Modeling Stochastic Interest Rates in Financial Institution Budgeting

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The current era of interest rate deregulation in U.S. financial markets began in 1979. Since that time, numerous crises have developed in the commercial banking industry, the savings and loan industry, and the U.S. Farm Credit System, affecting their customers, stockholders, insurers, and various funding sources. Much of the turmoil in financial institutions can be traced to management of the interest rate risk that escalated at the onset of deregulation. Since the early 1980s, many financial institutions have been practicing one or more forms of interest rate risk management, including asset/liability management, in which interest rate risk is recognized and quantified. In fact, beginning in 1983 many financial institutions were required to report a condensed version of an asset/liability repricing schedule as a supporting document to quarterly reports of condition and income.

The literature in asset/liability management speaks to interest rate or dollar gap and duration gap as measures of risk which can be quantified and managed.[1] In most applications, interest rate gap is quantified by the difference between the amount of rate sensitive assets and the amount of rate sensitive liabilities maturing or repricing within different time horizons (or "maturity buckets"), say 0-30 days, 31-60 days, 61-90 days, 91-180 days, 181-365 days, and beyond one year. The risk to financial institutions embodied in the interest rate gap is often assessed by evaluating net interest income in the event of a sudden 100 basis point shock to the yield curve. Such a shock may be upward or downward, and the impacts of each are compared to steady-state net interest income as a measure of risk. Another method is to forecast net interest income given forecasts in interest rate levels (Sheshunoff et al., 1980). Recent developments in the practice of gap analysis include varying the yield curve shift to accomodate basis point shifts of 50, 150 or other amounts of interest.

There are other sources of uncertainty in the performance of financial institutions. Tales of large loan losses in U.S. agricultural banks and the Farm Credit System institutions are well known. Such losses, combined with other factors, damaged the financial stability of many institutions, with resulting losses to insurers and equity holders well documented (Melichar, 1986; FDIC, 1988). With the advent of special accounting provisions, capital forbearance plans, and risk-based capital standards, pressure increased for financial institutions to prepare accurate budgets, with forecasts of expected financial performance and condition.

Given the inherent uncertainty in the performance of financial institutions, a single-point estimate of end-of-period income statement and balance sheet accounts does not reflect the risk associated with the management plan that gives rise to the estimates. An alternative approach to financial

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1 For a better understanding of asset/liability management methods, see Mitchell (1985), French (1988), or Rose and Fraser (1988).

institution budgeting is to adopt a probability-based simulation framework which produces estimated probability distributions for key variables. Management alternatives can be analyzed through simulation by comparing estimated probability distributions of outcomes. Similarly, management alternatives which yield unacceptable down-side risk can be more easily identified by quantifying the risk.

This paper describes the development and testing of such a simulation model. It is an annual model which facilitates quarterly fluctuations in interest rates. Financial statements are constructed for a representative (common-size) commercial bank, condensing account categories for convenience and tractability. Relationships among variables affecting performance and condition are then quantified. This is followed by a presentation of simulation results and a discussion of interpretation of model output. The final section demonstrates the effects of incorporating elasticities into the demand for loans and the supply of loanable deposits.

Model Construction and Initialization

The model is divided into a number of components, each of which is discussed separately. These components are initial position, available decisions, and relationships among variables.

Initial Position

A representative commercial bank balance sheet was selected and the composition and maturities of assets and liabilities were identified. These were scaled to a common-size basis (total assets = $100 million), with some categories being condensed for convenience. Table 1 shows the balance sheet structure. For simplification, maturities among asset and liability categories are assumed to be spread evenly across possible maturity dates. Thus, all one-month and three-month maturities are allowed to reprice the following quarter, while only one-half of the six-month maturities (Treasuries and CDs) reprice the following quarter; the other half reprice two quarters hence. All commercial loans reprice quarterly, but existing personal and real estate loans do not reprice throughout the year. Variables modeled as affecting performance and condition are listed in Table 2 with initial values used in the simulations reported here.

Available Decisions

The decision set available to be modeled includes non-interest operating expenses, volumes of the assets and liabilities listed in Table 2, and dividends to be paid. Decisions to liquidate assets and liabilities are available, but prices are assumed to be at par. Rather, the decision set is designed to accommodate alternative re-investment of maturing assets and the re-funding of maturing liabilities, decisions to promote general or specific growth of the institution, and decisions affecting non-interest expenses such as wages and occupancy. Thus, plans to re-allocate maturing securities to grow the loan portfolio are accommodated, along with plans for rearranging the maturity structure and volume of interest bearing deposits.

Relationship Among Variables

The motivation for this study is to model the effects of interest rate movements on institution performance and condition. Thus, much of the focus is on interest rates and their relationships to one another. Additionally, certain non-interest rate variables affecting outcomes are modeled as stochastic.

One of the shortcomings of conventional asset/liability management is the assumption that the shape of the yield curve does not change when evaluating a 100-basis point shock. This assumption is relaxed here and replaced by random draws from different distributions for each interest rate. Certain interest rates are allowed to move freely at either end of the yield curve (federal funds, prime rate and ten-year Treasury bond). Other interest rates are hypothesized to move in relation to the freely moving interest rates. The relationship chosen is a linear function of quarterly basis point movement, with random effects characterized by the error term from a regression equation. Table 3 contains the correlation coefficients between the quarterly movements in various rates from 1972 through 1988.[2] Table 4 describes the quarterly movements in interest rates defined by OLS regression. The Jarque-Berra test for normality of the residuals is employed to justify selecting the error term from a normal distribution with mean zero and variance as specified in the table.[3] The error term on the one-month CD rate was modeled as being normal for simplicity, despite the Jarque Berra statistic. Draws for freely moving interest rates and changes in GNP come from a uniform distribution of historic data over the same period.

Included in Table 4 are two variables whose effect on performance and condition are of particular interest: net charge offs (loan losses) as a percent of total loans and the volume of non-performing (non-accrual) loans as a percent of total loans. Regression equations to describe changes in these categories fit poorly, as documented, but are used nonetheless to specify distributions from which random draws are made.

Other relationships among variables are specified as constraints to portfolio composition or minimum expenses. Cash and Due from Banks is held at 5.5 percent of assets net of fed funds and reserve deposits to provide a minimum liquidity level. A maximum allowable loan/deposit ratio of 0.65 is also imposed. Reserve deposits are specified according to the prevailing reserve requirement (Board of Governors of the Federal Reserve System, 1991). Service Charge income is specified as 1.18 % of non-time deposits (Federal Reserve District Banks, 1989). FDIC expense reflects a 23 basis point charge on deposits. Federal funds sold (asset) and purchased

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2 Data sources are discussed in Laduzinski (1992), as is further information on the specification of relationships.

3 The simulation model is built using @RISK, a Lotus 1-2-3 add-in program designed for simulation modeling. The parameters of the distribution function specify the distribution from which the simulation model selects random draws.

(liability) are used as a remainder investment for excess funds or a source of additional funds, depending upon which is necessary to balance the institution's balance sheet.

Simulation Results

Two sets of simulation results are reported here. The first set pertains to the basic model, analyzing differences between deterministic budgeting and the stochastic simulation budgeting under two different planning scenarios. The second set of simulation runs incorporates interest rate elasticities of demand for loans and supply of deposits and their potential effects on institution performance and condition.

Differences Between Stochastic and Deterministic Budgeting

The model described in the previous section was run under a management plan for steady state operations (no growth). That is, all maturing assets were assumed to be reinvested in identical assets of similar original maturities and all maturing liabilities were replaced with new liabilities of identical original maturities. The fundamental difference between the two budgeting methods lies in the movement of interest rates and other selected variables described above; the deterministic model has no interest rate movements. Distributions for stochastic models were obtained from two hundred iterations.

Table 5 contains the projected results from a year's operations. Under the stochastic framework, the expected values of the key indicators are very close to the deterministic values. However, an interesting dispersion in net profit is introduced, based somewhat on interest rate movements affecting net interest margin. Net Interest Margin varies from a low of 2.578 percent to a high of 6.320 percent, with an expected value of 4.417 and a standard deviation of 0.701. An institution planning deterministically for a net interest margin of 4.45 percent has a better than 50 percent chance of not obtaining that level (given the assumptions in the model) unless it properly adjusts during the year. The dispersion of potential outcomes is also apparent in the distribution of return on assets. Also of interest is the $202,000 standard deviation in loan losses compared to the $317,000 standard deviation in profit. Because the relationship between loan losses and interest rate movements is poorly specified, there is little conclusion to be inferred from this observation.

Another scenario that was evaluated was a plan to increase loans by five percent during the year. This plan assumes that loans would grow to a target of $61,740,000. Maintaining a loan/deposit ratio of 65 percent requires $4,523,077 growth in deposits, of which $248,770 is remanded to Cash and Due from Banks and the remainder to Treasury securities ($1,334,307). All growth was attributed to commercial loans for simplicity, with funding from 3 month CDs and investments in 3 month T-Bills to avoid the introduction of external gap problems. Table 6 contains the results of this simulation, which used the same random draws as the previous simulation. Compared to the no-growth scenario, there is a slightly wider dispersion in performance as measured by net income and net interest margin. Loan losses again seem to play an important yet unspecified role in introducing uncertainty about performance.

From the perspective of bank management, the meaningful data to be obtained from these simulations is likely embodied in the distribution on net interest income. Incorporating effects of seemingly random loan losses provides little information that management or regulators could use in adjusting their strategies for the next four quarters. Although economic shocks have presented challenges to loan loss reserves in the past, one would expect management and regulators to be able to more precisely identify potential loan losses than does the model. Furthermore, because of the lack of meaningful stochastic elements other than interest rates, the complexity of the model could be reduced if it were solely directed at asset/liability management through net interest income.

Introduction of Elasticities

The above interpretation holds when asset allocation and funding can occur with some certainty. However, with changing interest rates, elasticities of supply and demand affect the volumes of loans and deposits a financial institution is able to procure or retain. Ham and Melnick (1987) concluded that the interest rate elasticity of loan demand for large firms is -1.46. A search of related literature yielded no estimates of other loan demand or deposit supply elasticities since deregulation. Large firms are likely to be more price sensitive in their financial management than are small firms. Additionally, interest rate elasticities are likely to be sensitive to the current level of interest rates.

Thus, two steps were taken to incorporate elasticities. First, the model was initialized with interest rates at their mean over the period 1972-1988, rather than as they existed at any single point in time. Second, loan and deposit elasticities were parametrically varied using a test grid of 0, 0.05, 0.5, and 1.5, with equal but opposite values used for loans and deposits. All simulations were run on the same 200 iterations. Planned volumes of loans and deposits were constrained by the elasticities or planned volume, whichever was higher. Thus if interest rates were decreasing rapidly, the model allows loan growth to occur unchecked by management. Concurrently, a drop off in deposits would cause the fed funds market to be the default funding source. In reality, an institution could incur an interest margin squeeze by bidding higher rates for CDs. However, this nuance was not incorporated as interest rates paid on deposits are not decision variables in the model.

Figures 1 and 2 show cumulative probability distributions for simulated net income/ average assets and net interest margin, respectively, for each of the four elasticities. Very little difference between the simulated distributions of different elasticities is discernable, although there is a slight apparent upward shift in the net interest margin CDF for higher elasticities. In contrast, Figures 4, 5 and 6 show cumulative distributions for assets, deposits and net loans, respectively. In each case the dispersion of these account volumes increases markedly with increasing elasticities. The lack of a similar increase in the dispersion of performance measures remains unexplained. However, the potential for growth or contraction in an unstable interest rate environment is clearly evident.

Implications

The results of development and testing of this model point toward two issues. First, it was demonstrated that the stochastic modeling of interest rates may provide useful information about the potential impacts of interest rate fluctuations on net interest margin, given an asset and liability repricing schedule. However, the introduction of random effects from imprecisely specified variables offers little in terms of understanding the sources of risk in financial institution budgeting. Furthermore, less than a near complete specification of the decision set relative to non-interest income and expenses does not appear to add usefulness to the framework of evaluating stochastic outcomes. Exceptions to this would be the evaluation of a major change in fixed costs, such as the impact of a new building, or a merger or consolidation of two or more institutions. There is also a need to better understand the nature of loan demand and deposit supply elasticities. The era of financial institution deregulation has coincided with sufficient movements in interest rates, to both tremendously high levels and unimaginably low levels, that sufficient data should exist from which to begin such an effort.

Policy trends toward market valuation of assets and liabilities indicate yet another application of stochastic interest rate modeling. However, it may be necessary to allow updated information to feedback into the decision set to properly assess institution performance and condition.

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Table 1. Condensed Balance Sheet Structure

ASSETS

Cash & Due
Reserve Deposit

INVESTMENTS

US Treasury
Fed Funds Sold

TOTAL INVESTMENTS

LOANS
Non-Farm Commercial Loans
Farm Commercial Loans
Personal and Student Loans
Real Estate Loans

Non-Accrual Loans
TOTAL LOANS

Reserve for Loan Losses

TOTAL LOANS NET

Other Assets
Bank Premises and Equip.

TOTAL ASSETS

LIABILITIES

DEPOSITS
Demand Deposits

NOW Deposits

Savings Deposits

Money market Deposits
Other Time Deposits (CD's)

TOTAL DEPOSITS

Fed Funds Purchased
Other Borrowed Funds
Other Liabilities

TOTAL LIABILITIES

EQUITY

Capital Stock
Surplus
Undivided Profits

TOTAL EQUITY

TOTAL LIABILITIES+EQUITY

Table 2. Initial Rates and Volumes

Category	Initial Rate (%)	Initial Volume ($)
Fed Funds	8.60	5,200,000
Three-Month TBill	7.61	500,000
Six-Month TBill	7.78	2,650,000
Twelve-Month TBill	7.78	2,800,000
Three-Year TBond	8.80	10,550,000
Ten-Year TBond	8.60	10,000,000
Prime Rate	10.00	n/a
Non-Farm Commercial Loans	12.00	20,174,000
Personal and Student Loans	13.00	4,000,000
Real Estate Loans	11.00	23,500,000
Farm Operating Loans	12.00	12,000,000
Non-Performing Loans	1.67	(% of total loans)
Expected Net Charge Offs	3.60	(% of total loans)
Demand Deposits	0.00	9,800,000
NOW Deposits	5.25	16,500,000
Savings Deposits	5.25	4,000,000
Money Market Deposits	6.50	13,500,000
One-Month CD	8.50	9,000,000
Three-Month CD	8.60	9,000,000
Six-Month CD	8.80	9,000,000
One-Year CD	8.80	9,000,000
Three-Year CD	8.80	9,000,000
Other Borrowings	8.00	3,600,000
Other Liabilities	n/a	78,000
Capital Stock	n/a	1,900,000
Surplus	n/a	2,800,000
Undivided Profits	n/a	2,822,000
Bank Premises and Equip.	n/a	2,000,000
Other Assets	n/a	2,500,000
Salaries and Benefits	n/a	1,400,000
Occupancy Expense	n/a	230,000
Data Processing	n/a	280,000
Other Expense (Not FDIC)	n/a	598,102
Other Income	n/a	19,600
Dividends Paid, 1st and 3rd Quarter	each qtr.	300,000

Table 3. Correlation Coefficients Between Selected Interest Rates, Quarterly Differences, 1972-1988.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PRIME	(1)	1.000										
CD, 1 mo.	(2)	.802	1.000									
CD, 3 mo.	(3)	.773	.993	1.000								
CD, 6 mo.	(4)	.732	.968	.989	1.000							
Fed Funds	(5)	.832	.972	.954	.914	1.000						
FHLMC (Real Estate)	(6)	.714	.594	.601	.612	.612	1.000					
T-Bond, 10 yr.	(7)	.444	.642	.680	.725	.565	.721	1.000				
T-Bill, 12 mo.	(8)	.655	.922	.947	.971	.861	.611	.785	1.000			
T-Bill, 3 mo.	(9)	.694	.945	.942	.929	.902	.531	.682	.944	1.000		
T-Bill, 6 mo.	(10)	.684	.945	.959	.966	.886	.582	.746	.986	.982	1.000	
T-Bond, 3 yr.	(11)	.581	.817	.851	.897	.744	.688	.897	.954	.853	.915	1.000

Table 4. Regression Models for Selected Interest Rates, Quarterly Differences

Dependent Variable	Explanatory	Estimated Coefficient (t statistic)	Adj. R^2	Variance of Estimate	Jarque-Berra[a]
TBOND3	TBILL12	.5921	.9664	.0002832	0.0166
		(17.36)			
	TBOND10	.5753			
		(10.31)			
TBILL3	CD3	.7303	.8836	.0016762	7.8934
		(21.17)			
CD1	FEDFUND	.9530	.9458	.0012695	113.5730
		(32.1)			
CD3	CD1	1.0019	.9850	.0003365	3.2464
		(64.23)			
CD6	CD3	.9548	.9778	.0004936	2.6949
		(50.91)			
NPLI[b]	%GNP CHANGE	-6.2918	.1968	.0031652	0.4059
		(-2.06)			
FHLMC[c]	PRIME	.2355	.7248	.0013000	4.5596
		(6.560)			
	TBOND10	.5614			
		(6.730			
TBILL6	TBILL3	.5756	.9855	.0001850	0.0195
		(14.76)			
	CD6	.3027			
		(9.646)			
NCOI[d]	CONSTANT	.0056	.6204	.0002435	0.6937
		(1.569)			
	%GNP CHANGE	-6.2068			
		(-1.30)			
	PRIME	.1719			
		(3.112)			

[a] Distributed chi square with 2 degrees of freedom.
[b] Non-performing loans as a percent of total loans.
[c] Delivery rate on Federal Home Loan Mortgage Corporation 30 yr. real estate loans.
[d] Net charge-offs (loan losses) as a percent of total loans.

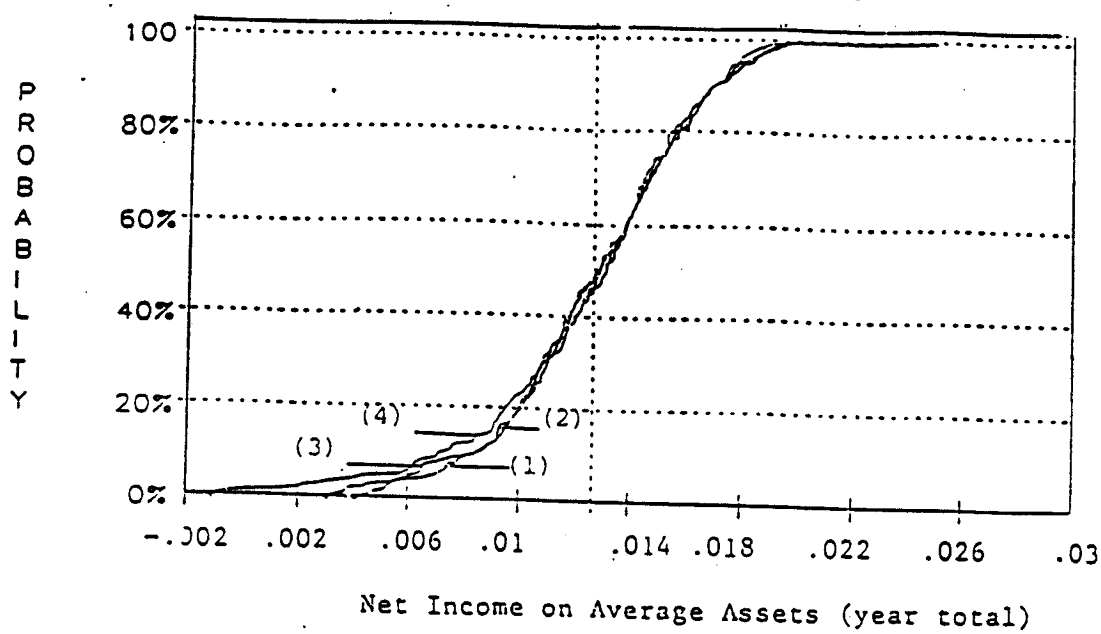
Table 5. Simulation Results for No Growth Scenario

	Net Profit	Ending Assets	Ending Deposits	Ending Loans (net)	Net Interest Margin	Net Income/ Avg. Assets	Loan Loss Prov/ Assets
Deterministic Simulation	$1,294,967	$100,694,967	$88,800,000	$58,725,520	4.45 %	1.29 %	0.93
Stochastic Simulation							
Expected Value	1,292,387	100,692,400	88,800,000	58,771,830	4.417	1.271	0.925
Minimum	269,134	99,669,130	88,800,000	58,725,520	2.578	0.420	0.238
Median	1,316,000	100,716,000	88,800,000	58,725,500	4.375	1.273	0.929
Maximum	1,925,116	101,325,100	88,800,000	59,521,070	6.320	2.185	1.429
Std. Deviation	317,061	317,061	0	133,958	0.701	0.345	0.202

Table 6. Simulation Results for Five Percent Loan Growth Scenario

	Net Profit	Ending Assets	Ending Deposits	Ending Loans (net)	Net Interest Margin	Net Income/ Avg. Assets	Loan Loss Prov/ Assets
Deterministic Simulation	$1,243,200	$105,166,277	$93,323,077	$61,606,720	4.31 %	1.21 %	0.93
Stochastic Simulation							
Expected Value	1,234,321	195,157,400	93,323,070	61,667,290	4.259	1.181	0.926
Minimum	303,503	104,226,600	93,323,070	61,606,720	1.863	0.036	0.251
Median	1,226,200	105,149,300	93,323,070	61,606,720	4.312	1.186	0.928
Maximum	2,272,462	106,195,500	93,323,070	62,420,690	6.395	2.206	1.508
Std. Deviation	343,595	343,595	0	142,220	0.712	0.357	0.201

Figure 1. Cumulative Distribution of Simulated Annual Net Income on Average Assets, Mean Initialization, by Elasticity.



Legend for all Figures:

No.	Elasticit
1	0
2	0.05
3	0.50
4	1.50

Figure 2. Cumulative Distribution of Simulated Annual Net Interest Margin, Mean Initialization, by Elasticity.

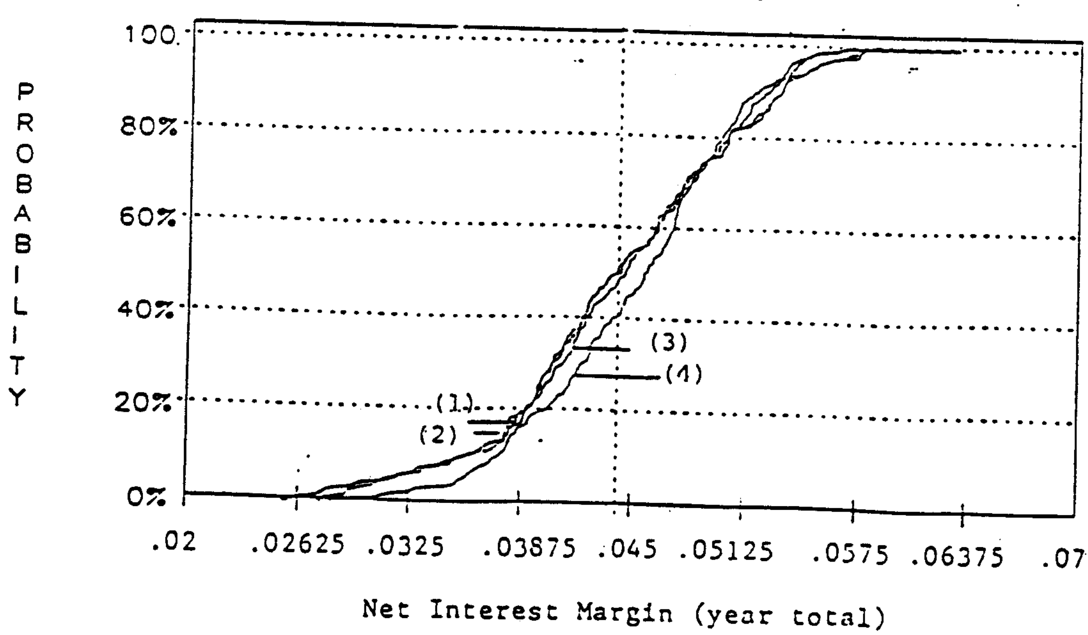


Figure 3. Cumulative Distribution of Simulated Fourth Quarter Total Assets, Mean Initialization, by Elasticity.

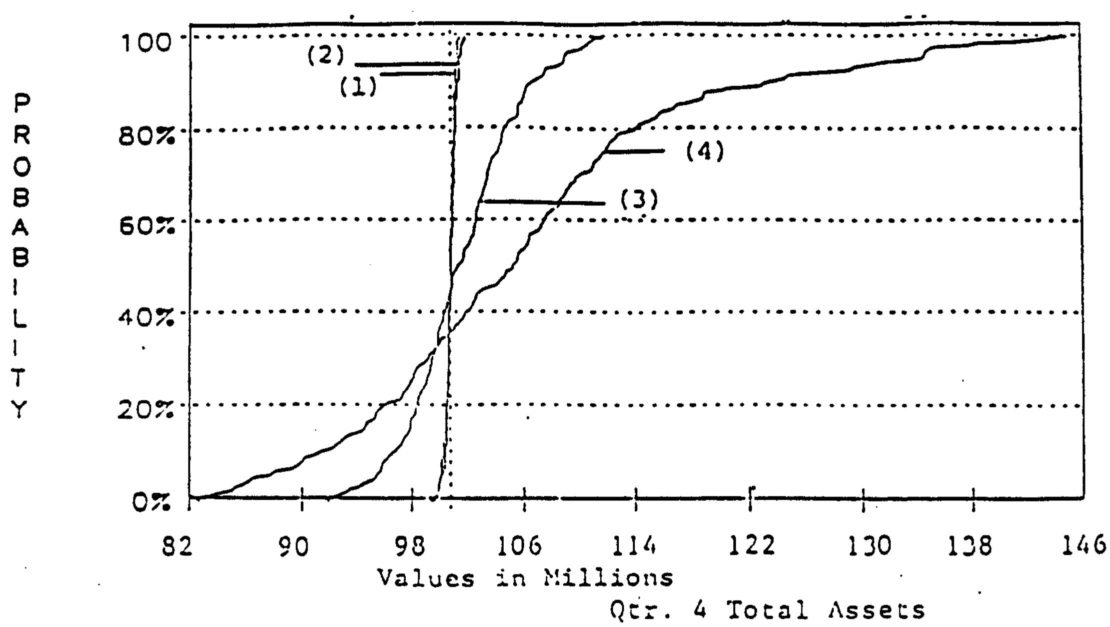


Figure 4. Cumulative Distribution of Simulated Fourth Quarter Total Deposits, Mean Initialization, by Elasticity.

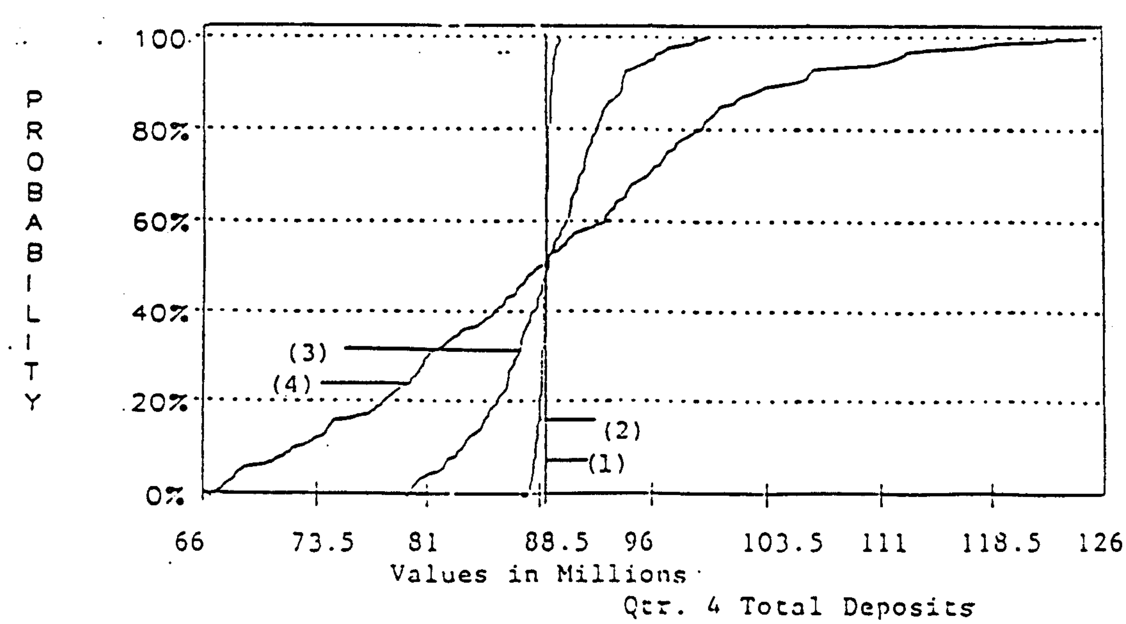


Figure 5. Cumulative Distribution of Simulated Fourth Quarter Total Loans Net, Mean Initialization, by Elasticity.