral (GC) repo rate, which is a rate differential of collateralized loan. On the other hand, the TED spread (3-month LIBOR rate minus 3-month Treasury bill rate) is rate differential of uncollateralized loan. As proxies for counterparty credit risk 5 year CDS premium of local and global banks are used. We conduct the standard unit root tests and results in Table 6 suggest that all the variables seem to have unit root, except for MBS-GC spread, CDS spread of Deutsche bank, and unexplained CIP deviation for 3m and 6m. However these 4 variables also show unit root in the augmented Dicky-Fuller test. To be conservative we use first-differenced variables for all analysis hereafter.

[Insert TALBE 6 here]

We only report the result when L1G0 model is calculated with KB as a local bank and JPM as a global bank. The other banks combinations show qualitatively similar results to the reported case here. Table 7 shows results from regressions of the unexplained CIP deviations of each maturity on the 5 year CDS premium of KB financial group and JP Morgan Chase, the CBOE VIX, the TED spread, and the MBS-GC repo spread. The regression is estimated for the whole sample period and for the 4 sub-sample periods: pre-crisis period (Jan. 2, 2006 – June 1, 2007), turmoil period (June 4, 2007 – Sep. 12, 2008)[10], after Lehman failure period (Sep. 16, 2008 – Dec. 1, 2008), and Fed swap line period (Dec. 2, 2008 – Dec. 30, 2009).[11]

[Insert TALBE 7 here]

Panel A of Table 7 shows results for the whole sample period. The CDS spread of JP Morgan Chase show significant estimates for all month maturities, and which are all negative. As we discussed above this is because a heightened credit risk of the global banks may lower the implied USD rates. However, significance of the estimates suggests that our model has a limitation in capturing credit risk of the global banks. CBOE VIX show significant and positive estimates for all month maturities, meaning that global market uncertainty has a strong effect on the CIP deviation for the whole sample period.

For the first two sub-periods shown in the panel B and C Table 7 there is no variable with the explanatory power over the all maturities. Panel D of Table 7 shows results for the after-Lehman-bankruptcy period. The CBOE VIX and Ted spread are estimated positively and significantly for all month maturities, which means that global market uncertainty and the capital constraints of arbitrageurs have affected CIP deviations. Significance of the estimates for the

[10] We follow Baba and Shim (2014) who did a structural break analysis of CIP deviation and identified June 4, 2007 as the starting date of the recent crisis.

[11] After the Lehman bankruptcy, Korean government provided US dollar liquidity to exporting enterprises and banks with its own foreign reserve. And from December 2, 2008, liquidity was provided by a series of auctions using the dollar proceeds of swap transactions with the Fed. Baba and Shim (2014) reported that the latter was effective in reducing CIP deviations, whereas the former was not.

CBOE VIX hold to the Fed-swap-line period in panel E of Table 7 for all maturities, while that of the Ted spread have disappeared for the 3m and 6m maturities. This is consistent with the founding of Baba and Shim (2014), who report that liquidity provision from the proceeds of swaps with the Fed were effective in reducing CIP deviations for the 3 month maturity market.

6. Conclusion

In this study we presented a model for pricing defaultable FX swaps. Using the model in combination with real market data, we price the USD/KRW FX swap under counterparty default possibilities; this enabled us to directly measure the influence of counterparty creditworthiness on the unprecedentedly severe CIP violations observed in the USD/KRW FX swap market during the recent financial dislocations.

Our model, though yielding a highly tractable semi-analytical solution, assumed only one market factor to account for both of the FX and firms' asset movements. This indeed is somewhat restrictive, considering the potentially complication interaction between the FX and firms' asset dynamics. One possible extension of our model could be to incorporate another market factor, for example, a state variable representing the market index, which works as the market portfolio that governs the firms' asset returns and affects the FX as well.

References

Arora, N., Gandhi, P., and Longstaff, F. A., 2012, Counterparty Credit Risk and the Credit Default Swap Market, *Journal of Financial Economics*, 103, 280-293.

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

Baba, N. and F. Packer, 2009a, Interpreting Deviations from Covered Interest Parity during the Financial Market Turmoil of 2007-08, *Journal of Banking & Finance*, 33, 1953–1962.

Baba, N. and F. Packer, 2009b, From Turmoil to Crisis: Dislocations in the FX Swap Market before and after the Failure of Lehman Brothers, *Journal of International Money and Finance*, 28, 8, pp1350-1374.

Baba, N. and I. Shim, 2014, Dislocations in the Won-Dollar Swap Markets during the Crisis of 2007-09, *International Journal of Finance and Economics,* doi: 10.1002/ijfe.1492.

Bharath, S. and T. Shumway, 2008, Forecasting Default with the Merton Distance to Default Model, *Review of Financial Studies*, 21, 3, pp 1339-1369.

Baz, J., 1995, Three Essays on Contingent Claims, Ph.D. Dissertation, Harvard University, Cambridge, MA.

Black, F. and M. Scholes, 1973, The Pricing of Options and Corporate Liabilities, *Journal of Political Economy*, 81, pp. 637-654.

Breeden, D. and R. Litzenberger, 1978, Prices of State-Contingent Claims Implicit in Option Prices, *Journal of Business*, 51, pp. 621-651.

Buraschi, A., E. Sener, and M. Menguturk, 2011, The Dynamics of Limits to Arbitrage: An Empirical Investigation, Working paper.

Coffey, N., W. Hrung, H. Nguyen, and A. Sarkar, 2009, Capital Constraints, Counterparty Risk and Deviations from Covered Interest Rate Parity, Working paper.

Collin-Dufresne, P. and B. Solnik, 2001, On the Term Structure of Default Premia in the Swap and LIBOR Markets, *Journal of Finance*, 56, pp. 1095-1115.

Cooper, I. and A. Mello, 1991, The Default Risk on Swaps, *Journal of Finance*, 46, pp. 597-620.

Coval, J., J. Jurek, and E. Stafford, 2009a, Economic Catastrophe Bonds, *American Economic Review*, 99, pp. 628-666.

Coval, J., J. Jurek, and E. Stafford, 2009b, The Pricing of Investment Grade Credit Risk during the Financial Crisis, Working Paper, Harvard University, Cambridge, MA.

Crosbie, P. and J. Bohn, 2003, Modeling Default Risk: Modeling Methodology. Moody's KMV.

Duffie, D. and M. Huang, 1996, Swap Rates and Credit Quality, *Journal of Finance*, 51, pp. 921-949.

Duffie, D. and K. Singleton, 1997, An Econometric Model of the Term Structure of Interest Rate Swap Yields, *Journal of Finance*, 52, pp. 1287-1381.

Duffie, D. and K. Singleton, 1999, Modeling Term Structures of Defaultable Bonds, *Review of Financial Studies*, 12, pp. 687-720.

Feldhutter, P. and D. Lando, 2008, Decomposing Swap Spreads, *Journal of Financial Economics*, 88, 375-405.

Gatheral, J., 2004, A Parsimonious Arbitrage-free Implied Volatility Parameterization with Application to the Valuation of Volatility Derivatives (slides). Merrill Lynch.

He, H., 2000, Modeling Term Structures of Swap Spreads, Working Paper, Yale University

Hull, J. and A. White, 1995, The Impact of Default Risk on the Prices of Options and Other Derivative Securities, *Journal of Banking and Finance*, 19, pp. 299-322.

Hübner, G., 2001, The Analytic Pricing of Asymmetric Defaultable Swaps, *Journal of Banking and Finance*, 25, pp. 295-316.

Hübner, G., 2004, The Credit Risk Components of a Swap Portfolio, *Journal of Futures Markets*, 24, pp. 93-115.

Li, H., 1998, Pricing of Swaps with Default Risk, *Review of Derivatives Research*, 2, pp. 231-250.

Liu, J., F.A. Longstaff, and R.E. Mandell, 2006, The Market Price of Risk in Interest Rate Swaps: The Roles of Default and Liquidity Risks, *Journal of Business*, 79, pp. 2337-2359.

Longstaff, F.A., 1990, The Valuation of Options on Yields, *Journal of Financial Economics*, 26, pp. 97-121.

Merton, R. C., 1974, On the Pricing of Corporate Debt: The Risk Structure of Interest Rates, *Journal of Finance*, 29, pp. 449–470.

Nandi, S., 1998, Valuation Models for Default-Risky Securities: An Overview, *Economic Review*, Fourth Quarter, Federal Reserve Bank of Atlanta, pp. 22-35.

Sorensen, E.H. and T.F. Bollier, 1994, Pricing Swap Default Risk, *Financial Analysts Journal*, May-June, pp. 23-33.

TABLE 1. Descriptive statistics of market quoted and models fitted volatilities

'Market Quoted Volatility' shows the descriptive statistics for market-quoted USD/KRW FX option-implied volatilities on each day for the 5 moneyness levels of 10Δ Put, 25Δ Put, ATM, 25Δ Call and 10Δ Call and for the 4 maturities of 3, 6, 9, and 12 months during the sample period from Jan. 3, 2006 to Dec. 30, 2010. 'SVI model fitted Volatility' and 'tanH model fitted Volatility' show the descriptive statistics for the SVI and tanH model fitted values, respectively, for each maturity and moneyness. RMSE denotes root mean squared error.

		Market Quoted Volatility				SVI model fitted Volatility					tanH model fitted Volatility				
maturity	money.	mean	s.d.	min	max	mean	s.d.	min	max	RMSE	mean	s.d.	min	max	RMSE
3m	10D Put	12.16	8.21	4.31	44.02	11.97	7.99	4.31	43.28	0.35	11.62	7.81	3.81	43.05	1.44
	25D Put	11.82	8.35	3.82	46.62	12.00	8.53	3.82	46.72	0.28	12.51	8.90	3.82	47.80	0.95
	ATM	12.55	9.67	3.40	55.50	12.57	9.67	3.40	55.45	0.21	13.59	10.39	3.83	57.83	0.80
	25D Call	14.68	12.17	3.48	68.84	14.73	12.21	3.48	68.75	0.10	15.02	12.50	3.83	71.33	0.71
	10D Call	17.54	15.44	3.60	84.72	17.52	15.41	3.60	84.70	0.10	16.45	14.45	3.84	80.93	1.58
6m	10D Put	11.44	6.67	4.41	34.77	11.26	6.46	4.41	34.57	0.32	10.79	6.13	3.88	33.42	1.16
	25D Put	11.11	6.83	3.93	36.63	11.31	7.02	3.93	36.95	0.28	11.81	7.36	3.89	39.44	0.87
	ATM	11.94	8.25	3.53	44.06	11.93	8.23	3.53	44.09	0.17	13.09	9.05	3.90	48.27	0.88
	25D Call	14.34	11.02	3.63	57.80	14.38	11.05	3.63	57.95	0.07	14.86	11.57	3.92	61.03	0.75
	10D Call	17.70	14.71	3.92	76.66	17.69	14.70	3.92	76.61	0.06	16.52	13.62	3.93	70.39	1.49
9m	10D Put	11.47	6.03	4.54	30.90	11.28	5.83	4.54	30.73	0.30	11.09	6.33	3.94	41.36	2.18
	25D Put	11.15	6.23	4.05	33.09	11.37	6.42	4.05	33.13	0.29	12.12	7.30	3.96	42.77	1.62
	ATM	12.09	7.72	3.63	40.56	12.08	7.69	3.63	40.82	0.15	13.39	8.69	3.98	44.91	1.04
	25D Call	14.76	10.66	3.70	54.21	14.81	10.69	3.70	54.35	0.07	15.17	10.90	3.99	57.68	1.06
	10D Call	18.56	14.62	3.98	72.88	18.55	14.60	3.98	72.85	0.06	16.92	12.85	4.01	66.35	2.58
12m	10D Put	10.77	5.55	4.29	28.62	10.58	5.36	4.24	28.25	0.28	10.54	6.05	3.97	39.32	2.34
	25D Put	10.50	5.66	4.18	30.55	10.70	5.88	4.09	30.52	0.31	11.50	6.92	3.99	41.13	1.82
	ATM	11.40	7.15	3.68	37.86	11.42	7.07	3.78	38.12	0.16	12.68	8.14	4.01	43.54	1.14
	25D Call	14.01	10.13	3.66	51.64	14.07	10.14	3.75	51.81	0.08	14.37	10.17	4.03	49.44	1.27
	10D Call	17.85	14.18	4.11	70.93	17.81	14.20	3.87	70.89	0.08	16.07	12.11	4.05	56.41	2.99

TABLE 2. Parameter Estimates of the implied volatility functions

On each day and for each maturity two types of the implied volatility functions (the stochastic volatility inspired, 'SVI', and the hyperbolic tangent function, 'tanH') are fitted to the market-quoted USD/KRW FX option-implied volatilities with the 5 moneyness levels of 10Δ Put, 25Δ Put, ATM, 25Δ Call and 10Δ Call during the sample period from Jan. 3, 2006 to Dec. 30, 2010. The table shows the mean, standard deviation, min, and max of the parameter estimates.

		SVI model					tanH model		
maturity		a	b	s	ρ	m	a	b	c
3m	mean	0.0190	0.0753	0.0013	0.4889	-0.0023	0.1347	143.8066	-1.7029
	Std.	0.0298	0.0688	0.0456	0.6926	0.0233	0.1014	157.4340	2.1523
	min	-0.0767	0.0092	-0.2446	-1.0566	-0.2224	0.0383	0.0560	-7.0483
	max	0.1871	0.3858	0.4183	1.2647	0.0511	0.5548	468.8567	0.0000
6m	mean	0.0154	0.0582	0.0140	0.5499	-0.0003	0.1292	71.1337	-1.4248
	Std.	0.0198	0.0489	0.0531	0.6069	0.0285	0.0873	79.6815	1.6543
	min	-0.0275	0.0075	-0.0751	-0.4680	-0.2786	0.0390	0.0602	-5.7472
	max	0.1083	0.2590	0.5453	1.4812	0.0823	0.4595	256.2616	0.0000
9m	mean	0.0147	0.0511	0.0107	0.5711	0.0008	0.1319	116.1935	-1.2080
	Std.	0.0172	0.0410	0.0667	0.6210	0.0345	0.0839	132.0732	1.3737
	min	-0.0757	0.0071	-0.1704	-0.7015	-0.2671	0.0398	0.0622	-4.2893
	max	0.0836	0.2403	0.8569	1.2159	0.0852	0.4428	402.4315	0.0000
12m	mean	0.0129	0.0426	0.0143	0.5785	0.0053	0.1260	248.5287	-1.0137
	Std.	0.0145	0.0360	0.0637	0.5896	0.0357	0.0801	226.0520	1.2367
	min	-0.0134	0.0021	-0.4253	-0.6409	-0.2885	0.0401	0.0646	-3.7712
	max	0.0752	0.1743	0.3707	1.8782	0.0844	0.4278	649.8272	0.0000

TABLE 3. Calibration of 3 firm value parameters

We calibrate 3 firm-specific parameters appearing in equation (7): firm i 's asset volatility, σ_i, the sensitivity of asset value to the USD/KRW FX rate, β_i, and debt-to-asset ratio, $D_i / A_{i,t}$. For the calibrations of σ_i and β_i we use two different approaches. First one is to use firm i 's equity values as a proxy for its asset values (we estimate asset volatility using 120 days or 252 days of historical equity return data and regress it on the changes of FX rates to calculate β_i). Second way is to filter out asset value processes and its return volatilities using Merton's (1974) bond pricing model. In the application of Merton's (1974) model, we take the face value of the debt as the sum of the book values of current liabilities and a half of the long-term liabilities (CL) or as all book values of debt account (All). With filtered asset values, β_i is obtained by regressing filtered asset value processes on the changes of FX rates. Given book values of debt (CL or All) and filtered asset values, we can directly calculate the debt-to-asset ratio at date t, $D_i / A_{i,t}$. Alternatively, we extract the debt-to-asset ratio, $D_i / A_{i,t}$, given σ_i and β_i, from firm i 's 1 year market CDS (Credit Default Swap) premium quotes. The second and third columns of the table show the methods used for the parameter calibrations. The last column show the implied volatility model applied to the equation (13) and (14).

Comb.	Firm volatility (σ_i) and FX beta (β_i)	D/A ratio (D_i / A_i)	Imp. vol. model
1	Merton (1974), CL, 120 days	book value (CL)/ asset by Merton (1974)	SVI
2	Merton (1974), CL, 252 days	book value (CL)/ asset by Merton (1974)	SVI
3	Merton (1974), All, 120 days	book value (All)/ asset by Merton (1974)	SVI
4	Merton (1974), All, 252 days	book value (All)/ asset by Merton (1974)	SVI
5	Merton (1974), CL, 120 days	book value (CL)/ asset by Merton (1974)	tanH
6	Merton (1974), CL, 252 days	book value (CL)/ asset by Merton (1974)	tanH
7	Merton (1974), All, 120 days	book value (All)/ asset by Merton (1974)	tanH
8	Merton (1974), All, 252 days	book value (All)/ asset by Merton (1974)	tanH
9	equity, 120 days	extraction from CDS with SVI	SVI
10	equity, 252 days	extraction from CDS with SVI	SVI
11	Merton (1974), CL, 120 days	extraction from CDS with SVI	SVI
12	Merton (1974), CL, 252 days	extraction from CDS with SVI	SVI
13	Merton (1974), All, 120 days	extraction from CDS with SVI	SVI
14	Merton (1974), All, 252 days	extraction from CDS with SVI	SVI
15	equity (120 days)	extraction from CDS with tanH	tanH
16	equity (252 days)	extraction from CDS with tanH	tanH
17	Merton (1974), CL, 120 days	extraction from CDS with tanH	tanH
18	Merton (1974), CL, 252 days	extraction from CDS with tanH	tanH
19	Merton (1974), All, 120 days	extraction from CDS with tanH	tanH
20	Merton (1974), All, 252 days	extraction from CDS with tanH	tanH

TABLE 4. RMSE of the Model Implied Rates: KB vs. JPM

The table reports the root-mean-square-error (RMSE) of each model-implied USD rates from the CIP implied USD rates for 3m, 6m, 9m and 12m, and for each combination of model parameter calibration methods reported in Table 3. 'Libor' is the market quoted USD Libor; 'L1G0' ('L0G1') is calculated taking into account the state dependent counterparty default risk of the USD (KRW) paying party only at the swap maturity; 'L1G1' is calculated assuming asymmetric bilateral counterparty default risks accounted for in the sense that at the swap maturity not only the USD paying party (local banks) but also the KRW paying party (global banks) are defaultable but with different probabilities.

A. Whole sample period

	3m				6m				9m				12m			
Comb.	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1
1	2.50	1.73	2.54	1.77	2.12	1.37	2.22	1.41	1.99	1.22	2.13	1.27	2.22	1.32	2.38	1.45
2	2.66	1.93	2.70	1.97	2.25	1.52	2.36	1.58	2.13	1.34	2.27	1.42	2.37	1.44	2.54	1.60
3	2.50	1.65	2.55	1.69	2.12	1.28	2.21	1.33	1.99	1.14	2.09	1.21	2.22	1.27	2.35	1.40
4	2.66	1.87	2.72	1.92	2.25	1.40	2.35	1.47	2.13	1.23	2.23	1.32	2.37	1.36	2.51	1.52
5	2.50	1.84	2.56	1.88	2.12	1.47	2.29	1.52	2.00	1.34	2.24	1.39	2.24	1.41	2.54	1.54
6	2.66	2.07	2.73	2.11	2.25	1.65	2.44	1.70	2.13	1.49	2.39	1.56	2.39	1.54	2.71	1.71
7	2.50	1.76	2.57	1.80	2.12	1.35	2.27	1.41	2.00	1.26	2.19	1.33	2.24	1.37	2.50	1.51
8	2.66	2.04	2.74	2.09	2.25	1.51	2.43	1.58	2.13	1.36	2.34	1.46	2.39	1.46	2.66	1.64
9	2.42	1.73	2.41	1.73	2.04	1.23	2.00	1.24	1.90	1.07	1.86	1.09	2.16	1.19	2.12	1.23
10	2.42	1.73	2.41	1.73	2.04	1.33	2.00	1.33	1.90	1.17	1.86	1.18	2.16	1.26	2.12	1.30
11	2.57	1.94	2.55	1.94	2.16	1.45	2.12	1.45	1.99	1.24	1.95	1.25	2.29	1.36	2.24	1.40
12	2.75	2.13	2.73	2.13	2.31	1.61	2.26	1.61	2.13	1.39	2.09	1.40	2.45	1.51	2.40	1.55
13	2.57	2.27	2.57	2.28	2.16	1.44	2.13	1.45	1.99	1.21	1.95	1.22	2.29	1.35	2.24	1.38
14	2.75	2.53	2.75	2.54	2.31	1.62	2.28	1.62	2.13	1.35	2.09	1.36	2.45	1.49	2.40	1.53
15	2.46	1.91	2.47	1.91	2.08	1.34	2.09	1.35	1.92	1.17	1.96	1.19	2.19	1.29	2.25	1.34
16	2.46	1.85	2.47	1.85	2.08	1.43	2.09	1.43	1.92	1.29	1.96	1.30	2.19	1.37	2.26	1.41
17	2.61	2.12	2.61	2.12	2.20	1.60	2.21	1.60	2.02	1.38	2.06	1.40	2.31	1.46	2.39	1.51
18	2.80	2.32	2.80	2.32	2.35	1.76	2.37	1.77	2.16	1.54	2.20	1.55	2.47	1.62	2.56	1.66
19	2.61	2.60	2.63	2.61	2.20	1.63	2.22	1.64	2.02	1.34	2.06	1.36	2.31	1.44	2.39	1.48
20	2.80	2.88	2.81	2.89	2.35	1.83	2.38	1.83	2.16	1.50	2.21	1.51	2.47	1.59	2.56	1.63
Avg.	2.59	2.05	2.62	2.06	2.19	1.49	2.24	1.52	2.04	1.30	2.11	1.34	2.31	1.41	2.41	1.49

B. Post Lehman period

	3m				6m				9m				12m			
Comb.	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1
1	3.08	1.81	3.15	1.87	2.56	1.27	2.72	1.35	2.33	1.00	2.53	1.11	2.71	1.13	2.96	1.40
2	3.08	1.96	3.15	2.02	2.56	1.40	2.73	1.49	2.33	1.11	2.54	1.24	2.71	1.24	2.96	1.52
3	3.08	1.67	3.17	1.74	2.56	1.08	2.71	1.18	2.33	0.81	2.48	0.97	2.71	1.01	2.91	1.30
4	3.08	1.88	3.17	1.95	2.56	1.18	2.71	1.32	2.33	0.88	2.49	1.08	2.71	1.08	2.92	1.40
5	3.08	2.01	3.18	2.07	2.56	1.45	2.83	1.53	2.33	1.21	2.70	1.31	2.74	1.27	3.19	1.55
6	3.08	2.18	3.18	2.25	2.56	1.60	2.84	1.69	2.33	1.32	2.71	1.45	2.74	1.37	3.20	1.66
7	3.08	1.86	3.20	1.93	2.56	1.20	2.81	1.32	2.33	1.04	2.63	1.19	2.74	1.19	3.13	1.48
8	3.08	2.13	3.20	2.21	2.56	1.35	2.82	1.48	2.33	1.09	2.64	1.28	2.74	1.21	3.14	1.54
9	3.15	1.97	3.13	1.97	2.60	1.13	2.53	1.14	2.36	0.77	2.28	0.80	2.78	1.06	2.69	1.13
10	3.15	1.97	3.13	1.98	2.60	1.38	2.53	1.38	2.36	1.07	2.28	1.08	2.78	1.27	2.70	1.32
11	3.17	2.19	3.15	2.19	2.61	1.49	2.54	1.49	2.36	1.16	2.28	1.17	2.78	1.33	2.70	1.38
12	3.17	2.28	3.15	2.28	2.61	1.60	2.54	1.60	2.36	1.29	2.29	1.30	2.78	1.45	2.71	1.51
13	3.17	2.84	3.15	2.84	2.61	1.60	2.55	1.60	2.36	1.18	2.28	1.19	2.78	1.35	2.70	1.41
14	3.17	2.98	3.15	2.98	2.61	1.74	2.55	1.73	2.36	1.31	2.29	1.32	2.78	1.47	2.71	1.53
15	3.22	2.27	3.22	2.27	2.65	1.31	2.67	1.33	2.39	0.95	2.45	0.98	2.81	1.21	2.91	1.29
16	3.22	2.17	3.22	2.17	2.65	1.51	2.67	1.51	2.39	1.23	2.45	1.24	2.81	1.39	2.91	1.45
17	3.23	2.46	3.23	2.46	2.66	1.69	2.68	1.69	2.40	1.35	2.46	1.36	2.81	1.45	2.92	1.51
18	3.23	2.54	3.23	2.54	2.66	1.79	2.68	1.79	2.40	1.46	2.46	1.47	2.81	1.55	2.93	1.61
19	3.23	3.31	3.24	3.31	2.66	1.87	2.69	1.87	2.40	1.37	2.45	1.38	2.81	1.46	2.92	1.52
20	3.23	3.45	3.24	3.45	2.66	2.00	2.69	2.00	2.40	1.49	2.46	1.50	2.81	1.56	2.92	1.62
Avg.	3.15	2.30	3.18	2.32	2.60	1.48	2.67	1.53	2.36	1.15	2.46	1.22	2.77	1.30	2.91	1.46

TABLE 5. Summary of RMSEs: local vs. global banks

For each combination of 3 local banks and 3 global banks, we calculate the root-mean-square-error (RMSE) of each model-implied USD rates from the CIP implied USD rates for 3m, 6m, 9m and 12m maturities and for each combination of model parameter calibration methods reported in Table 3. The table reports the average of the 20 RMSEs. 'Libor' is the market quoted USD Libor; 'L1G0' ('L0G1') is calculated taking into account the state dependent counterparty default risk of the USD (KRW) paying party only at the swap maturity; 'L1G1' is calculated assuming asymmetric bilateral counterparty default risks accounted for in the sense that at the swap maturity not only the USD paying party (local banks) but also the KRW paying party (global banks) are defaultable but with different probabilities.

A. Whole sample period

		3m				6m				9m				12m			
local	global	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1
KB	JPM	2.59	2.05	2.62	2.06	2.19	1.49	2.24	1.52	2.04	1.30	2.11	1.34	2.31	1.41	2.41	1.49
KB	BOA	2.59	2.05	2.69	2.13	2.19	1.49	2.32	1.58	2.04	1.30	2.18	1.40	2.31	1.41	2.48	1.55
KB	DB	2.57	2.04	2.83	2.12	2.18	1.49	2.20	1.51	2.03	1.30	2.04	1.33	2.30	1.40	2.34	1.46
SH	JPM	2.53	2.15	2.58	2.18	2.22	1.56	2.32	1.61	2.09	1.25	2.22	1.32	2.52	1.37	2.69	1.51
SH	BOA	2.53	2.15	2.72	2.29	2.22	1.56	2.45	1.72	2.09	1.25	2.34	1.43	2.52	1.37	2.81	1.62
SH	DB	2.52	2.14	2.81	2.13	2.21	1.55	2.26	1.59	2.08	1.26	2.14	1.30	2.52	1.37	2.60	1.46
WR	JPM	2.44	2.35	2.46	2.35	2.05	1.51	2.09	1.51	1.93	1.27	2.00	1.29	2.16	1.29	2.25	1.35
WR	BOA	2.44	2.35	2.52	2.38	2.05	1.51	2.17	1.55	1.93	1.27	2.06	1.33	2.16	1.29	2.32	1.40
WR	DB	2.42	2.34	2.66	2.31	2.04	1.51	2.06	1.52	1.92	1.27	1.94	1.28	2.16	1.29	2.19	1.33

B. Post Lehman period

		3m				6m				9m				12m			
local	global	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1	Libor	L1G0	L0G1	L1G1
KB	JPM	3.15	2.30	3.18	2.32	2.60	1.48	2.67	1.53	2.36	1.15	2.46	1.22	2.77	1.30	2.91	1.46
KB	BOA	3.15	2.30	3.29	2.43	2.60	1.48	2.80	1.64	2.36	1.15	2.57	1.33	2.77	1.30	3.02	1.57
KB	DB	3.12	2.29	3.47	2.38	2.59	1.48	2.61	1.51	2.35	1.15	2.37	1.20	2.76	1.30	2.80	1.40
SH	JPM	2.73	2.24	2.79	2.28	2.37	1.57	2.47	1.62	2.21	1.21	2.34	1.28	2.68	1.32	2.85	1.48
SH	BOA	2.73	2.24	2.93	2.39	2.37	1.57	2.61	1.74	2.21	1.21	2.46	1.40	2.68	1.32	2.97	1.60
SH	DB	2.72	2.24	3.02	2.23	2.36	1.57	2.41	1.61	2.20	1.21	2.25	1.26	2.67	1.32	2.75	1.43
WR	JPM	3.17	3.04	3.20	3.05	2.62	1.73	2.69	1.74	2.37	1.24	2.46	1.28	2.77	1.26	2.91	1.39
WR	BOA	3.17	3.04	3.20	3.05	2.62	1.73	2.69	1.74	2.37	1.24	2.46	1.28	2.77	1.26	2.91	1.39
WR	DB	3.14	3.03	3.49	2.98	2.60	1.73	2.63	1.74	2.35	1.25	2.37	1.27	2.76	1.26	2.81	1.35

TABLE 6. Unit root test

We conduct the standard unit root tests (Augmented Dicky-Fuller test and Phillips-Perron test) and report the results for the (a) independent variables and (b) dependent variables. The dependent variables are market basis minus L1G0 model implied basis, defined in equation (18) and (19), respectively, for each maturity. And here KB financial group and JP Morgan Chase are applied to the local and global bank, respectively. ***: 1%, **: 5%, *: 1% significance level.

	Augmented Dicky-Fuller test				Phillips-Perron test			
	level		1st difference		level		1st difference	
(a) independent variables								
T-Bill 3m	-2.35		-12.19	***	-5.18		-1004.21	***
Libor 3m	-2.47		-8.43	***	-4.82		-893.13	***
Ted spread 3m	-3.01		-10.13	***	-15.37		-999.99	***
OIS 3m	-2.34		-6.41	***	-3.33		-1952.48	***
GC repo 3m	-2.33		-12.29	***	-4.65		-1622.03	***
MBS repo 3m	-2.61		-9.69	***	-3.80		-1582.08	***
MBS-GC spread	-3.08		-13.33	***	-78.82	***	-1490.40	***
CBOE VIX	-2.45		-11.51	***	-17.96		-1474.25	***
CDS 5y JPM	-2.77		-13.35	***	-20.09		-1064.22	***
CDS 5y BAC	-3.00		-13.58	***	-23.64		-1012.57	***
CDS 5y DB	-2.92		-13.49	***	-30.95	***	-1077.42	***
CDS 5y KB	-1.81		-11.51	***	-10.21		-1102.27	***
CDS 5y SH	-1.87		-11.52	***	-8.58		-1182.21	***
CDS 5y WR	-1.91		-10.48	***	-8.18		-1161.46	***
(b) dependent variables: market - model rate								
3m	-2.68		-10.44	***	-19.53	*	-1045.98	***
6m	-2.35		-11.45	***	-23.17	**	-1014.73	***
9m	-1.97		-11.17	***	-13.91		-1048.54	***
12m	-1.68		-10.83	***	-12.41		-1255.69	***

TABLE 7. Regression results for CIP deviations

The table shows results from regressions of the unexplained CIP deviation (i.e. CIP implied USD rate – L1G0 implied USD rate) on the 5 year CDS premiums of KB financial group and JP Morgan Chase, the CBOE VIX, TED spread, and MBS-GC repo spread. The regression is estimated for the whole sample period and for the 4 sub samples: pre-crisis, turmoil, after Lehman failure, and Fed swap line. ***: 1%, **: 5%, *: 1% significance level

A. Whole sample

	3m			6m			9m			12m		
	estimate		s.e.	estimate		s.e.	estimate		s.e.	estimate		s.e.
const.	0.0107	***	0.0005	0.0083	***	0.0004	0.0075	***	0.0004	0.0101	***	0.0003
CDS 5y KB	0.7458	*	0.4370	0.4561		0.3586	0.2701		0.3269	0.5129	*	0.2793
CDS 5y JPM	-4.0195	***	1.0072	-3.0566	***	0.8263	-1.9164	**	0.7582	-1.4916	**	0.6434
CBOE VIX	0.0006	***	0.0002	0.0006	***	0.0002	0.0005	***	0.0002	0.0003	**	0.0002
Ted spread	0.4272		0.6437	1.1019	**	0.5283	-0.0323		0.4918	-0.2521		0.4119
MBS-GC spread	0.5127		0.4069	0.3616		0.3339	0.3852		0.3042	0.1679		0.2600
R^2 adj.	0.0186			0.0205			0.0089			0.0079		

B. Pre-crisis period

	3m			6m			9m			12m		
	estimate		s.e.	estimate		s.e.	estimate		s.e.	estimate		s.e.
const.	0.0031	***	0.0002	0.0034	***	0.0001	0.0024	***	0.0001	0.0028	***	0.0000
CDS 5y KB	3.7466		2.8972	0.7721		2.4877	1.4167		1.5034	0.9655		0.8985
CDS 5y JPM	-7.2303	***	2.6346	-2.2242		2.2622	-1.4010		1.4651	-1.1105		0.8171
CBOE VIX	0.0002		0.0002	0.0000		0.0002	0.0000		0.0001	0.0000		0.0001
Ted spread	0.5224		0.6807	0.4004		0.5845	0.3777		0.3607	0.3099		0.2111
MBS-GC spread	-0.0231		1.0725	-0.1002		0.9209	0.2931		0.5560	0.0358		0.3326
R^2 adj.	0.0180			0.0178			0.0123			0.0012		

C. Turmoil period

	3m			6m			9m			12m		
	estimate		s.e.	estimate		s.e.	estimate		s.e.	estimate		s.e.
const.	0.0191	***	0.0006	0.0180	***	0.0004	0.0178	***	0.0004	0.0188	***	0.0004
CDS 5y KB	-1.0767		0.9879	-0.8793		0.7573	-1.1240		0.7696	-0.5004		0.7560
CDS 5y JPM	-1.7956		1.2039	-1.2798		0.9223	-1.2447		0.9168	-1.4784		0.9204
CBOE VIX	-0.0001		0.0004	-0.0001		0.0003	-0.0001		0.0003	-0.0002		0.0003
Ted spread	0.5989		0.4894	0.5873		0.3752	0.2438		0.3721	0.1655		0.3751
MBS-GC spread	-0.0095		0.4400	-0.1084		0.3374	-0.0119		0.3286	-0.0436		0.3367
R^2 adj.	0.0066			0.0103			0.0083			0.0052		

D. After Lehman failure

	3m			6m			9m			12m		
	estimate		s.e.	estimate		s.e.	estimate		s.e.	estimate		s.e.
const.	-0.0393	***	0.0072	-0.0241	***	0.0046	-0.0115	**	0.0042	0.0030		0.0029
CDS 5y KB	-1.2467		1.4318	-1.0265		0.9208	-1.2291		0.8286	-0.2639		0.5820
CDS 5y JPM	-6.8732		8.5495	-5.2991		5.4981	-5.5128		4.9477	-2.8468		3.4750
CBOE VIX	0.0019	*	0.0010	0.0013	*	0.0006	0.0012	**	0.0006	0.0007	*	0.0004
Ted spread	15.4227	***	4.2679	7.9229	***	2.7446	9.8447	***	2.4699	6.4257	***	1.7347
MBS-GC spread	-0.0086		1.3980	-0.0523		0.8991	-0.0041		0.8091	-0.1603		0.5682
R^2 adj.	0.2626			0.1619			0.3208			0.2959		

E. Fed swap line

	3m			6m			9m			12m		
	estimate		s.e.	estimate		s.e.	estimate		s.e.	estimate		s.e.
const.	0.0126	***	0.0009	0.0045	***	0.0008	0.0023	***	0.0007	0.0081	***	0.0006
CDS 5y KB	-0.4643		0.9599	0.1016		0.9157	0.0996		0.7230	0.2927		0.6583
CDS 5y JPM	-3.6788	**	1.5723	-3.9665	***	1.4999	-2.5188	**	1.1842	-2.3116	**	1.0784
CBOE VIX	0.0009	*	0.0005	0.0011	**	0.0005	0.0007	*	0.0004	0.0007	**	0.0003
Ted spread	3.1298		3.3610	5.2034		3.2062	6.9071	***	2.5314	5.1027	**	2.3051
MBS-GC spread	1.5198		0.9794	1.0564		0.9343	1.0730		0.7377	1.0554		0.6717
R^2 adj.	0.0237			0.0312			0.0409			0.0348		

FIGURE 1. Time series of USD/KRW FX spot and 3 month FX forward

For each Friday from Jan. 2007 to May 2010, a total of 167 closes of USD/KRW FX spot, USD/KRW 3 month FX forward, USD/KRW 3 month FX swap point, KRW IRS 3 month zero rate, USD 3 month IRS rate, and USD/KRW FX swap point implied USD zero rate are depicted.

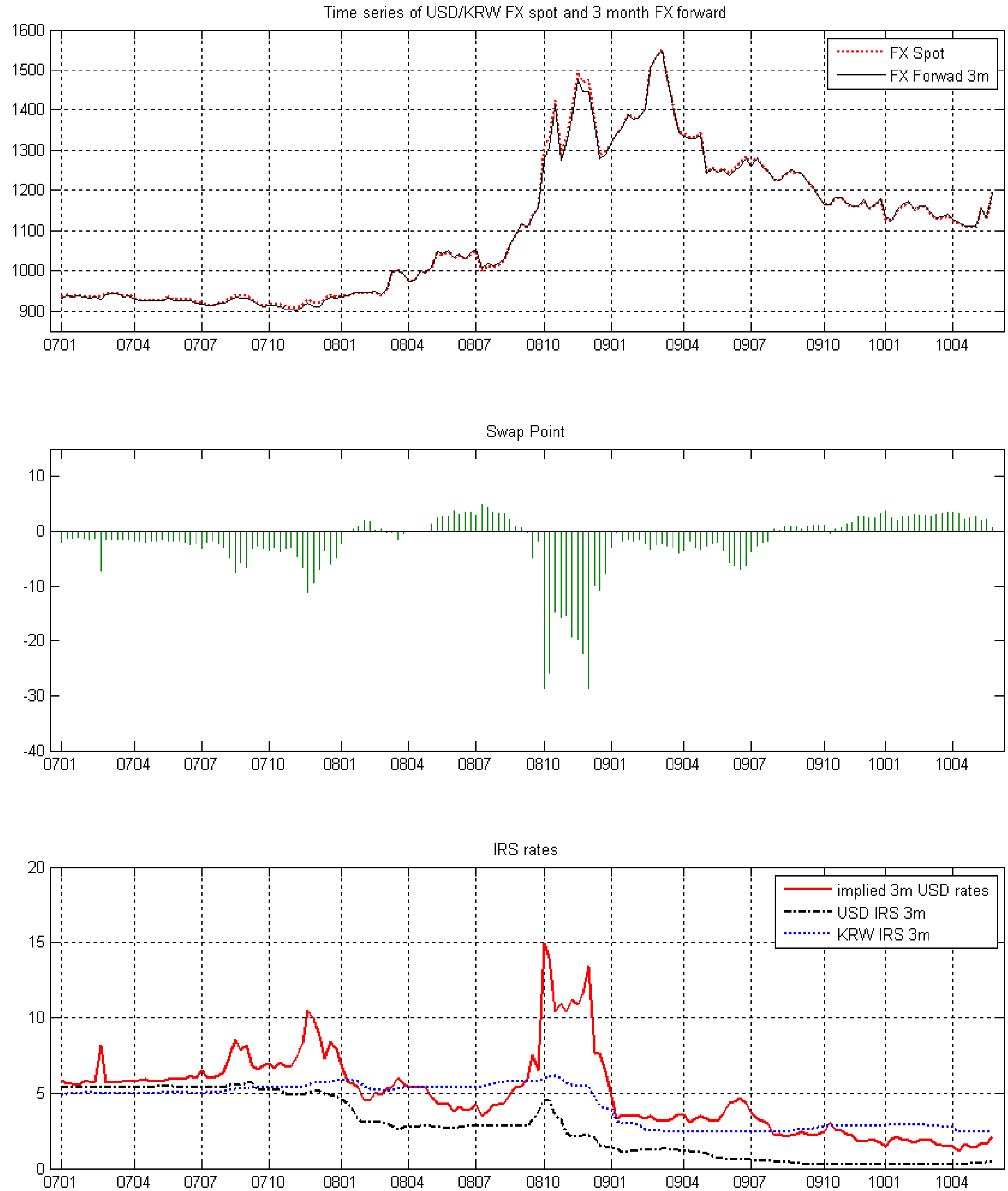

FIGURE 2. CIP deviations and CDS premium

For each Friday from Jan. 2007 to May 2010, a total of 167 observations of a measure of USD/KRW CIP deviation and 5 year CDS premium level differences between Korean banks and US/European financial institutions are depicted: 'CIP Deviation' is USD/KRW FX swap point implied USD zero rate less USD 3 month IRS zero rate; 'AVG.5Y.CDS.Diff. (KOR - EUR.IB)' is average 5 year CDS premium level differences between Korean banks (IBK, KDB, KB, SH, Woori and Hana) and European banks (ING, Calyon, Barclays and Deutsche); and 'AVG.5Y.CDS.Diff (KOR - US.IB)' is average 5 year CDS premium level differences between Korean banks (IBK, KDB, KB, SH, Woori and Hana) and US banks (JPM and Citi).

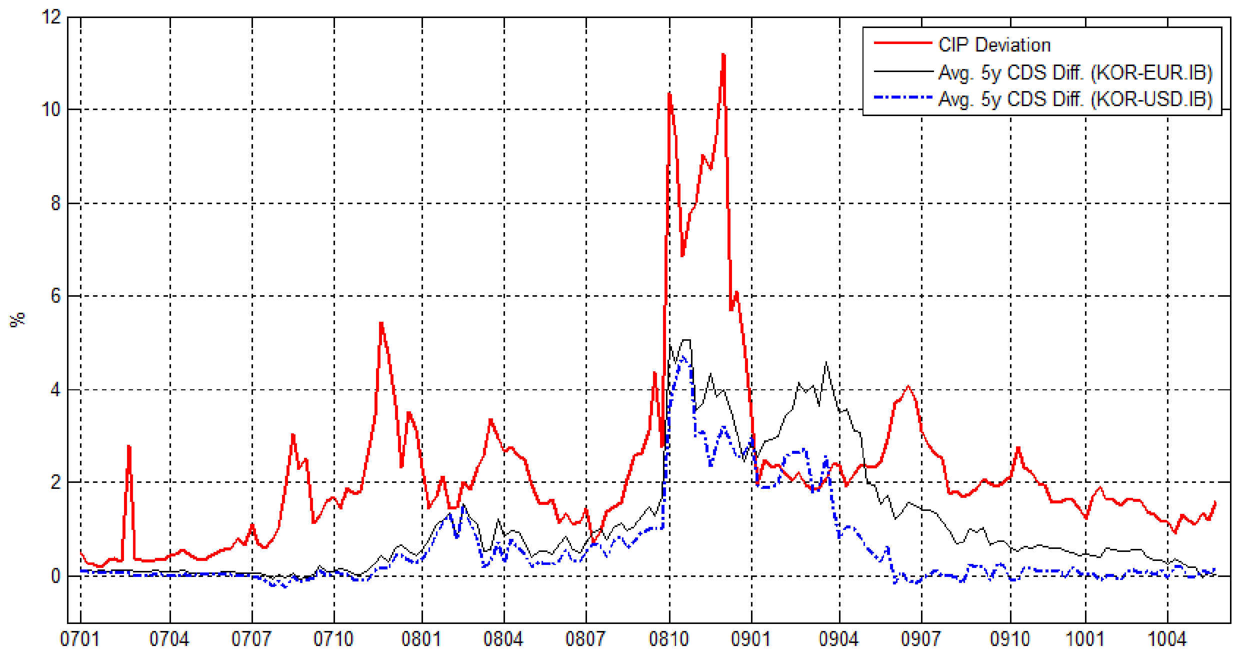

FIGURE 3. Arrow-Debreu state price density

USD/KRW FX option-implied Arrow-Debreu state price densities for each maturity of 3m, 6m, 9m, and 12m are depicted. The densities are computed according to equation (14) with two different implied volatility functions: the tanH model (blue dashed line) of the equation (15) and the SVI model (red real line) of the equation (16).

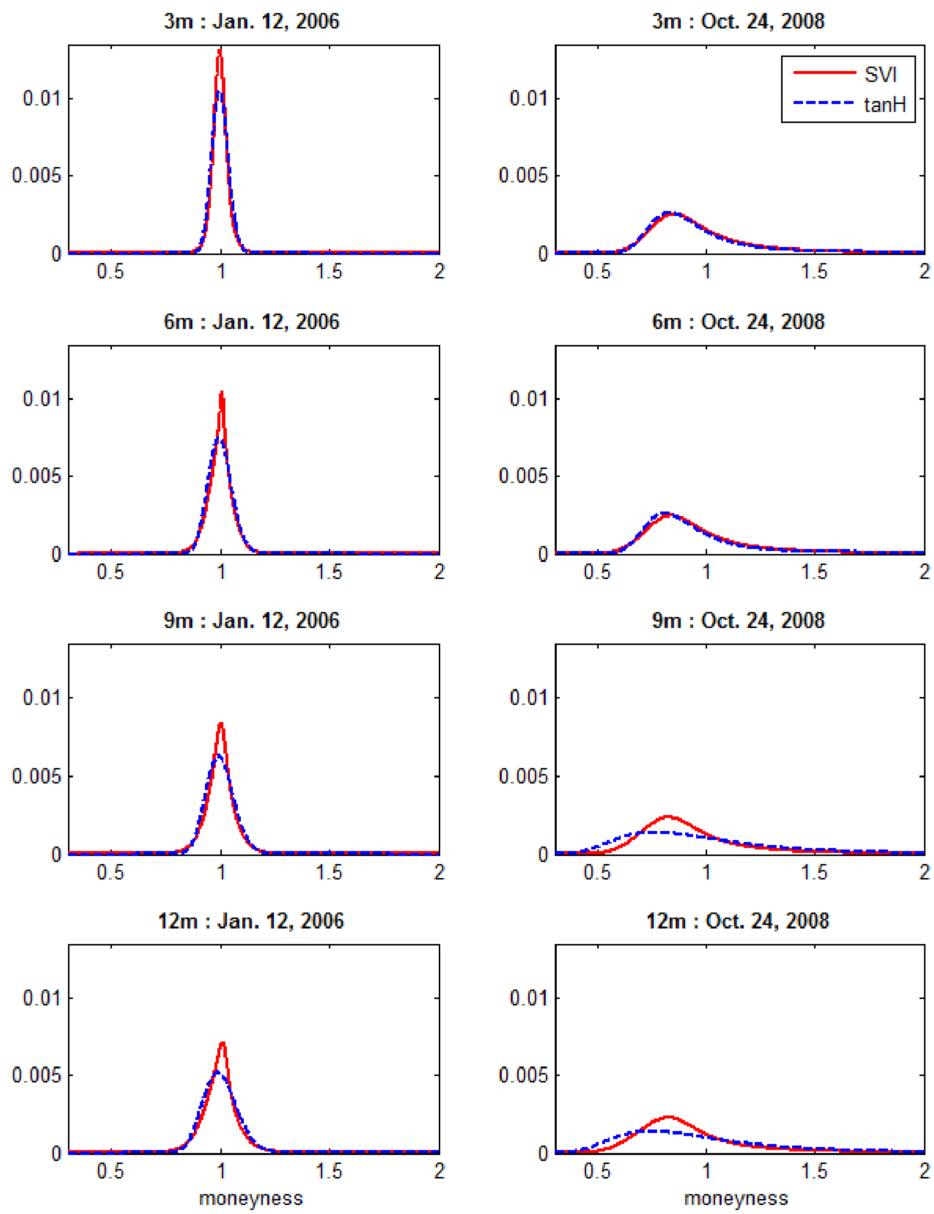

FIGURE 4. Estimates of firm value parameters

Panel (a) shows the filtered KB financial group's asset value and asset return volatility (σ_i) and panel (b) shows the estimates of asset beta (β_i) and initial debt-to-asset ratio ($D_i / A_{i,t}$). Those for the JP Morgan Chase are shown in panel (c) and (d), respectively. For the filtration of the firm's asset value and its return volatilities we apply Merton's (1974) bond pricing model, and here we take the face value of the debt as the sum of the book values of current liabilities and a half of the long-term liabilities. β_i is obtained by regressing filtered asset value processes on the changes of FX rates. Given book values of debt and filtered asset values, we calculate the debt-to-asset ratio at date t, $D_i / A_{i,t}$.

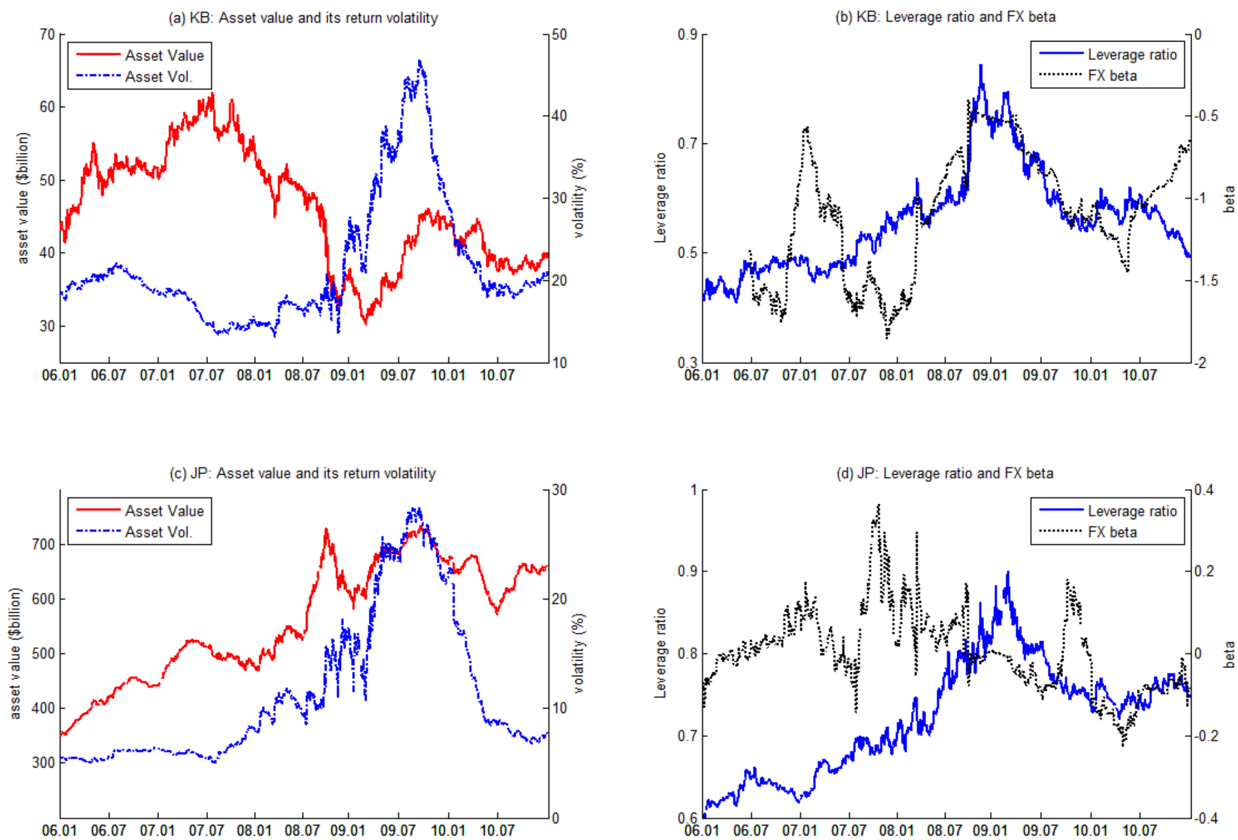

FIGURE 5. Market v.s. model FX swap implied USD interest rates

CIP implied USD rate and model-implied USD rates for 3m, 6m, 9m and 12m are depicted. 'Market' is market quoted USD/KRW swap points implied USD interest rates. 'L1G0' ('L0G1') is calculated taking into account the state dependent counterparty default risk of the USD (KRW) paying party only at the swap maturity, for which in this case we choose KB financial group (JP Morgan Chase). 'L1G1' is calculated assuming asymmetric bilateral counterparty default risks accounted for in the sense that at the swap maturity not only the USD paying party but also the KRW paying party are defaultable but with different probabilities.