APPLYING A TWO-STEP MAXIMUM LIKELIHOOD METHOD TO EXAMINE THE DEPOSIT INSURANCE PROGRAM OF TAIWAN

David K. Wang
Department of Finance, National University of Kaohsiung, Kaohsiung, Taiwan, R.O.C.

Chun-Chou Wu
Department of Finance, National Kaohsiung First University of Science and Technology, Kaohsiung, Taiwan, R.O.C.,
wucc123@seed.net.tw

Heng-Chih Chou
Department of Shipping and Transportation Management, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

APPLYING A TWO-STEP MAXIMUM LIKELIHOOD METHOD TO EXAMINE THE DEPOSIT INSURANCE PROGRAM OF TAIWAN

Acknowledgements

APPLYING A TWO-STEP MAXIMUM LIKELIHOOD METHOD TO EXAMINE THE DEPOSIT INSURANCE PROGRAM OF TAIWAN

David K. Wang[1], Chun-Chou Wu[2], and Heng-Chih Chou[3]

ABSTRACT

This paper examines the deposit insurance program of Taiwan. We adopt Duan *et al*. [4]'s deposit insurance pricing model, and estimate the deposit insurance premium by the Duan and Simonato two-step maximum likelihood method [5]. Our results show that the maximum likelihood estimates for the deposit insurance premium are considerably higher than the official rates currently charged by the Central Deposit Insurance Corporation (CDIC), the deposit insuring agency of Taiwan, indicating that the CDIC deposit insurance program appears to hand out a substantial subsidy to the banks in Taiwan. Our results also show that the CDIC in fact grants too much capital forbearance to the banks, and that the semiannual bank audits currently mandated by the CDIC are in fact much less frequent than our estimated values. These findings may also explain why the estimated rates for the deposit insurance premium are much higher than the current CDIC rates.

I. INTRODUCTION

The deposit insuring agency of Taiwan, Central Deposit Insurance Corporation (CDIC), has been in operation since 1985. The deposit insurance program was voluntary at first, but has become mandatory since 1999 for all the depository institutions in Taiwan. The CDIC employed a flat-rate deposit insurance scheme from 1985 through 1999. Since 2000, a risk-based deposit insurance scheme has been employed. The risk-based premium rates charged by the CDIC range from 5 basis points to 6 basis points.

Merton [12] shows that deposit insurance can be modeled as a put option on its assets. The value of deposit insurance can then be calculated using the Black and Scholes [2] option pricing model. Subsequent to Merton [12], a large literature on deposit insurance has emerged, in part due to the U.S. savings and loan debacle in the 1980s and early 1990s; for example, Merton [13], McCulloch [11], Ronn and Verma [17], Kane [9], Pennacchi [15, 16], Duan and Yu [6, 7], Duan *et al*. [4], Nagarajan and Sealey [14] and Schreiber [18], among many others.

The empirical implementation of Merton [12]'s deposit insurance pricing model mostly relies on the Ronn and Verma [17] estimation method. However, as argued in Duan [3], the theoretical premise of Merton [12]'s deposit insurance pricing model implies stochastic equity volatilities. The Ronn and Verma [17] estimation method, by assuming constant equity volatilities, is thus incompatible with Merton [12]'s deposit insurance pricing model. Therefore, the Ronn and Verma [17] estimation method yields inconsistent estimates and produces unreliable inferences for the deposit insurance value.

In Duan *et al*. [4], the Ronn and Verma [17] estimation method is modified so that it can be applied to their deposit insurance pricing model under stochastic interest rates. They then use the modified procedure to obtain the empirical estimates for a large sample of U.S. banks, and to evaluate the interest rate risk exposure of both the deposit taking institutions and the deposit insuring agent. Not surprisingly, the same criticism on the Ronn and Verma [17] estimation method also applies to Duan *et al*. [4]'s modified procedure. It is also conceivable that the empirical inconsistency in the case of Duan *et al*. [4] may be more severe because of the greater complexity of the underlying stochastic system induced by stochastic interest rates.

Duan and Simonato [5] propose a two-step maximum likelihood estimation method for Duan *et al*. [4]'s deposit insurance pricing model. The maximum likelihood estimates are compared to those obtained by employing the modified Ronn and Verma [17] estimation method. Although the two-step maximum likelihood estimation method is theoretically superior due to its many desirable asymptotic properties, its actual performance can only be gauged with a Monte Carlo simulation study. Duan and Simonato [5] thus also conduct a Monte

Carlo simulation study to evaluate the quality of the proposed framework. Their results suggest that the two-step maximum likelihood estimation method, although relying on asymptotic inferences, performs satisfactorily for a sample of 10 large U.S. commercial banks.

Hwang *et al*. [8] price deposit insurance with explicit consideration of bankruptcy costs and closure policies. They apply the isomorphic relationship between deposit insurance and put option, and develop a deposit insurance pricing model under a barrier option framework. In their pricing model, bankruptcy costs are considered as a function of asset return volatility, and capital forbearance is accounted for by closure policies. The numerical simulations show that the properties of Hwang *et al*. [8]'s model are consistent with the risk-based pricing scheme.[1]

The purpose of this paper is to examine the deposit insurance program of Taiwan. We adopt Duan *et al*. [4]'s deposit insurance pricing model, and estimate the deposit insurance premium by the Duan and Simonato [5] two-step maximum likelihood method. Our maximum likelihood estimates for the deposit insurance premium are compared to the official rates currently charged by the CDIC. In order to investigate the discrepancy between our estimates and the current CDIC rates, we also estimate both the capital forbearance factor and the audit interval factor by the two-step maximum likelihood method. Finally, we examine the capital forbearance policy and the bank audit interval currently employed by the CDIC, and discuss the policy implications from our estimation results.

The remainder of this paper is organized as follows. Our deposit insurance framework is presented in Section 2. Our data set is described in Section 3. Our empirical findings are reported in Section 4. A concluding remark is made in the final section.

II. MODEL

In this section, we present our deposit insurance framework.

Vasicek [19] assumes that the instantaneous interest rate is governed by the following mean-reverting stochastic process

$$dr_t = q(m - r_t)dt + \upsilon dZ_{r_t}, \qquad (1)$$

where r_t is the instantaneous risk-free rate of interest at time t, m is the long-run mean of the interest rate, υ is the volatility of the interest rate, q is a positive constant measuring the magnitude of the mean-reverting force, and Z_{r_t} is a Wiener process.

Using the above process as the basis and with the assumption of a constant risk premium λ, Vasicek [19] shows that the price of a default-free zero-coupon bond with \$1 face value

and maturity of T periods equals

$$P(r_t, t, T) = e^{\left(m + \frac{\upsilon\lambda}{q} - \frac{\upsilon^2}{2q^2}\right)\left\{\frac{1}{q}[1 - e^{-q(T-t)}] - (T-t)\right\} - \frac{\upsilon^2\left\{\frac{1}{q}[1 - e^{-q(T-t)}]\right\}^2}{4q} - \frac{1}{q}[1 - e^{-q(T-t)}]r_t}. \qquad (2)$$

Duan *et al*. [4] follow that of Merton [12]. At time $t = 0$, the bank acquires an asset portfolio, V, and finances its assets with insured interest-bearing deposits with face value of F and maturing at T. The bank's asset value is assumed to follow a log-normal process given by

$$\frac{dV_t}{V_t} = \mu dt + \sigma_V dZ_{V_t}, \qquad (3)$$

where V_t is the value of bank assets at time t, μ is the instantaneous expected return on bank assets, σ_V is the total volatility of the bank's asset return, and Z_{V_t} is a Wiener process. The processes Z_{V_t} and Z_{r_t} are correlated with a correlation coefficient of η.

Let $X = Fe^{R(t,T)T}$ denote the equity holders' terminal obligation to depositors where $R(t, T)$ is the time t yield to maturity of a default-free bond with maturity T. Given the previous assumptions about the stochastic process for the instantaneous interest rate and the bank asset value, Duan *et al*. [4] show that the market value of deposit insurance per dollar of insured deposits at time t can be written as

$$I_t(V_t, r_t) = XP(r_t, t, T)[1 - N(h_t - \delta_t)] - V_t[1 - N(h_t)], \qquad (4)$$

where

$$h_t = \frac{1}{\delta_t}\ln\left[\frac{V_t}{P(r_t, t, T)X}\right] + \frac{\delta_t}{2},$$

$$\delta_t = \sqrt{\begin{array}{l}(\phi_V^2\upsilon^2 + \psi^2)(T-t) + 2\phi_V\upsilon^2\left[\dfrac{T}{q} + \dfrac{1}{q^2}(e^{-qT} - 1)\right] \\[2mm] + \upsilon^2\left[\dfrac{T}{q^2} + \dfrac{2}{q^3}(e^{-qT} - 1) + \left(\dfrac{1 - e^{-2qT}}{2q^3}\right)\right]\end{array}},$$

$$\phi_V = \frac{\sigma_V\eta}{\upsilon},$$

$$\psi = \sigma_V\sqrt{1 - \eta^2},$$

and $N(\cdot)$ denotes the standard normal cumulative distribution function. The parameter ϕ_V is interpreted as the instantaneous interest rate elasticity of the bank's assets because it is the

---

regression coefficient of the percentage change in the asset value on the change in the instantaneous interest rate. The parameter ψ is interpreted as the credit risk because it is the variability of the component of the asset return that is orthogonal to the interest rate risk. Moreover, Duan *et al.* [4] also show that the bank's equity value at time t can be written as

$$S_t = V_t N(h_t) - XP(r_t, t, T)N(h_t - \delta_t). \tag{5}$$

Similar to the Merton [12] model, difficulties arise in implementing the deposit insurance model in Eq. (4). The parameter values of the system must be estimated. Without direct observations of the instantaneous interest rate, r_t, and the bank's asset value, V_t, parameter estimates are hard to obtain. Even if parameter estimates are able to be obtained, the lack of values for the bank's assets and instantaneous interest rate can still make it impossible to apply the model. To overcome these difficulties, we follow Duan and Simonato [5] to develop an estimation procedure for the deposit insurance model in Eq. (4).

Let θ denote the vector containing the parameters associated with the stochastic processes postulated for the instantaneous interest rate, r_t, and the bank's asset value, V_t; that is, $\theta = [q, m, \upsilon, \lambda, \mu, \sigma_V, \eta]'$. Define

$$u_t = \left[r_t, \ \ln\left(\frac{V_t}{V_{t-1}}\right) \right]' \text{ and } \hat{u}_t(\theta) = \left[\hat{r}_t(\theta), \ln\left(\frac{\hat{V}_t(\theta)}{\hat{V}_{t-1}(\theta)}\right) \right]'$$

where the elements of $\hat{u}_t(\theta)$ are computed using the inverse transformations of the bond pricing model in Eq. (2) and the equity valuation model in Eq. (5) evaluated at the parameter value θ. Duan and Simonato [5] show that the logarithm of the full-information likelihood function for the deposit insurance model in Eq. (4) can thus be written as

$$L(\theta; P(r_t, t, T), S_t, t = 1, ..., n)$$

$$= -\frac{n-1}{2}\ln(\Sigma) - \frac{1}{2}\sum_{t=2}^{n}\left[\hat{u}_t(\theta) - E_{t-1}(u_t)\right]\Sigma^{-1}\left[\hat{u}_t(\theta) - E_{t-1}(u_t)\right]'$$

$$- \sum_{t=2}^{n}\ln\left[P(r_t, t, T)\frac{1}{q}\left[1 - e^{-q(T-t)}\right]V_t N(h_t)\right]$$

$$\tag{6}$$

where $E_{t-1}(u_t)$ is the only first moment of normal transition densities of $\ln\left(\frac{V_t}{V_{t-1}}\right)$, and Σ is the covariance matrix of u_t.

The log-likelihood function in Eq. (6) can be used to obtain the maximum likelihood parameter estimates. Let $\hat{\theta}_n$ denote the maximum likelihood parameter estimator for θ based on the sample size n. Using the maximum likelihood parameter estimates, it is then possible to calculate the estimates for the bank's asset value, $\hat{V}_t(\hat{\theta}_n)$, the deposit insurance premium, $\hat{I}_t(\hat{\theta}_n)$, the interest rate elasticity, $\hat{\phi}_V(\hat{\theta}_n)$, and the bank's credit risk, $\hat{\psi}(\hat{\theta}_n)$, for every time point.

Although directly optimizing the log-likelihood function in Eq. (6) looks like a sensible way of approaching the estimation problem, it is actually not an ideal approach in practice. First, the log-likelihood function in Eq. (6) is defined for the data set comprising one specific bank's equity value series and the common bond price series. When there are many banks in the sample, it is however not practical to expand the log-likelihood function to include all banks in the sample to conduct a joint estimation. Second, there exists a difference in the time horizons for bond pricing and equity valuation. The bond pricing model in Eq. (2) reflects the long-run mean reversion in interest rates. It is therefore reasonable to expect that the mean-reversion parameter can only be pinned down using a relatively long interest rate data series. On the other hand, the equity valuation model in Eq. (5) depends on the bank's asset volatility parameter. Since the variation of the asset value under the diffusion specification is large, the asset volatility parameter can usually be estimated with precision using a relatively short equity value time series. As a result, the use of an equity value time series shorter than the interest rate data series may be more desirable.

We thus follow Duan and Simonato [5] to devise a two-step estimation procedure. The first step estimates, through maximizing the log-likelihood function given in Duan [3], the bond pricing model parameters using the interest rate data. The second step estimates the asset value parameters with the log-likelihood function in Eq. (6) while fixing the interest rate parameters at the values obtained from the first step. This two-step estimation procedure ensures that the interest rate parameter estimates are the same for all banks in the sample. Moreover, it allows one to use a longer time series of interest rates to pin down the mean-reversion parameter for the interest rate dynamic. Since the parameters governing the asset value dynamic do not enter the bond pricing model in Eq. (2), this two-step estimation procedure is able to yield consistent parameter estimates.

III. DATA

We examine the deposit insurance program of Taiwan by analyzing 14 largest Taiwanese commercial banks during the period from 2003 to 2006.[2] These 14 Taiwanese banks are

---

[2] Note that there are a total of 37 local banks and 31 foreign banks in Taiwan. The 14 banks in our sample certainly do not represent the whole Taiwanese banking industry. We thank one anonymous reviewer for raising this concern.

Table 1. Estimation results for the interest rate parameters.

	Jul., 1993-Jun., 2003	Jan., 1994-Dec., 2003	Jul., 1994-Jun., 2004	Jan., 1995-Dec., 2004	Jul., 1995-Jun., 2005	Jan., 1996-Dec., 2005	Jul., 1996-Jun., 2006	Jan., 1997-Dec., 2006
M	0.0549	0.0632	0.0598	0.0209	0.0431	0.0296	0.0184	0.0232
	(0.0129)*	(0.0157)*	(0.0142)*	(0.0084)**	(0.0119)*	(0.0104)*	(0.0066)**	(0.0087)**
Q	0.0839	0.0751	0.0694	0.0837	0.0591	0.0654	0.0684	0.0583
	(0.0002)**	(0.0006)**	(0.0007)**	(0.0008)**	(0.0007)**	(0.0008)**	(0.0017)**	(0.0015)**
υ	0.0059	0.0053	0.0053	0.0055	0.0049	0.0051	0.0047	0.0046
	(0.0002)**	(0.0001)**	(0.0001)**	(0.0002)**	(0.0001)**	(0.0001)**	(0.0001)**	(0.0001)**
λ	0.4410	0.6220	1.5133	2.0557	0.4000	0.2943	0.5306	1.0931
	(0.0252)*	(0.0389)*	(0.0175)*	(0.0351)*	(0.0177)*	(0.0316)*	(0.0460)*	(0.0337)*

Note: * denotes significance at the 5% level. ** denotes significance at the 1% level.

Chang Hwa Bank, Standard Chartered Bank, Bank SinoPac, King's Town Bank, Taichung Commercial Bank, Taiwan Cooperative Bank, The Chinese Bank, Taiwan Business Bank, Bank of Kaoshiung, Cosmos Bank, Union Bank of Taiwan, Far Eastern International Bank, Ta Chong Bank, and Entie Commercial Bank.

Data are collected from the Taiwan Economic Journal (TEJ) database. The interest rate data are based on the daily prices of the three-month commercial papers issued by the Taiwanese government-owned corporations. Because we need a longer interest rate data series in order to pin down the interest rate parameters, our interest rate data series starts in July, 1993 and runs all the way to December, 2006 to ensure that we have 10 years worth of price data for the first year in our sample. The equity value time series is updated daily. For each quarter, the first observation of the equity value time series is the book value of equity from the balance sheet and the subsequent observations are obtained using the stock returns. The debt value is the level of total deposits plus total borrowing. Since the balance sheet figures are available quarterly, the debt value time series can only be updated quarterly.

IV. EMPIRICAL RESULTS

We make several simplifying assumptions to the theoretical model for the purpose of empirical tractability. First, we assume that all debts have the same maturity, which is the semiannual interval between bank audits currently mandated by the CDIC. In other words, $T = 0.5$ years. Second, we assume that the debt is rolled over every quarter. During the estimation procedure, the value of T is reset to 0.5 years at the beginning of each quarter. Third, we assume that the CDIC enforces bank closures only after they have negative net worth, i.e., capital forbearance is granted to the banks. To account for this assumption, the equity valuation model in Eq. (5) can be modified as

$$S_t = V_t N(h_t^*) - \rho X P(r_t, t, T) N(h_t^* - \delta_t), \qquad (7)$$

where $h_t^* = \dfrac{1}{\delta_t} \ln\left[\dfrac{V_t}{\rho P(r_t, t, T) X} \right] + \dfrac{\delta_t}{2}$, and ρ is the capital forbearance factor. Following Ronn and Verma [17], Duan *et al.* [4], and Duan and Simonato [5], we assume that $\rho = 0.97$.

1. Estimation of Interest Rate Parameters and Asset Value Parameters

We implement the two-step estimation procedure as follows. The first step estimates, through maximizing the log-likelihood function given in Duan [3], the bond pricing model parameters using the interest rate data series for the 10-year period preceding a particular 0.5-year interval. The second step estimates the asset value parameters over the 0.5-year interval with the log-likelihood function in Eq. (6) while fixing the interest rate parameters at the values obtained from the first step. The same procedure is repeated for every 0.5 years in our sample from 2003 to 2006.

Table 1 presents the estimation results for the interest rate parameters. Since the first 0.5-year interval in our sample is from January, 2003 to June, 2003, the interest rate data series thus begins in July, 1993 to yield a 10-year sample from July, 1993 to June, 2003. Similarly, the last interest rate data series covers the 10-year period from January, 1997 to December, 2006. The *p*-values of the estimates are reported in the parentheses. It is worth noting that the estimates for both the mean-reversion parameter *q* and the volatility parameter *υ* are fairly stable during different sample periods, but the estimates for the long-run mean parameter *m* and the risk premium parameter *λ* vary a great deal.

Tables 2-4 present the estimation results for the asset value parameters. Since the results are of the same nature for all the banks in our sample, we present the average results for the 14 banks in Table 2. The detailed results for individual banks are reported in Tables 3 and 4. In these tables, equity values are the interval-end market values in millions of New Taiwan (NT) dollars. Debt values are the interval-end book values in millions of NT dollars. Asset values are the sum of equity

Table 2. Estimation results for the asset value parameters for the average of 14 banks.

	Jan., 2003-Jun., 2003	Jul., 2003-Dec., 2003	Jan., 2004-Jun., 2004	Jul., 2004-Dec., 2004	Jan., 2005-Jun., 2005	Jul., 2005-Dec., 2005	Jan., 2006-Jun., 2006	Jul., 2006-Dec., 2006
Equity	39.88	36.81	31.65	27.82	27.48	35.16	37.23	36.24
Debt	488.78	479.00	468.47	447.96	419.69	488.91	510.89	516.52
Asset	528.66	515.81	500.12	475.78	447.17	524.07	548.12	552.76
$\hat{\psi}(\hat{\theta}_n)$	0.5696	0.5332	0.5659	0.5714	0.6029	0.6205	0.6595	0.6607
$\hat{\phi}_V(\hat{\theta}_n)$	-0.7982	-0.8277	-0.9278	-0.8873	-1.0847	-1.0995	-1.3157	-1.3346
$\hat{V}_t(\hat{\theta}_n)$	616.77	601.24	589.57	562.82	531.24	623.06	655.60	660.71
$\hat{I}_t(\hat{\theta}_n)$	7.20	6.50	7.30	7.50	8.10	8.50	9.40	9.50

Note: All the estimates are significant at the 5% level.

Table 3. Estimation results for the asset value parameters for individual banks.

	Equity	Debt	Asset	$\hat{\psi}(\hat{\theta}_n)$	$\hat{\phi}_V(\hat{\theta}_n)$	$\hat{V}_t(\hat{\theta}_n)$	$\hat{I}_t(\hat{\theta}_n)$
Chang Hwa Bank	68.41	974.34	1042.75	0.60	-1.01	1236.91	8.08
Standard Chartered Bank	16.44	290.08	306.52	0.56	-0.96	363.32	7.36
Bank SinoPac	31.75	290.47	322.22	0.67	-1.22	379.80	9.18
King's Town Bank	7.42	119.06	126.48	0.54	-0.91	149.07	6.89
Taichung Commercial Bank	14.13	210.28	224.41	0.55	-0.93	264.61	7.01
Taiwan Cooperative Bank	18.77	415.11	433.88	0.50	-0.82	512.16	6.24
The Chinese Bank	16.02	184.84	200.86	0.61	-1.02	237.08	8.00
Taiwan Business Bank	41.62	814.09	855.71	0.50	-0.84	1008.42	6.27
Bank of Kaohsiung	10.11	129.28	139.39	0.59	-0.98	164.31	7.69
Cosmos Bank	17.54	193.33	210.87	0.66	-1.17	249.86	9.18
Union Bank of Taiwan	16.75	167.26	184.01	0.61	-1.03	216.33	7.96
Far Eastern Intl. Bank	16.42	164.74	181.16	0.67	-1.22	214.03	9.25
Ta Chong Bank	16.53	186.45	202.98	0.56	-0.95	237.97	7.08
Entie Commercial Bank	15.91	179.64	195.55	0.59	-0.98	230.29	7.70

Note: All the estimates are significant at the 5% level.

Table 4. Estimation results for the deposit insurance premium for individual banks.

	Jan., 2003-Jun., 2003	Jul., 2003-Dec., 2003	Jan., 2004-Jun., 2004	Jul., 2004-Dec., 2004	Jan., 2005-Jun., 2005	Jul., 2005-Dec., 2005	Jan., 2006-Jun., 2006	Jul., 2006-Dec., 2006
Chang Hwa Bank	7.87	6.73	7.60	7.40	7.68	8.04	9.67	9.61
Standard Chartered Bank	5.51	4.92	6.42	6.81	8.17	8.25	9.11	9.70
Bank SinoPac	7.96	7.61	8.17	8.96	9.09	9.68	10.78	11.21
King's Town Bank	5.64	5.06	6.31	5.78	6.61	6.93	9.14	9.68
Taichung Commercial Bank	6.01	5.59	7.00	5.97	6.64	7.18	8.61	9.00
Taiwan Cooperative Bank	6.53	5.06	6.07	5.43	5.76	6.89	7.16	7.04
The Chinese Bank	8.23	7.95	8.48	8.18	7.92	7.88	7.96	7.39
Taiwan Business Bank	6.41	5.34	6.01	5.15	5.68	6.33	7.53	7.71
Bank of Kaohsiung	6.59	6.58	6.91	7.41	7.57	7.63	9.02	9.84
Cosmos Bank	6.78	6.85	8.34	9.26	10.10	10.58	11.14	10.43
Union Bank of Taiwan	7.58	6.68	7.36	7.44	8.19	8.67	9.01	8.76
Far Eastern Intl. Bank	7.64	7.15	7.53	8.16	10.32	11.13	11.03	11.07
Ta Chong Bank	6.19	5.49	6.27	6.08	7.50	7.72	8.42	8.48
Entie Commercial Bank	7.03	6.40	7.05	6.75	7.77	8.27	9.14	9.16

Note: All the estimates are significant at the 5% level.

Table 5. Estimation results for the capital forbearance factor and the bank audit interval.

	Jan., 2003-Jun., 2003	Jul., 2003-Dec., 2003	Jan., 2004-Jun., 2004	Jul., 2004-Dec., 2004	Jan., 2005-Jun., 2005	Jul., 2005-Dec., 2005	Jan., 2006-Jun., 2006	Jul., 2006-Dec., 2006
$\hat{\rho}(\hat{\theta}_n)$	0.5310	0.5207	0.5246	0.5188	0.5236	0.5287	0.5404	0.5418
	(0.0362)*	(0.0315)*	(0.0333)*	(0.0298)*	(0.0279)*	(0.0303)*	(0.0305)*	(0.0297)*
$\hat{T}(\hat{\theta}_n)$	0.2284	0.2203	0.2243	0.2218	0.2279	0.2315	0.2429	0.2438
	(0.0186)*	(0.0161)*	(0.0167)*	(0.0046)**	(0.0058)**	(0.0161)	*(0.0056)**	(0.0059)**

Note: * denotes significance at the 5% level. ** denotes significance at the 1% level.

values and debt values in millions of NT dollars.[3] $\hat{\psi}(\hat{\theta}_n)$ and $\hat{\phi}_V(\hat{\theta}_n)$ are the maximum likelihood estimates of the instantaneous credit risk and instantaneous interest rate elasticity of bank assets on an annualized basis. $\hat{V}_t(\hat{\theta}_n)$ and $\hat{I}_t(\hat{\theta}_n)$ are the maximum likelihood estimates for the interval-end asset value expressed in millions of NT dollars and the insurance premium per NT dollar of insured deposits expressed in basis points.

It is interesting to observe that the maximum likelihood estimates for the credit risk parameter, $\hat{\psi}(\hat{\theta}_n)$, increase greatly over the sample period right before the beginning of the global financial crisis in 2007. For the average of 14 banks, the estimates change from 0.5332 during the July, 2003-December, 2003 period to 0.6607 during the July, 2006-December, 2006 period, an almost 24 percent increase in magnitude. Furthermore, the maximum likelihood estimates of the instantaneous interest rate elasticity of bank assets, $\hat{\phi}_V(\hat{\theta}_n)$, are found to be negative for the average of 14 banks as well as for individual banks. This finding is consistent with a negative correlation typically expected between asset value and interest rate.

It is also interesting to observe that the maximum likelyhood estimates for the interval-end asset value, $\hat{V}_t(\hat{\theta}_n)$, are well above the book values of debts for the average of 14 banks as well as for individual banks, effectively making equity a deep in-the-money call option. Furthermore, the maximum likelihood estimates for the deposit insurance premium, $\hat{I}_t(\hat{\theta}_n)$, are found to be considerably higher than the maximum official rate of 6 basis points charged by the CDIC over the sample period. For the average of 14 banks, the highest estimate is found to be 9.5 basis points during the July, 2006-December, 2006 period and the lowest estimate is found to be 6.5 basis points during the July, 2003-December, 2003 period. This statement is, in most cases, true for individual banks as well.

2. Estimation of Capital Forbearance and Audit Interval

Our results on the considerably higher deposit insurance premium indicate that the CDIC deposit insurance program appears to hand out a substantial subsidy to the banks in Taiwan. To examine whether the higher deposit insurance premium is caused by our simplifying assumptions to the theoretical model, we estimate the capital forbearance factor ρ and the bank audit interval T by the maximum likelihood method.

The two-step estimation procedure is modified and implemented as follows. The first step estimates, through maximizing the log-likelihood function given in Duan [3], the bond pricing model parameters using the interest rate data series for the 10-year period preceding a particular 0.5-year interval. The second step estimates the asset value parameters, including the capital forbearance factor and the bank audit interval, over the 0.5-year interval with the log-likelihood function in Eq. (6) while fixing the interest rate parameters at the values obtained from the first step. The same procedure is repeated for every 0.5 years in our sample from 2003 to 2006.

Table 5 presents the estimation results. Since the results are of the same nature for all the banks in our sample, we present the average results for the 14 banks. $\hat{\rho}(\hat{\theta}_n)$ and $\hat{T}(\hat{\theta}_n)$ are the maximum likelihood estimates for the capital forbearance factor and the bank audit interval, respectively. The *p*-values of the estimates are reported in the parentheses. As the results show, the maximum likelihood estimated values for both the capital forbearance factor, $\hat{\rho}(\hat{\theta}_n)$, and the bank audit interval, $\hat{T}(\hat{\theta}_n)$, are much lower than the assumed values over the sample period. On average, the estimated value for the capital forbearance factor is 0.53, which is lower than the assumed value of 0.97. As for the bank audit interval, the average estimated value is 0.23 years, which is also lower than the assumed value of 0.5 years.

Clearly, our assumption about the capital forbearance factor, i.e. $\rho = 0.97$, cannot apply to the Taiwanese market. The es-

---

[3] Note that the average bank size (i.e., the bank's asset value) in our sample is actually very small, if compared with the U.S. banks. For example, the average size of ten largest U.S. banks during our sample period 2003-2006 is around US$880,677,000, while the average size of fourteen largest Taiwanese banks in our sample is around US$11,016,000 (which is calculated using an exchange rate of NT$30/US$1). Thus, the average U.S. bank is almost 80 times the size of an average Taiwanese bank! This huge difference in bank size could have potential impact, if the framework proposed in this paper is to be applied in the U.S. market. Thanks to one anonymous reviewer for pointing this out.

timated values for the capital forbearance factor are found to be much lower than the assumed value. This finding may explain why the estimated rates for the deposit insurance premium are much higher than the maximum official rate charged by the CDIC. Moreover, our assumption about the bank audit interval, i.e. $T = 0.5$ years, is found to be much higher than the estimated values. On average, the estimated value is 0.23 years, which is much lower than the assumed value. This finding may also explain why the estimated rates for the deposit insurance premium are much higher than the CDIC rate.

Our findings also have interesting policy implications. Capital forbearance arises from the insuring agent's intentional delay in forcing a bank closure. The source of capital forbearance is that the bank closure occurs only when its asset value slides below a fixed percentage of the insured liabilities at the time of bank audit. Thus, a lower value of the capital forbearance factor corresponds to a higher degree of capital forbearance. Our findings show that the estimated values for the capital forbearance factor are much lower than the assumed value, indicating that the CDIC in fact grants more capital forbearance to the banks in Taiwan. According to Kane [9] and Kaufman [10], capital forbearance is likely to induce a failing bank to adopt risky asset portfolio strategies, a situation known in the literature as moral hazard. Given that the CDIC grants more capital forbearance to the banks, the moral hazard problem is then more likely to occur. Therefore, we suggest that the CDIC should employ a tighter capital forbearance policy to resolve the moral hazard problem and to prevent the banks in Taiwan from engaging in any excessive risk-taking behavior.

Furthermore, bank audits help identify future bank failures. The length of time between bank audits affects the quality of information available to the auditors. Berger, Davies, and Flannery [1] argue that only the very recent bank audits provide useful information and the information becomes much less useful over time, a situation known in the literature as informational time decay. Thus, more frequent bank audits generate more timely information about the current condition of banks and allow the auditors to address emerging problems more quickly. Our findings show that, on average, the estimated value for the bank audit interval is 0.23 years, which is about a quarter of a year. Currently, the CDIC mandates semiannual bank audits in Taiwan, which are in fact much less frequent than our estimation. Therefore, we suggest that the more frequently bank audits should take place, e.g. quarterly bank audits, in order for the CDIC to have access to information that accurately reflects the current condition of banks in Taiwan.

V. CONCLUSION

In this paper, we examine the deposit insurance program of Taiwan. We adopt Duan *et al*. [4]'s deposit insurance pricing model, and estimate the deposit insurance premium by the Duan and Simonato two-step maximum likelihood method [5]. Our results show that the maximum likelihood estimates are considerably higher than the official rates currently charged by the CDIC, indicating that the CDIC deposit insurance program appears to hand out a substantial subsidy to the banks in Taiwan.

To examine whether the higher deposit insurance premium is caused by our simplifying assumptions to the theoretical model, we also estimate the capital forbearance factor and the bank audit interval by the two-step maximum likelihood method. Our results show, the maximum likelihood estimated values for the capital forbearance factor and the bank audit interval are much lower than our assumed values, indicating that our assumptions about the capital forbearance factor and the bank audit interval cannot apply to the Taiwanese market. This finding may explain why the estimated rates for the deposit insurance premium are much higher than the current CDIC rates.

Our results have important policy implications. A lower value of the capital forbearance factor corresponds to a higher degree of capital forbearance. The estimated values for the capital forbearance factor are shown to be much lower than the assumed value, indicating that the CDIC in fact grants more capital forbearance to the banks in Taiwan. According to Kane [9] and Kaufman [10], capital forbearance is likely to induce a failing bank to adopt risky asset portfolio strategies, a situation known in the literature as moral hazard. Given that the CDIC grants more capital forbearance to the banks, the moral hazard problem is then more likely to occur. Therefore, we suggest that the CDIC should employ a tighter capital forbearance policy to resolve the moral hazard problem and to prevent the banks in Taiwan from engaging in any excessive risk-taking behavior. Furthermore, Berger *et al*. [1] argues that only the very recent bank audits provide useful information and the information becomes much less useful over time, a situation known in the literature as informational time decay. Thus, more frequent bank audits generate more timely information about the current condition of banks and allow the auditors to address emerging problems more quickly. The estimated values for the bank audit interval are shown to be much lower than the assumed value, indicating that the semiannual bank audits currently mandated by the CDIC are in fact much less frequent than our estimation. Therefore, we suggest that the more frequently bank audits should take place, e.g. quarterly bank audits, such that for the CDIC to have access to information that accurately reflects the current condition of banks in Taiwan.

REFERENCES

1. Berger, A., Davies, S., and Flannery, M., "Comparing market and supervisory assessment of bank performance: who knows what when?" *Finance and Economics Discussion Series*, Paper No. 1998-32, Board of Governors of the Federal Reserve System (1998).

2. Black, F. and Scholes, M., "The pricing of options and corporate liabilities," *Journal of Political Economy*, Vol. 81, pp. 637-654 (1973).

3. Duan, J., "Maximum likelihood estimation using price data of the derivative contract," *Mathematical Finance*, Vol. 4, pp. 155-167 (1994).

4. Duan, J., Moreau, A., and Sealey, C., "Deposit insurance and bank interest rate risk: pricing and regulatory implications," *Journal of Banking and Finance*, Vol. 19, pp. 1091-1108 (1995).

5. Duan, J. and Simonato, J., "Maximum likelihood estimation of deposit insurance value with interest rate risk," *Journal of Empirical Finance*, Vol. 9, pp. 109-132 (2002).

6. Duan, J. and Yu, M., "Forbearance and pricing deposit insurance in a multiperiod framework," *Journal of Risk and Insurance*, Vol. 61, pp. 575-591 (1994).

7. Duan, J. and Yu, M., "Assessing the cost of Taiwan's deposit insurance," *Pacific-Basin Finance Journal*, Vol. 2, pp. 73-90 (1994).

8. Hwang, D., Shie, F., Wang, K., and Lin, J., "The pricing of deposit insurance considering bankruptcy costs and closure policies," *Journal of Banking and Finance*, Vol. 33, pp. 1909-1919 (2009).

9. Kane, E., "Dangers of capital forbearance: the case of the FSLIC and zombie S&Ls," *Contemporary Policy Issues*, Vol. 5, pp. 77-83 (1987).

10. Kaufman, G., "Bank capital forbearance and public policy," *Contemporary Policy Issues*, Vol. 5, pp. 84-91 (1987).

11. McCulloch, J., "Interest-risk sensitive deposit insurance premia," *Journal of Banking and Finance*, Vol. 9, pp. 137-156 (1985).

12. Merton, R., "An analytic derivation of the cost of deposit insurance and loan guarantees," *Journal of Banking and Finance*, Vol. 1, pp. 3-11 (1977).

13. Merton, R., "On the cost of deposit insurance when there are surveillance costs," *Journal of Business*, Vol. 51, pp. 439-451 (1978).

14. Nagarajan, S. and Sealey, C., "Forbearance, prompt closure, and incentive compatible bank regulation," *Journal of Banking and Finance*, Vol. 19, pp. 1109-1130 (1995).

15. Pennacchi, G., "Alternative forms of deposit insurance: pricing and bank incentive issues," *Journal of Banking and Finance*, Vol. 11, pp. 291-312 (1987).

16. Pennacchi, G., "A reexamination of the over- or under- pricing of deposit insurance," *Journal of Money, Credit and Banking*, Vol. 19, pp. 340-360 (1987).

17. Ronn, E. and Verma, A., "Pricing risk-adjusted deposit insurance: an option-based model," *Journal of Finance*, Vol. 41, pp. 871-895 (1986).

18. Schreiber, B., "The owner-manager conflict in insured banks: predetermined salary versus bonus payments," *Journal of Financial Services Research*, Vol. 12, pp. 303-326 (1997).

19. Vasicek, O., "An equilibrium characterization of the term structure," *Journal of Financial Economics*, Vol. 5, pp. 177-188 (1977).