Finance Research Letters xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Finance Research Letters

journal homepage: www.elsevier.com/locate/frl

Deposit insurance pricing under GARCH

Hailong Liu[a], Rui Li[a,b], Jinjian Yuan[a,*]

[a] Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai, 200030, China
[b] School of Economics and Finance, Xi'an Jiaotong University, Xi'an, 710061, China

ARTICLE INFO

Keywords:
Deposit insurance
GARCH
Option pricing
Capital forbearance

ABSTRACT

As homoscedasticity assumption of asset return is questionable, traditional deposit insurance pricing analysis based on the Black-Scholes model always performs poorly. This paper focuses on deposit insurance pricing under a GARCH framework. A closed-form pricing formula is derived, and an estimation method for the pricing model with market data is also presented. We apply the pricing model on a sample of 40 U.S. exchange-listed banks and the results reaffirm the importance of GARCH framework. The premium rate under the GARCH framework is always much lower than its Black-Scholes counterpart during high-risk periods.

1. Introduction

In a seminal paper, Merton (1977) modeled deposit insurance as a put option on the bank's assets. Since then, a stream of research has followed Merton (1977) and valuated deposit insurance within Black-Scholes option pricing framework, even though with different model specifications.[1] However, it is widely acknowledged that the constant volatility assumption of Black-Scholes framework is questionable. For example, the Black-Scholes implied volatility always contradicts with the constant volatility assumption and exhibits the “volatility smile” phenomenon as well as the term structure phenomenon. As shown in the review article by Bollerslev et al. (1992), a large number of empirical researches demonstrated that financial asset returns always exhibit many features such as volatility clustering and leverage effects, which also contradicted with the constant volatility assumption. It has become a consensus that variances of asset return change through time, and a popular choice to characterize this is GARCH models. Furthermore, several studies demonstrated that the GARCH option pricing model significantly outperforms the Black-Scholes model (e.g., Duan, 1995; Heston and Nandi, 2000; Christoffersen et al., 2008, etc.). Therefore, in this paper, we develop a pricing model for deposit insurance under GARCH framework.

Among this stream of literature, the closest research to our analysis is Duan and Yu (1999), who proposed a multi-period deposit insurance pricing model under GARCH and affirmed the importance of GARCH framework.[2] However, they could not obtain a closed-form formula, which is very essential for empirical research and practical application. Without closed-form formula, it is impossible to estimate the bank asset process and evaluate the deposit insurance premium, because the underlying asset price (i.e. the bank asset value) is unobservable. Therefore, Duan and Yu (1999)'s model under GARCH framework is less applicable in empirical research,

* Corresponding author.
E-mail addresses: hlliu@sjtu.edu.cn (H. Liu), reinglee@sjtu.edu.cn (R. Li), yuanjinjian@sjtu.edu.cn (J. Yuan).

[1] Some papers considered regulation policies, such as stochastic audit (Merton, 1978; Pennacchi, 1987a), capital forbearance (Ronn and Verma, 1986; Duan and Yu, 1994), and capital standard (Cooperstein et al., 1995; Pennacchi, 2005). And some other papers tried to characterize bank default risk more accurately, for example, considering interest risk (Pennacchi, 1987b; Duan et al., 1995; So and Wei, 2004), lending risk (Dermine and Lajeri, 2001), and systematic risk (Lee et al., 2015; Zhang and Shi, 2017). There were also papers taking into account some other factors affecting deposit insurance premium, such as the default risk of guaranty fund (Episcopos, 2004), and bankruptcy costs (Hwang et al., 2009).

[2] They found that the premium rate under GARCH framework is always higher than its Black-Scholes counterpart.

https://doi.org/10.1016/j.frl.2018.02.013
Received 16 August 2017; Received in revised form 7 January 2018; Accepted 22 February 2018
1544-6123/

especially in practices to evaluate the deposit insurance premium rate for specific banks.

In this paper, we obtain a closed-form deposit insurance pricing formula under the GARCH framework proposed by Heston and Nandi (2000). Based on the closed-form formula, we also propose a method for estimating the pricing model and evaluating deposit insurance premium rate from market data. Thus, this paper provides a rewarding tool for the empirical analysis of deposit insurance pricing practices, which is the most important contribution to the existing literature.[3] We apply the pricing model on a sample of 40 U.S. banks during 2008–2017. The results indicate that the premium rate under the GARCH framework is always much lower than its Black-Scholes counterpart during high-risk periods, because the constant volatility assumption of Black-Scholes framework overestimates the variance of asset return as well as the default risk. However, the results are inconsistent with Duan and Yu (1999), who found that the model based on Black-Scholes framework underestimates deposit insurance premium. Considering the subjective setting in their numerical analysis, our empirical results are much more reliable.[4] We also examine the effect of capital forbearance on deposit insurance pricing. And the results show that, with capital forbearance, deposit insurance premium rates increase substantially.

2. The deposit insurance pricing model

We consider a discrete-time economy in which time is indexed as 0, 1, 2, …, T. The value of the bank's asset at time t is denoted by V_t. The face value of the deposit is denoted by D. As the deposit is insured, it grows at a risk-free rate. The deposit insurance with maturity T is priced at time t.

The bank's asset value follows an asymmetric GARCH process:

$$log(V_t) = log(V_{t-1}) + r + \left(\lambda - \frac{1}{2}\right)h_t + \sqrt{h_t}\varepsilon_t \tag{1}$$

$$h_t = \omega + \alpha(\varepsilon_{t-1} - \gamma\sqrt{h_{t-1}})^2 + \beta h_{t-1} \tag{2}$$

where h_t is the conditional variance of asset return, r is the risk-free rate, and ε_t is a standard normal disturbance. This GARCH process is slightly different from the conventional one used in Duan (1995). It is first presented in Heston and Nandi (2000), then used in Christoffersen et al. (2008) for option valuation. In both studies, the GARCH process performed well, and most importantly it provided a basis for deriving a closed-form option valuation formula.

To value the deposit insurance, the risk-neutral distribution of the bank asset at time T is needed. According to Heston and Nandi (2000), the moment generating function of the logarithm of V_T under the risk-neutral measure Q takes the following form:

$$f(\varphi) = E_t^Q[V_T^\varphi] = V_t^\varphi exp(A(t; T, \varphi) + B(t; T, \varphi)h_{t+1}) \tag{3}$$

where

$$\begin{aligned} A(t; T, \varphi) &= A(t+1; T, \varphi) + \varphi r + \omega B(t+1; T, \varphi) \\ &- \tfrac{1}{2}log(1 - 2\alpha B(t+1; T, \varphi)) \end{aligned} \tag{4}$$

$$B(t; T, \varphi) = \varphi\left(\gamma + \lambda - \frac{1}{2}\right) - \frac{1}{2}(\gamma + \lambda)^2 + \beta B(t+1; T, \varphi) + \frac{\frac{1}{2}(\varphi - \gamma - \lambda)^2}{1 - 2\alpha B(t+1; T, \varphi)} \tag{5}$$

$A(t; T, \varphi)$ and $B(t; T, \varphi)$ can be calculated recursively from the terminal condition, $A(T; T, \varphi) = B(T; T, \varphi) = 0$.

A bank will not go bankrupt unless its asset falls below $\rho De^{r(T-t)}$, where ρ represents the capital forbearance. Thus, the payoff of the deposit insurance agent at time T can be described by

$$G(V_T) = \begin{cases} 0 & if\ V_T \geq \rho De^{r(T-t)}, \\ De^{r(T-t)} - V_T & otherwise. \end{cases} \tag{6}$$

The fair price of the deposit insurance should equal the present value of the expected payoff of the insurance agent under the risk-neutral measure Q. Following similar procedure of Heston and Nandi (2000), the deposit insurance premium rate can be derived as follows:

[3] In fact, Duan and Yu (1999) also pointed out that “Such an empirical analysis will be a fruitful undertaking in future research.”

[4] Duan and Yu (1999) chose the S&P 500 series as bank asset value process to estimate the GARCH process and chose the stationary volatility as the variance of Black-Scholes model.

$$\begin{aligned}\delta_t &= \frac{e^{-r(T-t)}E_t^Q[G(V_T)]}{D}\\ &= -\frac{V_t}{2D} + \frac{e^{-r(T-t)}}{\pi D}\int_0^\infty Re\left[\frac{e^{-i\varphi \log(\rho D e^{r(T-t)})}f(i\varphi+1)}{i\varphi}\right]d\varphi\\ &\quad + \frac{1}{2} - \frac{1}{\pi}\int_0^\infty Re\left[\frac{e^{-i\varphi \log(\rho D e^{r(T-t)})}f(i\varphi)}{i\varphi}\right]d\varphi\end{aligned} \tag{7}$$

where $f(i\varphi)$ is the character function of the logarithm of V_T, and $Re[\cdot]$ denotes the real part of a complex number.

3. Model estimation

The parameters of the pricing model, $\theta = (\lambda, \omega, \alpha, \gamma, \beta)$, can be estimated by the transformed-data approach of Duan (1994). E_t, $t = 1, \ldots, N$, denotes the observation of a stream of equity values. The equity of a bank can be treated as a call option on the value of the bank's asset. However, according to Ronn and Verma (1986), with the capital forbearance, the strike price of the call option equals the default point, say, $\rho De^{r(T-t)}$. Following the option valuation formula of Heston and Nandi (2000), the equity can be denoted as follows:

$$\begin{aligned}E_t &= g(V_t) = \frac{1}{2}V_t + \frac{e^{-r(T-t)}}{\pi}\int_0^\infty Re\left[\frac{K^{-i\varphi}f(i\varphi+1)}{i\varphi}\right]d\varphi\\ &\quad - Ke^{-r(T-t)}\left(\frac{1}{2} + \frac{1}{\pi}\int_0^\infty Re\left[\frac{K^{-i\varphi}f(i\varphi)}{i\varphi}\right]d\varphi\right)\end{aligned} \tag{8}$$

where $K = \rho De^{r(T-t)}$.

Appendix A demonstrates that the functional relation between asset V and equity E in Eq. (8) is one-to-one for every parameter vector θ, and derives the derivative of the equity with respect to the asset, which is given by

$$\frac{dg}{dV_t} = \frac{1}{2} + \frac{e^{-r(T-t)}}{\pi V_t}\int_0^\infty Re\left[\frac{K^{-i\varphi}f(i\varphi+1)}{i\varphi}\right]d\varphi. \tag{9}$$

Thus, according to Duan (1994), the log-likelihood function for equity E can be expressed as

$$L_E(E_t,\ t=1,\ldots,N;\ \theta) = L_V(\widehat{V}_t(\theta),\ t=1,\ldots,N;\ \theta) - \sum_{t=2}^{N}\log\left|\frac{dg}{dV_t}\right|_{V_t=\widehat{V}_t} \tag{10}$$

where $\widehat{V}_t(\theta) = g^{-1}(E_t)$, and $L_V(.;\theta)$ denotes the log-likelihood function of asset value V. From Eqs. (1) and (2), $L_V(.;\theta)$ can be expressed as

$$L_V(V_t,\ t=1,\ldots,N;\ \theta) = -\frac{1}{2}\sum_{t=2}^{N}(\log(h_t) + \varepsilon_t^2) \tag{11}$$

Substituting Eq. (11) into Eq. (10),

$$L_E(E_t,\ t=1,\ldots,N;\ \theta) = -\frac{1}{2}\sum_{t=2}^{N}(\log(\hat{h}_t) + \hat{\varepsilon}_t^2) - \sum_{t=2}^{N}\log\left|\frac{dg}{dV_t}\right|_{V_t=\widehat{V}_t} \tag{12}$$

where $\hat{h}_t$ and $\hat{\varepsilon}_t$ are derived through Eqs. (1) and (2) with $V_t = \widehat{V}_t$. Eq. (12) can be used to obtain the maximum likelihood estimates of the asset parameters.

4. Empirical implication

4.1. Data

Our empirical analysis uses a set of banks that trade on the NYSE from 2007 to 2016. 40 U.S. banks are selected from CRSP/Compustat Merged tapes. The stock and balance sheet data are taken from the CRSP Daily Stock file and the Compustat Bank Fundamentals Quarterly tapes respectively. We use the 1-year Treasury Constant Maturity Rate as the risk-free rate, which is obtained from the Data Download Program of the Board of Governors of the Federal Reserve System.[5] Equity value is calculated as the product of the daily closing price and the number of shares outstanding. Bank debt is calculated as the sum of total deposits and total borrowing.

[5] Available at https://www.federalreserve.gov/datadownload/.

Table 1
Deposit insurance premium rate (ρ = 0.97).

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Panel A. Premium rate under the GARCH framework										
Bank of America Corp.	0.02	334.80	6.69	4.00	39.41	0.06	0.00	0.00	0.01	0.00
JPMorgan Chase & Co.	0.09	124.72	16.54	0.09	3.52	0.01	0.00	0.00	0.00	0.00
Wells Fargo & Co.	0.25	78.65	55.35	0.24	1.05	0.00	0.00	0.00	0.00	0.00
U.S. Bancorp	0.00	40.40	8.49	0.01	0.28	0.00	0.00	0.00	0.00	0.00
BNY Mellon Corp.	69.50	138.14	17.69	0.00	3.85	0.00	0.00	0.00	0.00	0.00
Sample Average	8.20	164.72	177.79	34.86	51.69	0.27	18.75	4.66	12.38	3.68
Sample Median	0.86	99.76	20.68	0.28	3.73	0.01	0.00	0.00	0.01	0.00
Panel B. Premium rate under the Black-Scholes framework										
Bank of America Corp.	0.00	602.21	162.20	3.89	55.91	0.06	0.00	0.00	0.01	0.00
JPMorgan Chase & Co.	0.04	244.96	27.51	0.09	3.62	0.00	0.00	0.00	0.00	0.00
Wells Fargo & Co.	0.05	179.96	172.89	0.11	1.02	0.00	0.00	0.00	0.00	0.00
U.S. Bancorp	0.00	68.32	76.06	0.01	0.13	0.00	0.00	0.00	0.00	0.00
BNY Mellon Corp.	5.53	336.47	50.79	0.00	3.71	0.00	0.00	0.00	0.00	0.00
Sample Average	6.67	307.35	461.65	128.06	312.17	0.24	0.68	3.76	18.32	12.28
Sample Median	0.59	137.02	72.72	0.31	3.67	0.01	0.00	0.00	0.00	0.00

Note: All numbers are in basis points.

Table 2
Deposit insurance premium rate (ρ = 1).

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Panel A. Premium rate under the GARCH framework										
Bank of America Corp.	0.00	213.52	12.14	1.19	11.62	0.01	0.02	0.00	0.00	0.00
JPMorgan Chase & Co.	0.01	70.30	2.59	0.02	0.96	0.00	0.02	0.00	0.00	0.00
Wells Fargo & Co.	0.03	44.38	10.26	0.04	0.30	0.00	0.00	0.00	0.00	0.00
U.S. Bancorp	0.00	28.33	6.02	0.00	0.03	0.00	0.00	0.00	0.00	0.00
BNY Mellon Corp.	177.65	136.39	11.57	0.00	0.95	0.00	0.00	0.00	0.00	0.00
Sample Average	7.38	90.98	78.76	36.01	15.32	0.09	9.11	3.57	9.56	1.74
Sample Median	0.29	43.31	12.43	0.19	0.95	0.00	0.00	0.00	0.00	0.00
Panel B. Premium rate under the Black-Scholes framework										
Bank of America Corp.	0.00	451.45	96.26	0.99	17.17	0.01	0.00	0.00	0.00	0.00
JPMorgan Chase & Co.	0.01	158.63	12.63	0.02	0.92	0.00	0.00	0.00	0.00	0.00
Wells Fargo & Co.	0.02	132.69	117.43	0.03	0.31	0.00	0.00	0.00	0.00	0.00
U.S. Bancorp	0.00	44.71	49.47	0.00	0.04	0.00	0.00	0.00	0.00	0.00
BNY Mellon Corp.	3.45	262.20	32.25	0.00	1.14	0.00	0.00	0.00	0.00	0.00
Sample Average	3.83	235.79	363.13	74.77	290.76	0.09	0.54	3.07	13.33	6.48
Sample Median	0.14	124.34	39.77	0.08	1.03	0.00	0.00	0.00	0.00	0.00

Note: All numbers are in basis points.

4.2. Empirical results

Some simplifying assumptions are made for the sake of empirical tractability. First, the deposit and other debt are of equal seniority. Second, the deposit insurance for a particular year is priced at the end of the preceding year, with the maturity equaling 1 year. Third, the equity option has the same maturity date as the deposit insurance. The empirical procedure is as follows. First, for a given year, the asset parameters are estimated using the daily equity values of the preceding year and the last known level of debt. Second, the bank's asset value and conditional variance are computed using Eqs. (1), (2), and (8). Finally, we calculate the deposit insurance premium rate using the pricing formula.

Since the results for all banks in the sample have a similar nature, we only report the premium rates of five big banks as well as the sample average and median. The premium rates reported in Table 1 are with capital forbearance (ρ = 0.97), and in Table 2 are without capital forbearance (ρ = 1).[6] In both tables, panel A and panel B report the results under the GARCH framework and the Black-Scholes framework respectively. We find that the premium rates for 2009 and 2010 are substantially higher than those for other years due to the recent banking crisis. Actually, according to the sample median, most of the premium rates are less than one basis point for the years other than 2009 and 2010.

Comparing the results in panel A with those in panel B in Table 1, the premium rates under the GARCH framework is consistently lower than their Black-Scholes counterparts during high-risk periods, that is 2009 and 2010. The conclusion still holds when there is

[6] See Ronn and Verma (1986) and Duan et al. (1995) about the choice of ρ.

Table 3
Standard deviation of asset return and default probability (ρ = 0.97).

	2009		2010	
	GARCH	BS	GARCH	BS
Panel A standard deviation of asset return				
Bank of America Corp.	0.0045	0.1184	0.0022	0.0805
JPMorgan Chase & Co.	0.0031	0.0925	0.0032	0.0634
Wells Fargo & Co.	0.0067	0.1671	0.0041	0.1237
U.S. Bancorp	0.0065	0.1274	0.0037	0.1232
BNY Mellon Corp.	0.0071	0.1766	0.0030	0.1251
Panel B default probability				
Bank of America Corp.	0.3943	0.5158	0.0159	0.2215
JPMorgan Chase & Co.	0.1877	0.2923	0.0319	0.0499
Wells Fargo & Co.	0.0883	0.1640	0.0741	0.1876
U.S. Bancorp	0.0522	0.0818	0.0148	0.0917
BNY Mellon Corp.	0.1506	0.2675	0.0259	0.0633

Note: GARCH means the variables are calculated under the GARCH framework, while BS under Black-Scholes framework.

no capital forbearance as shown in Table 2. The results of the rest banks for 2009 and 2010 are reported in Appendix B, and the conclusion is true for all of these banks with very few exceptions. As the premium rates for other years are very small, the conclusion is not so obvious. The findings are inconsistent with those of Duan and Yu (1999) due to the subjectively chosen model parameters in their numerical analysis.

We argue that the potential reason is the Black-Scholes framework overestimates the variance of asset return and the default risk. We further estimate the standard deviation of bank asset return as well as bank default probability in 2009 and 2010. Table 3 reports the results of 5 big banks,[7] showing that both the standard deviation of bank asset return and bank default probability under GARCH framework are consistently smaller than those under Black-Scholes framework. The results for other banks are similar with very few exceptions. The findings suggest that the constant variance assumption of the Black-Scholes framework overestimates the variance of the bank asset return and bank default risk during high-risk periods, which results in much higher premium rates.

Comparing the results reported in Tables 1 and 2, the premium rate for ρ = 0.97 is always higher than that for ρ = 1, which suggests that the deposit insurance premium rate is very sensitive to capital forbearance. The capital forbearance lowers the strike price of the equity option (e.g., from De^{rT} to ρDe^{rT}) with the option price unchanged, which results in a lower estimate of the asset value and/or a higher estimate of the variance of the asset return and thus a higher premium rate. The result is also reasonable because the capital forbearance makes the insurance agent lose the opportunity of avoiding larger loss, that is, it liquidates the bank once its asset value falls below its total debt, and thus the agent should ask for a higher premium rate.

5. Conclusion

This paper develops a closed-form pricing formula under the GARCH framework. We also present a method for calculating deposit insurance premium rates from market data through a transformed-data maximum likelihood estimation approach. Empirical results show that during high-risk periods, the premium rate under GARCH is always lower than its Black-Scholes counterpart, and that the capital forbearance increases the premium rate substantially.

As most of the current research on deposit insurance pricing is mainly based on the Black-Scholes framework, which is known to perform poorly in option pricing practices, our deposit insurance pricing model under the GARCH framework provides a useful tool for future research, especially for the empirical analysis of deposit insurance pricing practices.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (No. 71273169) and (No. 71320107002).

Appendix A. Derivation of Eq. (9):

According to corollary 2.4 of Duan (1995),

$$\frac{dg}{dV_t} = e^{-r(T-t)} E_t^Q \left[\frac{V_T}{V_t} 1_{\{V_T \geq K\}} \right] > 0 \tag{A.1}$$

where $1_{\{V_T \geq K\}}$ is an indicator function. As a result, the functional relation between equity and asset is one-to-one.

[7] The results of rest banks are reported in Appendix C. Since the results is very similar, we only report the results that with capital forbearance (ρ = 0.97).

Denote $x = log(V_T)$, and let $p(x)$ denote the probability density corresponding to the moment generating function $f(\varphi)$. Let $q(x) = \exp(x)p(x)/f(1)$. According to Heston and Nandi (2000), $q(x)$ is a probability density, and its moment generating function is

$$\int_{-\infty}^{+\infty} e^{\varphi x} q(x)dx = \frac{1}{f(1)} \int_{-\infty}^{+\infty} e^{(\varphi+1)x} p(x)dx = \frac{f(\varphi+1)}{f(1)} \tag{A.2}$$

From the character function of $log(V_T)$, the conditional expectation in Equation (A.1) can be given by

$$\begin{aligned} E_t^Q\left[V_T 1_{\{V_T \ge K\}}\right] &= \int_{\log(K)}^{+\infty} e^x p(x)dx = f(1) \int_{\log(K)}^{+\infty} q(x)dx \\ &= f(1)\left(\frac{1}{2} + \frac{1}{\pi}\int_0^{+\infty} Re\left[\frac{K^{-i\varphi} f(i\varphi+1)}{i\varphi f(1)}\right] d\varphi\right) \end{aligned} \tag{A.3}$$

According to corollary 2.2 of Duan (1995), $exp(-rt)V_t$ is a Q-martingale,

$$f(1) = E_t^Q[V_T] = e^{rT} E_t^Q[e^{-rT} V_T] = e^{r(T-t)} V_t \tag{A.4}$$

As a result, the derivative in Equation (A.1) can be given by

$$\frac{dg}{dV_t} = \frac{e^{-r(T-t)}}{V_t} E_t^Q\left[V_T 1_{\{V_T \ge K\}}\right] = \frac{1}{2} + \frac{e^{-r(T-t)}}{\pi V_t} \int_0^{+\infty} Re\left[\frac{K^{-i\varphi} f(i\varphi+1)}{i\varphi}\right] d\varphi \tag{A.5}$$

Appendix B

Table B.1.

Table B.1
Supplement of deposit insurance premium rate.

	ρ = 0.97				ρ = 1			
	GARCH		BS		GARCH		BS	
	2009	2010	2009	2010	2009	2010	2009	2010
TCF Financial Corp.	150.24	12.29	279.29	48.82	115.89	9.97	190.71	26.70
FNB Corp.	198.09	138.58	259.97	275.89	67.13	20.95	219.06	100.66
Webster Financial Corp.	216.34	64.65	237.77	103.09	153.26	40.26	143.67	50.94
First Bancorp.	168.60	197.95	142.32	622.05	16.58	114.92	77.78	336.62
OFG Bancorp.	325.94	159.78	334.07	108.68	194.48	23.20	236.70	47.28
Central Pacific Financial Corp.	213.20	421.55	990.39	3917.43	147.93	368.15	503.72	2914.62
Associated Banc-Corp	53.20	78.85	105.48	178.87	40.51	45.83	68.77	109.73
Bank of Hawaii Corp.	33.23	2758.74	69.96	1.61	20.98	0.50	36.84	0.94
Synovus Financial Corp.	125.26	538.78	190.26	1612.01	43.42	472.44	115.99	1180.19
Comerica, INC.	209.73	11.80	297.91	54.27	74.74	58.29	191.97	25.53
Cullen/Frost Bankers, INC.	24.82	0.86	32.88	4.10	15.13	0.30	20.64	2.01
Regions Financial Corp.	358.21	271.47	1107.88	558.76	233.04	164.10	939.84	377.62
M&T Bank Corp.	94.97	3.56	131.72	10.41	57.75	12.73	81.88	4.25
First Horizon National Corp.	631.75	9.38	725.76	29.50	209.55	5.18	618.00	16.99
PNC Financial Services Group, INC.	63.45	96.05	122.31	208.89	43.19	18.31	80.41	139.76
KeyCorp	489.53	112.56	757.14	481.25	351.20	155.07	594.39	360.51
SunTrust Banks, INC.	197.99	167.88	377.58	221.62	101.47	5.63	271.21	139.03
BB&T Corp.	110.78	8.88	205.41	31.65	42.08	4.72	142.97	15.71
State Street Corp.	121.96	63.10	286.05	586.53	82.66	146.53	189.96	462.06
Suffolk Bancorp.	21.39	6.76	40.37	28.88	13.15	4.31	23.46	9.65
First Commonwealth Financial Corp.	26.04	114.44	60.84	262.63	24.15	96.73	54.74	161.87
Midsouth Bancorp., INC.	43.37	32.41	39.03	1926.79	20.10	110.98	514.72	2159.20
Astoria Financial Corp.	104.55	20.56	100.68	50.27	46.95	3.12	50.67	17.32
New York Community Bancorp., INC	68.01	6.49	106.70	4.30	34.13	3.02	67.80	1.79
Valley National Bancorp.	38.02	10.04	64.01	26.23	24.20	52.34	43.61	13.06
Ocwen Financial Corp.	20.98	9.78	101.46	13.53	28.84	10.22	71.51	22.14
Flagstar Bancorp., INC.	1140.76	847.27	987.58	3913.86	567.04	640.75	758.85	3603.81
BancorpSouth, INC.	32.80	2.58	69.06	12.86	23.97	3.42	42.93	6.40
Prosperity Bancshares, INC.	42.98	0.25	75.54	1.31	23.43	0.03	58.36	0.50
Sterling Bancorp.	23.37	10.39	38.39	69.37	12.82	3.86	45.34	16.92
Community Bank System, INC.	24.56	6.49	34.42	7.44	15.92	2.06	20.90	3.99
Berkshire Hills Bancorp., INC.	10.22	6.68	37.20	28.23	5.24	3.06	43.29	3.77
Banc of California, INC.	43.16	184.89	51.99	1970.94	15.55	130.85	553.35	1290.77
Provident Financial Services, INC.	54.61	20.81	94.93	51.92	28.18	22.00	56.30	24.62
Western Alliance Bancorp.	390.02	610.17	2305.89	552.47	251.71	354.15	1251.77	570.10

Note: GARCH means the premium rate is calculated under the GARCH framework, while BS means the premium rate is calculated under Black-Scholes framework. All numbers are in basis points.

Appendix C

Tables C.1, C.2.

Table C.1
Supplement of standard deviation (ρ = 0.97).

	2009		2010	
	GARCH	BS	GARCH	BS
TCF Financial Corp.	0.0063	0.1380	0.0023	0.0722
F.N.B Corp.	0.0089	0.1629	0.0055	0.1260
Webster Financial Corp.	0.0041	0.0693	0.0025	0.0524
First Bancorp.	0.0042	0.0636	0.0014	0.0617
OFG Bancorp.	0.0027	0.0582	0.0028	0.0459
Central Pacific Financial Corp.	0.0034	0.1815	0.0019	0.3198
Associated Banc-Corp	0.0049	0.1063	0.0025	0.0814
Bank of Hawaii Corp.	0.0071	0.1432	0.0123	0.0701
Synovus Financial Corp.	0.0044	0.0976	0.0046	0.2004
Comerica, INC.	0.0031	0.0826	0.0019	0.0621
Cullen/Frost Bankers, INC.	0.0057	0.1250	0.0027	0.0805
Regions Financial Corp.	0.0036	0.1749	0.0042	0.1208
M&T Bank Corp.	0.0048	0.0981	0.0024	0.0609
First Horizon National Corp.	0.0085	0.1752	0.0025	0.0783
PNC Financial Services Group, INC.	0.0062	0.1178	0.0036	0.1153
KeyCorp	0.0060	0.1389	0.0024	0.1177
SunTrust Banks, INC.	0.0044	0.1141	0.0033	0.0890
BB&T Corp.	0.0060	0.1277	0.0023	0.0708
State Street Corp.	0.0036	0.0960	0.0049	0.2257
Suffolk Bancorp.	0.0038	0.1248	0.0033	0.0997
First Commonwealth Financial Corp.	0.0053	0.1152	0.0028	0.0933
Midsouth Bancorp., INC.	0.0042	0.0652	0.0147	0.4314
Astoria Financial Corp.	0.0039	0.0684	0.0018	0.0466
New York Community Bancorp., INC	0.0040	0.1152	0.0191	0.0819
Valley National Bancorp.	0.0060	0.1288	0.0043	0.0894
Ocwen Financial Corp.	0.0103	0.2226	0.0189	0.3111
Flagstar Bancorp., INC.	0.0043	0.0675	0.0064	0.3946
BancorpSouth, INC.	0.0052	0.1092	0.0025	0.0772
Prosperity Bancshares, INC.	0.0076	0.1513	0.0025	0.0802
Sterling Bancorp.	0.0051	0.1077	0.0029	0.0907
Community Bank System, INC.	0.0047	0.1030	0.0025	0.0584
Berkshire Hills Bancorp., INC.	0.0044	0.0969	0.0033	0.0725
Banc of California, INC.	0.0030	0.0412	0.0026	0.2286
Provident Financial Services, INC.	0.0049	0.1217	0.0025	0.0736
Western Alliance Bancorp.	0.0076	0.3806	0.0048	0.1195

Note: GARCH means the standard deviation is calculated under the GARCH framework, while BS means the standard deviation is calculated under Black-Scholes framework.

Table C.2
Supplement of bank default probability (ρ = 0.97).

	2009		2010	
	GARCH	BS	GARCH	BS
TCF Financial Corp.	0.1770	0.2637	0.0247	0.0802
F.N.B Corp.	0.1908	0.2268	0.1769	0.2743
Webster Financial Corp.	0.3101	0.3279	0.1269	0.1810
First Bancorp.	0.2462	0.2211	0.4247	0.7021
OFG Bancorp.	0.4580	0.4653	0.2605	0.2001
Central Pacific Financial Corp.	0.2849	0.5882	0.6577	0.9434
Associated Banc-Corp	0.0785	0.1326	0.1342	0.2395
Bank of Hawaii Corp.	0.0430	0.0783	0.6525	0.0032
Synovus Financial Corp.	0.1734	0.2305	0.5413	0.7527
Comerica, INC.	0.2953	0.3621	0.0255	0.0944
Cullen/Frost Bankers, INC.	0.0321	0.0426	0.0017	0.0074
Regions Financial Corp.	0.4118	0.6424	0.3395	0.4842
M&T Bank Corp.	0.1320	0.1678	0.0076	0.0203

(continued on next page)

Table C.2 (*continued*)

	2009		2010	
	GARCH	BS	GARCH	BS
First Horizon National Corp.	0.4551	0.4840	0.0179	0.0486
PNC Financial Services Group, INC.	0.0873	0.1429	0.1342	0.2286
KeyCorp	0.4695	0.5593	0.1860	0.4397
SunTrust Banks, INC.	0.2560	0.3713	0.2298	0.2744
BB&T Corp.	0.1396	0.2132	0.0179	0.0543
State Street Corp.	0.1865	0.3255	0.0835	0.3612
Suffolk Bancorp.	0.0278	0.0514	0.0120	0.0425
First Commonwealth Financial Corp.	0.0389	0.0778	0.1794	0.3081
Midsouth Bancorp., INC.	0.0743	0.0683	0.0505	0.6049
Astoria Financial Corp.	0.1621	0.1579	0.0458	0.0987
New York Community Bancorp., INC	0.0911	0.1283	0.0110	0.0077
Valley National Bancorp.	0.0472	0.0767	0.0177	0.0410
Ocwen Financial Corp.	0.0242	0.0841	0.0083	0.0109
Flagstar Bancorp., INC.	0.8827	0.8675	0.6925	0.9043
BancorpSouth, INC.	0.0481	0.0897	0.0052	0.0225
Prosperity Bancshares, INC.	0.0518	0.0813	0.0005	0.0025
Sterling Bancorp.	0.0348	0.0531	0.0201	0.0990
Community Bank System, INC.	0.0354	0.0491	0.0128	0.0150
Berkshire Hills Bancorp., INC.	0.0170	0.0544	0.0136	0.0483
Banc of California, INC.	0.0909	0.1064	0.3247	0.7938
Provident Financial Services, INC.	0.0721	0.1124	0.0391	0.0841
Western Alliance Bancorp.	0.3582	0.7117	0.5033	0.4829

Note: GARCH means the standard deviation is calculated under the GARCH framework, while BS means the standard deviation is calculated under Black-Scholes framework.

The default probability under GARCH framework could be estimated as follow

$$\begin{aligned} Prob_{GARCH} &= Prob(log(V_T) < \log(K)) = \int_{-\infty}^{log(K)} p(x)dx \\ &= \frac{1}{2} - \frac{1}{\pi}\int_0^{\infty} Re\left[\frac{K^{-i\varphi}f(i\varphi)}{i\varphi}\right]d\varphi \end{aligned} \tag{C.1}$$

References

Bollerslev, T., Chou, R., Kroner, K., 1992. ARCH modeling in finance: A review of the theory and empirical evidence. J. Econometrics 52 (1–2), 5–59.
Christoffersen, P., Jacobs, K., Ornthanalai, C., Wang, Y., 2008. Option valuation with long-run and short-run volatility components. J. Financial Econ. 90 (3), 272–297.
Cooperstein, R., Pennacchi, G., Redburn, S., 1995. The aggregate cost of deposit insurance: A multiperiod analysis. J. Financial Intermediation 4 (3), 242–271.
Dermine, J., Lajeri, F., 2001. Credit risk and the deposit insurance premium: a note. J. Econ. Bus. 53 (5), 497–508.
Duan, J.C., 1994. Maximum likelihood estimation using price data of the derivative contract. Math. Finance 4 (2), 155–167.
Duan, J.C., 1995. The GARCH option pricing model. Math. Finance 5 (1), 13–32.
Duan, J.C., Moreau, A.F., Sealey, C.W., 1995. Deposit insurance and bank interest rate risk: Pricing and regulatory implications. J. Banking Finance 19 (6), 1091–1108.
Duan, J.C., Yu, M.T., 1994. Forbearance and pricing deposit insurance in a multiperiod framework. J. Risk Insur. 61 (4), 575–591.
Duan, J.C., Yu, M.T., 1999. Capital standard, forbearance and deposit insurance pricing under GARCH. J. Banking Finance 23 (11), 1691–1706.
Episcopos, A., 2004. The implied reserves of the Bank Insurance Fund. J. Banking Finance 28 (7), 1617–1635.
Heston, S.L., Nandi, S., 2000. A closed-form GARCH option valuation model. Rev. Financial Stud. 13 (3), 585–625.
Hwang, D.Y., Shie, F.S., Wang, K., Lin, J.C., 2009. The pricing of deposit insurance considering bankruptcy costs and closure policies. J. Banking Finance 33 (10), 1909–1919.
Lee, S.C., Lin, C.T., Tsai, M.S., 2015. The pricing of deposit insurance in the presence of systematic risk. J. Banking Finance 51, 1–11.
Merton, R.C., 1977. An analytic derivation of the cost of deposit insurance and loan guarantees an application of modern option pricing theory. J. Banking Finance 1 (1), 3–11.
Merton, R.C., 1978. On the cost of deposit insurance when there are surveillance costs. J. Bus. 51 (3), 439–451.
Pennacchi, G., 1987a. Alternative forms of deposit insurance: Pricing and bank incentive issues. J. Banking Finance 11 (2), 291–312.
Pennacchi, G., 1987b. A reexamination of the over – (or under-) pricing of deposit insurance. J. Money Credit Banking 19 (3), 340–360.
Pennacchi, G., 2005. Risk-based capital standards, deposit insurance, and procyclicality. J. Financial Intermediation 14 (4), 432–465.
Ronn, E.I., Verma, A.K., 1986. Pricing risk-adjusted deposit insurance: An option-based model. J. Finance 41 (4), 871–896.
So, J., Wei, J.Z., 2004. Deposit insurance and forbearance under morall hazard. J. Risk Insur. 71 (4), 707–735.
Zhang, Y.J., Shi, B.S., 2017. Systematic risk and deposit insurance pricing: Based on market model and option pricing theory. China Finance Rev. Int. 7 (4), 390–406.