PRICING DEPOSIT INSURANCE IN THE UNITED KINGDOM

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CONTENTS

Abstract

The valuation of bank deposit guarantees depends crucially on the point at which troubled financial institutions are closed. Under different assumptions about regulatory policies, we use data on the equity value and deposits of eight large UK banks to value their deposit insurance. The models we implement include standard Merton-style audit models of deposit guarantee valuation, an endogenous closure rule model, and a model with endogenous subsidies in which equity-holders remain in control of the financially troubled bank.

PRICING DEPOSIT INSURANCE IN THE UNITED KINGDOM

1 INTRODUCTION

The cost to governments of deposit insurance depends crucially on the bank closure rule applied by regulators. In this paper, using data on large publicly-quoted UK banks, we implement empirically a series of models that allow us to explore the impact of different approaches to bank closure.

1.1 Theoretical Models of Closure

Closure rules have been the subject of much recent theoretical study. This research has, in part, been stimulated by widespread criticism of the slowness with which US Savings and Loans regulators closed insolvent thrifts in the 1980s. Kane (1990) has argued that regulators are frequently captured by the industry in their charge and hence close troubled institutions long after they have zero net worth. Boot and Thakor (1993) provide a formal treatment of capture in a reputational model of a bank regulator.

An alternative interpretation of apparently late closure rules is provided by Fries *et al* (1994). Bank regulators concerned about dead-weight social costs associated with bank failure (either interior or exterior to the bank concerned) may wish to postpone liquidation for as long as possible. But delaying liquidation benefits equity-holders, so regulatory capture may be hard to distinguish empirically from the behavior of 'social-planner' regulators concerned about possible dead-weight losses to the financial system as a whole.

Whatever theoretical model of bank closure one finds most persuasive, in practice, the valuation of deposit insurance is all the more difficult because closure rules clearly vary over time in a complex, state-contingent manner. For example, George (1993) emphasises that the Bank of England's decision to support a failing bank heavily depends on the current state of the rest of the banking system.

1.2 Valuation of UK Deposit Insurance

Using time series data on the equity market capitalisations and deposits of eight large UK banks, we estimate the parameters of models embodying different assumptions about the bank closure rules. Of the various approaches we implement, Model 1 consists of Merton's classic (1977) model of deposit insurance as slightly extended and implemented empirically by Ronn and Verma (1986). In this framework, closures occur on exogenously given (annual) audit dates if the bank's underlying assets are less than total insured deposits.

The second model we implement (Model 2) allows for an Endogenous Closure Rule (ECR). Regulators, concerned about lump sum bankruptcy costs, possibly exterior to the bank concerned, allow ailing institutions to continue in operation as long as equity-holders are willing to meet operating losses. Thus, equity-holders' incentives to replenish the bank's capital limits the degree to which closure can be postponed. In this framework, closure may well occur long after the unlimited liability value of the bank's equity is negative.

Model 3 extends Model 2 by supposing that regulators can subsidise troubled banks, thereby prolonging their life. Such subsidies that are endogenously determined within the model support equity-values and enable regulators to postpone liquidation until the social costs of bankruptcy are minimised. Again, the bank is likely to have substantially negative net worth by the time it is closed. Our approach to estimation differs from that of past empirical work in this area in that we fully allow for the continuous-time nature of the models and consistently apply full maximum likelihood techniques.

1.3 Guarantee Coverage

The second important determinant of the cost of deposit insurance is the coverage provided. Countries vary widely in the maximum percentage of a given deposit that can be paid out and in the extent to which formal guarantees extend to large deposit holders [see CDIC (1993) for a survey]. It is important, however, to distinguish between the formal coverage implied by the precise rules of a deposit insurance scheme and informal, effective coverage which may be much greater.

For example, in the United States the ostensible ceiling of $100,000 for insured deposits has in the past contributed little towards limiting the authorities' liability in the event of bank failures. The reason is that the Federal Deposit Insurance Corporation (FDIC) has pursued a policy of so-called Purchase and Assumption by which troubled banks have been preserved as going concerns, effectively indemnifying notionally uninsured depositors.

In the present study, we shall calculate deposit insurance values assuming that all deposits are effectively covered. Since all the banks concerned are large, publicly quoted institutions, this approach could be justified by suggesting they are 'too big to fail'. Otherwise, our estimates should be regarded as upper bounds for deposit insurance liabilities.

1.4 Organisation of the Paper

The paper is organised as follows. Section 2 contains a description of the UK deposit insurance system. Section 3 outlines the models used for the guarantee valuation. Section 4 describes our empirical methodology, discussing the derivation of likelihood functions for discretely sampled data within our continuous-time models. Section 5 describes the data and estimation procedures. Section 6 analyses the results of the estimations, which can be found in tabular form at the end of the paper. The final section concludes.

2 DEPOSIT INSURANCE IN THE UNITED KINGDOM

2.1 The Formal Deposit Insurance System

The system of deposit insurance in the United Kingdom, known as the Deposit Protection Scheme (the Scheme), was established under the 1979 Banking Act and later revised by the Banking Act of 1987. It covers all UK authorised banks and is administered by the Deposit Protection Board (DPB). The Board is chaired by the Governor of the Bank of England and includes three other Bank representatives and three members selected from contributory institutions.

The Scheme, which began operating in 1982, provides cover to depositors who have "protected" deposits. These are defined as the principal plus accrued interest on sterling deposits, held in the name of the depositor with UK offices of the authorised bank in question immediately before the insolvency occurred. Secured deposits, deposits with an original maturity of more than five years, and deposits by other banks are not covered. Depositors become eligible for payments when a winding-up order or an administration order is made against the bank.

The Scheme allows for some co-insurance (in the sense that both the insured and the insurer suffer some loss in the event of a claim), namely a coverage ceiling and fixed proportional sharing. The coverage ceiling—the maximum value of individual protected deposits—currently stands at £20,000 (raised from the figure of £10,000 following the 1987 Banking Act). The ceiling reflects the Scheme's emphasis on the protection of small depositors, the argument being that these depositors lack the capacity and information required to assess risk when allocating resources between deposit-taking institutions. The fixed proportional sharing element restricts the payout to 75% of the protected deposit, which, given the coverage ceiling, yields a maximum payout of £15,000 per deposit holder.

2.2 Funding for the Formal System

Funding for the Scheme is provided by UK authorised banks, each of which is required, on authorisation, to make a one-off initial contribution to a standing fund, the Deposit Protection Fund (the Fund). The initial contribution is levied in relation to the bank's sterling deposit base (excluding secured and long-term deposits and interbank deposits) and is subject to a minimum of £10,000. Further contributions (at the end of the Board's financial year) may be required to maintain the Fund at the £5-6 million level and there is a maximum contribution (initial plus further contributions) of £300,000.

A special contribution from each authorised bank may be levied at any time if payments from the Fund are likely to exhaust its cash resources.[1] There is an overall limit on each institution's aggregate contribution (net of any repayments) of 0.3% of its sterling deposit base (as defined for deposit protection purposes) at the time that a particular call is made. In order to meet its liabilities during the period between the announcement of a call and receipt of funds, the DPB is empowered to borrow from the Bank of England, with interest levied at the Bank's base rate.[2]

Since bank failures are paid for through levies on other banks, the Scheme may be thought of as a mutual insurance arrangement resembling those currently operating in Germany [see Schmid (1987)] and France [see GAO (1991)]. It is interesting to note that similar arrangements were adopted by regional groupings of US banks in the 19th century [see Calomiris (1990)] and persisted until the introduction of federal deposit insurance.

2.3 Discretionary Policy and the Lender of Last Resort

The existence of the formal Scheme described above should not be allowed to obscure the importance of the informal deposit insurance provided by the central bank through its lender of last resort activities. Prior to the 1979 Banking Act, the UK authorities from time to time assisted ailing financial institutions. This would typically involve a collaborative effort by the Bank of England and solvent commercial banks to recapitalise the troubled institution in question. Often the Bank of England would guarantee loans by commercial banks to the institution in difficulty. At other times, it would encourage full take-overs or commit its own capital directly. A description of the approach taken by the authorities in assisting troubled banks over the last 20 years is contained in Appendix A.

[1] In 1992, to cover the costs of BCCI, the banks made a special contribution to the Fund (the first such call to be made) amounting to £80.3 million [see Deposit Protection Board (1993)].

[2] The borrowing facility currently stands at £35 million but peaked at £125 million during 1992, following the collapse of BCCI [see Deposit Protection Board (1993, 1994)].

The introduction of the Deposit Protection Scheme in a sense placed the obligations of healthy banks to contribute to the rescue of weaker institutions on a statutory basis; but it would be a mistake to imagine that this very substantially eliminated the authorities' liabilities. As mentioned in the Introduction, during times of financial stability, the Bank of England typically prefers to deal with small-scale bank failures by closure, financing losses through the Deposit Protection Scheme. Even when fairly large losses are involved the Bank may prefer this approach, so long as there is no chance of contagion effects that might harm the banking system more generally.

However, even if the ailing bank is small, when the failure could provoke worries about other institutions the Bank often prefers to support the troubled institution. A good example would be the small banks rescued through Bank of England intervention in 1991 [see Peston (1993) and Bank of England (1993a)]. In that case, the authorities guaranteed loans by the clearers to the group of small banks. The ultimate cost to the Bank is not yet known but its 1994 accounts provided for losses of £105 million.[3] Of course, an important feature of lender of last resort activities is that they effectively indemnify a much larger proportion of the stake-holders in the bank than would be allowed for in the formal Deposit Protection Scheme.

In the event of a major bank experiencing problems (say one of the clearers), it is quite implausible to suggest that the authorities would require the other major banks to assume the costs. In this sense, the informal deposit insurance implicit in the Bank's lender of last resort role remains the bulwark against a major financial crisis. Furthermore, even though, under the formal Scheme, the authorities do not bear the costs of bank failures, their effective liabilities may be considerable.

[3] A provision of £115 million was disclosed in the Bank's 1993 accounts (of which, £25 million was provided, but not disclosed in 1992). £10 million of this provision has since been written back [see Bank of England (1993b, 1994)].

3 PRICING MODELS

We shall examine three different models of deposit guarantee valuation. Model 1 is Merton's (1977) European-style option or audit model. This was slightly extended and implemented empirically on US data by Ronn and Verma (1986). Our application will improve upon Ronn and Verma's study in that we allow, in our approach to estimation, for the non-stationarity of equity volatility implied by the model and ignored in their estimations. Model 2 is the American option or Endogenous Closure Rule Model (ECR) described in Fries *et al* (1994) and implemented on US data by Fries and Perraudin (1993). Model 3 is the Endogenous Subsidy (ES) model also analysed in Fries *et al* (1994). In the latter model, the authorities are assumed to recapitalise the ailing bank without closing it down so that equity-holders' claims are not wholely written down.

3.1 Model 1: Merton

Merton (1977) showed how, under simple assumptions, the value of a deposit guarantee equals that of a European put option written on the bank's assets.[4] The maturity of the option is interpreted as the time of the next audit by the insuring agency. The guarantor is assumed to enforce closure if a bank is found to have negative net worth on the audit date. The value of the guarantee, therefore, arises from the possibility that the bank's net worth may turn negative between audits.

If the bank's underlying asset value follows a geometric Brownian motion with instantaneous volatility parameter, σ_S, from the analysis of Black and Scholes (1973), the value of the guarantee, N_t, simply equals the following expression for the price of a European put:

$$N(y_t) = D_t\Phi(y_t + \sigma_S\sqrt{T}) - \exp(-\delta T)S_t\Phi(y_t) \quad (1)$$

$$y_t \equiv \frac{ln[D_t/S_t\exp(-\delta T)] - \sigma_S^2 T/2}{\sigma_S\sqrt{T}} \quad (2)$$

where D_t is the current value of total insured deposits, S_t is the unobserved, post-insurance value of the bank's assets, σ_S is the unobserved, instantaneous standard deviation of the rate of return on the value of the bank's assets, T is the time until

[4] Merton's (1977) work was extended and implemented empirically by Merton (1978), Marcus and Shaked (1984), Ronn and Verma (1986), Pennacchi (1987a,b), and Brumbaugh, Carron and Litan (1989).

the next audit, δ is the per period dividend flow per pound of the bank's assets, and $\Phi(\cdot)$ is the cumulative distribution function of a standard normal random variable. The per pound deposit insurance premium is N_t/D_t.

One should note, first, that the risk-free interest rate does not appear in the above option pricing expression. This is because, following Ronn and Verma, we assume that all debt is issued at the risk-free rate. Hence, the strike price appears without discounting in the above formula. Second, one may easily extend the above model to allow for stochastic interest rates. However, Ronn and Verma find that guarantee values are little affected by this extension and we, therefore, feel justified in using the simpler model with constant interest rates.

Equations (1) and (2) are difficult to implement empirically since neither S_t, the value of the bank's underlying assets, nor σ_S, its instantaneous volatility, is observable. Ronn and Verma tackle this difficulty by using the fact that, under the above assumptions, the equity of a bank, U_t, is a call option on the value of the bank's assets, with the same maturity as the bank's debt, and with a strike price equal to the maturity value of the debt. Therefore, again under the assumptions of the Black-Scholes model, and noting that, as the recipient of dividends, equity is dividend protected, the value of the equity is:

$$U(x_t) = S_t\Phi(x_t + \sigma_S\sqrt{T}) - \xi D_t\Phi(x_t) \quad (3)$$

$$x_t \equiv \frac{ln[S_t/(\xi D_t)] - \sigma_S^2 T/2}{\sigma_S\sqrt{T}} \quad (4)$$

where ξ is a parameter representing the willingness of the insurer to intervene to save a failing bank that is explained below.

It might seem natural to assume that the closure rule of the insurer would be $S_t < D_t$, ie negative net present value on the date of an audit. Suppose, however, that instead of closing the bank, the insurer injects capital until $S_t = D_t$, returning the bank to solvency. Further, suppose that the insurer's generosity is limited so that it injects capital only if S_t lies between D_t and ξD, where $\xi \leq 1$. This alters the boundary condition to be applied to the equity, and valuation may then be carried out as if the insurer's closure rule (expressed in units of insured deposits) were $S < \xi D$.

As Ronn and Verma note, ξ is a policy parameter which is difficult if not impossible to observe. In what follows, we shall adopt the same values for ξ as Ronn and Verma, ie $\xi = 0.97$, although we also report estimates for $\xi = 1$. To ensure consistency with

Ronn and Verma, we also assume an audit frequency of one year. Note, however, that this value is arbitrary, its sole advantage being that it yields annualised deposit premia.

3.2 Model 2: Endogenous Closure Rules (ECR)

An alternative pricing model that one may apply to value deposit insurance is the Endogenous Closure Rule Model of Fries *et al* (1994). The Merton model of deposit insurance attributes a crucial role to audits by the banking authorities. If audits were costless then banking regulators could observe the value of the bank's assets on a continuous basis and insist on closure as soon as that value reaches zero. In this case, deposit guarantees would have zero value. Thus, the authorities' liability stems entirely from the possibility that the bank's net worth could deteriorate between exogenously given audit dates.[5]

In contrast, the ECR model assumes that the authorities allow the bank to continue *after* its net worth is zero in order to postpone bankruptcy costs such as disruption to the financial system. In the basic ECR model, the extent to which the banking regulators can put off reorganisation is then constrained by the willingness of bank equity-holders to inject capital to cover operating losses. The trigger point at which this occurs and the bank is closed depends on the parameters of the stochastic processes driving the model and is, in that sense, endogenous.

A more detailed derivation of the ECR model is given in Appendix B. Here we provide just a summary of the basic results. Assume that the bank's net cash flow available to equity-holders equals: $g_t - (r+\gamma)D_t$ where g_t is a latent variable measuring the flow of income earnt on the bank's assets, r is the interest rate, and γ is the deposit insurance premium rate. Suppose that g_t and D_t are geometric Brownian motions with instantaneous drift and standard deviation parameters, μ_g, μ_D, σ_g, and σ_D respectively and correlation coefficient ρ. The authorities' liability implied by this model, denoted $N(k_t, D_t)$, is then:

$$N(k_t, D_t) = D_t \left\{ \left[\frac{\underline{k}^*}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D} - c(\underline{k}^*) \right] \left(\frac{k_t}{\underline{k}^*} \right)^{\lambda_1} + \frac{\gamma}{r-\mu_D} \left[1 - \left(\frac{k_t}{\underline{k}^*} \right)^{\lambda_1} \right] \right\} \quad (5)$$

where $k_t \equiv g_t / D_t$. $\underline{k}^*$ is the constrained closure rule for the state variable, ie the lowest

[5] In some models, eg Pennacchi (1987b), the audit dates are the jump times of an exogenous Poisson process. Though stochastic, such audit dates are still exogenous to the basic deposit guarantee model.

level of k_t that the authorities can choose consistent with equity-holders' incentives to accept losses and replenish bank capital. Finally, $c(\underline{k})$ equals lump-sum, bankruptcy costs per pound of deposits.

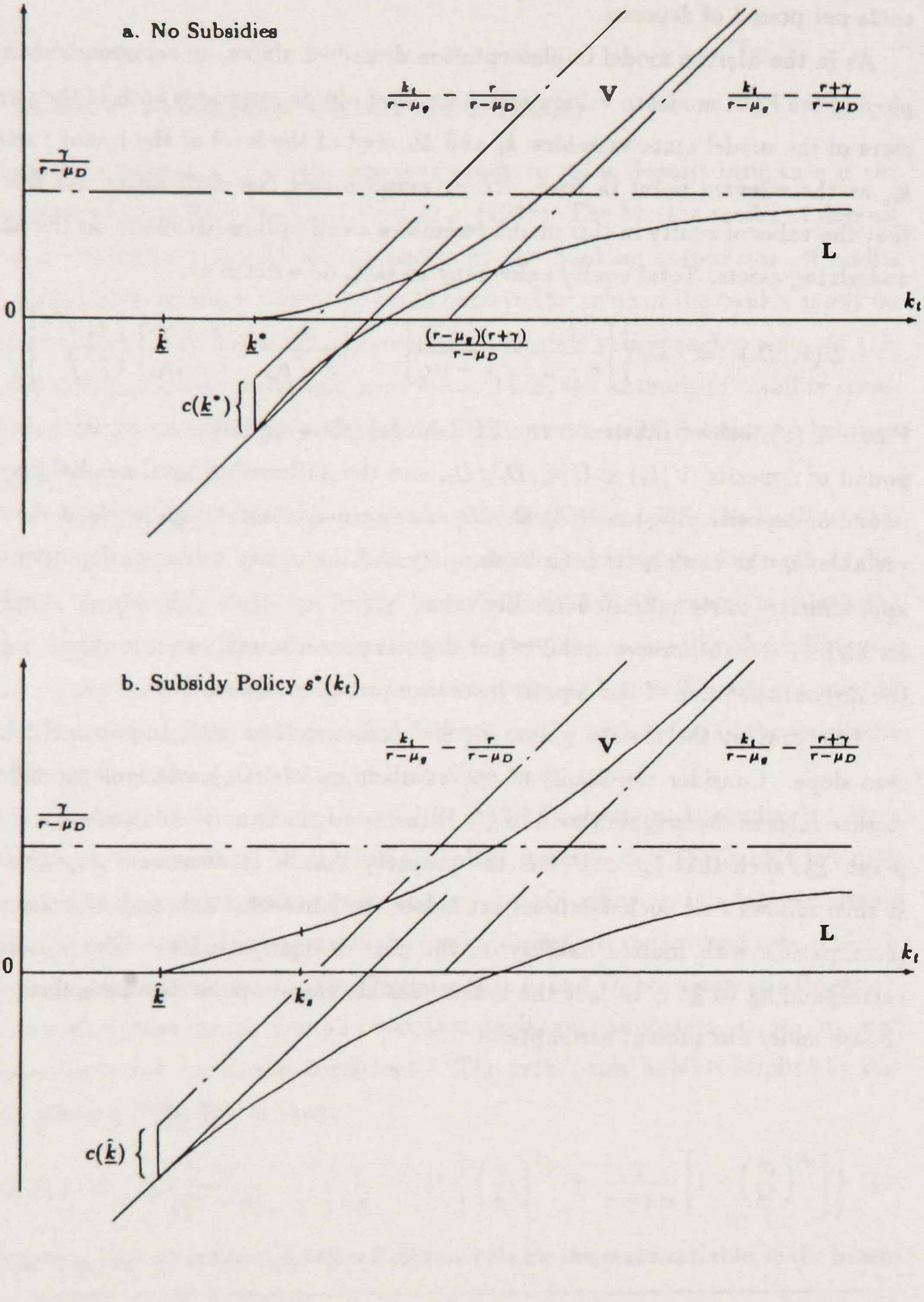
As in the Merton model implementation described above, an econometrician employing the ECR model to value guarantees must obtain estimates both of the parameters of the model state variables, k_t and D_t, and of the level of the latent variable, k_t, at the relevant point in time. To accomplish this, we shall again use the fact that the value of equity in this model resembles a call-option-like claim on the bank's underlying assets. Total equity value may, in fact, be written as:

$$U(k_t, D_t) \quad = \quad D_t \left\{ \left[\frac{k_t}{r - \mu_g} - \frac{r + \gamma}{r - \mu_D} \right] - \left[\frac{k_t}{r - \mu_g} - \frac{r + \gamma}{r - \mu_D} \right] \left(\frac{k_t}{\underline{k}^*} \right)^{\lambda_1} \right\} \tag{6}$$

Figure 1 (a), below, illustrates the ECR model, showing both the equity value per pound of deposits, $V(k_t) \equiv U(k_t, D_t)/D_t$, and the authorities' total net liability per pound of deposits, $L(k_t) \equiv N(k_t, D_t)/D_t$. As one may see, for high levels of the state variable, k_t, the bank is far from bankruptcy and the equity value per deposit pound approximates to its unlimited liability value, $k_t/(r - \mu_g) - (r + \gamma)/(r - \mu_D)$. Similarly, for high k_t the authorities' liability per deposit pound roughly equals $\gamma/(r - \mu_D)$, ie the discounted value of the deposit insurance premium income flow.

Note that at the closure point, $\underline{k}^*$, V equals zero but also, importantly, has a zero slope. Consider the family of curves made up of $V(k_t)$ solutions for different closure rules in the neighborhood of $\underline{k}^*$. It turns out that any V solution for a closure point, $\underline{k}_0$, such that $\underline{k}_0 < \underline{k}^*$ has the property that V is *downward-sloping* at $\underline{k}_0$. It then follows that such solutions cut below the horizontal axis and are, therefore, incompatible with limited liability on the part of equity-holders. The V solution corresponding to $\underline{k}^*$ is in fact the lowest feasible closure point bank regulators can choose under our present assumptions.

Figure 1


a. No Subsidies
$\frac{k_t}{r-\mu_e} - \frac{r}{r-\mu_D}$
V
$\frac{k_t}{r-\mu_e} - \frac{r+\gamma}{r-\mu_D}$
$\frac{\gamma}{r-\mu_D}$
L
0
k_t
$\hat{\underline{k}}$
$\underline{k}^*$
$\frac{(r-\mu_e)(r+\gamma)}{r-\mu_D}$
$c(\underline{k}^*)$
b. Subsidy Policy $s^*(k_t)$
$\frac{k_t}{r-\mu_e} - \frac{r}{r-\mu_D}$
V
$\frac{k_t}{r-\mu_e} - \frac{r+\gamma}{r-\mu_D}$
$\frac{\gamma}{r-\mu_D}$
L
0
k_t
$\hat{\underline{k}}$
k_s
$c(\hat{\underline{k}})$

3.3 Model 3: Endogenous Subsidy (ES)

The third model we investigate in the current paper is the Endogenous Subsidy (ES) Model of Fries *et al* (1994). In this model the authorities, as in the ECR model, have some closure level, $\hat{\underline{k}}$, at which they would prefer to close the bank so as to minimise social, dead-weight bankruptcy costs. However, we now assume that bank regulators have access to tax revenue that they can employ to subsidise financially distressed banks.

The ability to pay subsidies means that regulators can implement a given socially optimal closure rule, closing a bank when k_t reaches $\hat{\underline{k}}$ even if $\hat{\underline{k}}$ is less than the minimum feasible closure rule without subsidies, $\underline{k}^*$. In this sense, the ES model is a direct extension of the ECR model to the case in which bank regulators have access to tax revenues that they can use to support banks.

Fries *et al* (1994) investigate different subsidy policies that can implement a given, socially preferred closure rule. An obvious subsidy policy on which to focus is the policy which minimizes the bank regulatory authorities' guarantee liability. As Fries *et al* (1994) show, this policy consists of paying zero subsidies for $k_t > \underline{k}^*$ and meeting the bank's entire operating losses for all k_t below this point. Let $s(k_t)$ denote this subsidy policy. An interesting feature of $s(k_t)$ is that the value of equity turns out to be exactly the same as in the ECR model of the last subsection.

The liability minimizing subsidy policy, $s(k_t)$, is, in fact, a special case of a broader and quite tractible class of policies in which the authorities inject sufficient funds to maintain the per pound of deposit equity value of the bank greater than or equal to a linear function, ie $V(k_t) \geq \zeta(k_t - \hat{\underline{k}})$ for some constant ζ. Such a subsidy scheme yields an equity solution equal to $\zeta(k_t - \hat{\underline{k}})$ in an interval, $[\hat{\underline{k}}, k_s]$. Here, k_s is not freely chosen but instead is implied by the condition that the derivative of $V(k_t)$ be continuous at k_s.

Figure 1 (b), above, shows the solutions for per-pound-of-deposit equity and guarantee liability values in the ES model, As one may see, closure is enforced at the socially preferred point, $\hat{\underline{k}}$, which is less than the constrained no-subsidy closure point, $\underline{k}^*$. In the $[\hat{\underline{k}}, k_s]$ interval, the equity-deposit ratio, V, is linear with slope, ζ, while above that point it curves up, asymptoting eventually along the unlimited liability value.

4 ESTIMATION APPROACH

For our different models, estimates of the parameters of the underlying driving processes were obtained using maximum likelihood techniques. This section of the paper sketches the derivation of the probability densities used to construct the likelihood functions and describes in broad terms how estimation was carried out.

4.1 Model 1

The Merton model as implemented empirically by Ronn and Verma assumes that the value of the bank's assets, S_t, follows a geometric Brownian motion. In consequence, discrete time changes in the log of S_t are normally distributed. But, as mentioned in the last section, the bank's equity value per pound of deposits, U_t/D_t, is related to its underlying assets per deposit pound, S_t/D_t, by a known function. It is, therefore, simple to derive a likelihood function for the equity value as the latter is just a non-linear transformation of a random variable with a known density.

Note that since S_t is effectively a latent variable while the per deposit pound equity value is observed, to calculate the likelihood, we must invert expressions (3) and (4) to obtain the underlying state variable. This inversion must be performed for each observation in the sample every time that the likelihood is evaluated in the maximum likelihood estimation. Furthermore, since the relationship between S_t/D_t and U_t/D_t depends on the parameter to be estimated, σ_S, the likelihood function must be multiplied by a Jacobian adjustment term.

This full maximum likelihood econometric approach differs substantially from that of Ronn and Verma. In their study, the standard deviation of the bank's equity value, σ_V, is estimated from discretely sampled data as though it is a constant parameter. The equation: $\sigma_V = \sigma_S(S_t/V_t)\partial V_t/\partial S_t$ that links the instantaneous volatility of equity and underlying asset values is then used to infer σ_S. The problem with this procedure is, of course, that while σ_S is constant according to the assumptions of the model, σ_V is not.

Compared with their methods, the exact maximum likelihood technique described above has two advantages. First, it allows for the non-constancy of σ_V;[6] and, second,

[6] Ronn and Verma discuss the non-stationarity of σ_V, but do not give results for individual banks calculated on this basis.

it allows us to calculate asymptotic standard errors for our parameter estimates and deposit guarantees, rather than simply to quote point estimates.

4.2 Models 2 and 3

In many ways, our approach to estimating Models 2 and 3 resembles that employed in the case of the Merton model. Again, the observed bank equity value per pound of deposits is a function of a latent variable, in this case k_t. However, we may wish to estimate the deposit process parameters as well as those of k_t to calculate the authorities' liability. If the joint density of k_t and D_t can be obtained, full maximum likelihood estimation can be carried out, inverting $V(k_t)$ at each evaluation of the likelihood function as described in the last subsection.

However, it is somewhat more difficult to obtain the joint density of the k_t and D_t processes than of the S_t/D_t process in Model 1. As discussed in Fries and Perraudin (1993), in ECR models, bank closure can occur at any time between a given pair of dates, t_1 and t_2. If we observe that a bank is still in operation at t_2, however, it follows that the driving process, k_t cannot have fallen below the trigger level, $\underline{k}$.

Hence, to construct the likelihood function for a given observation, we need to condition on the fact that the sample paths lie wholely above the level $\underline{k}$. Fries and Perraudin (1993) derive the joint density of a bivariate Brownian motion when one of the two processes is absorbed at a barrier, conditional on absorption not yet having taken place.[7] This is the density required for estimation of the ECR model described above.

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[7] For the univariate case, the density is well known.

5 DATA AND ESTIMATION

Our study employs weekly data on eight large UK banks over the period January 1983 to June 1994. Data for two of the banks were only available for the latter parts of the sample period. Also, another ceased to be quoted late in the sample period. Weekly market value and dividend yield data were taken from Datastream. Weekly deposit-base data were obtained from the Bank of England's Monetary and Financial Statistics Division from unconsolidated, balance sheet data submitted by individual authorised banks on form W1. The deposit data were consolidated to give group figures consistent with the equity data for the quoted entities. Weekly stock market price indices were obtained from Datastream.

Estimation was performed using algorithms written in GAUSS. As already noted, in both models the underlying driving processes were not observed. Hence, at each evaluation of the likelihood, it was necessary to invert the non-linear relationships between the observed and unobserved variables, for each observation. This was computationally feasible because, in general, successive evaluations of the likelihood occurred at only slightly different sets of parameter values. Hence, by storing and updating starting values for the inversion procedure, it was possible to carry out inversions at very high speed.

6 RESULTS

6.1 Descriptive Statistics

In Table 1, we present descriptive statistics for differences in the logarithms of the total equity value and deposits of each bank, all expressed in nominal terms. The equity series appears free of the negative skewness that one frequently finds in such data although excess kurtosis (greater than the level of three characteristic of normally distributed random variables) *is* in evidence.

The differenced log deposit data exhibit considerable kurtosis, suggesting these series are far from being normally distributed. This was not, however, a major concern as the deposit series showed very little volatility so our results are likely to be quite insensitive to their stochastic properties.

6.2 Merton Model Results

Table 2 reports the results of estimating Merton-type audit models along the lines of Ronn and Verma (1986). An important initial point to make is that audit model premia represent per annum payments, in contrast to the ECR values given above which correspond to once-and-for-all payments. An implicit assumption in the Merton model calculations is that liabilities associated with default in future years may be left out of account. This approach is valid if one supposes that at the end of each year the deposit guarantee premium rate is adjusted so that the bank is fairly charged for the deposit insurance it receives. Of course, this is not the case in the United Kingdom or in any other country at the present time and so can only be justified as an extreme simplifying assumption.

Turning to the results given in Table 2, the guarantee values implied by the Merton model seem implausibly large. Average guarantee premia are of the order of 2%. This somewhat exceeds typical spreads on good quality corporate debt and is far higher than the deposit insurance premia typically charged in countries with deposit insurance. Ronn and Verma argue that the model should be used more for establishing the relative pattern of deposit insurance premia for a cross-section of banks and should not be taken as a guide of the absolute level. They stress this point particularly because of the difficulty in establishing an appropriate level for the parameter, ξ, which measures the authorities' willingness to bailout troubled banks. But, the implausibly high estimates one obtains imply the point would hold even if ξ were fully known.

Table 2 provides guarantee prices both for the value of ξ adopted by Ronn and Verma, 0.97, and for ξ equal to unity. As one may see, lowering ξ significantly increases the fair guarantee premium although the impact is not as great as found by Fries *et al* (1993) for the case of Japanese banks. The premia reported in the Table may be explained first by the estimated volatilities, σ_S, and second by the level, calculated for the very end of our sample, of the value to deposits ratio, V_t. For example, banks 2 and 4 have similar volatilities but quite different guarantee values because bank 2 has a much lower implicit net worth according to the model.

Another way in which one may see that the Merton model results are somewhat implausible is in the relative size of σ_S and the asset-deposits ratio for individual banks. Since the driving processes involved are geometric, the appropriate way to measure the 'distance' from a barrier in probabilistic terms is through ratios. For typical banks, assets exceed deposits by around 15% while volatility estimates reported on an annualised basis are of similar magnitude. The implication is that, according to the model, the banks are relatively close to bankruptcy, far closer in fact than one could plausibly argue.

6.3 ECR and ES Model Results

Tables 3 and 4 give the parameter estimates and the premium results for the ECR model. Bankruptcy costs are assumed to be 8% of deposits.[8] To interpret the guarantee values, note that if real interest rates are 3%, a claim representing say 10% of the deposit values would correspond to a perpetual flow of income of 30 basis points. While the guarantee value percentages given in the Table appear high they are not, therefore, substantially out of line with actual premia charged in the United States for example. They are also, it should be stressed, much lower than those implied by our Merton model estimations.

It is interesting to note that in some cases the ranking of banks differs significantly between the Merton and the ECR model. For example, bank 7 which appears one of the riskiest according to the Merton model guarantee calculations, is close to the average among the ECR results. This finding underlines the difficulty involved in using such models for practical policy applications although the results may give

[8] This seems reasonable given the estimates of James (1991).

broad guidance. Although there are cases like bank 7 for which the model specification significantly affects the rankings, the latter do in general show reasonable concordance.

The ECR results suggest that most of the banks are quite far from their closure points. Again, the ratio of $k_t/\underline{k}$ provides a measure of the 'probabilistic' distance from closure. Comparison with σ_k suggests that the banks are typically six 'annual standard errors' from closure. (One may get a rough idea of what such magnitudes imply if one recalls that the random variables involved are standard normal, and so the probability weight associated with values more than two standard errors from the mean is roughly five per cent.)

The ES model we employ, and for which premium results appear in Table 5, assumes that subsidies are designed to minimize the authorities' deposit insurance liabilities while implementing the socially optimal closure rule. This means that the equity value is the same as in the ECR model and hence we can use the parameter estimates given in Table 3. We also assume for simplicity that the optimal closure rule is extremely low, ie $\hat{\underline{k}} = 0$.

As Table 5 shows, the ES results we obtain closely resemble the premia implied by the ECR model. Given our assumptions, the difference between the two sets of premia is just that the ECR model results reflect an additional liability associated with the expected, discounted bankruptcy cost, comprising 8% of bank deposits at closure. Through endogenous subsidies, the deposit insurance corporation can put off reorganisation and hence spare itself this additional cost.

7 CONCLUSIONS

This paper has presented estimates of the value of deposit guarantees in the United Kingdom using pricing models based on the approaches of Merton (1978) and Ronn and Verma (1986), Fries and Perraudin (1993), and Fries *et al* (1994).

Our implementation of these models has inevitably abstracted from many important aspects of the UK system of banking regulation. In particular, we suppose that all deposits are covered by the insurance and that the regulatory authorities (rather than other banks through their Deposit Protection Fund contributions) bear the entire costs of failure.

One might justify this approach by the usual 'too big to fail' argument, ie that the banks in question are too important within the UK financial system for the authorities to permit their failure. Furthermore, bank rescues that involve maintaining banks as going concerns generally spare any depositors serious losses and hence imply that the coverage of guarantees is broader than nominally allowed for in deposit insurance schemes.

Readers who find the too big to fail argument unconvincing should regard the deposit insurance estimates here provided as upper bounds on the authorities' true liabilities.

8 APPENDIX A: REGULATORY INTERVENTIONS

8.1 The Secondary Banks (1973–75)

In 1973, several secondary (smaller, unregulated) banks and finance houses suffered heavy deposit withdrawals. As a result, the institutions found themselves unable to roll over their money market borrowings. The Bank of England, fearing that a crisis of confidence could spread to fully recognised banks, organised a rescue operation.

The Bank immediately sought several sources of financing in an effort to avoid injecting new money into the system. The Bank approached the clearing banks and asked them to form a 'lifeboat', agreeing to contribute 10% of the pooled funds. In collaboration with other members of the lifeboat, the Bank also sought other sources of financing for the secondary banks. Some of the largest shareholders, for example, were asked to provide additional funds, with the Bank sometimes adding support in the form of indemnities. In some cases the Bank pressurised banks and other creditors to forgo their right to foreclosure, and shareholders agreed to dilute their shareholdings. The Bank provided direct assistance to selected secondary banks by means of various types of credit arrangements; and it also arranged for many of the troubled banks to be merged with, or acquired by, healthy institutions. The Bank itself eventually acquired two large secondary banks.

At this time, of course, the United Kingdom did not have a formal system of deposit insurance.[9] It is interesting to note, though, that no (non-shareholding) depositor lost funds during this crisis. The Bank, however, is believed to have lost £100 million. For a description of this crisis see Bank of England (1978), Reid (1982), and Corrigan (1990).

8.2 Johnson Matthey (1984)

In October 1984 the Bank mounted a rescue operation for Johnson Matthey Bankers Ltd (JMB), one of five members of the London gold fixing. JMB was in trouble due to a severe deterioration in the quality of its loan book, and the Bank was concerned that JMB's failure would trigger problems elsewhere.

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[9]The secondary banking crisis prompted the 1979 Banking Act which introduced the formal Deposit Protection Scheme and strengthened the Bank's supervisory role.

The Bank was unable to find a purchaser for JMB and the parent company could not provide all the support required because it was itself in financial difficulty. However, the Bank did persuade the parent company to inject £50 million into JMB and the Bank bought JMB for a nominal £1. Support was then sought from banks and other members of the gold market. The Bank provided JMB with an indemnity of £150 million, and the banks and other members of the gold market agreed to counter-indemnify the Bank for 50% of any losses.

The Bank reorganised the board of directors, installed new management and implemented a new system of internal controls. In April 1986 the Bank disposed of the bulk of its holding in JMB, enabling it to recoup a proportion of its costs and has since recovered the remainder. Again, no depositor of JMB lost funds during the crisis. For a description of this crisis see Bank of England (1985), Corrigan (1990), GAO (1991), and Hall (1987a,b).

8.3 BCCI (1991)

In July 1991, following the detection of large-scale fraud, the Bank enforced the closure of the Bank of Credit and Commerce International (BCCI). Depositors received compensation from the Deposit Protection Scheme, which needed to levy a special contribution on the other banks totalling £80.3 million. See Bank of England (1992) for a description.

8.4 Small Banks (1990–91)

The Bank placed a number of small banks under close review during 1990–91. This followed the closure in mid-1990 of the British and Commonwealth Merchant Bank and the closure of a number of small banks later that year. This contributed to nervousness in the wholesale funding market and the Bank was concerned that this could spread and pose a systemic threat. By mid-1991 the Bank took the view that the situation was serious enough to warrant it providing liquidity support. This took the form of the Bank providing indemnities against loss to those large UK banks which helped to fund certain small banks. The Bank's provision for losses in this operation currently stands at £105 million [see Bank of England (1994)]. A description of this crisis is given in Bank of England (1993a), George (1993), and Peston (1993).

9 APPENDIX B: PRICING MODELS

9.1 Endogenous Closure Rule Models

This subsection develops an Endogenous Closure Rule (ECR) model in which the authorities' choice of when a bank is reorganised is determined by their desire to minimise the discounted value of lump-sum bankruptcy costs. Our results will depend upon the important assumption that regulators cannot directly subsidise banks so as to maintain them as going concerns. In Section 2, we investigate the consequences of relaxing this assumption.

9.1.1 Basic Assumptions

Let the total net cash flow available to bank equity-holders be:

$$g_t - (r + \gamma)D_t \tag{7}$$

Here, D_t is the bank's total deposits, γ is the deposit insurance premium it pays the insurer (for the moment, assumed constant), and r is the safe rate of interest. For simplicity, we shall suppose that safe loan and deposit rates are identical. Finally, g_t is a latent variable that represents the risky interest income on the bank's loan portfolio plus new deposits net of new loans extended.[10]

In most past studies, the value of the bank's assets rather than net cash flow has been the main state variable. To a great extent, the two approaches are equivalent, as the discounted, unlimited-liability value of our cash flow will turn out to be simple monotonic functions of the cash flow processes themselves. However, an important difference between our formulation and that adopted in past research [see, for example, Pennacchi (1987b)], is that we allow cash disbursements to shareholders to become negative in some states of the world.[11] We thereby capture the notion that capital injections by equity-holders may be required in order to maintain the bank as a going

[10]Note that we model the bank's cash flow here in a reduced-form manner. One may think of the process as representing cash flow *after* the bank has optimally adjusted its assets and liabilities given the current levels of g_t and D_t.

[11]Pennacchi, like other authors, assumes that the flow of payouts to equity-holders is a positive fraction of a value process which follows a geometric Brownian motion and hence is non-negative.

concern.[12] This is the basic modelling device that enables us to study the interaction of capital replenishment and bank closure rules.

Suppose that g_t and D_t are correlated, geometric Brownian motions, ie

$$dg_t = \mu_g g_t dt + \sigma_g g_t d\omega_{1t} \tag{8}$$

$$dD_t = \mu_D D_t dt + \sigma_D D_t d\omega_{2t} \tag{9}$$

where μ_i, σ_i, $i = g, D$ are constant parameters, ω_{gt} and ω_{Dt} are standard Brownian motions and $d\omega_{1t} d\omega_{2t} = \rho dt$ for a constant correlation coefficient, ρ.

Let U_t denote the market value of the bank's equity and suppose that agents are risk neutral. In equilibrium, the required return on bank equity, rU_t, must equal the flow of income to equity-holders plus expected capital gains,[13]

$$rU_t = g_t - (r+\gamma)D_t + \frac{d}{d\Delta} \mathrm{E}_t U_{t+\Delta} \Big|_{\Delta} \tag{10}$$

9.1.2 Bank Equity Valuation

To obtain an expression for the bank's equity as a function of the state variables, g_t and D_t, suppose that is can be written as a twice, continuously differentiable function $U(g_t, D_t)$. Applying Ito's lemma inside the expectations operator in equation (10), one obtains the partial differential equation:

$$\begin{aligned} rU_t &= g_t - (r+\gamma)D_t + g_t\mu_g \frac{\partial U_t}{\partial g_t} + D_t \mu_D \frac{\partial U_t}{\partial D_t} \\ &+ g_t^2 \frac{\sigma_g^2}{2} \frac{\partial^2 U_t}{\partial g_t^2} + D_t^2 \frac{\sigma_D^2}{2} \frac{\partial^2 U_t}{\partial D_t^2} + g_t D_t \rho \sigma_g \sigma_D \frac{\partial^2 U_t}{\partial g_t \partial D_t} \end{aligned} \tag{11}$$

$U(g_t, D_t)$ also satisfies boundary conditions. Let k_t denote the ratio of the cash flow variable to deposits, ie $k_t \equiv g_t / D_t$. We shall suppose, first, that the authorities close the bank when the k_t, hits some level $\underline{k}$.[14] (Below, we shall discuss in detail what might determine $\underline{k}$.) Since closure of the bank requires its shareholders to relinquish

[12] We suppose that such capital replenishment are required over and above any optimal actions by the bank to overcome liquidity short-falls.

[13] One may introduce risk aversion straightforwardly by replacing the operator, $\mathrm{E}_t(\cdot)$, with an expectations operator based on risk-adjusted probabilities [see Harrison and Kreps (1979)].

[14] Note that a reorganisation rule based on k_t is entirely equivalent to a rule based on the level of the bank's underlying value per dollar of deposits, since, as we show below, the two quantities are linearly related.

their claim to the bank's earnings stream, in the absense of arbitrage, it must be the case that $V(\underline{k}) = 0$.

Ruling out bubbles in the equity solution implies a second boundary condition. Since the probability of bankruptcy disappears as k_t becomes large, it must true that:

$$\lim_{k_t \to \infty} \left\{ U(g_t, D_t) - \mathrm{E}_t \left[\int_t^\infty [g_\tau - (r+\gamma) D_\tau] \exp[-r(\tau - t)] d\tau \right] \right\} = 0 \qquad (12)$$

To solve (11) subject to these boundary conditions, one may exploit the homogeneity of the differential equation and the boundary conditions, looking for solutions of the form: $U(g_t, D_t) = V(g_t/D_t) D_t$ for a function $V(\cdot)$. By a minor abuse of notation, we shall henceforth write U_t as a function of the variables $k_t \equiv g_t/D_t$ and D_t, so this becomes: $U(k_t, D_t) = V(k_t) D_t$. This yields the following result:

Proposition 1 *The value of the bank's equity, U_t, equals $U(k_t, D_t) = V(k_t) D_t$ where:*

$$V(k_t) = \frac{k_t}{r - \mu_g} - \frac{r+\gamma}{r-\mu_D} - \left[\frac{\underline{k}}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D} \right] \left(\frac{k_t}{\underline{k}} \right)^{\lambda_1} \qquad (13)$$

λ_1 is the negative root of $\lambda^2 \sigma_k^2/2 + \lambda(\mu_g - \mu_D - \sigma_k^2/2) - (r - \mu_D) = 0$, and $\sigma_k \equiv \sqrt{\sigma_g^2 + \sigma_D^2 - 2\rho\sigma_g\sigma_D}$ is the instantaneous standard deviation of k_t.

Proof of Proposition 1: Assume that when the bank is closed, equity-holders receive nothing. Assume that U_t can be written in the form $U_t = V(k_t) D_t$ and then confirm this by constructing a solution. Begin by evaluating the derivatives of U_t:

$$\frac{\partial U_t}{\partial g_t} = D_t V'\left(\frac{g_t}{D_t}\right) \frac{1}{D_t} = V'(k_t) \qquad (14)$$

$$\frac{\partial U_t}{\partial D_t} = V\left(\frac{g_t}{D_t}\right) - D_t V'\left(\frac{g_t}{D_t}\right) \frac{g_t}{D_t^2} = V(k_t) - k_t V'(k_t) \qquad (15)$$

$$\frac{\partial^2 U_t}{\partial g_t^2} = V''\left(\frac{g_t}{D_t}\right) \frac{1}{D_t} = \frac{1}{D_t} V''(k_t) \qquad (16)$$

$$\frac{\partial^2 U_t}{\partial D_t^2} = -V'\left(\frac{g_t}{D_t}\right) \frac{g_t}{D_t^2} + V'\left(\frac{g_t}{D_t}\right) \frac{g_t}{D_t^2} + V''\left(\frac{g_t}{D_t}\right) \frac{g_t^2}{D_t^3} = \frac{k_t^2}{D_t} V''(k_t) \qquad (17)$$

$$\frac{\partial^2 U_t}{\partial g_t \partial D_t} = -V''\left(\frac{g_t}{D_t}\right) \frac{g_t}{D_t^2} = -\frac{k_t}{D_t} V''(k_t) \qquad (18)$$

Hence:

$$rU_t = g_t - (r+\gamma) D_t + g_t \mu_g V'(k_t) + D_t \mu_D (V(k_t) - k_t V'(k_t)) + g_t^2 \frac{\sigma_g^2}{2} \frac{1}{D_t} V''(k_t) + D_t^2 \frac{\sigma_D^2}{2} \frac{g_t^2}{D_t^3} V''(k_t) - g_t D_t \rho \sigma_g \sigma_D \frac{\partial^2 U_t}{\partial g_t \partial D_t} \frac{g_t}{D_t^2} V''(k_t) \qquad (19)$$

$$(r - \mu_D) V(k_t) = k_t - (r+\gamma) + (\mu_g - \mu_D) k_t V'(k_t) + \frac{\sigma_k^2}{2} k_t^2 V''(k_t) \qquad (20)$$

Solving this ODE subject to $V(\underline{k}) = 0$ yields the solution in the Proposition. **Q.E.D.**

Assumption A *Bank regulators cannot bailout banks through direct subsidies and can just select the closure point* $\underline{k}$.

The importance of this assumption is that if regulators cannot inject subsidies to maintain an ailing bank as a going concern, the willingness of equity-holders to re-capitalise troubled financial institutions may become a binding constraint on banking policy.

To see this, note that if regulators act as social planners, they will select $\underline{k}$ to minimise discounted, expected lump-sum bankruptcy costs, ignoring the additional cost to the insurance corporation of taking on the bank's portfolio of deposits and loans.[15] Let us then define the unconstrained socially optimal closure rule $\hat{\underline{k}}$ as:

$$\hat{\underline{k}} \equiv \operatorname{argmin} \left\{ c(\underline{k}) \left(\frac{k_t}{\underline{k}} \right)^{\lambda_1} \right\} \tag{21}$$

If $\hat{\underline{k}}$ is sufficiently low and Assumption A holds, however, it may not be possible for regulators to implement such a closure rule as equity-holders may be unwilling to continue injecting new capital as long as is required. A simple case to consider is that in which c is independent of $\underline{k}$ so that $\hat{\underline{k}} = 0$, ie regulators wish to postpone reorganisation indefinitely.[16] Then, one may obtain:

Proposition 2 *Under Assumption A, if $c > 0$ is independent of $\underline{k}$, regulators will be unable to implement the closure rule $\hat{\underline{k}}$ and the constrained, socially optimal closure rule will equal:*

$$\underline{k}^* = \frac{-\lambda_1}{1-\lambda_1} \frac{r-\mu_g}{r-\mu_D} (r+\gamma) \tag{22}$$

where $\underline{k}^*$ is the closure rule that maximises the bank's equity value.

Proof of Proposition 2: For a given closure rule $\underline{k}$, the current discounted value of the bankruptcy cost is $-c(\underline{k})\ (k_t/\underline{k})^{\lambda_1}$. An actuarially fair insurance rate is obtained by solving the equation:

$$V(k_0) \equiv \frac{k_0}{(r-\mu_g)} - \frac{(r+\gamma)}{r-\mu_D} - \left[\frac{\underline{k}}{(r-\mu_g)} - \frac{(r+\gamma)}{r-\mu_D} \right] \left(\frac{k_0}{\underline{k}} \right)^{\lambda_1} \tag{23}$$

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[15] This is, of course, only one possibility. Dreyfus, Saunders and Allen (1994), for example, suppose that bank regulators seek to minimise their total deposit insurance liability.

[16] Since k_t is the ratio of two geometric Brownian motions it is a geometric Brownian motion itself. Such processes hit zero with a zero probability in any finite time.

$$= \frac{k_0}{(r-\mu_g)} - \frac{r}{r-\mu_D} - c(\underline{k})\left(\frac{k_0}{\underline{k}}\right)^{\lambda_1} \tag{24}$$

Here, the RHS represents the value of the bank's income flow exclusive of deposit insurance premia and without limited liability minus the discounted value of bankruptcy costs. Rearranging gives the fair deposit insurance premium, γ_f, in closed form. **Q.E.D.**

As a final result in this section, one can derive the value of the authorities' deposit insurance liability, $M(k_t, D_t)$:

Proposition 3 *The authorities' liability under Assumption A and with closure rule $\underline{k}^*$ is $M(k_t, D_t) = L(k_t)D_t$ where:*

$$L(k_t) = \frac{\gamma}{r-\mu_D} + \left[\frac{\underline{k}^*}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D} - c(\underline{k}^*)\right]\left(\frac{k_t}{\underline{k}^*}\right)^{\lambda_1} \tag{25}$$

Proof of Proposition 3: Simple application of methods used in Proof of Proposition 1.

Here again, one may interpret the expressions as the sum of the value of an annuity proportional to deposits, $\gamma D_t/(r-\mu_D)$, plus bracketed terms that equal negative the value of the put option that the authorities have effectively written for equity-holders by providing the guarantee to take over the bank and meet bankruptcy costs.

9.2 Endogenous Bailout Models

Now, suppose that Assumption A does not hold, ie that regulators *do* have access to tax revenue that they can use to support ailing banks. Suppose that the social planner's unconstrained problem yields a strictly positive optimum, ie $\hat{\underline{k}} > 0$. In this section, we shall consider different state contingent subsidy rules that support $\hat{\underline{k}}$.

First, it is interesting to ask, what is the subsidy or bailout policy that implements the closure $\hat{\underline{k}}$ while minimising the authorities' financial liability? Consider the following candidate per-£-of-deposit subsidy policy, $s_*(k_t)$:

$$s_*(k_t) \equiv \begin{cases} 0 & \forall\ k_t \geq \underline{k}^* \\ -k_t + (r+\gamma) + \nu & \forall\ k_t \in [\hat{\underline{k}}, \underline{k}^*] \end{cases} \tag{26}$$

where $\nu > 0$ is an arbitrarily small number.

Proposition 4 *The value of the equity and the deposit insurance liability when the authorities adopt the subsidy policy* $s_*(k_t)D_t$ *are* $U_i(k_t, D_t) = V_i(k_t)D_t$ *and* $M_i(k_t, D_t) = L_i(k_t)D_t$ $i = 1,2$ *respectively for the two intervals* $I_1 \equiv [\hat{\underline{k}}, \underline{k}^*]$, $I_2 \equiv [\underline{k}^*, +\infty]$ *where* $V_1(k_t) = 0$ *for* $k_t \in [\hat{\underline{k}}, \underline{k}^*]$ *while* $V_2(k_t)$ *is as in Proposition 1 for* $k_t \in [\underline{k}^*, +\infty]$, *and*

$$L_1(k_t) = \frac{\underline{k}^*}{r-\mu_g} - \frac{r}{r-\mu_D} - c(\hat{\underline{k}})\left(\frac{k_t}{\hat{\underline{k}}}\right)^{\lambda_1} \quad for \quad k_t \in [\hat{\underline{k}}, \underline{k}^*] \tag{27}$$

$$L_2(k_t) = \frac{\gamma}{r-\mu_D} + \left[\frac{\underline{k}^*}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D}\right]\left(\frac{k_t}{\underline{k}^*}\right)^{\lambda_1} - c(\hat{\underline{k}})\left(\frac{k_t}{\hat{\underline{k}}}\right)^{\lambda_1} \quad for \quad k_t \in [\underline{k}^*, +\infty] \tag{28}$$

Proof of Proposition 4: Let $V_1(k_t)$ and $V_2(k_t)$ denote the equity solutions on intervals $[\hat{\underline{k}}, \underline{k}^*]$ and $[\underline{k}^*, +\infty]$ and similarly $L_1(k_t)$ and $L_2(k_t)$. The hypothesised solutions satisfy the differential equations corresponding to the equilibrium conditions while the boundary conditions $L_1(\underline{k}^*) = L_2(\underline{k}^*)$, $L_1'(\underline{k}^*) = L_2'(\underline{k}^*)$, $V_1(\underline{k}^*) = V_2(\underline{k}^*)$, $V_1'(\underline{k}^*) = V_2'(\underline{k}^*)$ also hold. **Q.E.D.**

Proposition 5 *The subsidy policy* $s_*(k_t)$ *is the policy which implements* $\hat{\underline{k}}$ *while yielding the smallest financial liability to the deposit insurance corporation.*

Proof of Proposition 5: For a given closure rule $\hat{\underline{k}}$, the total value of the bank (including the authorities liability) is a given function of k_t. Hence, minimising the authorities' deposit insurance liability is equivalent to minimising the equity value of the bank subject (i) to the liability constraint, $V(k_t) \geq 0 \;\; \forall\, k_t \geq \hat{\underline{k}}$ and (ii) the possibility of subsidies $s(k_t) \geq 0$. Let $\mathcal{A}$ denote the set of piecewise continuous subsidy functions satisfying (i) and (ii). For any $s^\alpha \in \mathcal{A}$, let $V^\alpha(k_t)$ denote the corresponding equity value. Now, $V^\alpha(\hat{\underline{k}}) = V(\hat{\underline{k}}) = 0$ while $\lim_{k_t \to +\infty} V^\alpha(k_t) \geq \lim_{k_t \to +\infty} V(k_t)$. Hence, if there exists some k_0 such that $V^\alpha(k_0) < V(k_0)$ then by continuity there exists k_1, k_2 (where k_2 is possibly $+\infty$) such that $\forall\, k_t \in [k_1, k_2]$ $V^\alpha(k_t) < V(k_t)$ and $V^\alpha(k_1) = V(k_1)$, $V^\alpha(k_2) = V(k_2)$. But if $V(k_t) > V^\alpha(k_t)$ for given k_t then $V(k_t) > 0$ or else limited liability would not be satisfied. But when $V(k_t) > 0$ $s(k_t) = 0$. $s^\alpha(k_t) \geq s(k_t) \quad \forall\, k_t \in [k_1, k_2]$. But it is easy to show that $\{\, s^\alpha(k_t) \geq s(k_t)$ $\forall\, k_t \in [k_1, k_2]$, $V^\alpha(k_1) = V(k_1)$, and $V^\alpha(k_2) = V(k_2) \,\} \Rightarrow \{\, V^\alpha(k_t) \geq V(k_t)$ $\forall\, k_t \in [k_1, k_2] \,\}$, ie a contradiction. **Q.E.D.**

Although $s_*(k_t)$ is the minimum financial liability subsidy function that implements $\hat{\underline{k}}$, it may be more realistic to consider subsidy functions that support the equity value to a greater degree. Consider $s_\xi(k_t)$ where $s_\xi(k_t)$ is the subsidy function such that, while subsidies are paid, $V(k_t) = \xi(k_t - \hat{\underline{k}})$ for some constant $\xi > 0$.

Proposition 6 *Suppose the authorities adopt subsidy policy $s_\xi(k_t)$. There exists a scalar k_s such that:*

$$s_\xi(k_t) = 0 \quad \forall\, k_t \geq k_s\,, \quad and \tag{29}$$

$$s_\xi(k_t) = [\xi(r-\mu_g)-1]k_t + r + \gamma - (r-\mu_D)\xi\hat{\underline{k}} \quad \forall\, k_t \in [\hat{\underline{k}}, k_s] \tag{30}$$

The value of the equity and the deposit insurance liability are defined as $U_i(k_t, D_t) = V_i(k_t)D_t$ and $M_i(k_t, D_t) = L_i(k_t)D_t$, $i = 1,2$ respectively for the two intervals $I_1 \equiv [\hat{\underline{k}}, k_s]$, $I_2 \equiv [k_s, +\infty]$ where:

$$V_1(k_t) = \xi(k_t - \hat{\underline{k}}) \tag{31}$$

$$V_2(k_t) = \frac{k_t}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D} - \left[\frac{k_s}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D}\right]\left(\frac{k_t}{k_s}\right)^{\lambda_1} + \xi(k_s - \hat{\underline{k}})\left(\frac{k_t}{k_s}\right)^{\lambda_1} \tag{32}$$

$$L_1(k_t) = \frac{k_t}{r-\mu_g} - \frac{r}{r-\mu_D} - \xi(k_t - \hat{\underline{k}}) - c(\hat{\underline{k}})\left(\frac{k_t}{\hat{\underline{k}}}\right)^{\lambda_1} \tag{33}$$

$$L_2(k_t) = \frac{\gamma}{r-\mu_D} + \left[\frac{k_s}{r-\mu_g} - \frac{r+\gamma}{r-\mu_D}\right]\left(\frac{k_t}{k_s}\right)^{\lambda_1} - c(\hat{\underline{k}})\left(\frac{k_t}{\hat{\underline{k}}}\right)^{\lambda_1} - \xi(k_s - \hat{\underline{k}})\left(\frac{k_t}{k_s}\right)^{\lambda_1} \tag{34}$$

$$\text{and} \quad k_s = \frac{-\lambda_1}{1-\lambda_1}\left[\frac{r+\gamma}{r-\mu_D} - \xi\,\hat{\underline{k}}\right] \Big/ \left[\frac{1}{r-\mu_g} - \xi\right] \tag{35}$$

Proof of Proposition 6: $V_1(k_t)$ and $V_2(k_t)$ may be derived simply using usual techniques. $L_1(k_t)$ and $L_2(k_t)$ may then be obtained by substracting $V_i(k_t)$ $i = 1,2$ from the total firm value. k_s is obtained from the smooth-pasting condition $V_1'(k_s) = V_2'(k_s)$ **Q.E.D.**

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Table 1: DESCRIPTIVE STATISTICS

JANUARY 1983 – JUNE 1994								
Bank	Δ Log Equity Value				Δ Log Deposits			
	Mean	Std.D	Skew.	Kurt.	Mean	Std.D	Skew.	Kurt.
1	2.83	25.78	0.74	5.19	1.15	6.36	0.27	15.71
2	3.29	24.61	0.58	7.40	2.45	18.14	4.72	69.55
3	2.29	30.14	0.54	7.44	1.37	13.14	0.55	3.13
4	2.79	30.09	0.06	4.55	1.59	18.60	0.07	12.08
5	2.41	29.33	0.23	6.78	1.48	14.82	0.56	3.52
6	0.88	26.70	0.17	3.99	1.23	11.49	0.37	4.19
7	2.32	32.16	1.21	15.00	1.43	17.46	0.48	3.15
8	3.04	30.84	0.16	5.25	2.40	21.93	7.99	133.62

Note: data are nominal, weekly, log changes.

Means and standard deviations are scaled by $\sqrt{52}$x100.

Table 2: MODEL 1 (MERTON): PREMIUM RESULTS

($\xi = 0.97$)				
Bank	1	2	3	4
Guarantee	0.29	5.38	1.68	2.14
Standard error (total)	0.47	17.90	3.78	6.17
Volatility (σ_S)	7.21	20.95	15.00	21.05
Standard error	0.41	0.78	0.58	0.78
Equity	13.60	15.23	18.75	27.75
Assets/deposits ratio	1.10	1.08	1.15	1.23
Bank	5	6	7	8
Guarantee	3.29	0.96	6.01	5.56
Standard error (total)	9.19	2.28	23.96	19.99
Volatility (σ_S)	17.19	12.24	20.68	24.65
Standard error	0.66	0.57	0.84	0.88
Equity	15.96	18.13	13.29	19.71
Assets/deposits ratio	1.11	1.15	1.06	1.12

Note: (i) entries are percentages of deposits unless otherwise indicated.

Standard errors of the guarantees are x10^{-4}.

Note: (ii) items are defined as follows:

Guarantee – value of put option on bank assets.

Volatility – standard deviation of the bank asset value.

Table 2: MODEL 1 (MERTON): PREMIUM RESULTS (Ctd.)

($\xi = 1$)				
Bank	1	2	3	4
Guarantee	0.13	4.61	1.27	1.79
Standard error (total)	0.16	16.45	2.90	5.19
Volatility (σ_S)	7.25	21.04	15.10	21.15
Standard error	0.42	0.78	0.59	0.78
Equity	13.60	15.23	18.75	27.75
Assets/deposits ratio	1.13	1.11	1.18	1.26
Bank	5	6	7	8
Guarantee	2.66	0.66	5.14	4.89
Standard error (total)	7.88	1.52	22.11	18.54
Volatility (σ_S)	17.29	12.35	20.74	24.74
Standard error	0.67	0.58	0.84	0.88
Equity	15.96	18.13	13.29	19.71
Assets/deposits ratio	1.13	1.18	1.08	1.15

Note: (i) entries are percentages of deposits unless otherwise indicated.

Standard errors of the guarantees are x10^{-4}.

Note: (ii) items are defined as follows:

Guarantee – value of put option on bank assets.

Volatility – standard deviation of the bank asset value.

Table 3: MODEL 2 (ECR): PARAMETER ESTIMATES

Bank	σ_k	σ_M	σ_D	ξ_{kM}	ξ_{kD}	β_{kM}
1	1.70	14.58	6.36	63.00	-22.53	7.36
	(0.11)	(0.65)	(0.28)	(3.71)	(4.64)	(0.68)
2	2.49	15.96	18.28	43.53	-59.80	6.79
	(0.11)	(0.47)	(0.53)	(2.70)	(2.40)	(0.51)
3	2.76	15.93	13.15	51.89	-36.94	9.01
	(0.12)	(0.46)	(0.38)	(2.84)	(3.09)	(0.67)
4	3.70	15.97	18.67	51.61	-48.05	11.96
	(0.17)	(0.47)	(0.55)	(2.67)	(2.73)	(0.83)
5	2.87	15.98	14.86	54.99	-39.67	9.88
	(0.13)	(0.47)	(0.43)	(2.68)	(2.95)	(0.67)
6	2.61	16.92	11.50	37.18	-41.14	5.73
	(0.14)	(0.61)	(0.41)	(4.02)	(3.93)	(0.73)
7	2.63	16.29	17.25	39.28	-45.68	6.34
	(0.14)	(0.52)	(0.55)	(3.45)	(3.33)	(0.67)
8	3.72	15.96	22.10	39.43	-59.22	9.19
	(0.18)	(0.47)	(0.65)	(2.86)	(2.48)	(0.79)

Parameters are multipled by 100. S.E.s appear in brackets. σ_k, σ_M, and σ_D are the instantaneous standard deviations of the state variable, k_t, the market portfolio, M_t, and deposits, D_t, respectively. ξ_{kM} and ξ_{kD} are the correlation coefficients of the pairs, (k_t, M_t) and (k_t, D_t), and β_{kM} is the 'CAPM beta' of the k_t process with respect to the market.

Table 4: MODEL 2 (ECR): PREMIUM RESULTS

BANKS 1–4				
Bank	1	2	3	4
Guarantee value	6.00	13.16	11.03	15.48
Standard error (total)	0.73	0.91	0.84	1.30
Standard error (partial)	0.76	0.98	0.88	1.34
Volatility (σ_k)	1.70	2.49	2.76	3.70
Standard error	0.11	0.11	0.12	0.17
Equity	13.60	15.23	18.75	27.75
Guarantee/equity ratio	0.44	0.86	0.59	0.56
Terminal value	15.23	18.75	27.75	15.96
Terminal $k_t/\underline{k}$ ratio	1.13	1.17	1.20	1.30
Shut-down point ($\underline{k}$)	23.00	22.17	22.09	21.21
Standard error	0.10	0.11	0.11	0.15

Note: (i) entries are % of deposits unless indicated.

Note: (ii) items are defined as follows:

Guarantee – non-linear term in stock price.

Volatility – standard deviation of $\log(k_t)$.

Equity – value of bank equity.

Terminal $k_t/\underline{k}$ – value at end of sample period.

Shut-down point – trigger for bank closure.

Table 4: MODEL 2 (ECR): PREMIUM RESULTS (Ctd.)

BANKS 5–8				
Bank	5	6	7	8
Guarantee value	13.79	9.44	13.40	20.59
Standard error (total)	0.91	0.90	0.98	1.46
Standard error (partial)	0.99	0.94	1.08	1.58
Volatility (σ_k)	2.87	2.61	2.63	3.72
Standard error	0.13	0.14	0.14	0.18
Equity	15.96	18.13	13.29	19.71
Guarantee/equity ratio	0.86	0.52	1.01	1.04
Terminal value	18.13	117.23	19.71	89.91
Terminal $k_t/\underline{k}$ ratio	1.18	1.18	1.16	1.25
Shut-down point ($\underline{k}$)	21.96	22.26	22.16	21.12
Standard error	0.12	0.12	0.12	0.17

Note: (i) entries are % of deposits unless indicated.

Note: (ii) items are defined as follows:

Guarantee – non-linear term in stock price.

Volatility – standard deviation of $\log(k_t)$.

Equity – value of bank equity.

Terminal $k_t/\underline{k}$ – value at end of sample period.

Shut-down point – trigger for bank closure.

Table 5: MODEL 3 (ES): PREMIUM RESULTS

BANKS 1–4				
Bank	1	2	3	4
Guarantee value	4.13	10.41	8.68	13.02
Standard error (total)	0.60	0.82	0.74	1.19
Standard error (partial)	0.63	0.89	0.79	1.23
Volatility (σ_k)	1.70	2.49	2.76	3.70
Standard error	0.11	0.11	0.12	0.17
Equity	13.60	15.23	18.75	27.75
Guarantee/equity ratio	0.30	0.68	0.46	0.47
Terminal value	15.23	18.75	27.75	15.96
Terminal $k_t/\underline{k}$ ratio	1.13	1.17	1.20	1.30
Shut-down point ($\underline{k}$)	23.00	22.17	22.09	21.21
Standard error	0.10	0.11	0.11	0.15

Note: (i) entries are % of deposits unless indicated.

Note: (ii) items are defined as follows:

Guarantee – non-linear term in stock price.

Volatility – standard deviation of $\log(k_t)$.

Equity – value of bank equity.

Terminal $k_t/\underline{k}$ – value at end of sample period.

Shut-down point – trigger for bank closure.

Table 5: MODEL 3 (ES): PREMIUM RESULTS (Ctd.)

BANKS 5–8				
Bank	5	6	7	8
Guarantee value	11.02	7.25	10.51	17.46
Standard error (total)	0.83	0.79	0.88	1.37
Standard error (partial)	0.91	0.83	0.98	1.49
Volatility (σ_k)	2.87	2.61	2.63	3.72
Standard error	0.13	0.14	0.14	0.18
Equity	15.96	18.13	13.29	19.71
Guarantee/equity ratio	0.69	0.40	0.79	0.89
Terminal value	18.13	117.23	19.71	89.91
Terminal $k_t/\underline{k}$ ratio	1.18	1.18	1.16	1.25
Shut-down point ($\underline{k}$)	21.96	22.26	22.16	21.12
Standard error	0.12	0.12	0.12	0.17

Note: (i) entries are % of deposits unless indicated.

Note: (ii) items are defined as follows:
Guarantee – non-linear term in stock price.
Volatility – standard deviation of $\log(k_t)$.
Equity – value of bank equity.
Terminal $k_t/\underline{k}$ – value at end of sample period.
Shut-down point – trigger for bank closure.

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