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Credit Risk Contagion and the Global Financial Crisis

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Abstract

This paper investigates how the market valuation of credit risk changed during 2008-2009 via a separation of the probability of default (PD) and the loss given default (LGD) of credit default swaps (CDSs), using the information implied by equity options. While the Lehman Brothers collapse in September 2008 harmed the stability of the financial systems in major industrialized countries, the CDS spreads of some major UK banks did not increase in response to this turmoil in financial markets including the decline in their own stock prices. This implies that the CDS spreads of financial institutions may not reflect all their credit risk due to the government interventions. Since CDS spreads are not appropriate to analyze the impact of the government interventions on credit risk and the cross sectional movement of credit risk, we investigate how the government interventions affect the PD and LGD of financial institutions and how the PD and LGD of financial institutions were related with those of non-financial firms. We demonstrate that the rise in the credit risk of financial institutions did not bring about that of non-financial firms (credit risk contagion) both in the US and UK using principal component analysis.

Keywords: Credit Default Swap (CDS); Probability of Default (PD); Loss Given Default (LGD); Credit Risk Contagion

JEL classification: C12, C53, G13

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1 Introduction

In this paper, we examine how the market valuation of credit risk changed during 2008–2009 via the separation of the probability of default (PD) and the loss given default (LGD) of the credit default swaps (CDSs) using the framework developed in Takeyama *et al.* (2012). The Lehman Brothers collapse in September 2008 triggered a drastic decline in the stock prices and a rise in the CDS spreads for financial institutions in major industrialized countries (Figures 1–5). It also caused the rise in the corporate CDS spreads (Figure 6). This clustering of the rise in default risk is referred to as credit risk contagion (Heise and Kühn, 2012), and CDSs have been criticized as "financial weapons of mass destruction".[1]

As Cont *et al.* (2009) discuss, CDSs create a new channel of credit contagion via counterparty risk in over-the-counter (OTC) derivative contracts in addition to the traditional counterparty risk in the lender–borrower relationship. Moreover, as Duffie *et al.* (2005, 2007) demonstrate, the liquidity and risk taking capacity of financial institutions are critical factors in OTC security markets, because OTC security prices depend largely on the activity of the intermediary dealers. Brunnermeier and Pedersen (2009), Duffie and Strulovici (2011) and Duffie (2010) analyze the interactions between bank capital, funding capability (liquidity) and asset prices. Counterparty risk is one of the potential sources of interaction. Thus the drastic shift in the credit risk valuation of large financial institutions can tighten their liquidity and capital capacity, because the monopolistic "dealer-hub" structure[2] of the CDS market implies that large financial institutions hold significant nominal value of CDS contracts of other large financial institutions. However, it remains unknown to what extent these channels influence CDS spreads.

As a preliminary analysis, we investigate firstly the relationship between CDS spreads of individual companies and the prices of other assets, such as stock and secondly the

[1] In 2002 Annual Report of Berkshire Hathaway, Warren Buffet described over-the-counter (OTC) derivatives as "financial weapons of mass destruction." Currently this phrase is often used only in criticizing CDSs. See "A nuclear winter? The fallout from the bankruptcy of Lehman Brothers", *Economist*, September 18, 2008 http://www.economist.com/node/12274112 and "CDS: modern day weapons of mass destruction", *Financial Times*, September 11, 2011 http://www.ft.com/cms/s/0/1c81fdf8-d4b9-11e0-a7ac-00144feab49a.html.

[2] See European Central Bank (ECB) (2009) for details regarding the structure of the CDS market.

relationship in CDS spreads of different corporations in order to assess the impact of the Lehman Brothers collapse and subsequent financial crisis had on CDS spreads.

First, we identify the relationship between stock prices and CDS spreads. Empirical studies document stock prices negatively Granger cause CDS spreads in both the US and European markets (Norden and Weber, 2009 and Forte and Peña, 2010). However, we do not observe that stock prices Granger cause CDS spreads in the "bailed out" UK banks such as the Royal Bank of Scotland (RBS) and Lloyds Banking Group (Lloyds) while we observe the Granger causality for US financial institutions and many of US and UK non-financial corporations. In other words, the CDS spreads of the "bailed out" UK banks reflect only part of the credit risk implied by their stock prices thanks to the government interventions (Table 1) while the Granger causality between stock prices and CDS spreads is observed in the case of Citigroup, the "bailed out" US bank.

Second we investigate the relationship between corporate CDS spreads in the US and UK. A panel data analysis indicates that the impact of the rise in large financial institutions' CDS spreads is limited or negligible for US and UK non-financial corporations.

The results of the second analysis are seemingly a concrete evidence that counterparty risk does not matter in CDS pricing under collateral transfers following the ISDA master agreement. Arora *et al.* (2011) demonstrate a similar regression analysis also find that the impact of the major CDS dealers' CDS spreads on CDS spreads quoted by these dealers is limited. However, the results of the first analysis indicate the possibility that the CDS spreads of some UK banks weakly reflect the credit risk. Thus we cannot determine the significance of the Lehman Brothers collapse and subsequent turmoil in financial markets for CDS markets using an analysis of CDS spreads that may contain incomplete risk information.

We estimate the PD and LGD of CDS using the stock options of the same entities to infer the information about CDS spreads. While it is possible to calculate the arbitrage price of debt instruments such as corporate debts (Duffie and Singleton, 1999) and CDS (Duffie, 1999) from PD and LGD, it is usually difficult to identify the parameters from the market price: observed prices are given approximately by the product of the PD and LGD, and thus a continuum of parameters is consistent with a unique market price. One solution to this problem is a joint specification of the PD with other asset prices of the same entity: if the LGD is known at least for one of the assets then it is possible to specify the PD. We measure the PD as the probability that the stock price becomes zero, and we estimate this probability from stock options using the framework of Takeyama *et al.* (2012).

Finally we demonstrate the impact of the PD and LGD of large financial institutions on those of the non-financial firms using principal component analysis. Our approach is to identify the homogeneous loading factors of principal components that make a large contribution to causing credit contagion. A principal component analysis of the PD does not indicate that the increase in the PD of distressed banks such as Citi, RBS and Lloyds caused a significant increase in the PD of other financial institutions and non-financial corporations in both the US and the UK. In the analysis of LGD, we do not find the evidence that the co-movement of LGD was stronger during the financial crisis. This lack of support for credit risk contagion in CDS markets is consistent with empirical studies that indicate that CDS pricing was more efficient than was generally thought (Arora *et al.*, 2011; Longstaff, 2010).

The rest of the paper is organized as follows. In Section 2, we present the results of VAR analysis that identify what occurred in CDS markets during 2008-2009. In Section 3, we outline the structure of the dataset and the procedure for estimating the PD and LGD of CDSs using stock options. In Section 4, we compare the PD and LGD of UK banks' CDSs (as implied by their stock options) with those of US banks' CDSs. This comparison reveals how the government commitments and interventions affect the credit risk of financial institutions. Moreover, we examine whether credit risk contagion originated in the financial sector using multivariate analysis. Finally we discuss the implications of the analysis in Section 5.

2 Preliminary Analysis

Before we commence the analysis of CDS spreads via the separation of the PD and LGD, we first investigate the relationship between individual corporations' CDS spreads and the stock prices, and the relationship between the CDS spreads of financial institutions and those of non-financial corporations. The results of these analyses guide us in understanding what occurred in CDS markets during 2008–2009.

2.1 The relationship between the stock price and CDS spread in individual names

First we examine the relationship between the stock price and CDS spread in individual names during 2008-2009. Norden and Weber (2009) demonstrate that stock prices Granger cause CDS spreads in the United States and European non-financial firms in daily, weekly and monthly interval during 2000–2002 using a second-order VAR model. Forte and Peña (2010) also find Granger causality during 2001–2003, using a vector error correction model. These findings imply that asset prices of the same entity reflect common risk information of the entity. Our first question is whether this relationship of Granger causality is still valid during the financial crisis.

We use the approach of Norden and Weber (2009) to test for Granger causality in daily and weekly data during 2008–2009.

$$\Delta CDS_t = \beta_0^{(1)} + \sum_{i=1}^{N} \beta_i^{(1)} \Delta CDS_{t-i} + \sum_{j=1}^{N} \gamma_j^{(1)} \Delta \log(\mathit{Stock}_{t-j}) + \epsilon_t^{(1)} \tag{1}$$

$$\Delta \log(\mathit{Stock}_t) = \beta_0^{(2)} + \sum_{i=1}^{N} \beta_i^{(2)} \Delta CDS_{t-i} + \sum_{j=1}^{N} \gamma_j^{(2)} \Delta \log(\mathit{Stock}_{t-j}) + \epsilon_t^{(2)} \tag{2}$$

where

$$\begin{aligned} \Delta CDS_t &= CDS_t - CDS_{t-1} \\ \Delta \log(\mathit{Stock}_t) &= \log(\mathit{Stock}_t) - \log(\mathit{Stock}_{t-1}) \end{aligned}$$

The order of the VAR model, N is 4 and 3 for the daily and weekly data, respectively.

We construct our sample with five groups of corporations:

- UK banks: HSBC Holdings (HSBC), Barclays, RBS and Lloyds.
- US financial institutions: JPMorgan Chase, Citigroup, Goldman Sachs and Morgan Stanley are used for comparison with the UK banks. As these financial institutions are contributing banks to Markit for the construction of the US CDS index (CDX

North America) and the European CDS index (iTraxx Europe), they are recognized major CDS dealers.[3]

- Continental European banks: We include all contributing banks. The sample data include BNP Paribas, Société Générale Group, Deutsche Bank, UBS and Credit Suisse. Thus, the sample data cover all of the contributing banks in both the US and Europe.

- US corporations: We select 20 financial and non-financial corporations from the member list of the CDX.NA.IG S12 (Table 2).

- UK corporations: As the counterpart of the US non-financial corporations, we select the UK corporations from iTraxx Europe S12. We restrict the sample data to public companies for 2008–2009 in order to analyze the relationship between CDS spreads and stock returns (Table 2).

The results of the VAR analysis are as follows (Tables 3–8):

- We observe Granger causality between stock prices and CDS spreads for almost all of the US corporations listed on the CDX (18 of the 20 sample corporations, $\gamma_1^{(1)}$ in Table 3) and for the majority of UK corporations listed on iTraxx (12 of the 20 sample corporations) in the daily data. As shown in Norden and Weber (2009), the relationship is stronger in the daily data than in the weekly data (Tables 6–8).

- We observe this Granger causality for all of the major US financial institutions in the sample but none of the major UK banks, except for HSBC (Table 4). Causality is observed for the other major European banks (three out of the selected five: BNP Paribas, UBS and Credit Suisse).

These findings imply that the negative Granger causality between stock prices and CDS spreads is statistically significant even in 2008–2009. However, we do not see causality at a statistically significant level for any major UK bank besides HSBC. The absence

[3]Although the Bank of America is also a contributing bank to Markit for the construction of these CDS indexes, we exclude it because it is difficult to adjust for the impact of their merger with Merrill Lynch.

of Granger causality for RBS and Lloyds contradicts the theoretical perspective of the structural approach (Merton, 1974) and the findings for other sample companies. That is, although their stock prices fell to around 10% of their precrisis level at the beginning of July 2008, their CDS spreads did not increase significantly.

These findings highlight the irregular movements of the CDS spreads of the major UK banks. While it is reasonable to assume that the drastic changes in the capital structure of the major UK banks via government capital injections caused this structural break, this does not explain why Granger causality is observed for the US and continental European banks.

2.2 The relationship between CDS spreads of financial institutions and non financial firms

In this section, we use the VAR model to examine the relationship between the CDS spreads of financial institutions and those of non-financial firms. More precisely, we investigate the influence of the structural break noted above on the relationship between UK banks' CDS spreads and CDS spreads across the entire credit market. As the above analysis shows that the only statistically significant variable is the first-order lag, we use this variable as an explanatory variable. To extract the average movement in stock and CDS markets, we include the stock index (FTSE100 and S&P500) and CDS index (iTraxx EU and CDX.NA.IG) as explanatory variables.

$$\begin{aligned}\Delta CDS_{n,t} &= \beta_0^{(3)} + \beta_1^{(3)}\Delta CDS_{n,t-1} + \beta_2^{(3)}\Delta CDSIndex_t \\ &\quad +\beta_3^{(3)}\Delta\log(Stock_{n,t-1}) + \beta_4^{(3)}\Delta\log(StockIndex_t) + \beta_5^{(3)}\Delta CDS_t^F + \epsilon_t^{(3)} \qquad (3)\end{aligned}$$

The analysis contains the four types of regressions:

1. The impact of the large global financial institutions' CDS spreads on the US corporations' CDS spreads (CDS^F is the average of the CDS spreads of Markit contributing banks, *CDSDealer*)

2. The impact of the large global financial institutions' CDS spreads on the UK corporations' CDS spreads (CDS^F is the average of the CDS spreads of Markit contributing banks, *USBankCDS*)

3. The impact of the large US financial institutions' CDS spreads on the US corporations' CDS spreads (CDS^F is the average of the CDS spreads of US Markit contributing banks, *CDSDealer*)

4. The impact of the large UK financial institutions' CDS spreads on the UK corporations' CDS spreads (CDS^F is the average of the CDS spreads of UK Markit contributing banks. *UKBankCDS*)

Tables 9 and 10 show the results of the pooled estimation. In all cases, the pool test and F test reject heterogeneity of the coefficients, and the Breusch–Pagan test rejects homogeneity of the residuals. In fact, we find little difference in the coefficient estimates and R-squared values yielded by the pooled estimation, within estimation and random effect estimation.

The results demonstrate that the $\beta_5^{(3)}$— estimators for the impact of financial institutions' CDSs—are statistically significant and positive for daily data. As discussed in Bielecki *et al.* (2011), the increase in counterparties' credit risk has a negative impact on CDS spreads in terms of counterparty risk in CDS pricing. Therefore, the positive estimator implies credit risk contagion from financial institutions to non-financial firms, where the impact is much smaller than the impact of the individual stock returns $\beta_1^{(3)}$ and CDS spreads $\beta_3^{(3)}$. This is consistent with theoretical and empirical studies on the counterparty risk of CDSs (Bielecki *et al.*, 2011; Arora *et al.*, 2011). In contrast, the impact of financial institutions' CDS spreads is not clear in the weekly data. For the US corporations, the $\beta_5^{(3)}$ are not statistically significant. For the UK corporations, the $\beta_5^{(3)}$ are statistically significant but negative.

The analysis of this section highlight two empirical results;

- The CDS spreads of the major financial institutions do not properly reflect the risk information implied by the prices of their other assets, especially in the case of the major UK banks.

- The impact of the increased CDS spreads of major financial institutions on the CDS spreads of non-financial corporations is limited in both the US and the UK.

The limited impact of the increase in financial institutions' CDS spreads is consistent with the finding of Arora *et al.* (2011). This finding, however, does not necessarily mean that credit risk contagion via the counterparty risk channel does not exist. Although a variety of stochastic recovery models have been proposed since the CDO market crash precipitated by the collapse of Bear Stearns in March 2008, there are few empirical studies on the correlation between the PD and LGD or on intercorporation co-movements of the PD and LGD. Therefore, we specify the PD and LGD using the methodology developed by Takeyama *et al.* (2012), and analyze the correlation and co-movements.

3 Data and Estimation Method

We analyze the cause of the results discussed in Section 2 via the separation of the PD and LGD using the framework developed in Takeyama *et al.* (2012). In this section we outline the dataset and the calibration procedure of an option pricing model for the estimation of the PD from stock options in the framework.

3.1 Data

We construct the dataset for the analysis of CDS spreads using stock options during July 2008–December 2009 in the following way.

1. CDS spreads

   We organize the sample data into the three following groups, to address the question in Section 2. All the 1 year CDS spread data are available from Markit.

   - Major US financial institutions

     Two investment banks: Goldman Sachs and Morgan Stanley

     Two commercial banks: JPMorgan Chase and Citi

   - Major UK financial institutions

     HSBC, Barclays, Lloyds and RBS

   - Non-financial firms

     We choose three representative non-financial corporations—BP (energy), BT (telecommunications) and TESCO (retail)—to analyze the impact of the financial institutions' credit risk on the non-financial corporations' credit risk.

We add three US non-financial firms—Exxon, AT&T and Walmart—as counterparts of the UK firms.

2. Stock prices

   We obtain the stock price data for the sample companies from Datastream. Some companies in the sample split or reverse-split their stock during 2008–2009. While we analyze the relationship between CDS spreads and stock prices adjusted for these splits in Section 2, here we use unadjusted stock prices for the estimation of the PD.

3. Stock dividends

   We obtain actual stock dividend data for the sample companies from each company's website. Unless a company announced it was not paying a dividend, the sum of the past four quarterly dividends was used as an estimate of the dividend in the following year.

4. Interest rates

   We use interbank interest rates as funding interest rates, which are often called risk-free interest rates. We construct the term structure of interest rates using LIBOR (interest rates with a maturity of less than one year) and swap rates (interest rates with a maturity of greater than one year) in both the US and the UK.

5. Stock option prices

   We obtain the stock option prices of the US corporations listed in CBOE from Option Metrics, and those of UK corporations listed in Euroclear from Datastream. The US corporations in the dataset are listed on the New York Stock Exchange, while the UK corporations are listed on the London Stock Exchange.

The sample period, July 2008–December 2009, includes the Lehman Brothers collapse, the subsequent financial crisis and the bank bailouts by the UK and US governments. The credit derivatives markets have been exposed to the most challenging and volatile conditions seen since the CDS market was established in the late 1990s.

We estimate the PD over a one-year horizon using the stock option data. However, options with a maturity of exactly one year are not always available because Euroclear and CBOE operate on a three-month expiring cycle. Hence, we use call and put options with remaining maturities of 6 to 18 months, and therefore effectively estimate the average of the PD between 6 and 18 months. The listed options are in American style, and we convert the prices into European style by extracting the early exercise premium, following the methodology of Bayraktar and Yang (2011) and Carr and Wu (2010).

3.2 The estimation methodology

We estimate the PD implied in stock options using the perturbation method based approximation, $\tilde{P}_{\epsilon,\delta}(T, K, \bar{\lambda}\ )$ (See Takeyama *et al.*, 2012)

$$\begin{aligned}\tilde{P}_{\epsilon,\delta}(T, K, \bar{\lambda}^{(1)}(z), V\ ) &= P_0(T, K, \bar{\lambda}^{(1)}(z)) + V_1^{\epsilon} g_1(T, K, \bar{\lambda}^{(1)}(z)) + V_2^{\epsilon} g_2(T, K, \bar{\lambda}^{(1)}(z)) \\ &+ V_3^{\epsilon} g_3(T, K, \bar{\lambda}^{(1)}(z)) + V_4^{\epsilon} g_4(T, K, \bar{\lambda}^{(1)}(z)) + V_5^{\epsilon} g_5(T, K, \bar{\lambda}^{(1)}(z)) \\ &+ V_6^{\epsilon} g_6(T, K, \bar{\lambda}^{(1)}(z)) + V_7^{\epsilon} g_7(T, K, \bar{\lambda}^{(1)}(z)) + V_1^{\delta} g_8(T, K, \bar{\lambda}^{(1)}(z)) \\ &+ V_2^{\delta} g_9(T, K, \bar{\lambda}^{(1)}(z))\,. \end{aligned} \quad (4)$$

We derive the LGD from the CDS spread that is consistent with the implied PD estimated in (4) using the following procedure.

First, we calculate the first term of (4). Second, we calibrate the volatility surface and estimate the implied PD. These procedures are proposed in Takeyama *et al.* (2012). Finally, we calculate the implied LGD from CDS spreads based on the implied PDs obtained from the second step using the framework of Takeyama *et al.* (2012).

In the first step, we estimate the mean value of the volatility of the underlying stock, $\bar{\sigma}_1$, the funding rate, $\bar{\sigma}_0$ and the correlation between stock price and the interest rates,$\bar{\rho}_1$, using the past 20 business days (approximately 1 month) data. Then we can calculate the first term of (4)

In the second step, the parameters of (4) are calibrated to actual daily data. There are 12 unknown parameters, (V_1^{ϵ}, V_2^{ϵ}, V_3^{ϵ}, V_4^{ϵ}, V_5^{ϵ}, V_6^{ϵ}, V_7^{ϵ}, V_1^{δ}, V_2^{δ}, $\bar{\lambda}^{(1)}$, β, η) to estimate in equation (4). In this procedure we minimize the weighted mean squared error to avoid the bias caused by the difference of the number of options, $N_{i,t}$, at individual maturities using an algorithm by Cont and Tankov (2004).

1. First, we estimate the parameters $V(= (V_1^{\epsilon}, V_2^{\epsilon}, V_3^{\epsilon}, V_4^{\epsilon}, V_5^{\epsilon}, V_6^{\epsilon}, V_7^{\epsilon}, V_1^{\delta}, V_2^{\delta}))$ with

$\bar{\lambda}_{t-1}^{(1)}$[4]

$$[\bar{V}\ \bar{\Psi}] = \arg\min_{V,\Psi} \sum_i \sqrt{\sum_j \left(\sigma_{impl}(T_i, K_{i,j}) - \sigma_{impl}^M(T_i, K_{i,j})\right)^2 / N_{i,t}} \tag{5}$$

where

$$\sigma_{impl}(T_i, K_{i,j}) - \sigma_{impl}^M(T_i, K_{i,j}) = \frac{P(t, T_i, K_{i,j}) - \tilde{P}_{\epsilon,\delta}(T_i, K_{i,j}, \bar{\lambda}_{t-1}, V, \Theta)}{vega(\sigma_{impl}(T, K))} \tag{6}$$

$N_{i,t}$ is the number of the maturity T_i options traded at t, the implied volatility $\sigma_{impl}(T_i, K_{i,j})$ and the option price sensitivity of the volatility $vega(\sigma_{impl}(T_i, K_{i,j}))$ are calculated using the Black-Scholes formula.

2. Second, we estimate PD with the parameters, $\bar{V}$ and $\bar{\Psi}$ from (5),

$$\bar{\lambda}_t^{(1)} = \arg\min_{\lambda_t^1} \sum_i \sqrt{\sum_j \left(\sigma_{impl}(T_i, K_{i,j}) - \sigma_{impl}^M(T_i, K_{i,j})\right)^2 / N_{i,t}} \tag{7}$$

where

$$\sigma_{impl}(T_i, K_{i,j}) - \sigma_{impl}^M(T_i, K_{i,j}) = \frac{P(t, T_i, K_{i,j}) - \tilde{P}_{\epsilon,\delta}(T_i, K_{i,j}, \lambda_t, \bar{V}, \bar{\Psi})}{vega(\sigma_{impl}(T, K))}. \tag{8}$$

As the final procedure in the second step, we convert the estimator of the PD in risk neutral measure $\hat{\lambda}_t^{RN}$ to the one in the actual world measure $\hat{\lambda}_t^{act}$ after the adjustment of the CDS spread of the government as discussed in Takeyama *et al.* (2012).

The third step is the estimation of the LGD implied in CDS by using the implied PD from stock options. The critical problem in the CDS pricing with counterparty risk is that the information on counterparties is generally unavailable. However, according to ECB (2009), the OTC derivative market has a "dealer-hub" structure, and the market share of the top five dealers is approximately 50%.[5] Thus, we assume that the actual

[4]The initial value of the PD, $\bar{\lambda}_0^1$, is calculated under 60% LGD using a counterparty risk free CDS pricing model by Bluhm et al. (2002). To eliminate the dependence on the initial value we ignore the first 20 days' results.

[5]We estimate that the market share of the top five dealers is about half of all CDS contracts. According to Deutsche Bank (2009), the notional volume of CDSs was around 2.5–3.5 trillion USD in the second half of 2008, yet this value differs among data sources such as BIS, ISDA and DTCC. The total notional volume of CDSs traded by the top five dealers consisted of 1.35 trillion USD (protection buy) and 1.30 trillion USD (protection sell) at March 2009.

market CDS spreads are the average of the CDS spreads offered by the major dealers to all potential counterparties under the following calibration of the CDS pricing model. This is consistent with the fact that the CDS spreads released by Markit are the average of the CDS spreads reported by the contributing banks.

1. Calibrate a vector of the LGD $(\hat{l}_{t,1},\cdots,\ \hat{l}_{t,5})$ implied by the CDS spreads of major CDS dealers.

$$[\hat{l}_{t,1}\ \hat{l}_{t,2}\ \hat{l}_{t,3}\ \hat{l}_{t,4}\ \hat{l}_{t,5}] = \arg\min_{l_{t,1}-l_{t,5}} \sum_i \sqrt{(CDS_i(t,T) - \sum_{j\neq i}\sum_{k\neq i,j} \hat{\kappa}^C_{i,j,k}/12)^2}\,. \qquad (9)$$

   where $\hat{\kappa}^C_{i,j,k}$ is the counterparty risky CDS spread of entity i, in which the buyer and seller are entities j and k, respectively, calculated using the Bielecki et al. (2011) model. We assume that market-to-market exposure is settled perfectly every business day (full collateralization) following the ISDA master agreement, and that the overnight index swap (OIS) rate is the yield rate of collateral assets. Thus, the OIS–LIBOR spread is the cost of collateralization.

2. Calibrate the LGD $(l_{t,i})$ implied by the CDS spread of other entities:

$$\hat{l}_{t,i} = \arg\min_{l_{t,i}} \sqrt{(CDS_i(t,T) - \sum_j\sum_{k\neq j} \hat{\kappa}^C_{i,j,k}/20)^2}\,. \qquad (10)$$

As the PD of the reference entities and counterparties and the dependency structure of default are given by equation (7) and Gaussian copula, the vector of LGD $(\hat{l}_{t,1},\cdots,\hat{l}_{t,5})$ is the only free parameters in the calibration of the CDS pricing model. As Bielecki et al. (2011) demonstrate that counterparty risk more or less affects CDS spreads, it also affects the LGD of CDSs. Thus, the LGD of counterparties calculated from a counterparty risk free CDS pricing model, such as the Bluhm et al. (2002) model, is not applicable to the calibration of the CDS pricing model. It is necessary to calibrate the LGD of the counterparties as well as that of the reference entity when calibrating the CDS pricing model to the CDS spread of major CDS dealers. Therefore, we calibrate the LGD of the reference entities and all of the possible counterparties simultaneously in (9), while the LGD of non-dealer entities is calibrated separately in (10).

4 Estimation Results

To confirm the PD implied by stock options for the market valuation of credit risk, we compare it to the benchmark calculation of the PD obtained from CDS spreads under the assumption of a constant 60% LGD using the counterparty risk free CDS pricing model (hereafter called the constant LGD model). Under the constant LGD model, movement in the CDS spread is due solely to changes in the PD. Although this assumption is already considered out of date by both academics and industry practitioners, it is still convenient for adjusting the level of CDS spreads to enable comparison with 'the PD obtained from listed stock options.

Next, we consider the LGD implied by the CDS spread. As we will demonstrate later, because the implied PD moves in the opposite direction to the CDS spread, the implied LGD is far from constant, and reflects the situation of the individual entity.

4.1 The interpretation of the implied PD of financial institutions

Although the credit events in CDSs do not match exactly the events that occur with a stock price of zero, the probability that the underlying stock price will become zero is effectively equivalent to the probability of default.[6] However, the applicability of the implied PD into the analysis of the financial institutions' CDS is not obvious especially during the recent financial crisis , because governments often intervened in the operations of financial institutions to achieve financial stability.

The PD implied by stock options, $\hat{\lambda}_t^{(1)}$, represents the probability that the underlying stock price will become zero at default. While this captures the probability that the institution or firm's managers (or regulatory authorities, in the case of banks) will decide to shut down the business, a stock price of zero does not necessarily imply the triggering of a credit event for CDS.

We can partition the state space and examples (credit events[7] and bailed out financial

[6] See Takeyama (2012) for details.

[7] Markit CREDITFIXING, http://www.creditfixings.com/CreditEventAuctions/fixings.jsp

institutions without a credit event[8]) in 2008,[9] as follows.

1. A credit event occurs, and the stock price becomes zero (Freddie Mac, Fannie Mae, Lehman Brothers and Washington Mutual in September 2008 and Kaupthing Bank in October 2008).

2. A credit event occurs, and the stock price is still positive (this is theoretically possible, but there are no examples from the recent crisis).

3. No credit event occurs, but the stock price becomes zero (Northern Rock in February 2008 and Bradford & Bingley in September 2008).

4. No credit event occurs, and the stock price is still positive (Bear Stearns in March 2008 and AIG in October 2008).

Although empirical studies demonstrate that some stocks of US companies that filed for Chapter 11 are still listed and traded (Dawkins *et al.*, 2007; Li and Zhong, 2011; Coelho *et al.*, 2010), the average total assets of these companies is much less than 1% of the average total assets of the sample non-financial and financial firms. This means that it is difficult for large corporations to file for Chapter 11 with a positive stock price by violating the absolute priority rule (APR), even under the flexible bankruptcy legal system in the US. Financial institutions obviously cannot choose this option, because it is unrealistic for them to expect to maintain credibility as a counterparty in various interbank transactions after an APR violation. Therefore, case 2 is unrealistic.

For case 3, the stock price of zero implies that banks fail to meet the regulatory capital requirement to continue their business. Therefore, the banks enter into a foreclosure process or default, unless they are fully nationalized. For the large banks in the sample, this is unrealistic. In the case of RBS and Lloyds, full nationalization, foreclosure and default are all unrealistic options for two reasons. First, the sum of assets held by RBS and Lloyds is larger than the nominal UK GDP in 2008. Second, these banks have large business arms outside their home countries. This makes it difficult for governments to

[8] We construct the dataset using Table 2 in Claessen *et al.* (2011).

[9] While we limit the information to that available in 2008 in order to discuss the issue from the investors' point of view in 2008, the discussion is generally applicable to the period 2009–2011.

take over and guarantee all of their assets and liabilities without resistance from taxpayers (and lawmakers). Moreover, because of the breadth of these banks' operations, the home–host country problem becomes yet another bottleneck impeding the resolution of their financial difficulties. Host-country authorities impose their own regulations on financial institutions operating in their territory.[10] Thus, it is generally difficult to establish a resolution scheme without some violation of the many different regulations to which these large banks are subject. As an exceptional example, a stock price of zero can occur without a credit event under the temporary government control of depository institutions in Japan, because it is designed so that financial institutions can continue their operations without triggering a credit event, as defined by the ISDA, and without breaching the regulatory restrictions in all of the industrialized countries. While the US FDIC has a similar system of temporary public control for relatively small domestic banks, the US or European governments have not yet established such a system for systemically important financial institutions (see Bernanke, 2009, for a discussion of the financial system reform after the Lehman Brothers collapse). Therefore, we can neglect case 3 for large corporations and financial institutions. We are left with cases 1 and 4, implying that a stock price of zero entails the triggering of a credit event.

4.2 The implied probability of default in stock options

It is clear from Figures 9 and 10 that the implied PD of the UK banks was not much higher than that of non-financial companies just after the Lehman Brothers collapse. Although the CDS spreads of the UK banks spiked temporarily following the collapse on September 15, 2008, the implied PD of the UK banks did not change significantly. In contrast, the implied PD of the US investment banks increased beyond 10%, while that of the US commercial banks and non-financial companies did not change significantly (Figures 11 and 12). It implies that the initial impact of the Lehman Brothers collapse was on the turmoil of the money market (Figures 7–8) and the PD of the US investment banks which largely depend on money markets for their funding. The liquidity crisis forced the investment banks to convert into bank holding companies in order to obtain

[10] In fact, BCBS (2004) is "the international convergence". The details of capital regulation are different in each country.

access to the liquidity supply programs of the Federal Reserve. To ease the turmoil, the UK government implemented capital injection measures and raised the limit of the bank deposit guarantee on October 3, while the US Congress accepted the Troubled Asset Relief Program (TARP) on October 14. As a consequence, the CDS spreads of UK and US financial institutions declined, but remained at a higher level than prior to the Lehman Brothers collapse (Figures 3–5).

In contrast, there are significant differences among the implied PDs of the UK banks during November and December of 2008 and the first quarter of 2009. The UK government provided Lloyds and RBS with public money to strengthen their capital bases at the beginning of October 2008. However, it did not contribute to stabilizing the implied PD. From the middle of October 2008, the implied PD of Lloyds increased and diverged from that obtained from the constant LGD model. The implied PD of RBS shows similar behavior from the middle of December 2008. From their peaks in March 2009, the implied PDs of these banks fell to around 30%, while the PDs of these banks obtained from the constant LGD model remained at around 3%. In contrast, the implied PD of HSBC remained at almost the same level as that obtained from the constant LGD model. Finally, the implied PD of Barclays exhibits behavior between that of the "bailed out" banks and HSBC. The implied PD of Barclays peaked at around 25% in March 2009. To summarize, although the CDS spreads of the UK banks were very similar, the implied PDs indicate clearly that there were significant differences between the perceived credit risks of RBS and Lloyds (and, to a lesser extent, Barclays) and that of HSBC.

There are also significant differences between the implied PDs of the UK banks and those of the US financial institutions in this period. Although the US government provided capital to all of the major financial institutions, the implied PDs of Morgan Stanley and Goldman Sachs continued to rise, reaching 40% and 30%, respectively. On the other hand, the implied PD of Citi surged to around 70%, although the US government injected additional capital in November 2008. Finally, the implied PD of JPMorgan Chase was stable at 5%, except for a temporary rise in March 2009.

The timing of the rise, as well as the level of the implied PD at the peak, indicates the view of investors in credit markets. We interpret the movement of the implied PD as follows.

1. The record high losses of Lloyds in the fourth quarter of 2008 were mainly a result of the losses incurred by HBOS, which was taken over by Lloyds. Although the UK government provided Lloyds with public funds to strengthen its capital structure in October 2008, investors did not consider these funds sufficient to absorb HBOS's losses. Even after the government announced the introduction of the Asset Protection Scheme (APS) and additional capital injection, investors were not confident that Lloyds could absorb the losses and avoid the credit event.

2. RBS also made record high losses in this period. In contrast to the case of Lloyds, this was mainly because of the markdown of securitized products and losses in ABN AMRO. Therefore, investors perceived the bank to be in danger of failure as asset prices, especially securitized product prices, fell rapidly at the end of the fourth quarter of 2008. Investors doubted the sustainability of RBS even under the APS and with additional capital injections. RBS also became a partly state-owned bank.

3. Barclays is a different case. Whilst Barclays already announced the issue of preferred shares to a Qatar government fund in October 2008, investors were not sure that Barclays could absorb the potential loss within its existing capital structure.

4. Citi also recorded high losses in this period. Although Citi raised capital several times after 2007, the US government arranged additional capital injections specifically for Citi. In addition, Citi had access to the US government's wider loss protection program in November 2008.

5. The implied PDs of the US investment banks Morgan Stanley and Goldman Sachs reacted more quickly to the Lehman Brothers default than did those of JPMorgan Chase and Citi. This is because the resultant turmoil in the interbank markets had a larger effect on the investment banks. In addition, these banks are predominantly trading book operations, and hence they quickly realized their losses. In addition to the public capital injection, these banks raised capital privately during this period. As a result, their implied PDs returned to below 10% in the first quarter of 2009, prior to Citi, whose PD only returned to these levels in July 2009. Citi had substantial banking book losses during this period.

Finally it can be seen from Figure 9 that for RBS and Lloyds (and Barclays) there is only a gradual decrease in the implied PDs from their peak. These results imply that the actions of the UK government did not result in the decrease in the implied PDs of the banks immediately. In fact the implied PDs rose gradually following the first capital injection in October 2008, and rose significantly around the time of the second capital injection in February and March 2009. Investors were unsure whether these banks could absorb the potential significant losses even after the new capital was obtained from the government. This contrasts with the CDS spreads of Lloyds and RBS. After the first capital injection in October 2008, the CDS spreads of RBS and Lloyds were nearly as high as that of HSBC before the announcement of the APS in the fourth quarter of 2008 (see Hall, 2009, for details). At the time of the second capital injection and the acceptance of the APS, the difference between the CDS spreads of RBS and Lloyds and that of HSBC was less than 100bp. These results demonstrate that investors care not only about direct government support but also about the banks' perceived ability to recover from significant losses; only when both criteria are satisfied does the implied PD recover.

The implied PDs of HSBC and the UK and US non-financial companies contrast with those of the financial institutions mentioned above (Figures 9–12). Whilst the implied PD does not necessarily match the PD obtained under the 60% LGD assumption, it does fluctuate closely around the constant-LGD value. The implied PD of TESCO, however, diverged significantly from the PD obtained under the constant-LGD assumption. This is mainly because TESCO raised funds to expand the business with debt finance. As a result, the ratio of equity to total assets fell to 39.5% in February 2009, down from 64.9% in February 2008. On the other hand, profitability does not change significantly (29.96 pence and 29.19 pence in 2008 and 2009, respectively). Thus, the increase in leverage caused a slight rise in the PD. These facts also imply that the PD estimator of the non-financial firms is inconsistent with the constant LGD assumption, even when the reference entities are not in the same irregular situation as the bailed-out US and UK banks.

4.3 The implied loss given CDS default

Figure 13 shows that the implied LGD of the UK banks increased temporarily after the Lehman Brothers collapse, followed by a rapid decrease (during September 2008). After September 2008, the implied LGD of UK banks (except HSBC) continued to decrease. In particular, the implied LGD reached minimum levels, less than 10% for RBS and Lloyds, and 10–20% for Barclays, after January 2009. The implied LGD of these banks remained at these low levels until the third capital injection into RBS and Lloyds in the fourth quarter of 2009, in contrast to that of HSBC and the nonfinancial companies (Figure 14). Thus, the correlation between the implied PD and LGD of these banks is much weaker than for HSBC and the nonfinancial companies (Table 11).

Similar behavior is observed in the implied LGD of the US financial institutions and non-financial companies (Figures 15–16). However, the implied LGDs of Citi, Morgan Stanley and Goldman Sachs increased earlier than did those of the UK banks. These results are interpreted as follows. The sharp rise in the implied LGD of the UK banks shortly after the Lehman Brothers collapse implies that the rise in the CDS spread in September 2008 was caused not by the threat of the insolvency of the individual institutions but by the threat of bankruptcy due to the liquidity shortage. In fact, this is the period during which the UK TED spread showed significant volatility (Figures 7–8). Therefore, the correlation between the PD and LGD of Citi is weaker than for non-financial firms, while the correlations for Goldman Sachs and Morgan Stanley are similar to those for the non-financial firms (Table 11). This caused the break in Granger causality between the stock returns and the CDS spreads of UK banks, as discussed in Section 2. As the decline in the LGD cancels out the rise in the PD, the CDS spreads of the UK banks did not response to the stock price change.

The low implied LGD of Lloyds and RBS, after January 2009, is interpreted as the CDS investors' expectation that these banks could reorganize their capital structure without a significant loss to the debt investors, even if they triggered a credit event. As discussed in Section 4.2, the government failed to convince the equity investors of these banks' solvency via the second capital injections and the APS in February–March 2009. However, the CDS investors were confident that the government would never fail or refuse to proceed with the orderly reorganization of these banks if they triggered a credit event.

Thus, investors did not have to be cautious about the risk of bankruptcy, as was the case for Lehman Brothers, or about a failure of resolution, as was the case for Kaupthing Bank. In other words, the government succeeded in reducing the investors' uncertainty regarding the reorganization options of these banks via a strong commitment as the largest shareholder of these banks as well as their regulator.

The implied LGDs of Citi, Morgan Stanley and Goldman Sachs, institutions into which the US government injected capital, demonstrate a different reaction by equity investors to that in the case of the troubled UK banks. The implied LGDs of Citi and the investment banks started to rise again in December 2008 and February 2009, respectively. This implies that the US government's actions were perceived as too weak to reassure equity investors that they could rule out the possibility of bankruptcy completely (as shown by the case of Lehman Brothers). In fact, the US government examined the solvency of major US financial institutions via a stress test in April 2009 and did not commit to further public capital injections into financial institutions that failed the stress test. Investors were therefore more cautious of US financial institutions, in contrast to the investors in UK banks, because the failure to pass the stress test and raise additional capital could trigger a credit event.

The rise in the implied LGDs of HSBC and the UK and US non-financial companies between the fourth quarter of 2008 and mid-2009 was a contributing factor to the rise in their CDS spreads. As the UK government did not introduce a support scheme for non-financial companies (analogous to the General Motors bankruptcy scheme instigated by the US government in July 2009), the movement in their implied LGD is independent of government actions, in contrast to the implied LGD of the UK banks. In fact, the positive correlation between the implied PD and LGD is observed in most of the non-financial sample companies. This is consistent with empirical studies on the LGD of bonds and loans (Altman *et al.*, 2005).

The impact of counterparty risk is generally limited, even in the midst of financial market turmoil. However, the impact of counterparty risk on the implied LGD is locally large for the nondealer entities—Citi, Walmart and Exxon—because the impact of counterparty risk depends on the dependency structure of default between the reference entity and counterparties.

4.4 The cross sectional movement of PD and LGD

Finally, we investigate the cross-sectional movement of the implied PD and LGD. In addition to the analysis of the full sample period, we divided the sample period into two parts. As TED spreads returned to their pre-Lehman Brothers collapse level by the end of March 2009 (Figures 7–8), we divide the data into two groups: July 2008–March 2009 and April 2009–December 2009. The first period was in the midst of the financial market turmoil, while the second period experienced relatively stable financial conditions.

The principal component analysis reveals that there is no significant co-movement of the daily changes in the PD (Figure 17). As Figure 23 shows, the contribution of the principal components to the movement of the PD is relatively low. The first and second principal components explain only the drastic movement of the bailed-out US banks' PD (Citi) and that of the bailed-out UK banks' PD (Lloyds), respectively. In other words, the spillover from the bailed-out banks to the other banks and nonfinancial corporations is quite limited both in the midst of the financial crisis (Figure 18) and after the crisis (Figure 19). These results indicate that there is no significant co-movement even between the US and UK bailed-out banks, although the cause of the severe credit valuation of these banks is common—that is, the financial crisis triggered by the Lehman Brothers collapse.

The first principal component of the daily change in the implied LGD is, in contrast, the co-movement of the implied LGD of all the sample companies (Figure 20). Moreover, the contribution of the first principal component of the implied LGD is much larger than that of the implied PD (Figure 23). This is consistent with a study on the liquidation value of defaulted firms (Shleifer and Vishny, 1992). The LGD is the hypothetical price of the company or the company's assets upon default, as assessed by the defaulted company's potential buyers. Therefore, the LGD is subject to the potential buyers' financial capacity as well as the fundamental value of the firm's assets. This means that LGD often reflects systematic risk as well as idiosyncratic risk, whereas the PD usually reflects the idiosyncratic risk.

This relationship becomes clearer when financial markets are relatively stable. In the second period (relative financial calm), the first principal component explains about 70% of the variance in LGD movement, and the score of the first component is homogeneous

(Figure 21 and Figure 23). In contrast, the first component explains only 25% of the variance in LGD movement in the first period (financial turmoil). This lower contribution to variance in the first period, in the midst of the financial crisis, indicates that the implied LGD (especially that of the bailed-out banks) reflects the demand of another potential buyer or, more accurately, the successor of the banking business: the government. These results support the homogeneous stochastic recovery model (Krekel, 2010; Amraoui *et al.*, 2009; Amraoui and Hitier, 2008), especially when financial markets are stable. In other words, investors do not attach great importance to the heterogeneity of LGD in the valuation of credit products such as CDOs, except when the markets are extremely distressed.

Finally, these findings yield no evidence of credit risk contagion in CDS markets, assuming homogeneous loading factors means the credit risk contagion. As the principal components of the implied PD have no homogeneous loading factors, contagion of credit risk did not occur. Moreover, although the first component of LGD has homogeneous scores for all the sample firms, in both the first and second period, the contribution of the first component in the first period is smaller than that in the second period. That is, the first component of LGD is inconsistent with the credit risk contagion hypothesis (the contribution in the first period should be larger than in the second period if the hypothesis is correct) while it is the only potential path of credit risk contagion. Therefore, we conclude that there is no quantitative evidence that the rise in CDS spreads in the market overall was driven by the rise in financial institutions' CDS spreads.

These principal component analyses provide a possible explanation of the irregular movements of the CDS spreads of RBS and Lloyds. While the US government implemented a series of policies to stabilize the financial system after the major US financial institutions were under distressed valuation, the UK government took action before credit risk contagion could occur directly from US financial institutions to UK banks. Of course, the actions of the UK government were not sufficient to support the credit of the bank with the distressed domestic business (Lloyds), or the one with the distressed US business (RBS). A series of UK government policies succeeded in achieving a relatively smooth transition to partial state control of these banks, although RBS and Lloyds held a larger proportion of troubled assets than did Citi.

5 Concluding Remarks

We investigated the market valuation of credit risk, especially that of the major UK banks, using the framework for the estimation of the PD based on stock options developed by Takeyama *et al.* (2012). The financial crisis had a devastating effect on the banking systems of many industrialized economies, forcing government intervention, including partial state ownership via capital injections. However, we do not necessarily find significant differences in CDS spreads between "bailed out" banks and other banks, especially in the UK. In order to explain this anomaly, we estimated the implied PD from a calibration of the implied volatility of listed stock options. The implied PD was then used to derive an implied LGD from the market-quoted CDS spread.

Separation of the PD and LGD allowed us to explain the benign levels of the UK banks' one-year CDS spreads during a period of intense market turmoil. This was a result of the significant interplay between implied PD and LGD. In particular, the LGD of RBS and Lloyds dropped below 10%, while their implied PD derived from the listed stock options peaked at around 70% in March 2009. This indicates strongly that the participants in the listed stock option markets saw significant risk of the erosion of existing shareholders' equity, whilst debt investors were confident that even a credit event would not pose a risk of significant loss. Therefore, although UK bank CDS spreads were relatively stable during this period, except for the short term turmoil after the Lehman Brothers collapse, this is evidence not of the soundness of the UK banks but rather of a high degree of debt investor confidence in the reorganization scheme during the period of UK government intervention. The impact of the government intervention can also be observed in the implied LGD of Citi, although RBS and Lloyds held a larger proportion of troubled assets than did Citi.

We also considered LGD using the counterparty risk-free CDS pricing model for comparison as a benchmark case. Our results confirm that counterparty risk does not influence LGD significantly with full collateralization under the ISDA master agreement.

The contagion of credit risk is observed neither between the US and UK financial institutions nor between financial institutions and nonfinancial corporations, according to our principal component analysis: the leading principal components of the PD had no homogeneous loading factors; and, in our analysis of LGD, the contribution of the leading principal components with homogeneous loading factors during the period of financial turmoil was less significant than during the period of relative financial stability.

These results provide a possible explanation of the irregular movement of the CDS spreads of RBS and Lloyds. While the US government implemented a series of policies designed to stabilize the financial system after the major US financial institutions were under distressed valuation, the UK government took action before credit risk contagion could occur directly from US financial institutions to UK banks.

Moreover, the results of our analysis of the co-movement of LGD provide a building block for modeling basket credit derivatives. The loading factors of the first principal component of LGD are equally weighted in all the sample companies, while the implied LGD is not constant over the sample period. This means that the homogeneous stochastic recovery model (Krekel, 2010; Amraoui *et al.*, 2009; Amraoui and Hitier, 2008) contains sufficient flexibility in the pricing of CDOs. However, the low explanatory power of the first component of LGD changes in the midst of the financial crisis, implying that it is necessary to consider the heterogeneous movement of LGD when modeling distressed situations.

Our results indicate that the CDS market was more efficient than was generally thought, even in the midst of the financial crisis. This is consistent with empirical studies on credit derivatives markets (Arora *et al.*, 2011; Longstaff, 2010). Moreover, it should be noted that the investigation of the impact of the financial market turmoil on the lower-grade and smaller companies, and the implementation of heterogeneous stochastic recovery in CDO pricing, are issues for future research. As we restricted the sample data here to large financial institutions and large non-financial corporations, we cannot conclude whether credit risk contagion or a credit crunch occurred throughout the entire financial system, or whether such a contagion or crunch—if they existed—amplified the business cycle.

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Table 1: *Major Events of the Financial Crisis in 2008-09*

Date	Event	Country
03/14/2008	FRB introduce lending facility for Bear Sterns	United States
03/16/2008	JP Morgan Chase take over Bear Sterns	United States
09/06/2008	Freddie Mac & Fannie Mae nationalized.	United States
09/15/2008	Lehman Brothers Collapse	United States
09/15/2008	Bank of America take over Merril Lynch.	United States
09/16/2008	FRB introduce lending facility for AIG.	United States
09/18/2008	Lloyds announces to take over HBOS.	United Kingdom
09/22/2008	Goldman Sachs & Morgan Stanley became Bank Holding Company (BHC)	United States
09/24/2008	Goldman Sachs announced capital raising from Berkshire Hathaway	United States
09/28/2008	Fortis was nationalized.	Benelux countries
09/29/2008	Morgan Stanley announced capital raising from Mitsubishi UFJ Financial Group (MUFG)	United States
09/29/2008	Bradford&Bingley (B&B) nationalized.	United Kingdom
09/30/2008	US congress rejected TARP (Troubled Asset Relief Program)	United States
10/03/2008	UK raises limit of bank deposit guarantee.	United Kingdom
10/12/2008	Capital injection for RBS, Lloyds and HBOS.	United Kingdom
10/14/2008	Capital injection for the US major banks.	United States
10/31/2008	Barclays announced capital raising.	United Kingdom
11/18/2008	Barclays announced details of the capital raising (existing shareholders and Qatar)	United Kingdom
11/23/2008	Capital Injection (2nd) and Asset Guarantee (Citi Group)	United States

Table 1: *Major Events of the Financial Crisis in 2008-09*

Date	Event	Country
01/16/2009	Capital Injection (2nd) and Asset Guarantee (Bank of America)	United States
01/17/2009	UK announces the asset protection scheme (APS).	United Kingdom
02/17/2009	UK announces the replacement of the preferred share with common stock (RBS).	United Kingdom
02/26/2009	Capital Injection (2nd) and the APS (RBS)	United Kingdom
03/02/2009	HSBC issues common stocks to shareholders	United Kingdom
03/07/2009	UK announced the replacement of the preferred share with common stock and the APS (Lloyds)	United Kingdom
03/30/2009	Barclays announced not to adopt the APS.	United Kingdom
06/17/2009	JP Morgan Chase and Morgan Stanley announces the repayment of the public capital.	United States
07/22/2009	Goldman Sachs repays the public capital.	
11/03/2009	Capital Injection (3rd, RBS & LLOYDS).	United Kingdom

Table 2: *The list of sample corporations in VAR analysis (1)-(2)*

	iTraxx EU members	CDX.NA.IG members
1.	Aviva (AV, Fin)	AIG (AIG, Fin)
2.	Anglo American (AAL, Ind)	American Express (AXP, Fin)
3.	British American Tabacco (BATS, Con)	AT&T (ATT, TMT)
4.	BP (BP, Ene)	Boeing (BA, Ind)
5.	BT Group (BT, TMT)	Catapiller (CAT, Ind)
6.	Cadbury (CBRY, Con)	CBS (CBS, TMT)
7.	Compass Group (CPG, Con)	E.I.du Pont (DD, Industry)
8.	DIAGEO (DGO, Con)	Eastman Chemical (EMN, Ind)
9.	Experian (EXPN, TMT)	Halburton (HAL, Industry)
10.	Marks&Spencer (MKS, Con)	Hewlett-Packard (HPQ, TMT)
11.	National Grid	IBM (IBM, TMT)
12.	NEXT (NXT, Con)	McDonald's (MCD, Con)
13.	Pearson (PSON, TMT)	MetLife (MET, Fin)
14.	Rolls-Royce (RR, Ind)	Motorola (MSI, TMT)
15.	SABMILLER (SAB, Con)	Sounthwest (SWA, Con)
16.	Sainsbury's (SBRY, Con)	The Altria Group (MO, Con)
17.	Safeway (SWY, Con)	The Dow Chemical (DOW ,Ind)
18.	TESCO (TSCO, Con)	Time Warner (TW, TMT)
19.	United Utilities (UU, En)	Wal-Mart (WMT, Con)
20.	VODAFONE (VOD, TMT)	Xerox (XRX, TMT)

Note: The symbols mean Con:Consumer goods and service, Ind: Industrial goods and service, TMT: Telecommunication, Media and Technology and En: Energy respectively. They are the industry categories in CDX.

Table 3: *The Estimation results of the VAR model (1)-(2) (Daily - I)*

	US non banks	UK non banks		US non banks	UK non banks
$\beta_0^{(1)}$	0.000 (0)	-0.107 (1)	$\beta_0^{(2)}$	-0.000 (0)	0.000 (0)
$\beta_1^{(1)}$	0.041 (3)	0.016 (1)	$\beta_1^{(2)}$	-0.048 (3)	-0.057 (5)
$\beta_2^{(1)}$	-0.001 (1)	-0.027 (0)	$\beta_2^{(2)}$	0.010 (1)	-0.098 (3)
$\beta_3^{(1)}$	-0.011 (0)	-0.003 (0)	$\beta_3^{(2)}$	-0.000 (0)	-0.83 (1)
$\beta_4^{(1)}$	-0.019 (0)	-0/003 (0)	$\beta_4^{(2)}$	-0.015 (1)	0.053 (0)
$\gamma_1^{(1)}$	-24.53 (18)	-19.726 (12)	$\beta_1^{(2)}$	0.000 (0)	0.006 (2)
$\gamma_2^{(1)}$	-14.92 (4)	-8.539 (3)	$\beta_2^{(2)}$	0.010 (0)	0.023 (0)
$\gamma_3^{(1)}$	-9.45 (3)	0.780 (0)	$\beta_3^{(2)}$	-0.001 (0)	0.000 (0)
$\gamma_4^{(1)}$	-0.03 (0)	-12.400 (0)	$\beta_4^{(2)}$	-0.015 (0)	-0.011 (0)

Note: The number indicates the median of the estimated value. The number in parenthesis is the number of the samples whose estimation values are statistically significant at 5% confidence level.

Table 4: *The Estimation results of the VAR model (1)-(2) (Daily - II)*

	major US banks	major UK banks		major US banks	major UK banks
$\beta_0^{(1)}$	-0.293 (0)	-0.040 (0)	$\beta_0^{(2)}$	-0.001 (0)	-0.002 (0)
$\beta_1^{(1)}$	0.002 (3)	0.119 (1)	$\beta_1^{(2)}$	0.010 (1)	0.078 (1)
$\beta_2^{(1)}$	-0.086 (1)	-0.061 (0)	$\beta_2^{(2)}$	-0.034 (0)	0.005 (0)
$\beta_3^{(1)}$	-0.088 (0)	0.018 (0)	$\beta_3^{(2)}$	-0.004 (0)	0.024 (0)
$\beta_4^{(1)}$	-0.082 (0)	0.029 (0)	$\beta_4^{(2)}$	-0.024 (1)	0.019 (0)
$\gamma_1^{(1)}$	-113.324 (4)	-9.470 (1)	$\beta_1^{(2)}$	0.000 (0)	0.000 (0)
$\gamma_2^{(1)}$	9.990 (1)	0.515 (0)	$\beta_2^{(2)}$	0.000 (0)	0.001 (0)
$\gamma_3^{(1)}$	1.494 (0)	-1.415 (0)	$\beta_3^{(2)}$	0.000 (0)	0.000 (0)
$\gamma_4^{(1)}$	-26.525 (0)	-1.413 (0)	$\beta_4^{(2)}$	0.000 (0)	0.000 (0)

Note: The number indicates the median of the estimated value. The number in parenthesis is the number of the samples whose F values are statistically significant at 5% confidence level.

Table 5: *The Estimation results of the VAR model (1)-(2) (Daily - III)*

	major EU banks		major EU banks
$\beta_0^{(1)}$	-0.064 (0)	$\beta_0^{(2)}$	-0.000 (0)
$\beta_1^{(1)}$	0.063 (1)	$\beta_1^{(2)}$	0.032 (0)
$\beta_2^{(1)}$	0.033 (0)	$\beta_2^{(2)}$	-0.015 (0)
$\beta_3^{(1)}$	-0.025 (0)	$\beta_3^{(2)}$	-0.005 (0)
$\beta_4^{(1)}$	0.008 (0)	$\beta_4^{(2)}$	0.020 (0)
$\gamma_1^{(1)}$	-6.235(2)	$\beta_1^{(2)}$	0.000 (0)
$\gamma_2^{(1)}$	2.902(1)	$\beta_2^{(2)}$	0.000 (0)
$\gamma_3^{(1)}$	-1.012(0)	$\beta_3^{(2)}$	0.000 (0)
$\gamma_4^{(1)}$	2.962(0)	$\beta_4^{(2)}$	0.000 (0)

Note: The number indicates the median of the estimated value. The number in parenthesis is the number of the samples whose F values are statistically significant at 5% confidence level.

Table 6: *The Estimation results of the VAR model (1)-(2) (Weekly - I)*

	US non banks	UK non banks		US non banks	UK non banks
$\beta_0^{(1)}$	0.000 (0)	-0.002 (0)	$\beta_0^{(2)}$	-0.000 (0)	0.000 (0)
$\beta_1^{(1)}$	0.041 (3)	-0.053 (1)	$\beta_1^{(2)}$	-0.028 (3)	-0.059 (3)
$\beta_2^{(1)}$	-0.001 (1)	0.059 (0)	$\beta_2^{(2)}$	0.010 (1)	-0.044 (1)
$\beta_3^{(1)}$	-0.011 (0)	0.003 (0)	$\beta_3^{(2)}$	-0.000 (0)	-0.004 (1)
$\gamma_1^{(1)}$	-19.43 (8)	-23.126 (9)	$\beta_1^{(2)}$	0.000 (0)	-0.002 (2)
$\gamma_2^{(1)}$	-6.92 (2)	-10.061 (3)	$\beta_2^{(2)}$	0.010 (0)	-0.014 (0)
$\gamma_3^{(1)}$	-4.45 (2)	-20.189 (1)	$\beta_3^{(2)}$	-0.001 (0)	0.001 (0)

Note: The number indicates the median of the estimated value. The number in parenthesis is the number of the samples whose F values are statistically significant at 5% confidence level.

Table 7: *The Estimation results of the VAR model (1)-(2) (Weekly - II)*

	major US banks	major UK banks		major US banks	major UK banks
$\beta_0^{(1)}$	-0.009 (0)	0.000 (0)	$\beta_0^{(2)}$	-0.001 (0)	-0.019 (0)
$\beta_1^{(1)}$	0.117 (1)	0.011 (1)	$\beta_1^{(2)}$	0.010 (1)	-0.170 (1)
$\beta_2^{(1)}$	-0.086 (0)	0.065 (0)	$\beta_2^{(2)}$	-0.034 (0)	-0.096 (0)
$\beta_3^{(1)}$	-0.088 (0)	-0.034 (0)	$\beta_3^{(2)}$	-0.004 (0)	-0.004 (0)
$\gamma_1^{(1)}$	-15.435 (2)	-13.270 (0)	$\beta_1^{(2)}$	0.000 (0)	-0.014 (0)
$\gamma_2^{(1)}$	-20.124 (1)	0.604 (0)	$\beta_2^{(2)}$	0.000 (0)	-0.002 (0)
$\gamma_3^{(1)}$	9.435 (0)	0.705(0)	$\beta_3^{(2)}$	0.000 (0)	-0.043 (0)

Note: The number indicates the median of the estimated value. The number in parenthesis is the number of the samples whose estimation value is statistically significant at 5% confidence level.

Table 8: *The Estimation results of the VAR model (1)-(2) (Weekly - III)*

	major EU banks		major EU banks
$\beta_0^{(1)}$	-0.024 (0)	$\beta_0^{(2)}$	-0.000 (0)
$\beta_1^{(1)}$	0.043 (1)	$\beta_1^{(2)}$	0.085 (1)
$\beta_2^{(1)}$	0.033 (0)	$\beta_2^{(2)}$	-0.044 (0)
$\beta_3^{(1)}$	-0.016 (0)	$\beta_3^{(2)}$	-0.016 (0)
$\gamma_1^{(1)}$	-9.235(3)	$\beta_1^{(2)}$	0.000 (0)
$\gamma_2^{(1)}$	8.290(1)	$\beta_2^{(2)}$	0.000 (0)
$\gamma_3^{(1)}$	-5.012(0)	$\beta_3^{(2)}$	0.000 (0)

Note: The number indicates the median of the estimated value. The number in parenthesis is the number of the samples whose estimation value is statistically significant at 5% confidence level.

Table 9: *The Credit Risk Contagion from financial sector's CDS (Daily)*

	US corporations		UK corporations	
Constant	-0.036	-0.035	-0.000	-0.003
	(95.00%)	(95.30%)	(99.99%)	(95.94%)
ΔCDS_{t-1}	25.333	25.817	1.740	2.252
	(0.03%)	(0.03%)	(15.47%)	(3.38%)
$\Delta CDSIndex_t$	0.347	0.393	0.445	0.398
	(0.52%)	(0.13%)	(0.00%)	(0.00%)
$\Delta \log(Stock_{t-1})$	-114.867	-116.19	-23.847	-23.968
	(0.00%)	(0.00%)	(0.00%)	(0.00%)
$\Delta \log(StockIndex_{t-1})$	-13.986	-14.560	-5.332	-5.712
	(70.37%)	(69.2%)	(27.22%)	(23.08%)
$\Delta CDSDealer_t$	0.193		0.008	
	(0.01%)		(0.17%)	
$\Delta USBankCDS_t$		0.061		
		(0.50%)		
$\Delta UKBankCDS_t$				0.082
				(0.00%)
$Adjusted R^2$	0.016	0.016	0.121	0.125

Note: The number in the parentheses is the p values of the estimators. The results are the pooling estimation. Pool test and F test reject the heterogeneity of coefficients and Breusch-Pagan test reject the homogeneity of the residuals. In fact, the estimators of parameters and adjusted R^2 are similar to those of the other method estimation.

Table 10: *The Credit Risk Contagion from financial sector's CDS (Weekly)*

	US corporations		UK corporations	
Constant	2.663	2.646	0.152	0.149
	(46.39%)	(46.66%)	(67.43%)	(68.23%)
ΔCDS_{t-1}	508.031	504.564	47.801	46.506
	(0.00%)	(0.00%)	(10.33%)	(0.00%)
$\Delta CDSIndex_t$	0.941	0.927	0.660	0.621
	(0.66%)	(0.59%)	(0.00%)	(0.00%)
$\Delta \log(Stock_{t-1})$	-335.885	-333.798	-1.037	-0.892
	(0.00%)	(0.00%)	(53.40%)	(59.37%)
$\Delta \log(StockIndex_{t-1})$	270.861	270.861	16.080	15.695
	(2.50%)	(2.50%)	(3.66%)	(4.21%)
$\Delta CDSDealer_t$	0.233		-0.081	
	(14.64%)		(0.04%)	
$\Delta USBankCDS_t$		0.125		
		(6.24%)		
$\Delta UKBankCDS_t$				-0.064
				(0.22%)
$AdjustedR^2$	0.105	0.105	0.201	0.195

Note: The number in the parentheses is the p values of the estimators. The results are the pooling estimation. Pool test and F test reject the heterogeneity of coefficients and Breusch-Pagan test reject the homogeneity of the residuals. In fact, the estimators of parameters and adjusted R^2 are similar to those of the other method estimation.

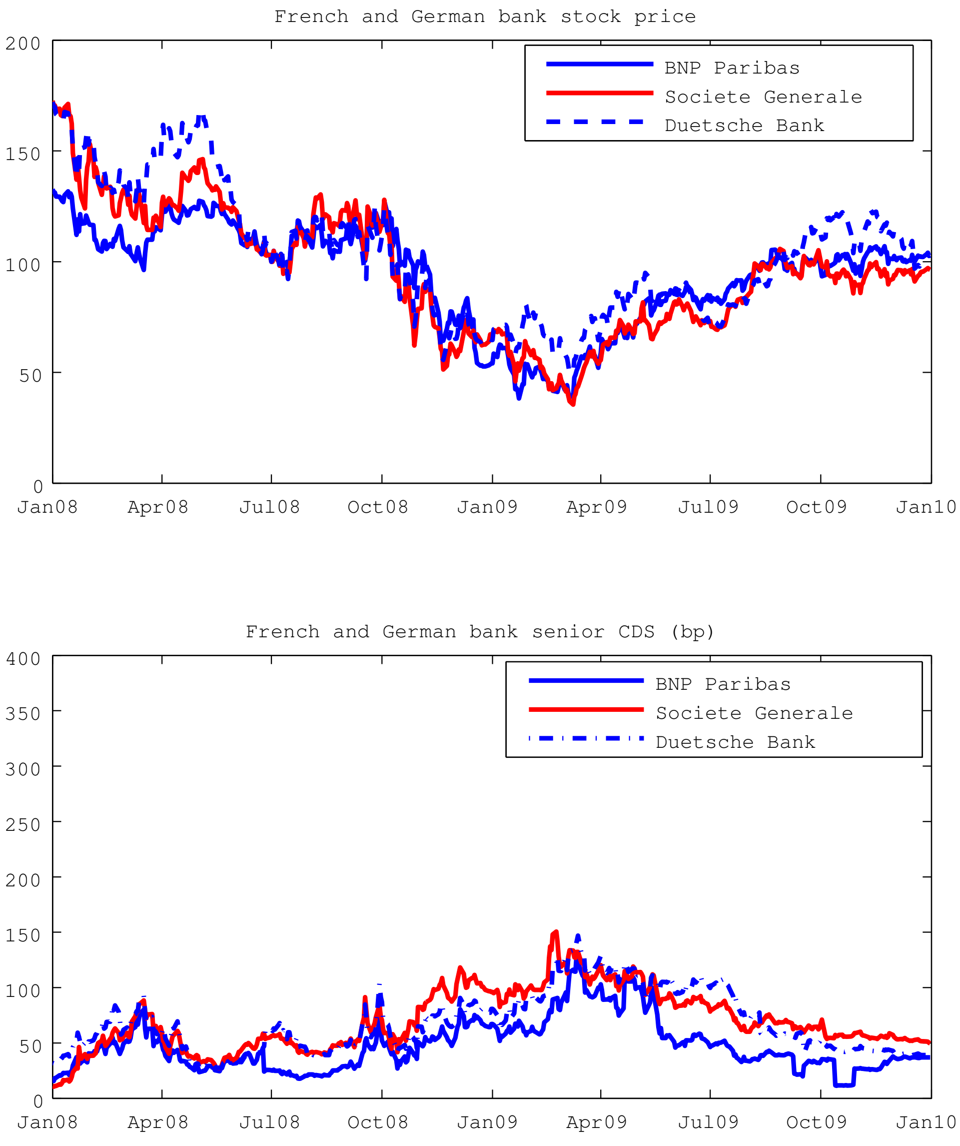
Table 11: *Correlation between the implied PD and LGD*

	HSBA	BARC	RBS	LLOY	BP	BT	TSCO
Daily	0.136	0.211	0.105	0.156	0.567	0.784	0.236
Weekly	0.370	0.171	0.124	0.165	0.123	0.710	0.293

	JPM	C	GS	MS	XOM	ATT	WM
Daily	0.565	0.190	0.487	0.555	0.507	0.546	0.677
Weekly	0.440	0.224	0.403	0.527	0.487	0.328	0.476

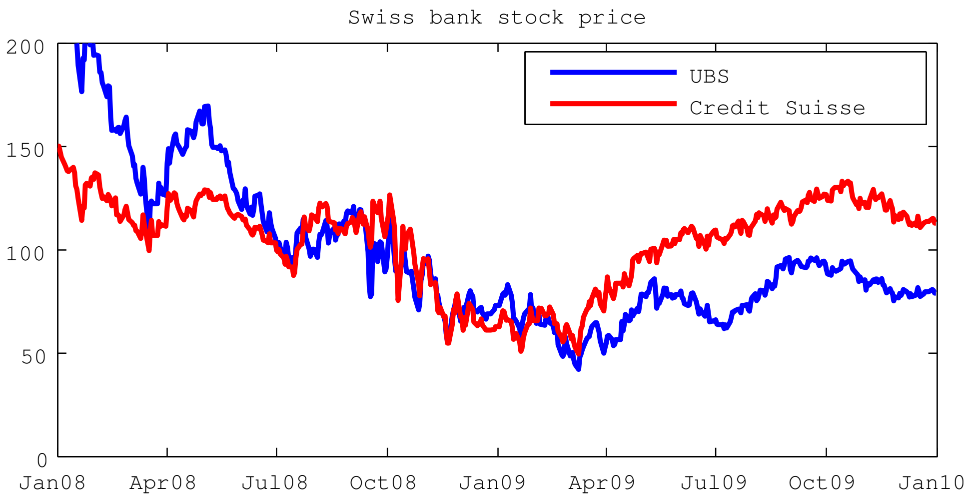
Note: The table shows the correlation efficient between the daily and weekly change of the implied PD and LGD in the sample period, July 2008 - December 2009. Ticker symbols respectively mean HSBA:HSBC, BARC:Barclays, LLOY:LLOYDS, TSCO:TESCO, JPM:JP Morgan, C:Citi, GS: Goldman Sachs, MS: Morgan Stanley, XOM: Exxon, ATT:AT&T, WM:Walmart.

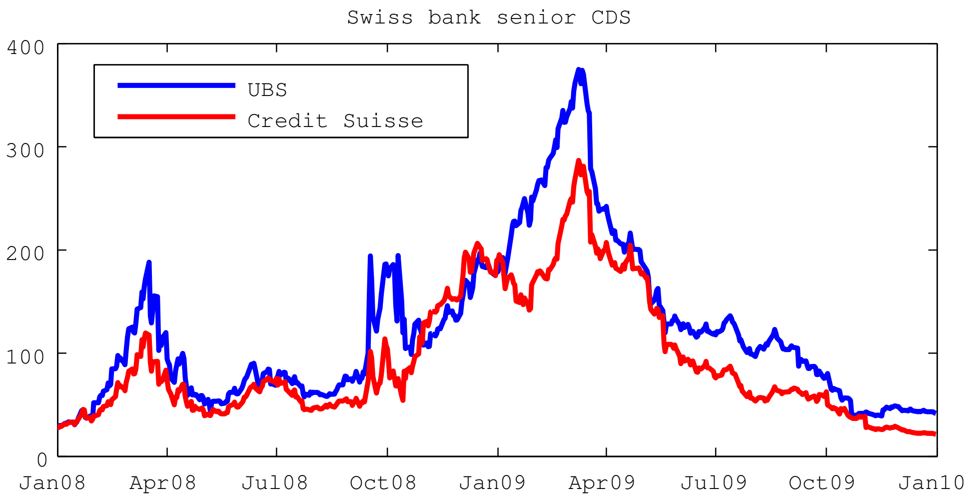
Figure 1: *Stock price and CDS spread of European Banks*



Note: Stock prices are indexed 100 at July 1, 2008.

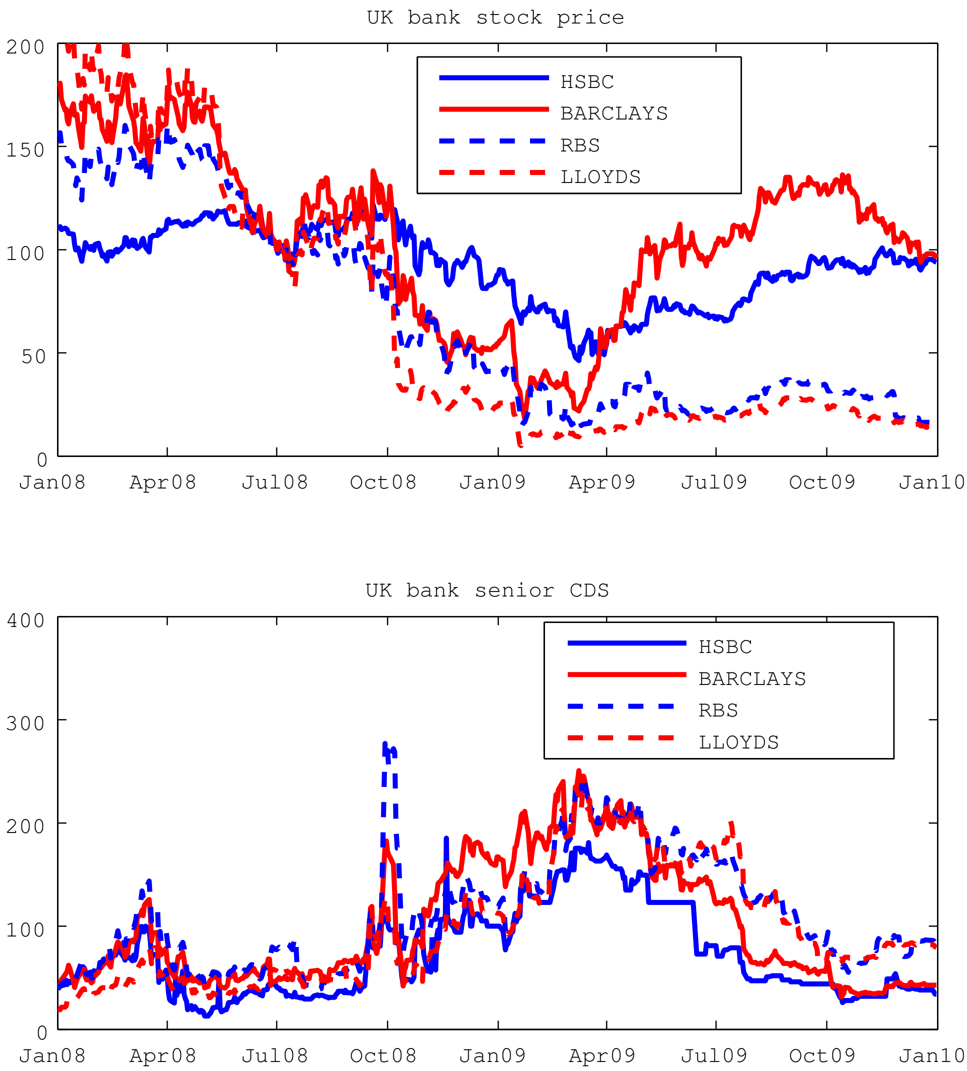
Figure 2: *Stock price and CDS spread of European Banks (2)*





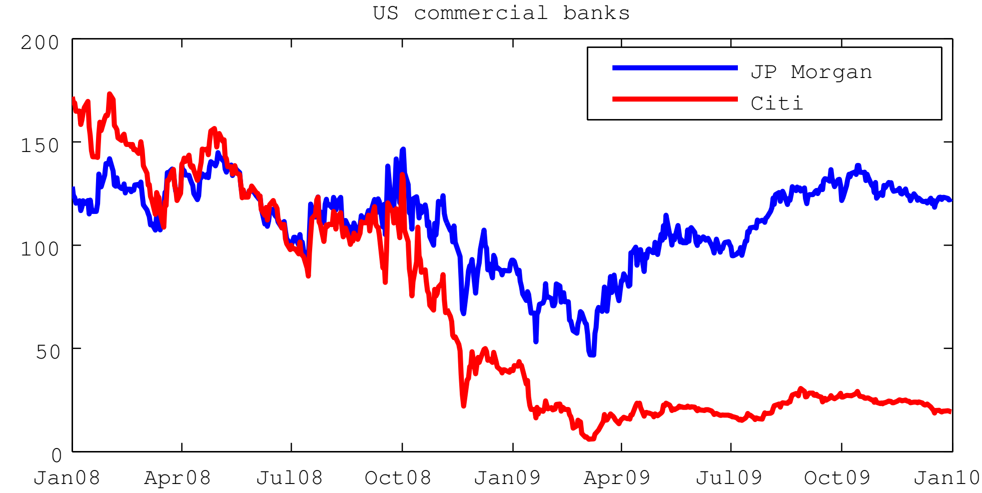
Note: Stock prices are indexed 100 at July 1, 2008.

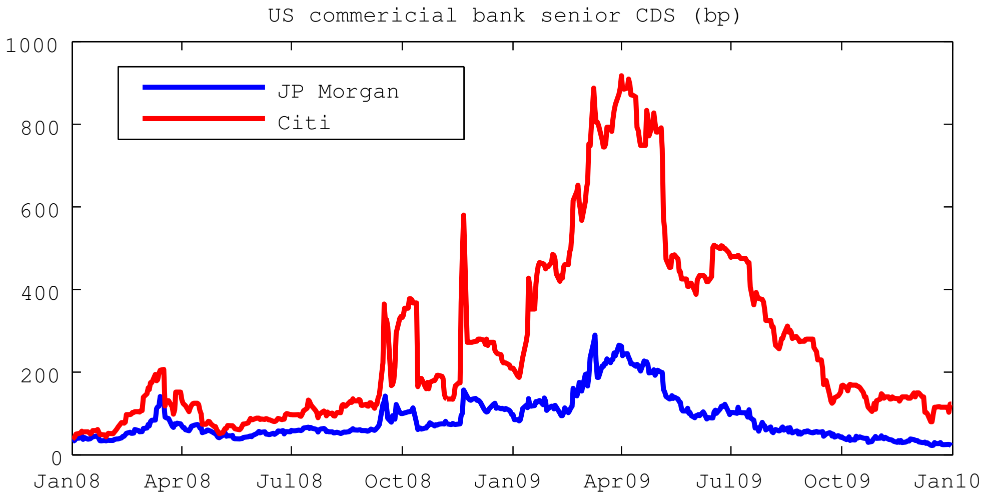
Figure 3: *Stock price and CDS spread of UK Banks*



Note: Stock prices are indexed 100 at July 1, 2008.

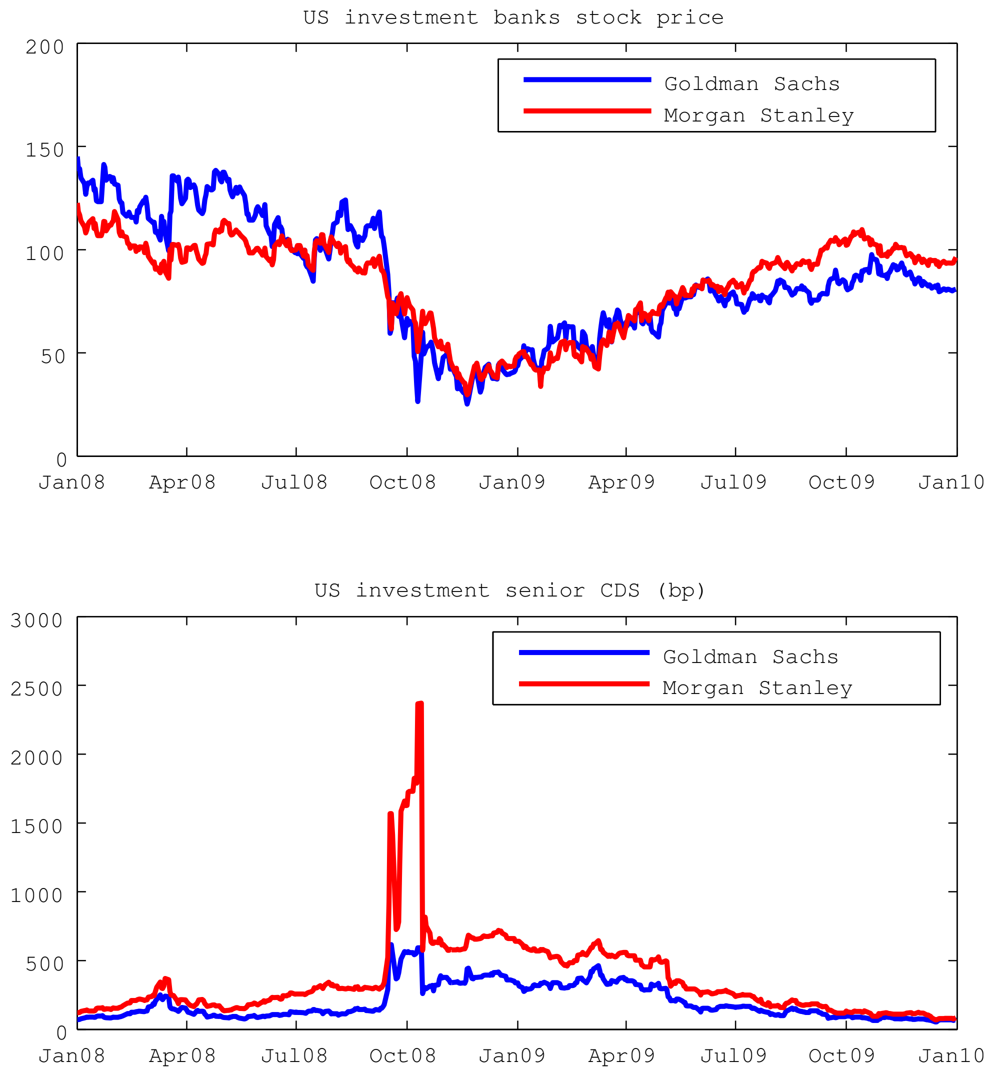
Figure 4: *Stock price and CDS spread of US Banks (1)*





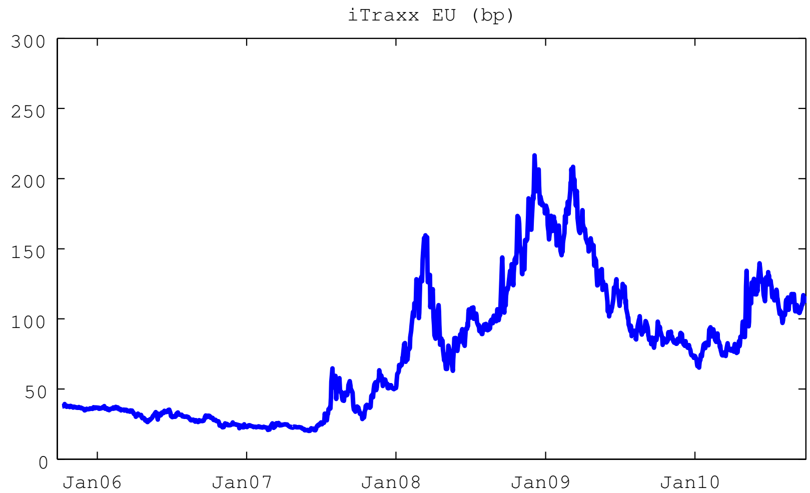
Note: Stock prices are indexed 100 at July 1, 2008.

Figure 5: *Stock price and CDS spread of US Banks (2)*



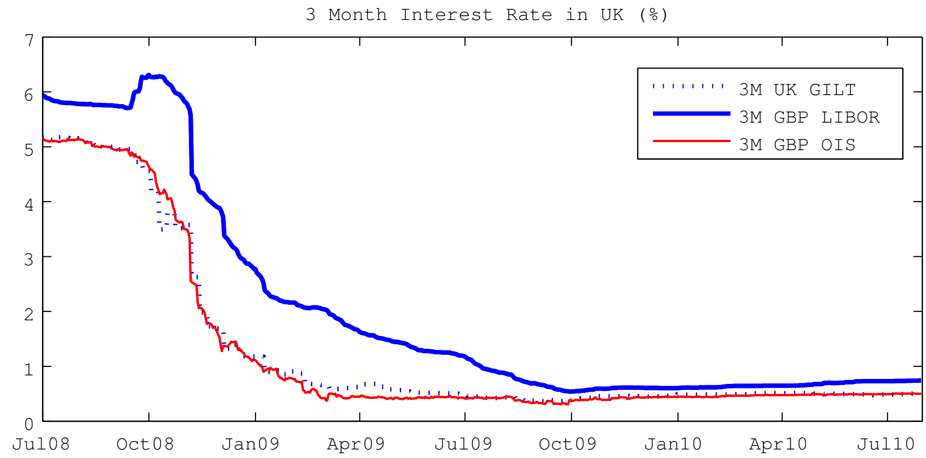
Note: Stock prices are indexed 100 at July 1, 2008.

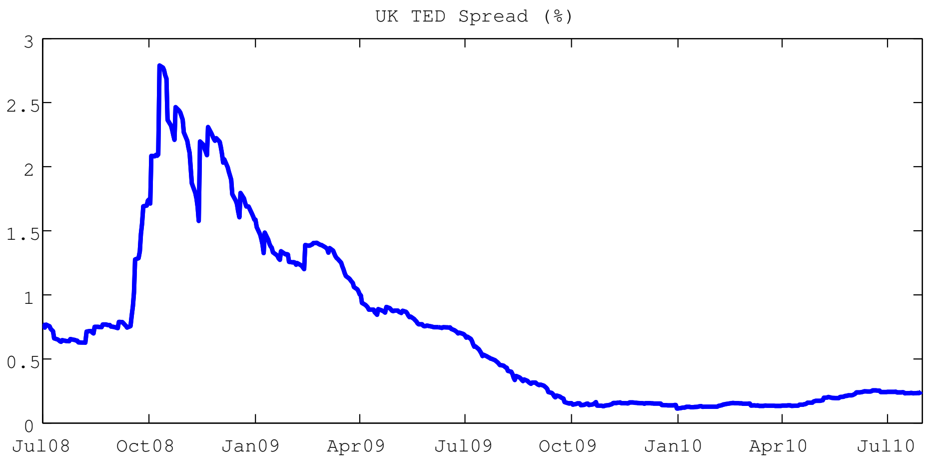
Figure 6: *CDS index in US and Europe*



Note: CDX North America investment grade (CDX.NA.IG) and iTraxx Europe (iTraxx EU) consist of the senior CDS of 125 North American and European corporations respectively. The members of the index are updated semiannually. The curves indicate the generic time series data of the 5 year index in the latest series respectively.

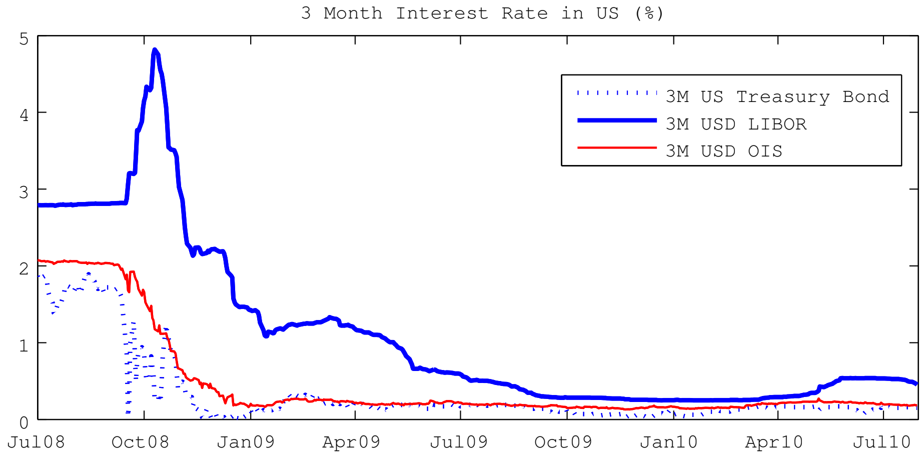
Figure 7: *Short Term Interest Rates in the UK*





Note: TED spread is originally defined as the spread between 3month ***T****reasury bill yield and 3month* ***E****uro* ***D****ollar rate. Recently TED spread just indicates the spread between Treasury bond yield and interbank rate. It generally represents the funding condition of financial institutions in interbank markets. We define the UK TED spread as the spread between 3 month LIBOR rate and 3month gilt yield.*

Figure 8: *Short Term Interest Rates in the US*



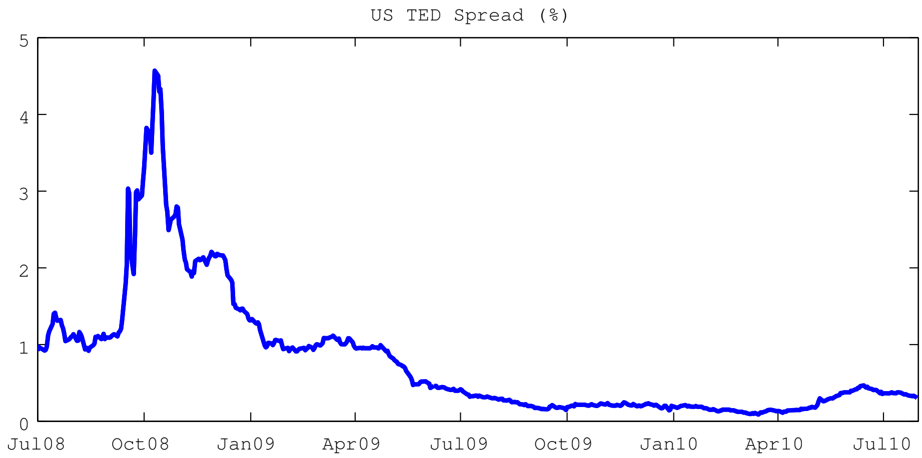
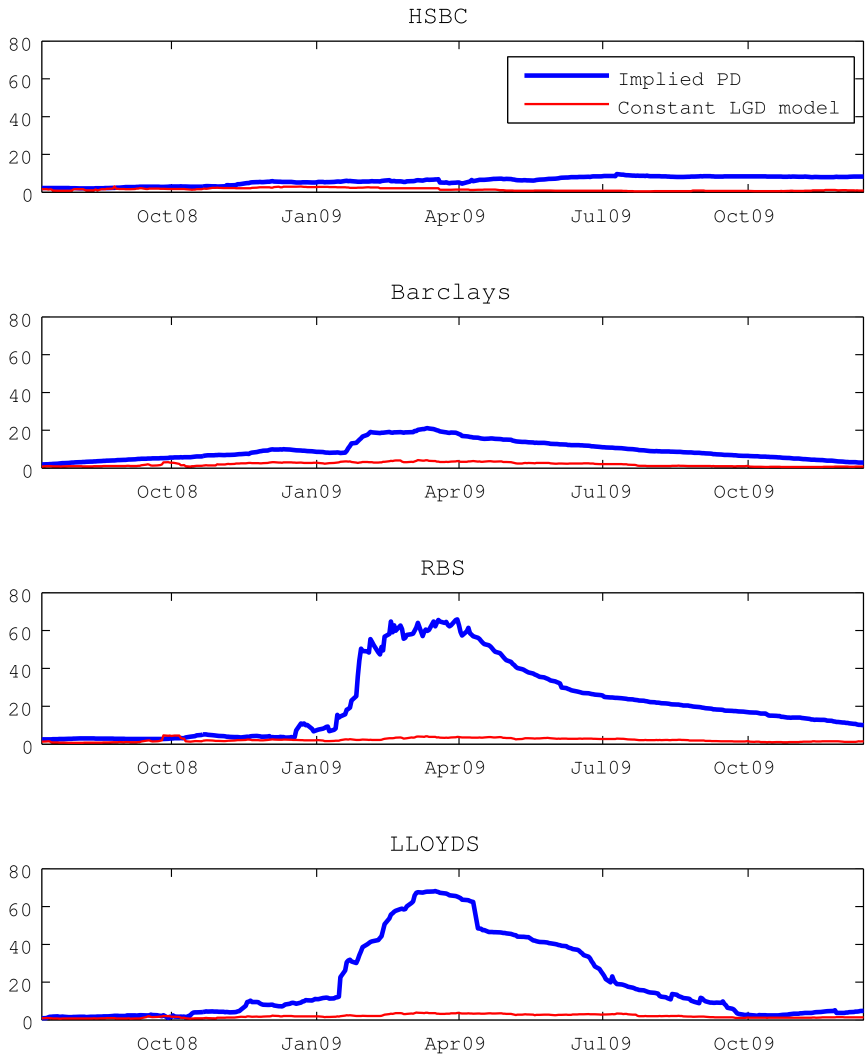
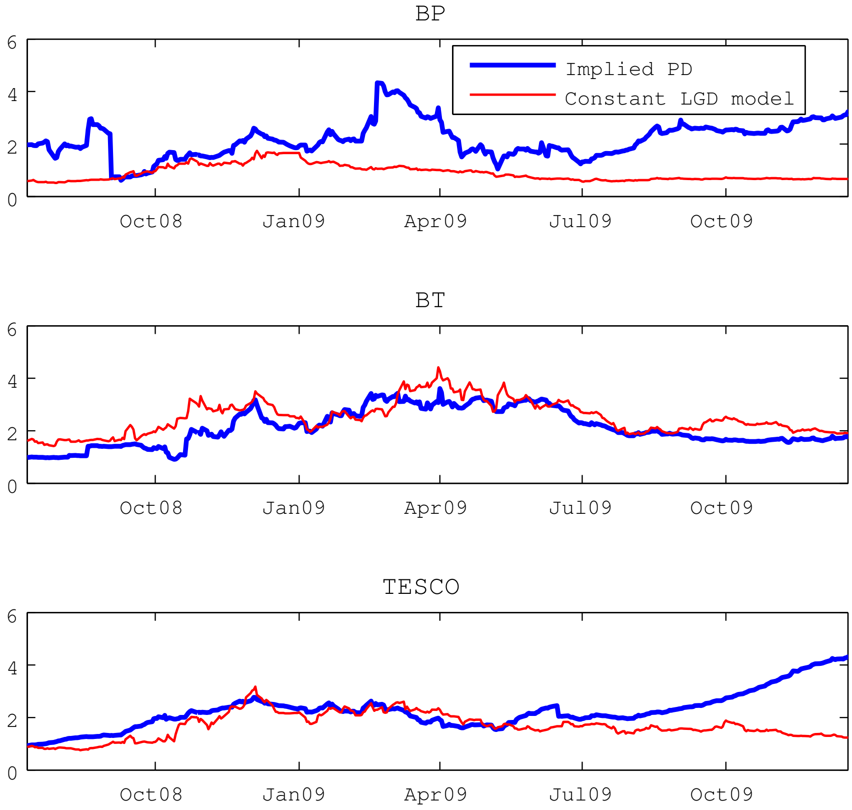


Figure 9: *Implied PD of the major UK Banks (%)*



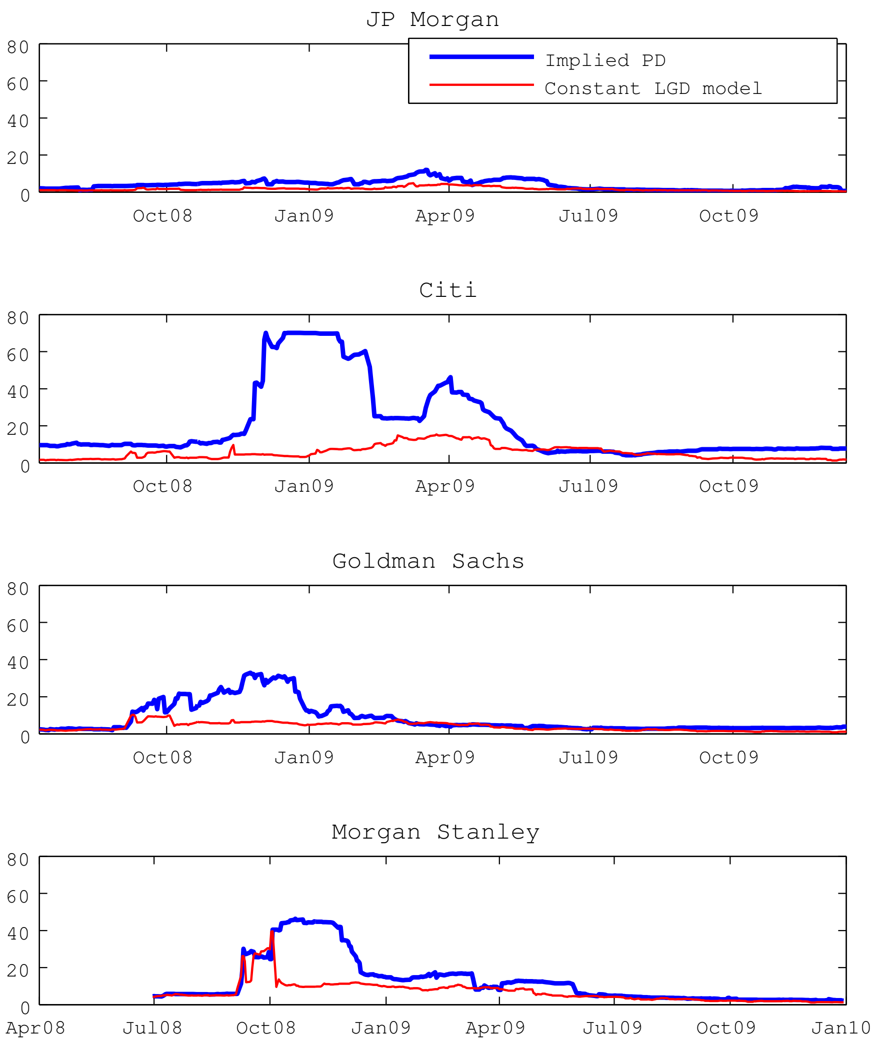
Note: The solid curve depicts the PD implied from listed stock options and the dashed curve shows the PD calculated using the counterparty risk free CDS pricing model assuming a constant 60% LGD.

Figure 10: *Implied PD of the UK non financial companies (%)*



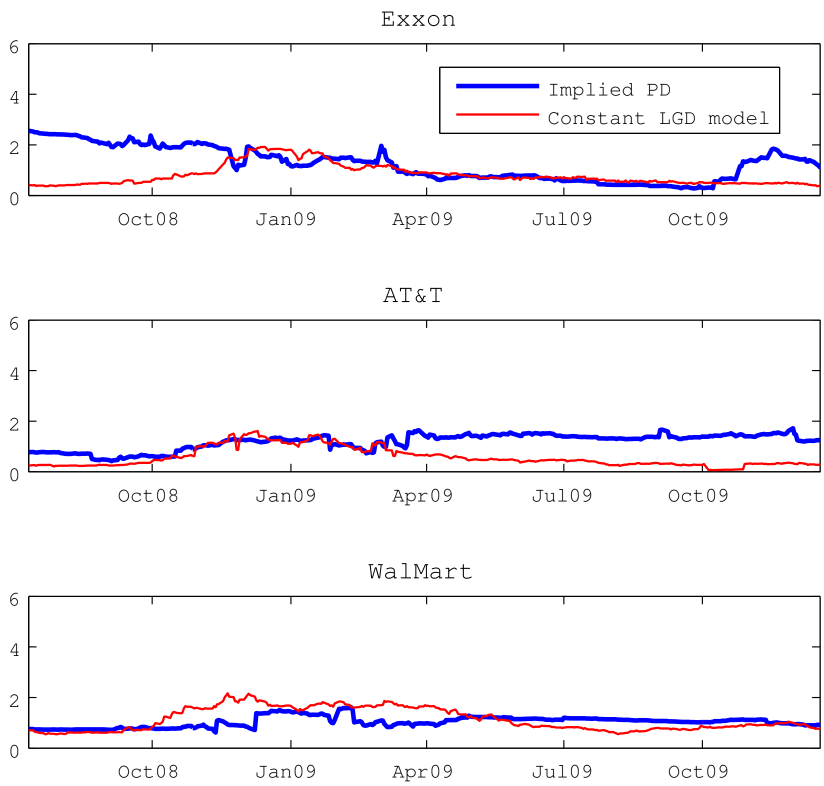
Note: The solid curve depicts the PD implied from listed stock options and the dashed curve shows the PD calculated using the counterparty risk free CDS pricing model assuming a constant 60% LGD.

Figure 11: *Implied PD of the major US Banks (%)*



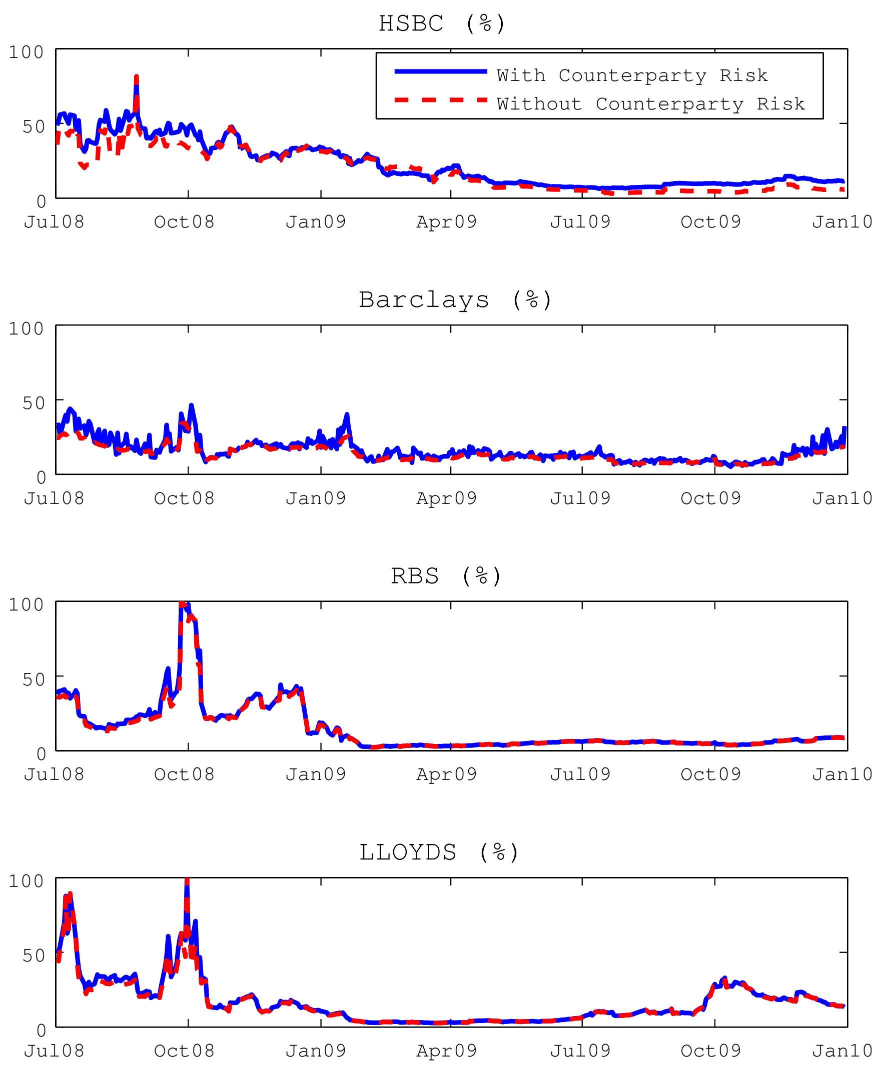
Note: The solid curve depicts the PD implied from listed stock options and the dashed curve shows the PD calculated using the counterparty risk free CDS pricing model assuming a constant 60% LGD.

Figure 12: *Implied PD of the US non financial companies (%)*



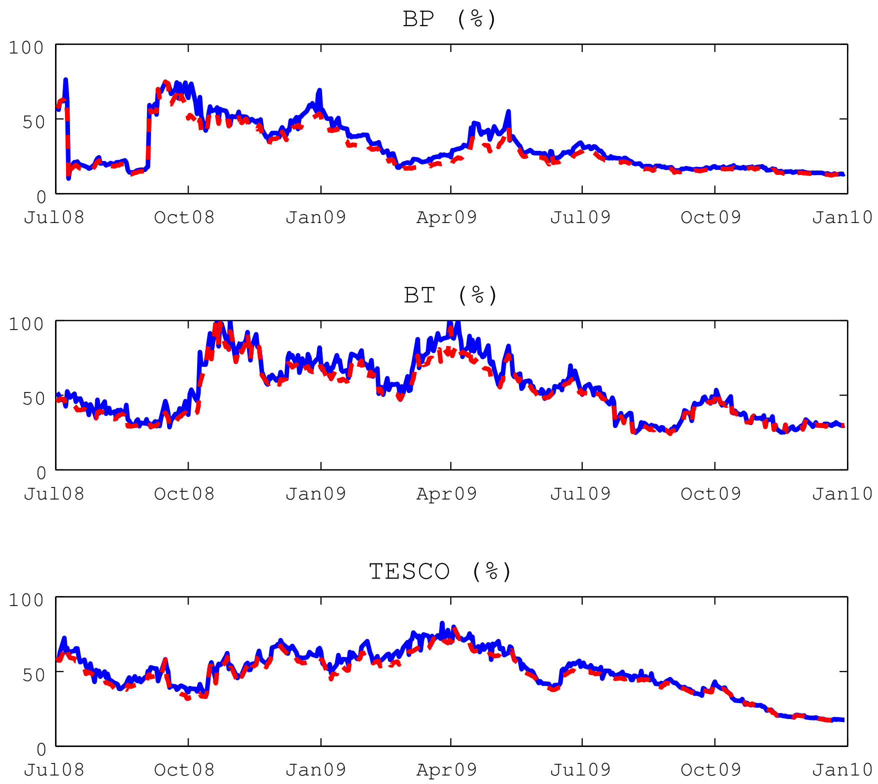
Note: The solid curve depicts the PD implied from listed stock options and the dashed curve shows the PD calculated using the counterparty risk free CDS pricing model assuming a constant 60% LGD.

Figure 13: *Implied LGD of the major UK Banks*



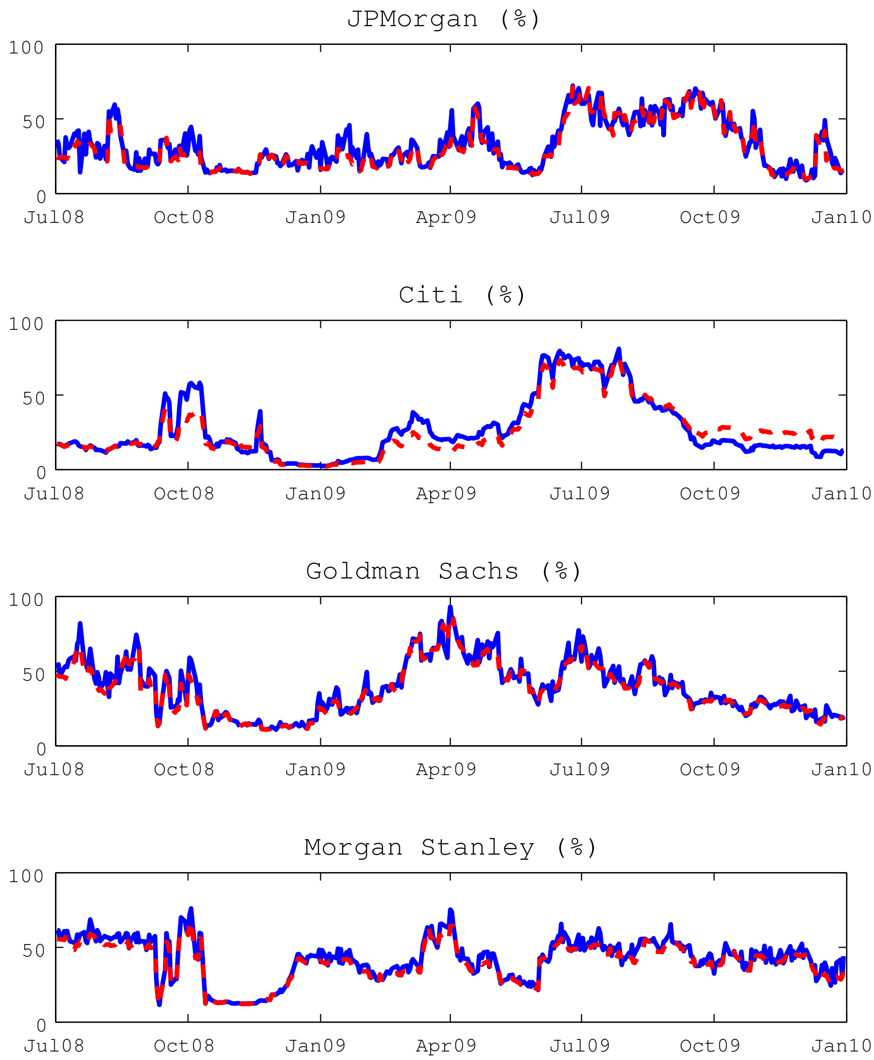
Note: The solid curve shows the LGD implied from the CDS spreads with counterparty risk and the dashed curve is the implied LGD without counterparty risk.

Figure 14: *Implied LGD of the UK non financial companies*



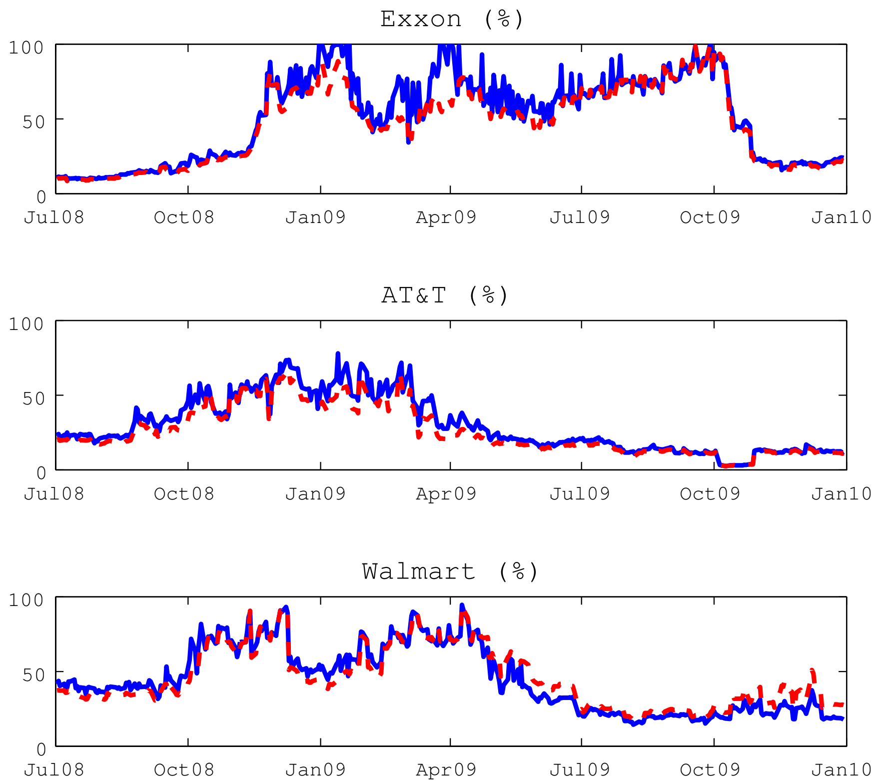
Note: The solid curve shows the LGD implied from the CDS spreads with counterparty risk and the dashed curve is the implied LGD without counterparty risk.

Figure 15: *Implied LGD of the major US financial institutions*



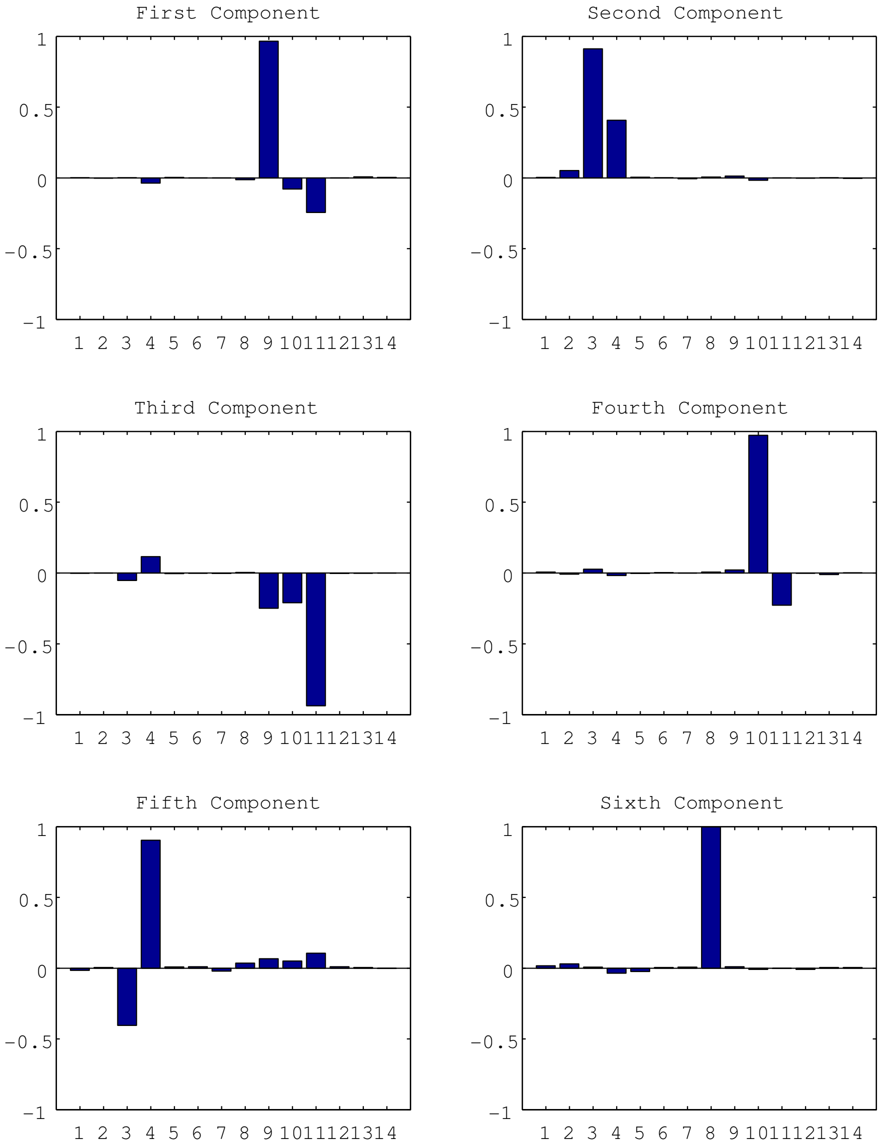
Note: The solid curve shows the LGD implied from the CDS spreads with counterparty risk and the dashed curve is the implied LGD without counterparty risk.

Figure 16: *Implied LGD of the US non financial companies*



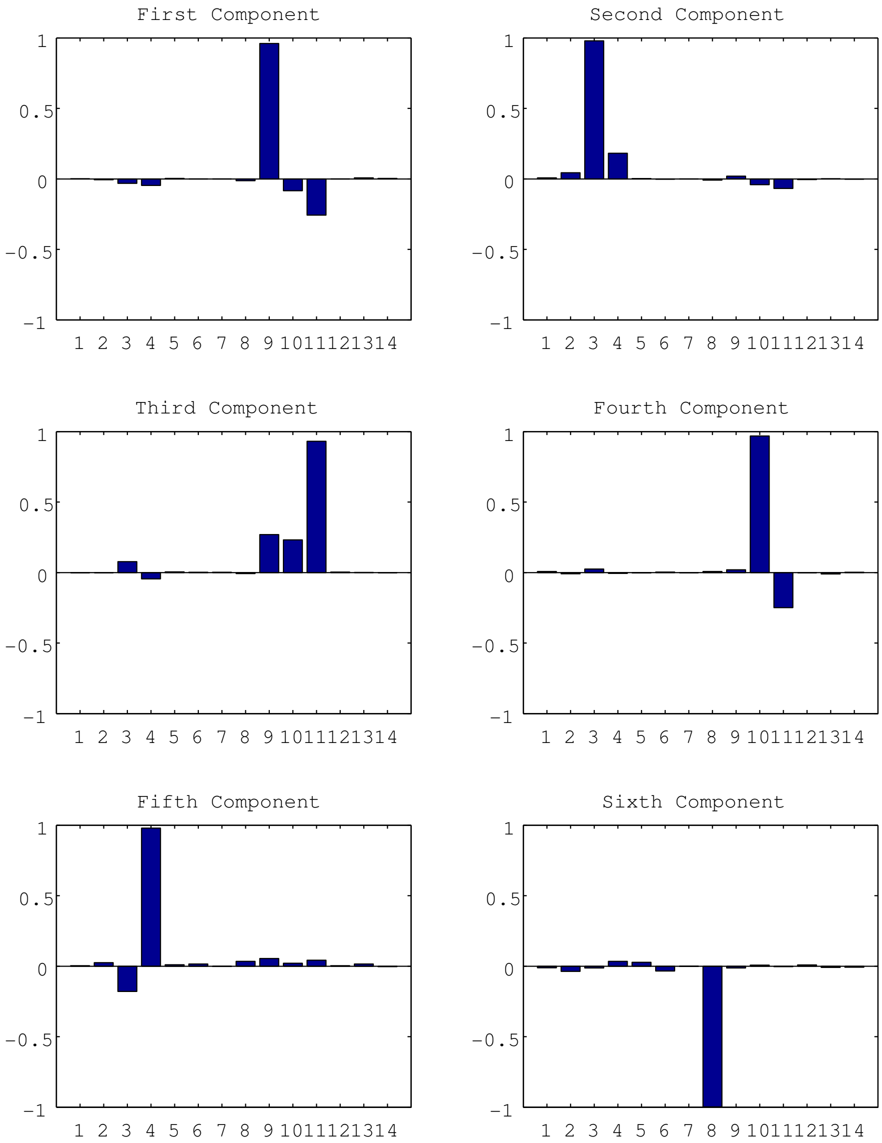
Note: The solid curve shows the LGD implied from the CDS spreads with counterparty risk and the dashed curve is the implied LGD without counterparty risk.

Figure 17: *Principal Components of the implied PD in Jul 2008 - Dec 2009*



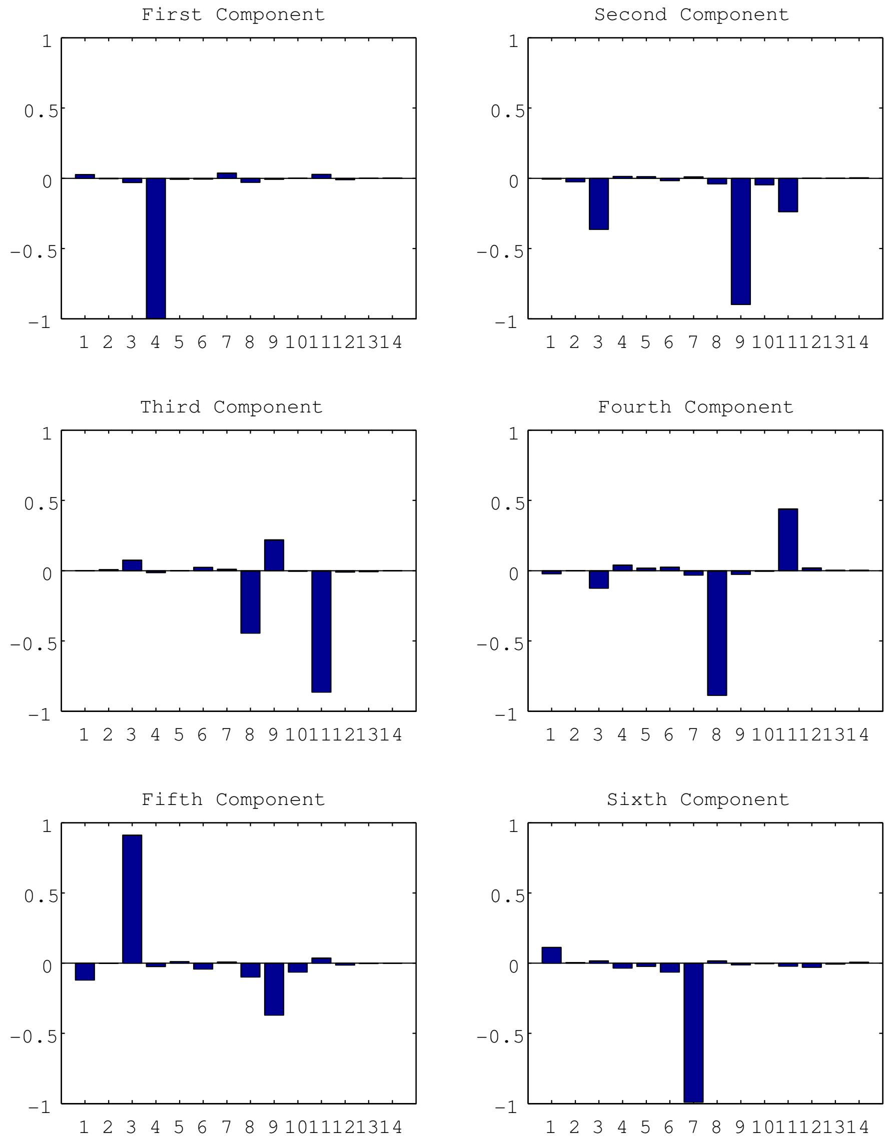
Note: Series 1: HSBC, Series 2: Barclays, Series 3: RBS, Series 4: LLOYDS, Series 5: BP, Series 6: BT, Series 7: TESCO, Series 8: JPMorgan, Series 9: Citi, Series 10: Goldman Sachs, Series 11: Morgan Stanley, Series 12: Exxon, Series 13: AT&T, Series 14: Walmart

Figure 18: *Principal Components of the implied PD in Jul 2008 - Mar 2009*



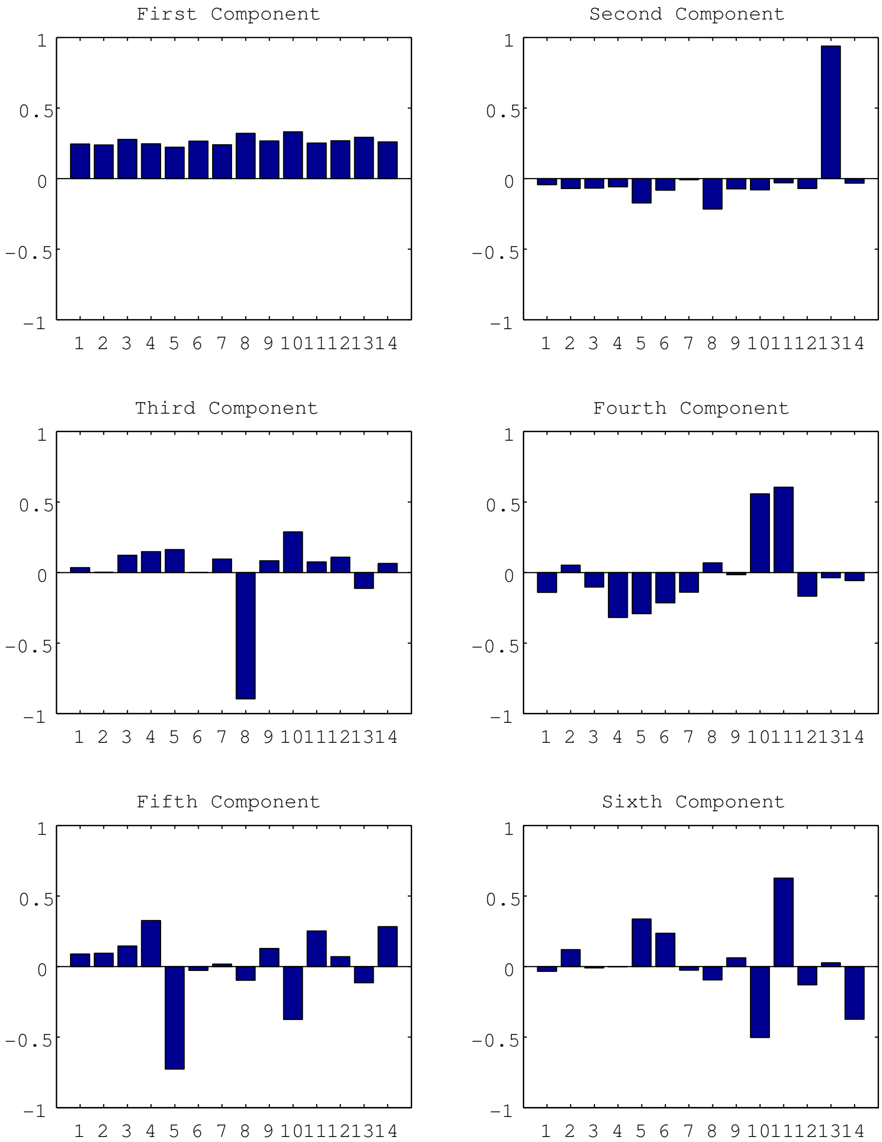
Note: Series 1: HSBC, Series 2: Barclays, Series 3: RBS, Series 4: LLOYDS, Series 5: BP, Series 6: BT, Series 7: TESCO, Series 8: JPMorgan, Series 9: Citi, Series 10: Goldman Sachs, Series 11: Morgan Stanley, Series 12: Exxon, Series 13: AT&T, Series 14: Walmart

Figure 19: *Principal Components of the implied PD in Apr 2009 - Dec 2009*



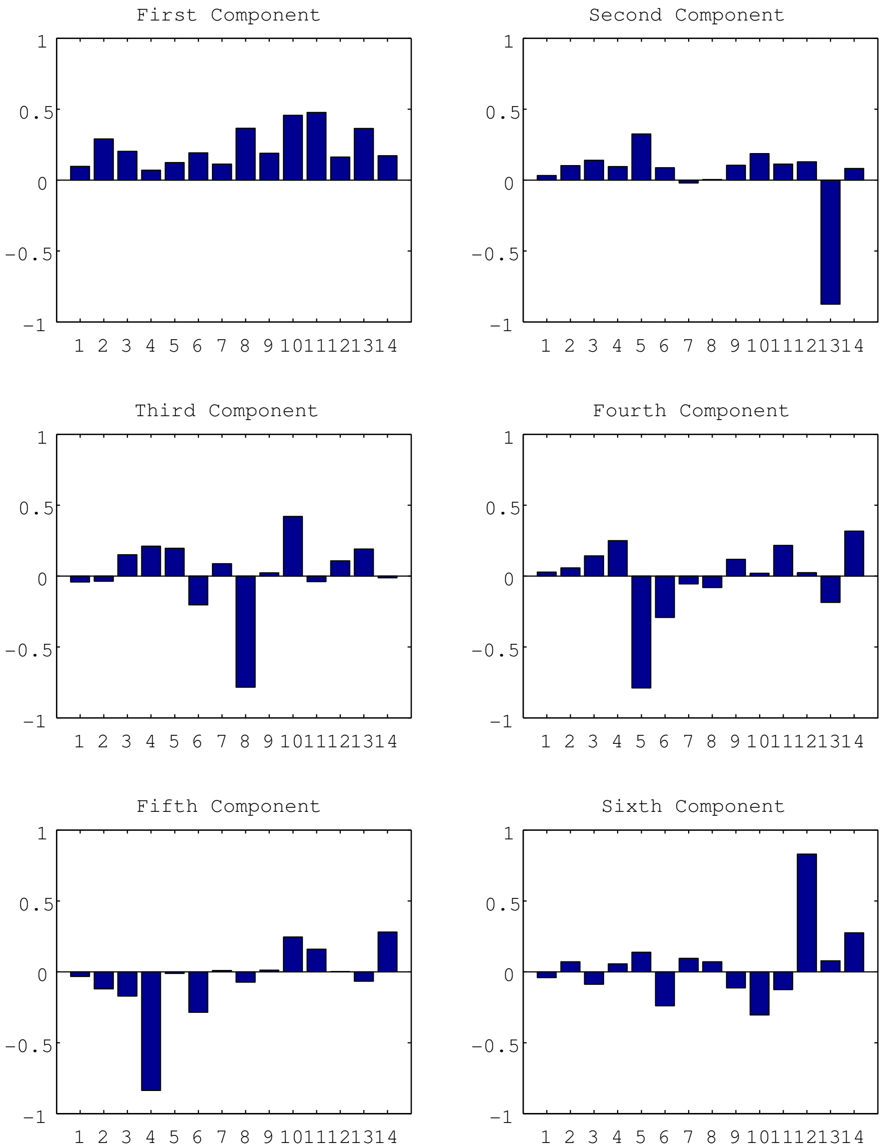
Note: Series 1: HSBC, Series 2: Barclays, Series 3: RBS, Series 4: LLOYDS, Series 5: BP, Series 6: BT, Series 7: TESCO, Series 8: JPMorgan, Series 9: Citi, Series 10: Goldman Sachs, Series 11: Morgan Stanley, Series 12: Exxon, Series 13: AT&T, Series 14: Walmart

Figure 20: *Principal Components of the implied LGD in Jul 2008 - Dec 2009*



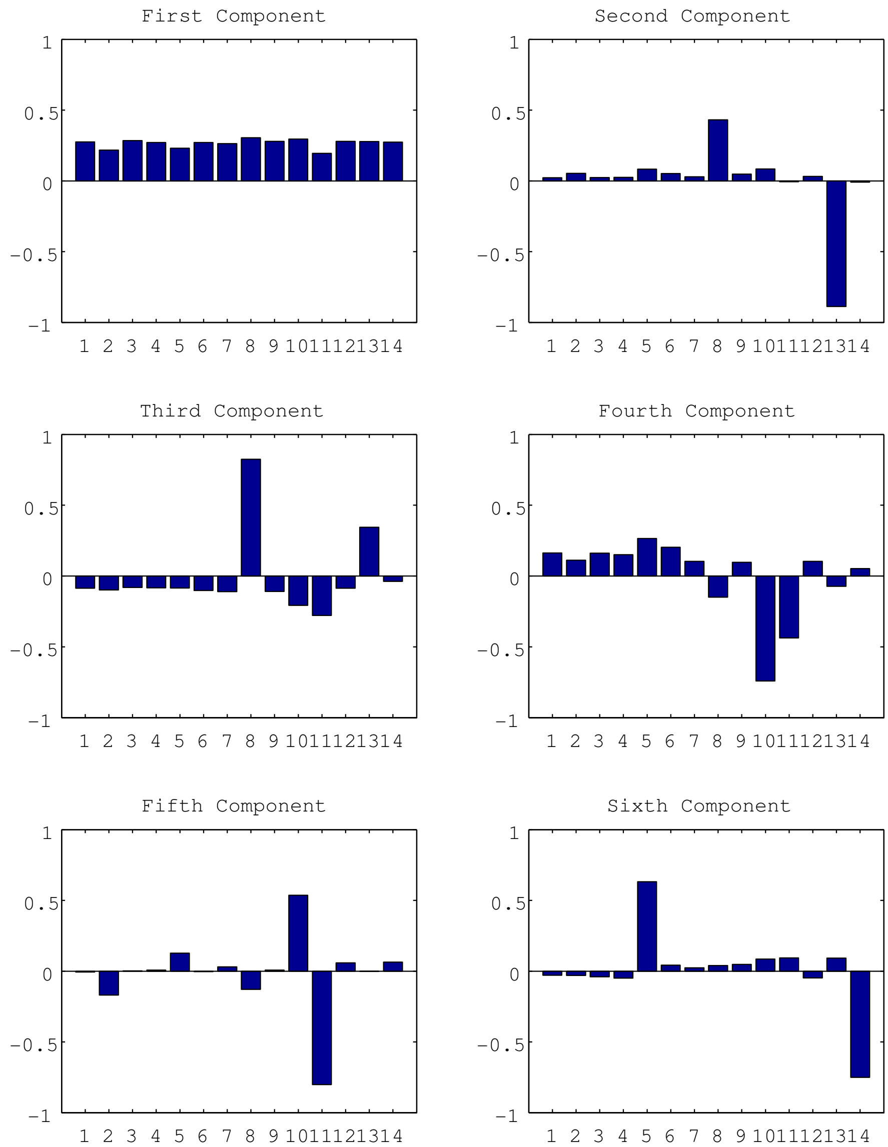
Note: Series 1: HSBC, Series 2: Barclays, Series 3: RBS, Series 4: LLOYDS, Series 5: BP, Series 6: BT, Series 7: TESCO, Series 8: JPMorgan, Series 9: Citi, Series 10: Goldman Sachs, Series 11: Morgan Stanley, Series 12: Exxon, Series 13: AT&T, Series 14: Walmart

Figure 21: *Principal Components of the implied LGD in Jul 2008 - Mar 2009*



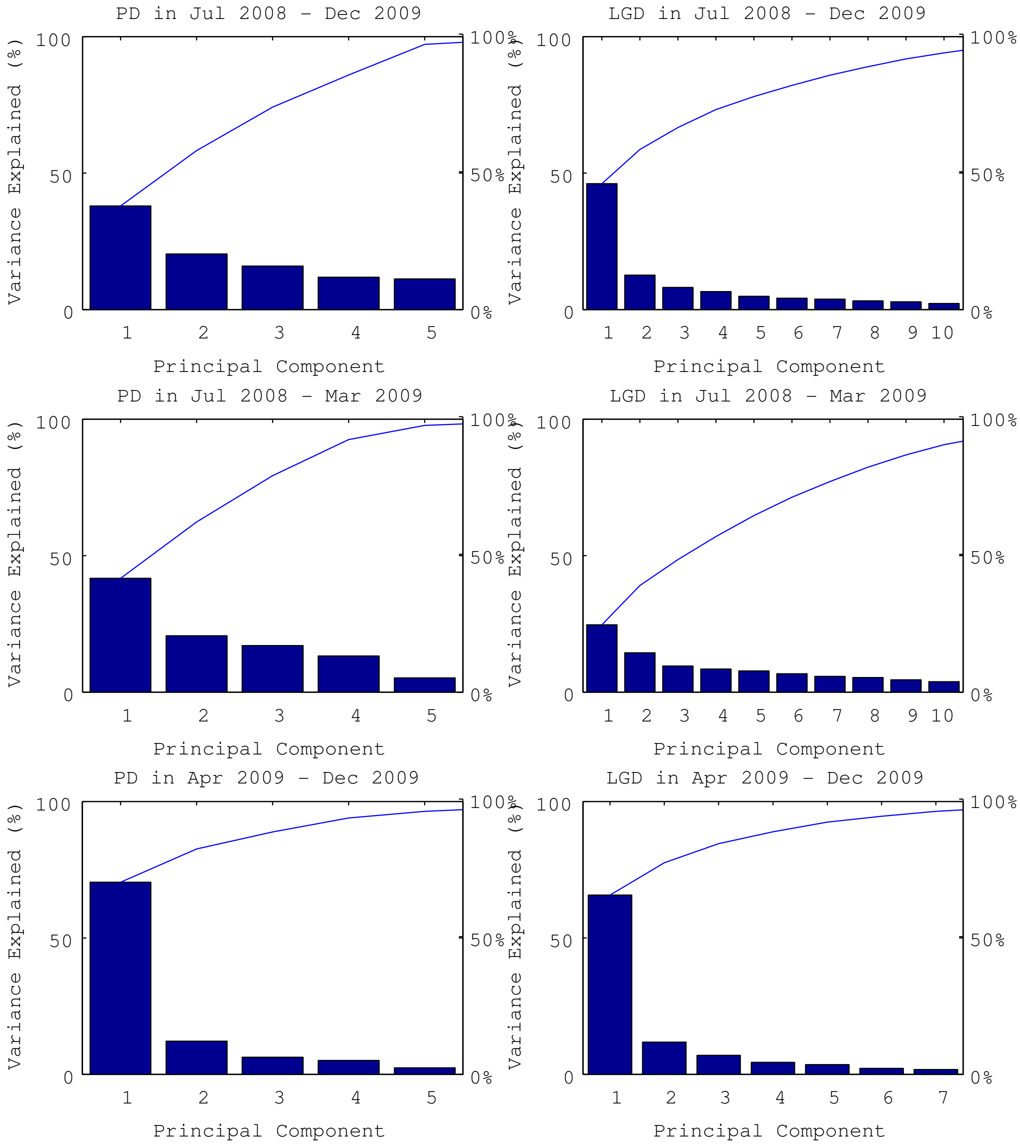
Note: Series 1: HSBC, Series 2: Barclays, Series 3: RBS, Series 4: LLOYDS, Series 5: BP, Series 6: BT, Series 7: TESCO, Series 8: JPMorgan, Series 9: Citi, Series 10: Goldman Sachs, Series 11: Morgan Stanley, Series 12: Exxon, Series 13: AT&T, Series 14: Walmart

Figure 22: *Principal Components of the implied LGD in Apr 2009 - Dec 2009*



Note: Series 1: HSBC, Series 2: Barclays, Series 3: RBS, Series 4: LLOYDS, Series 5: BP, Series 6: BT, Series 7: TESCO, Series 8: JPMorgan, Series 9: Citi, Series 10: Goldman Sachs, Series 11: Morgan Stanley, Series 12: Exxon, Series 13: AT&T, Series 14: Walmart

Figure 23: *Contribution of Principal Components*



Note: The bars indicate the contribution of individual principal components while the curve shows cumulative contribution of principal components.