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DEFAULTS ON MORTGAGE OBLIGATIONS AND CAPITAL REQUIREMENTS FOR US SAVINGS INSTITUTIONS: A POLICY PERSPECTIVE

BY

JOHN M. QUIGLEY

ROBERT VAN ORDER

GRADUATE SCHOOL OF BUSINESS ADMINISTRATION

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by
John M. Quigley
University of California
Berkeley

Robert Van Order
Federal Home Loan Mortgage Corporation
Washington, DC

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I. INTRODUCTION

The enormous public expenditures required in the next few years by the widespread failures of major home mortgage lending institutions in the US (building societies or savings and loan institutions, henceforth S&L's) will probably exceed all other government expenditures on housing in the United States. By way of comparison, it is currently estimated that the cost to US taxpayers of the government guaranteed deposits in the bankrupt S&L's will be around $100 billion in present value; the entire annual budget of the U.S. Department of Housing and Urban Development is currently $15 to $20 billion. All Federal government expenditures on housing for low income households (including subsidies from other welfare programs) run about $40 billion annually.

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The causes of these huge failures among government insured lending institutions include changes in the regulatory environment, lack of supervision and auditing, mismanagement, fraud, and just plain bad luck. Underneath all of this is the incentive to take risk (the moral hazard) arising from government guarantees.

In the light of the disastrous outcome, each of these causes has become a topic for intensive **ex post** analysis (e.g., Barth, *et al.*, 1989); at the same time, a variety of proposals has been made to prevent another round of S&L failures after the next interest rate cycle.

Conspicuous among these proposals is a strengthening of the capital requirements imposed on thrift institutions (S&L's) and on commercial banks as well. Several regulators have proposed similar, new capital requirements for deposit institutions. The "S&L bailout bill," passed in 1989, mandated that capital requirements for S&L's be at least as strong as those imposed on commercial banks. That more capital is needed and that specific capital requirements should be related to the riskiness of investments has become widely accepted, even among industry lobbyists and legislators.

While there is some agreement on principles, there is much disagreement about details, and there is almost no empirical foundation for current proposals. Risk-based capital proposals have attempted to segregate credit risk into a small number of categories. For example, the recent proposal by the Federal Home Loan Bank Board (FHLBB, now the Office of Thrift Supervision, OTS) distinguished among several categories of credit risk and assigned different requirements for capital as a fraction of assets to each risk category. There is general agreement that, for the most part, the categories chosen ("risk buckets") have ordered risk in a way that is qualitatively correct. Nonetheless, the proposals made so far are quite crude. They suffer from three major problems:

1. They have no underlying theoretical rationale. None of the proposals is derived from a concrete definition of risk or from a rigorous definition of an acceptable level of that risk.

2. They have little empirical foundation. No evidence has been presented about whether differences in capital requirements really do correspond **quantitatively** to differences in the riskiness of investment in various categories of assets.

3. They ignore interactions among risks. Under any of these proposals, risk categories are determined separately,

thus neglecting any possible benefits from the diversification of an institution's portfolio.[1]

This paper provides some analysis of each of these issues with regard to fixed rate mortgages on owner-occupied houses. The analysis is based upon records maintained by the Federal Home Loan Mortgage Corporation (Freddie Mac), a quasi governmental agency which buys home mortgages originated by savings institutions and by other lenders and which sells pools of such mortgages to investors in the secondary market. We analyze cohorts composed of some 300,000 of those mortgages originated during the 1976-1980 period and purchased by Freddie Mac. The underlying data include the date of origination and the date at which default or prepayment of the obligation occurred. For mortgages which have defaulted, we estimate the loss, as a fraction of the initial loan balance, at the date of default. From these data, we estimate average losses, and the variance and covariances of these losses by region over time. This analysis is conducted separately for mortgages with different loan-to-value ratios (LTV's).

The data allow us to model the default of loans by LTV and for portfolios of mortgages with differing degrees of regional diversification.[2] We then propose a simple capital

1 This applies only to credit risk. The Bank Board proposal includes a separate analysis of interest rate risk, which does take a portfolio approach.

2 See Corgel and Gay (1987) and Ogden, *et al.* (1989) for recent work on the gains to diversification.

requirement criterion, which is calibrated to reflect the revealed preference for acceptable risk as proposed by the Federal Home Loan Bank Board (OTS). Given this capital model, we estimate relative capital requirements that properly take account of the riskiness of mortgage assets as measured by LTV and regional diversification.

In the empirical analysis we evaluate the importance of several diversified portfolios in establishing capital adequacy. Compared to a risky regional portfolio of loans, we evaluate portfolios diversified within regions but not between regions. We evaluate portfolios with equal regional shares and with shares similar to Freddie Mac's experience during the period. We also estimate the appropriate capital requirements by mortgage loan-to-value category.

Finally, we compute the optimally diversified portfolio and evaluate its capital requirements relative to less diversified pools of mortgage loans.

II. MODELS

A. Capital

The major reason for imposing capital requirements upon lending institutions is to protect the deposit insurer, who must make up losses to depositors in the event of bankruptcy. In the case of federally chartered mortgage institutions in the US, the ultimate insurer was, until recently, the Federal Savings and Loan Insurance Corporation (FSLIC), a subsidiary of the FHLBB. In September 1989, the insurer responsibility was shifted to the Federal Deposit Insurance Corporation (FDIC).

Invested capital put up by the firm acts as a cushion for the insurer and is analogous to the "deductible" on other types of insurance. Moreover, capital "at risk" can provide a powerful incentive for owners and managers of S&L's to control those risks. Problems with deposit insurance and analyses of incentives and pricing have a long history.[3] We simply note at this point a central conclusion of this literature: a logical way to think of a capital requirement is as that amount which reduces risk by just enough to make insurance premiums "cover" default costs, in an expected present value sense, or at least enough to limit the expected present value of losses.

Deducing a specific capital requirement from this principle is clearly a formidable problem. It involves not only modeling the firm, but also solving a complicated pricing model. The latter requires modeling the timing of bankruptcy and the magnitude of losses conditional upon bankruptcy. Such

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3 See Kane (1985), Merton (1977), among others, on incentives and pricing.

a model is not a standard part of deposit insurers' repertoire.

A simplified and perhaps naive alternative is used by private rating agencies to evaluate the ability of mortgage insurance companies to pay claims. Moody's credit ratings, for example, are based upon the ability of a company to withstand a single and particular "stress test." The scenario used is a stylized characterization of the Great Depression -- a grand deflation. This requires modeling the firm to analyze how long it would last through the "stress" period (characterized by a particular set of inflation and interest rates). The analysis is simplified by assuming the firm conducts no new business during this period, pays no dividends, and becomes bankrupt when it runs out of cash. There is no specification of how much is lost when bankruptcy occurs. **Ad hoc** adjustments are made for other factors such as geographic concentration.

This approach has the advantage of simplicity, but it is, analytically, thin. It requires that firms be configured to survive throughout only a single known scenario. The approach has, moreover, no criterion for choosing an "acceptable" risk. To receive Moody's highest credit rating (AAA), for example, the firm must last through a ten year stress period, but there is no particular reason to choose ten years or to choose a particular definition of stress. The factors which "stress" one institution may not affect another at all.

In this analysis, we propose a simple, but reasonable, alternative approach. We postulate that capital is adequate if it is sufficient to insure that a firm will survive for a period of T years with probability ρ, and we calibrate a model so that ρ, T and volatility parameters are consistent with the revealed preferences of the Bank Board (OTS). The gain from this approach relative to Moody's is clear. The simulation of economic environments need not be confined to a single scenario. A Monte Carlo analysis, drawing economic conditions from a given distribution, estimates empirically the probability that a firm with a given portfolio will survive. The simulation approach is flexible enough to incorporate portfolios with different risks.

This approach still requires a criterion for capital adequacy. We assume the Bank Board (OTS) proposal reveals regulators' preferences. It is proposed that home mortgages with 20 percent downpayments or with insurance coverage require three percent of owners' capital at risk We calibrate the model so that three percent is the appropriate capital requirement for an undiversified portfolio of the riskiest of these mortgages. Details of this calibration are discussed below. Relative to this benchmark, we then calculate capital requirements by varying diversification and LTV.

B. Default and Prepayment

All modern research considers default on financial obligations from an "options perspective." In the mortgage market, default by a consumer amounts to exercising his option to sell the house back to the lender in exchange for the mortgage instrument (See Campbell and Dietrich, 1983, Vandell and Thibodeau, 1985, and Foster and Van Order, 1984). Transactions costs and the value of the borrower's reputation make the computation of the value of this option complex. Nevertheless, the key variable is the owner's equity, which is a crude measure of the extent to which the put option is "in the money." The key state variable that determines equity is the current value of the house.

By analogous reasoning, mortgage prepayment is an option which can be called at the discretion of the borrower. By prepaying a mortgage, the consumer exercises his option to exchange a fixed and known sum of money for the mortgage instrument (See Dunn and McConnell, 1981, Follain, *et al.*, 1988, and Quigley, 1987). Again transactions costs, expectations and exogenous reasons for residential mobility make the computation of the value of the option complex. Despite this, the key variable is the present value of the mortgage payment stream at current interest rates relative to its present value at the contract rate. Again, this is a crude measure of the extent to which the call is in the money. The key state variables are current interest rates on securities of different maturities.

The capital adequacy model described above depends upon mean "returns," their variances, and their covariances by asset category. "Returns" in this context means the net income from a portfolio of mortgages (where net is the difference between the fees charged for bearing credit risk and the actual losses), and the asset categories include home mortgages written with different LTVs in different geographical regions. Capital adequacy also depends upon the extent of mortgage prepayment and the fee income arising therefrom.

The moments of the distributions of returns could be estimated in a variety of ways. The most elegant would be an estimation of the underlying structural model of the decision to default or to prepay by individual homeowners. The parameters of such a model together with the distributions of the underlying state variables could be used to reconstruct the probability distributions of default losses and prepayments . Alternatively, the rich body of data on loans originated between 1976-1980 and followed until March 1989 can be used to estimate the probability distributions directly, provided we accept the proposition that these are representative years.

We adopt the latter approach in this paper. This strategy has distinct advantages as well as disadvantages. On the one hand, the empirical estimates of default and prepayment lack an explicit theoretical foundation. On the other hand, however, this period experienced a wide range of economic changes (high inflation, low default periods, and low inflation, high default periods), and is probably representative enough not to require more precise theoretical restrictions. More relevant to the policy question is the fact that capital requirements set by legislation cannot be expected to vary when certain key parameters of theoretical interest change (*e.g.*, the expected inflation rate). As a regulatory matter, the best one can expect is that the requirements conform as closely as possible with experience. Hence, we compute means, variances and covariances of probability distributions of returns without relating them to an explicit microeconomic model of optimizing behavior. In this respect, our approach is similar to applications of the capital asset pricing model, which use historical returns and their moments without a detailed microeconomic specification.

III. EMPIRICAL ANALYSIS

A. Defaults and Losses

The Freddie Mac data on its mortgage loan purchases were matched to data on subsequent defaults and the losses resulting from foreclosure. These administrative records were not originally intended for research purposes, and a variety of assumptions were employed in merging and matching records and in verifying the underlying data.[4]

The available information consists of mortgage default and prepayment transactions on thirty-year, fully-amortizing, fixed-rate loans of various ages and loan-to-value (LTV) categories, conditional upon survival until that age. These observations are available for each of five Freddie Mac regions for mortgages originated during the 1976-1980 period. The LTV categories are: less than 81 percent, 81 to 90 percent, and greater than 90 percent.

Since mortgages originated before 1976 are not included in the data base, the maximum observed age is only about thirteen years (through March 1989), and mortgages in the sample were written for a duration of thirty years. This limitation in data availability is more apparent than real, however, since other empirical research indicates that

4 See Zorn (1989) for a discussion of the underlying data.

prepayment and default options are typically exercised early in the life of mortgage contracts, if at all.

For each category of LTV, region, and age, we estimated the loss incurred by each mortgage default. The loss was computed as the sum of the outstanding loan balance plus all out-of-pocket costs to the mortgagor (attorney's fees, court costs, etc.) plus the opportunity cost of the mortgagor's equity, from the date the lender took over a property from the mortgagor to its final disposition (at 15 percent), minus the proceeds from the disposition of the asset, expressed in present value terms discounted (at 15 percent) to the date of default. The ratio of this loss to the original loan balance is the conditional loss associated with default.

Table 1 summarizes the default and loss data which have been computed. Panel A presents unweighted averages of default and loss data reported by region, year of origin and age of loan; panel B presents summary information weighted by the number of loans "at risk" in each category (*i.e.*, the number surviving up to the beginning of the year of duration).

As is indicated in the table, annual default rates were not trivially small in this period, averaging about four tenths of a percent for the US as a whole. The variation in default rates by region is quite substantial. Default rates in the Northcentral states were about five times as large as default rates in the Southeastern states and about four times

TABLE 1

SUMMARY LOSS DATA BY REGION

	Northeast	Northcentral	Southeast	Southwest	West	US
A. Unweighted Annual Averages						
Average Annual Default Rate (x 100)	0.111	0.447	0.087	0.374	0.228	0.371
Average Conditional Loss (Fraction of Loan)	0.294	0.438	0.238	0.396	0.261	0.349
Standard Deviation of Conditional Loss (Fraction of Loan)	0.124	0.287	0.162	0.129	0.066	0.086
Average Loss (in percent)	0.034	0.207	0.022	0.163	0.055	0.137
Standard Deviation of Loss (in percent)	0.027	0.186	0.019	0.229	0.061	0.235
B. Weighted by Volume of Business						
Average Annual Default Rate (x 100)	0.132	0.502	0.107	0.357	0.255	0.432
Average Conditional Loss (Fraction of Loan)	0.316	0.522	0.236	0.396	0.260	0.351
Standard Deviation of Conditional Loss (Fraction of Loan)	0.124	0.287	0.162	0.129	0.066	0.086
Average Loss (in percent)	0.039	0.242	0.024	0.155	0.062	0.161
Standard Deviation of Loss (in percent)	0.027	0.186	0.019	0.229	0.061	0.235

as large as default rates in the Northeastern states. These differences reflect the credit rate risk associated with the real estate markets in each of the regions, the fortunes of the regional economies, and the loan-to-value ratios and ages of the mortgages.

Regional variations also reflect institutional differences and legal restrictions in various states. In some states, the Northcentral states, but also New York, legislatures and courts impose substantial impediments to foreclosure on home loan defaults. The longer time interval between default, foreclosure, and ultimate disposition greatly increases the loss rates on defaulted properties.

The loss rates on defaulted mortgages are surprisingly large. For the US as a whole, about 35 percent of the initial mortgage loan was lost upon default of a mortgage during this period. As suggested above, a large part of this loss is accounted for by the considerable lags involved. On average, it takes almost two years from the time a homeowner stops payment until the home is sold. (This can cost 20 to 25 percent of value in interest alone.) Hence even with insurance, typically covering only the first 25 percent of loss, the net cost to the lender can be significant. As is discussed below, high LTV loans with insurance have higher default costs than low LTV loans without insurance. While the loss per default is smaller (as a result of insurance) for the higher LTV loans, these loans default much more frequently.

Together, variations in loss rates and conditional losses yield the average losses reported in the table. For the nation as a whole, the average annual loss associated with a mortgage originated between 1976 and 1980 was 0.13 to 0.16 percent of the contract amount. The average loss varied by a factor of ten among the five regions, from 0.02 percent in the Southeast to almost a quarter of a percent, on average, in the Northcentral "rust belt."

Table 2 presents estimates of proportional hazard models for each of the five geographical regions and for the US as a whole. The dependent variable is the hazard of default at each age (the probability of default, conditional on survival to that age). The baseline hazard varies by age, separately for each LTV class.[5]

Specifically, we assume that the hazard, H_{ijt}, the probability of default for a loan in LTV class i, which has survived up to age j and was originated in year t, is given by

$$(1) \quad H_{ijt} = \lambda_{ij}\, e^{\Sigma\beta_t t} \quad .$$

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5 In the jargon of hazard or reliability theory, this model is "blocked" by LTV class.

TABLE 2

HAZARD MODELS OF DEFAULT PROBABILITIES BY REGION*

$$H_{ijt} = \lambda_{ij} e^{\Sigma \beta_t t}$$

(Asymptotic t ratios in parentheses)

	Northeast	Northcentral	Southwest	Southeast	West	U.S.
LTV ≤ 80%						
observations	15,462	16,280	20,962	5,870	111,208	169,782
defaults	22	178	148	12	484	844
80% < LTV ≤ 90%						
observations	13,612	16,464	17,610	4,560	58,392	110,638
defaults	96	536	408	22	1,070	2,132
LTV > 90%						
observations	13,738	7,624	18,124	6,000	11,428	56,914
defaults	134	564	936	68	520	2,222
Origin year coefficients, β_t						
1976	-1.751	-3.376	-3.605	-9.235	-6.574	-3.941
	(4.90)	(4.72)	(12.26)	(0.22)	(6.54)	(19.40)
1977	-1.300	-2.287	-2.613	-0.239	-4.398	-2.839
	(4.23)	(11.49)	(15.37)	(0.38)	(17.31)	(31.90)
1978	-0.955	-1.205	-1.552	-2.356	-2.650	-1.721
	(3.51)	(9.56)	(10.80)	(5.36)	(25.73)	(30.07)
1979	-0.667	-0.548	-0.783	-1.231	-1.379	-0.992
	(2.70)	(4.64)	(5.26)	(3.98)	(19.99)	(19.44)
χ^2	33.42	241.85	505.28	60.86	2040.42	2357.23

* H_{ijt} = hazard for LTV class i, age j, and origin year t.
λ_{ij} = baseline hazard for LTV class i and age j.

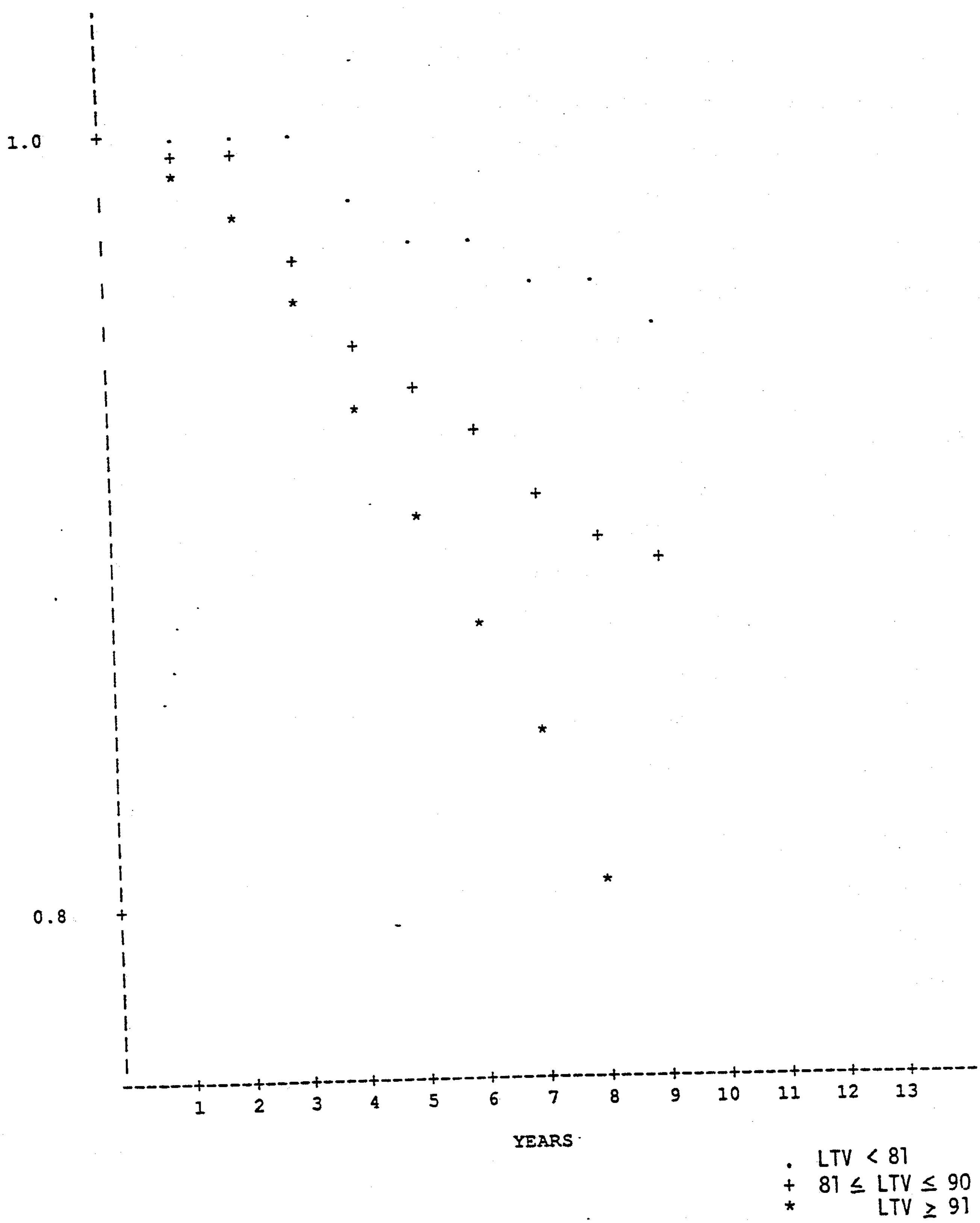
The baseline term λ_{ij} indicates the age profile of defaults for the excluded vintage, given LTV. The profile is shifted for different origination years by the exponential terms.

Separate parameters are estimated for each of the origin years 1976-1979 for each region. Each of the hazard models is highly significant, and the coefficients exhibit a similar pattern in five of the six samples. Compared to mortgages issued in 1980, those issued earlier have a significantly lower hazard of default. In all regions outside of the Southeast, there is a monotonic increase in the hazard of default for mortgages issued later. An intuitive explanation for this pattern of defaults on fixed rate mortgages is found in the course of the macroeconomy during this period. Holders of fixed rate mortgages issued earlier benefited more from the high levels of inflation in the late 1970's, which reduced the real value of payment streams and also generated subtantial homeowner equity. This inflation benefit proved even more valuable in reducing the higher default risks expected the early 1980's as a result of the major recession.

Figure 1 illustrates the survival probabilities predicted by the hazard models. For the Western region, it presents the estimated survivor rates for mortgages in each of the three LTV classes originated in 1980. For these computations, the baseline hazard (which varies separately by LTV class) is

FIGURE 1

SURVIVAL PROBABILITIES FOR MORTGAGES ORIGINATED IN THE WESTERN STATES IN 1980 BY LTV



estimated by the Meier-Kaplan method (See Kalbfleisch and Prentice, 1980). Quite clearly, at higher LTV's loans are substantially more risky.

Appendix Tables A1 through A3 present logit estimates of the probability of default separately by region and LTV class. These models document the decline in the conditional default probabilities for more seasoned mortgages. A significant quadratic relationship is estimated between the age of the loan and the default logit. The conditional default logit declines with the age of the mortgage, and the decline is slightly less than proportional. The logit models also highlight the differences in defaults for mortgages originated in different years throughout this period. Mortgages issued later have significantly higher default rates.

Both default rates and loan losses clearly vary by region and LTV, and the pattern of these outcomes varies by age. Presumably some of these risks can be modified with regional diversification.

Tables 3 and 4 summarize the degree of independence in the default and loan loss experience across regions. Table 3 indicates the residuals in the estimation of default probabilities using the hazard models. The standard deviation of the residuals is presented together with the correlation of residuals across regions. These data are presented separately for each LTV category.

TABLE 3

RESIDUALS FROM HAZARD ESTIMATES OF DEFAULT BY REGION AND LOAN TO VALUE RATIO

	Standard Deviation of Residual x 10^2	Correlation of Residuals in Estimating Default Probabilities					
		Northeast	Northcentral	Southeast	Southwest	West	US
LTV < 80%							
NE	0.027	1.000	0.375	0.790	0.438	-0.354	-0.180
NC	0.132		1.000	0.689	0.852	0.070	0.549
SE	0.067			1.000	0.650	-0.377	-0.031
SW	0.215				1.000	0.182	0.609
W	0.030					1.000	0.832
US	0.072						1.000
81% < LTV < 90%							
NE	0.057	1.000	0.233	-0.104	0.627	0.236	0.288
NC	0.380		1.000	0.102	0.789	0.744	0.956
SE	0.215			1.000	0.581	-0.495	-0.150
SW	0.734				1.000	0.344	0.756
W	0.094					1.000	0.854
US	0.248						1.000
LTV > 90%							
NE	0.081	1.000	0.651	-0.078	0.606	0.253	0.664
NC	0.722		1.000	0.524	0.814	0.759	0.934
SE	0.149			1.000	0.444	0.788	0.569
SW	1.908				1.000	0.547	0.937
W	0.348					1.000	0.752
US	0.959						1.000

TABLE 4

RESIDUALS FROM PREDICTED AND ACTUAL LOAN LOSS RATES BY REGION AND LOAN TO VALUE RATIO

	Standard Deviation of Residual (Loss rates in percent)	Correlation of Residuals in Estimating Loan Rates				
		Northeast	Northcentral	Southeast	Southwest	West
LTV < 80%						
NE	0.007	1.000	-0.306	-0.005	-0.043	0.466
NC	0.086		1.000	-.685	0.900	0.375
SE	0.036			1.000	0.889	0.343
SW	0.135				1.000	0.458
W	0.004					1.000
81% < LTV < 90%						
NE	0.021	1.000	0.441	0.501	0.190	0.391
NC	0.188		1.000	0.405	0.823	0.808
SE	0.041			1.000	0.571	0.863
SW	0.327				1.000	0.482
W	0.022					1.000
LTV > 90%						
NE	0.026	1.000	0.467	0.061	0.528	0.262
NC	0.325		1.000	0.709	0.860	0.813
SE	0.040			1.000	0.499	0.751
SW	1.019				1.000	0.630
W	0.104					1.000

Table 4 presents similar information for the loan loss rates as a fraction of initial loans. The entries in Table 4 were computed by multiplying the residuals in the estimation of default probabilities by the average loss rates computed separately for the 780 combinations of region, age, LTV and year of origin. The correlations reported in the tables are rather striking. Holding LTV and age constant, there is a negative correlation between default rates in the Northeastern and the Western regions for the safest loans (LTV ≤ 80%). A negative correlation also exists between the Northeastern and Southeastern regions for the riskiest loans. When the loan loss rates are considered, the correlations are again negative for several comparisons across geographical regions, for example, between losses in the Northeast and the Northcentral regions. The pattern of covariances in these returns suggests that portfolio risk can be reduced by geographical diversification, holding other determinants of credit risk constant.

B. Capital Requirements

As discussed above, the recently proposed risk-based capital requirements mandated among other things, that three percent of the unpaid balance of mortgages with LTV less than 80 percent or with insurance be held as a buffer against risk. Almost all of the mortgages in our sample fall into this category.[6] We take this proposal as the "revealed preference" of regulators and develop a model to calculate relative capital requirements, using the statistical results reported above.

We evaluate a criterion for capital adequacy analogous to the one described above for portfolios of mortgages of varying LTV and diversification. For a portfolio of a particular type, enough capital must be held so that the probability that the firm will survive T years without "bankruptcy" is at least ρ.

1. Pricing Credit Risk

We abstract from issues of transactions costs and taxes, and we focus on pure credit costs (alternatively, we assume that these other costs are nonstochastic and that the lender charges the appropriate fees for them). The lender who holds a portfolio of mortgages also receives fee income from taking on credit risk. This income, as well as required capital, provides some cushion against bankruptcy. We assume that the credit risk fee, R, received by lenders is equal to the marginal cost of default losses. More precisely, the lender charges an annual fee such that the expected present value of

6 Some of the high LTV loans in this sample did not have commercial insurance; instead the seller provided the coinsurance. About 10 percent of the defaults with LTV greater than 0.8 in our sample fell into this category.

receipts from R equals the expected present value of losses. That is, R must be such that

$$(2) \quad \sum_{t=1}^{N} \frac{R}{(1+r)^t} UPB_t = \sum_{t=1}^{N} \frac{E(L_t)}{(1+r)^t} UPB_t$$

where UPB_t is the unpaid balance on the pool, r is the appropriate discount rate, N is the term of the mortgages in the pool, and $E(L_t)$ is the expected loss per dollar of UPB at time t. To simplify computations, we assume that r and UPB are non stochastic, so that L is the only random variable. $E(L_t)$ can be calculated directly from the hazard model, equation (1), for mortgages with varying LTV in different regions with loss rates varying by LTV, region, age, and year of origin. UPB changes largely due to mortgage prepayments. We assume that prepayments follow the commonly used rule of thumb that also approximates prepayment rates on average during the period.[7]

We estimated the λ_{ij} matrices for 13 ages (j) and 3 LTV categories (i), separately for each of the 5 regions.[8] Their

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7 We assume that the prepayment rate is initially zero and rises linearly over time so that after two years, it is at an annual rate of thirteen percent. Thirteen percent was chosen so as to make the interest sensitivity of mortgages equal to its historical level. It is roughly the historical average and is a variant on the so-called PSA rule of thumb.

patterns, not reproduced here, are similar to those reported for the logit models (Appendix Tables 1A, 2A, 3A) -- a systematic but less than proportionate decline in hazard with age. We use these λ's and the coefficients reported in Table 2 to compute fair prices for credit risk by LTV category. We average across region and compute prices for the "representative" origination year during the period. That is, we assume that, for administrative reasons, it is not possible to price credit risk separately by region,[9] and that variations in default risk by origin year are not known **ex ante**. At an interest rate of 10 percent, we calculate the expected loss rates as a fraction of the initial balance, and, using the prepayment assumption, we compute the fee, R, which yields the required expected present value. Panel A in Table 5 summarizes the calculations.

We should note two things about these premiums. First they are rather low (the fee for loans with LTV below 80 percent is only about two basis points). Second, they vary sharply with LTV (ranging up to 22 basis points for the riskiest loan). That they are low may be, in part, a reflection of the fact that loans originated early in the

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8 These matrices, the baseline hazards, are estimated by the Kaplan-Meier method for the hazard models reported in Table 2.

9 In fact, congressional wrath would probably prevent price discrimination by region even if **ex ante** documentation of geographic variation in risk were incontrovertible.

period benefited from abnormal inflation, and were probably safer than can generally be expected.[10]

2. Determining Capital Adequacy

We take the approach to capital adequacy indicated above, and apply it to new pools of loans, rather than to firms. The pool begins with some capital invested by the lenders; the stock of invested capital is reduced when default costs exceed fee receipts. The pool is bankrupt when it runs out of cash (that is, the pool can neither to borrow nor pay dividends). The model is a simple difference equation.

In period t, the cash flow (CF) is:

$$(3) \quad CF_t = rK_t + R_t - L_t = K_t - K_{t-1} \quad ,$$

where K_t is the capital on hand at the beginning of the period and r is the interest rate. Again R_t is the fee for credit risk received, and L_t are aggregate losses from default. CF_t is thus the change in capital. The initial level of capital, K_o, is the required level, such that the probability that K_T is zero is less than ρ.

10 However, these losses are not much different from those calculated from Freddie Mac loans purchased after 1983, a period of low inflation.

The only stochastic variable is L_t, which is the loss rate (as estimated from the hazard models) together with the conditional losses times the unpaid balance (UPB_t) at the beginning of the period. UPB declines over time, again because some mortgages are prepaid. The premium, R, is calculated above.

Given an initial level of K, the variance of loss rates (which will change with diversification), the expected default losses and credit risk premium, we can estimate the probability that K_t is positive for ten consecutive years. This estimate can be obtained by Monte Carlo techniques. For example, we can run 10,000 simulations of (3) and use the fraction that survive ten years as in estimate of ρ. Using the same techniques, we can work backwards and find the value of K_0 that makes this probability, say, 0.999.

Our strategy is to find the ρ which validates the three percent rule. The model permits an analysis of capital requirements in terms of three sources of risk: errors made in forecasting patterns of default probabilities by region, LTV category, and origination year. If authorities were capable of varying capital requirements along all three dimensions, then capital requirements would arise only from the stochastic disturbances in equation (1).

These features are captured in the model and its calibration. We interpret the revealed preference of regulators (the FLHBB/OTS proposal) as requiring three percent of capital to be withheld to cushion against the worst case of defaults -- loans in the riskiest (LTV > 90) category originated in 1980 in a representative region, but with no regional diversification. We estimate the probability of bankruptcy in this case by Monte Carlo simulation. We then compute the capital requirement sufficient to yield the same value of ρ in other circumstances.

We begin by estimating the value of ρ separately for each of the five regions, given a three percent capital requirement, by drawing from the distribution of disturbances and their variances, and by computing the average probability of bankruptcy.

The benefits of diversification across regions come from two sources: the covariance matrix of disturbances across regions (see Table 4); and the unequal variances of disturbances across regions. A region with a higher variance of disturbances will have a more-than-proportionately higher bankruptcy rate than a region with a lower variance. Hence, even if disturbances were perfectly correlated across regions, a diversified portfolio would require less capital; the "excess capital" in regions with low variance could be used to protect against risks in high variance regions.

We consider portfolios with returns equal to the national average but with different variances. The variance (V) of a portfolio is

$$V = \mathbf{w}\,\mathbf{C}\,\mathbf{w}' \quad , \tag{4}$$

where **C** is the variance-covariance matrix of disturbances and w is the vector of regional weights. The optimal portfolio is the set of shares that minimizes (4) subject to the constraint that all weights are positive and that they sum to one.

C. Results

Calibration of the model yields the result that if institutions in the five regions all held three percent capital, and were exposed to the worst vintage (1980), then the average institution would have a 0.04 probability of failure over the next decade. The failures would, of course, be concentrated in the Northcentral and Southwestern regions, but the average would be 0.04. Hence we use ρ=0.96 as the criterion for capital adequacy. Compared to this baseline, the model indicates that a 0.9 percent rule is adequate to keep the national failure rate the same for LTV's between 81 and 90 percent. For the safest mortgages with LTV's below 81 percent, only 0.4 percent capital is required. Panel C of Table 5 reports these results as the baseline capital requirements.

TABLE 5

CREDIT RISK FEES, STANDARD DEVIATIONS AND CAPITAL REQUIREMENTS BY LOAN-TO-VALUE RATIO AND LEVEL OF DIVERSIFICATION

	Loan-to-Value Ratio		
	Less than 81%	81-90%	Greater than 90%
A. Fees for Credit Risk[a]			
	2.2	7.2	22.0
B. Standard Deviation			
Portfolio			
Representative	2.9	9.6	40.0
Actual Experience	2.0	6.8	21.7
Equal Shares	4.6	10.8	28.7
Optimal	0.4	1.8	2.8
C. Capital Requirement[b]			
Portfolio			
Baseline	0.4	0.9	3.0[c]
Representative	0.1	0.5	1.5
Actual Experience	0.1	0.3	1.0
Equal Shares	0.1	0.3	1.1
Optimal	0.0	0.1	0.1

a Annual fees, as a fraction of unpaid balances,in basis points.

b Initial capital required for each portfolio, as percent of loan balances.

c Benchmark capital requirement for undiversified mortgages issued in 1980.

The table also considers an undiversified portfolio with expected 1980 default costs given by a weighted average of default losses across region (the weights are given in Table 1). Again, in this simulation, fee revenues vary from pricing by LTV but not by region. We assume a standard deviation of residuals equal to the weighted average standard deviation (This standard deviation is noted panel B of Table 5). The implied capital requirements are presented in Part C of Table 5. Capital requirements are reduced because regional extremes have been averaged.

Part B of table 5 also presents the standard deviations for the other portfolios discussed above. Note that it is always the case that higher LTV portfolios have higher standard deviations. Part C of the Table presents the capital requirements for these portfolios.

The capital requirements for portfolios weighted by actual loan originations and those weighted equally are similar. In contrast, the optimally weighted portfolio reduces risk, and hence capital requirements, substantially. The optimal weights vary by LTV, but in each case the weights are extreme, requiring little or no investment in the Southeast, Southwest or the Northcentral region.[11]

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11 For LTV's below 81 percent, the uncontrolled weights were 140 percent for the West, minus 40 percent in the East, and zero elsewhere. In the calculations reported in the Table

Table 6 presents analogous results when credit risk is not priced by LTV category. In these simulations, prices are fixed at 7.2 basis points (the weighted average for all LTV classes). Not surprisingly, capital requirements decline for low LTV's and rise substantially for riskier portfolios. Current industry practice is that credit risk is not priced by LTV, and these results indicate that there are substantial losses from mispricing. The mispricing leads to substantially higher capital requirements for high LTV loans.

IV. CONCLUSIONS AND COMMENTS

This paper presents a complete model of defaults, fees and capital adequacy, in which empirical evidence on default rates is used to calculate premiums for different levels of risk. Default rates and their variations, together with premium fees, are then used to calculate capital requirements using a consistent model.

The results clearly indicate that fixed rate, 30 year mortgages on owner occupied properties with low loan to value ratios or with insurance are not very risky. For low LTV loans, three percent is clearly a high capital requirement.

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we the weights were set at 100 percent for the West and zero elsewhere.

TABLE 6

CAPITAL REQUIREMENTS WHEN CREDIT RISK IS NOT PRICED SEPARATELY BY LOAN-TO-VALUE RATIO

	Loan-to-Value Ratio		
	Less than 81%	81-90%	Greater than 90%
Portfolio			
Baseline	0.2	0.9	4.3
Representative	0.0	0.4	1.5
Actual Experience	0.0	0.5	2.2
Equal Shares	0.0	0.5	2.2

The experience with loans originated between 1976 and 1980 suggests that premiums of 2 to 22 basis points would cover that risk, on average.

This analysis does not address other types of mortgages, such as adjustable rate mortgages and multifamily (or more generally, investor-owned) mortgages. Presumably, these mortgages have greater default risks than those we have analyzed. Note however, that an increase in average default losses would not affect our conclusions at all if it left the variances and covariances of returns unchanged and if it were incorporated into the fee charged for credit risk.

In this analysis, we have avoided the question of whether this recent time period was truly "representative" and whether there is "enough" variance in the model by calibrating the volatility of residuals so that the proposed three percent capital requirement is "just right" for LTV's above 90 percent originated in the worst year (1980), and that were not diversified nationally.

Under these and other conditions reported in the paper, diversification clearly matters. The standard deviation of a nationally diversified portfolio is about a third of an undiversified portfolio, and its estimated capital requirements about a third of the requirement for an undiversified portfolio. The capital requirement for the optimal portfolio is less by about 80 to 90 percent.

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TABLE A1

LOGIT MODELS OF DEFAULT PROBABILITIES BY REGION FOR LOAN-TO-VALUE LESS THAN 81 PERCENT
(t ratios in parentheses)

	Northeast	Northcentral	Southwest	Southeast	West	U.S.
Age	-1.187 (1.98)	-0.990 (4.72)	-1.743 (5.32)	-0.510 (0.71)	-0.822 (8.84)	-0.633 (8.87)
Age squared	0.096 (2.01)	0.067 (4.34)	0.086 (4.32)	0.027 (0.51)	0.059 (7.59)	0.037 (6.88)
1977 Origin	-0.302 (0.27)	-2.919 (0.67)	0.118 (0.26)	-3.592 (0.32)	-0.155 (0.28)	-0.363 (1.10)
1978 Origin	-0.311 (0.29)	-3.972 (0.91)	-0.692 (1.59)	-1.808 (0.16)	-0.705 (1.31)	-1.171 (3.73)
1979 Origin	-0.994 (1.03)	-4.347 (1.00)	-1.921 (4.28)	-2.90 (0.25)	-1.980 (3.72)	-2.017 (6.43)
1980 Origin	-1.251 (1.29)	-4.758 (1.09)	-2.406 (4.59)	-4.155 (0.37)	-3.398 (6.37)	-3.027 (9.55)
Constant	12.036 (5.91)	13.678 (3.10)	15.612 (11.97)	12.523 (1.09)	11.503 (20.12)	11.095 (30.37)
χ^2	40.00	45.90	50.10	26.96	132.56	745.72
No. of Observations*	86,912	99,972	122,455	28,712	687,655	1,025,706
No. of Distinct Covariate patterns	39	38	34	29	38	164

* Includes multiple observations on loans surviving for two or more years.

TABLE A2

LOGIT MODELS OF DEFAULT PROBABILITIES BY REGION FOR LOAN-TO-VALUE BETWEEN 81 AND 90 PERCENT
(t ratios in parentheses)

	Northeast	Northcentral	Southwest	Southeast	West	U.S.
Age	-0.557	-0.673	-1.276	-0.301	-0.744	-0.509
	(2.34)	(5.78)	(7.12)	(0.56)	(11.97)	(11.75)
Age square	0.040	0.046	0.058	0.012	0.055	0.029
	(2.36)	(5.47)	(5.29)	(0.30)	(10.34)	(8.99)
1977 Origin	-0.262	0.481	-0.370	-3.160	0.559	-0.121
	(0.78)	(1.18)	(1.17)	(0.27)	(1.34)	(0.68)
1978 Origin	-0.037	-0.255	-1.312	-2.666	-0.694	-0.917
	(0.10)	(0.66)	(4.25)	(0.23)	(1.87)	(5.55)
1979 Origin	-0.120	-0.780	-2.275	-3.682	-1.621	-1.487
	(0.35)	(2.02)	(7.08)	(0.32)	(4.41)	(8.97)
1980 Origin	-0.564	-1.362	-3.257	-5.418	-3.090	-2.654
	(1.45)	(3.40)	(9.11)	(0.47)	(8.39)	(15.75)
Constant	8.470	7.850	13.073	11.938	9.596	8.921
	(9.16)	(14.41)	(18.05)	(1.03)	(24.64)	(43.96)
χ^2	62.26	100.11	63.91	22.76	239.56	1351.77
No. of Observations*	80,017	101,181	101,876	21,825	362,246	667,245
No. of Distinct Covariate patterns	39	38	34	29	38	164

* Includes multiple observations on loans surviving for two or more years.

TABLE A3

LOGIT MODELS OF DEFAULT PROBABILITIES BY REGION FOR LOAN-TO-VALUE GREATER THAN 90 PERCENT
(t ratios in parentheses)

	Northeast	Northcentral	Southwest	Southeast	West	U.S.
Age	-0.202 (1.06)	-0.726 (6.31)	-1.687 (12.04)	-0.152 (0.47)	-0.875 (8.95)	-0.523 (10.25)
Age squared	0.016 (1.21)	0.054 (6.18)	0.082 (9.76)	0.011 (0.46)	0.057 (7.30)	0.024 (6.80)
1977 Origin	0.114 (0.33)	0.804 (1.94)	-0.511 (1.98)	0.966 (0.79)	-2.507 (0.97)	-0.571 (3.29)
1978 Origin	-0.327 (1.06)	0.040 (0.10)	-1.555 (6.18)	0.957 (0.92)	-4.220 (1.65)	-1.491 (9.06)
1979 Origin	-0.432 (1.35)	-0.674 (1.74)	02.217 (8.56)	0.285 (0.28)	-5.496 (2.15)	-2.134 (12.85)
1980 Origin	-1.257 (3.78)	-1.149 (2.87)	-3.036 (10.91)	-0.492 (0.47)	-6.607 (2.58)	-2.802 (16.39)
Constant	7.176 (10.22)	6.883 (12.94)	14.115 (24.16)	6.074 (4.27)	13.012 (5.06)	9.037 (39.93)
χ^2	63.78	100.07	153.46	39.93	66.64	1804.17
No. of Observations*	82,780	46,907	108,018	29,013	72,020	338,738
No. of Distinct Covariate patterns	39	38	34	29	38	164

* Includes multiple observations on loans surviving for two or more years.