Information and Accuracy in Interest-Rate-Risk Simulation

Mike Carhill

Office of the Comptroller of the Currency
Economic & Policy Analysis
Working Paper 94 - 7
October 1994

The views expressed herein are those of the author and do not necessarily reflect the views of the Office of the Comptroller of the Currency. Christina Benson, Jeff Brown, Bob DeYoung, Ed Irmler, Kevin Jacques, Elizabeth Mays, Jim O'Brien, and Mark Winer provided useful commentary and advice.

Questions regarding subscriptions to the OCC Economic and Policy Analysis Working Paper Series should be addressed to Communications Division, Comptroller of the Currency, Washington, DC 20219.

Introduction

Advances in computing technology are making interest-rate-risk simulations affordable for an increasing number of intermediaries. Perhaps the major reason why simulations are superior to "duration" and "repricing gap" approaches is that simulations can incorporate a much wider range of information about firms' options exposures. This extra power requires the modeller to make judgments about the costs and benefits of incorporating extra information into the model. To explore those costs and benefits, we quantified the errors that result from the information economies employed in the interest-rate-risk model proposed by the Bank Regulatory Agencies (BA). We compared that model's results to results from more information-intensive models, particularly the model used by the Office of Thrift Supervision (OTS).[1]

The OTS model requires some or all of the following information for about two dozen different types of financial instruments (excluding off-balance-sheet positions):

(1) Weighted-average remaining term to maturity or repricing.
(2) Weighted-average coupons (WACs) for portfolios.
(3) Intra-portfolio coupon dispersions.
(4) Institution-specific coupon and balance history.
(5) Periodic and lifetime caps on adjustable-rate commercial and residential mortgage loans.
(6) Margins on ARMs.
(7) Indices for ARMs.
(8) Amortization class.
(9) The breakdown of loans of given types between adjustable- and fixed-rate loans.
(10) Original maturity.

In contrast, the only information input to the BA model is remaining maturity, which is collected for only 13 separate classes of instruments.

To assess the value of the various information inputs, we calculate how each input changes the instrument's estimated sensitivity to a 200 basis-point, parallel, upward shift in the yield curve (interest-rate "shock"). For example, a typical adjustable-rate residential mortgage (ARM) with no lifetime caps might decline in value by 100 basis points (one percent of its current or par value) when interest rates increase by 200 basis points; an otherwise identical ARM with lifetime caps might decline by 400 basis points in that interest-rate scenario. Therefore, the latter ARM's lifetime caps cause a "model difference" in estimated sensitivity of 300 basis points.

There are two different types of model differences. The first type, exemplified by the maturity-aggregation errors that we analyze in Chapter One, implies differences in the estimated "bottom-line" sensitivity of portfolio equity. In our first two chapters, we describe the two main sources

[1] The OTS Final Rule on interest-rate risk is published as 12 CFR Parts 563, 567, and 571 (Docket No. 93-100). The Banking Agencies' Notice of Proposed Rulemaking is published as 12 CFR Part 3 (Docket No. 93-11). The Banking Agencies include the Federal Reserve System, the Federal Deposit Insurance Corporation, and the Office of the Comptroller of the Currency.

of these bottom-line differences between the OTS and BA models: the superior maturity data collected by the BA, and the superior coupon data collected by the OTS.

The second type of model difference applies to specific assets or liabilities, such as the ARM with lifetime caps discussed above. Depending on a particular institution's characteristics, such instrument-specific differences may either offset or compound other differences when calculating bottom-line sensitivity. Hence, there is not necessarily any systematic relation between instrument-specific differences and bottom-line differences. However, in all cases instrument-specific differences can create incentives for banks to structure their portfolios in ways that reduce capital charges but do not necessarily reduce the "true" interest-rate exposures.

Those incentives become artificial incentives when model differences are in fact model "errors." Where we discover significant model differences, we use published research and our own modelling to discriminate between the two models' results. In most cases, we are able to establish that one or both models is in error. When such discrimination is possible, we refer to model differences as "model error."

With a few minor exceptions, we find that model errors are due to inadequate information rather than the poor use of available information. There are several potential sources of instrument-specific errors for every kind of financial instrument; we analyze only the most widely held financial instruments. With regard to on-balance-sheet instruments, the two most important information deficiencies in the BA model appear to be its lack of coupon data on fixed-rate residential mortgage instruments (FRM), and the simplistic treatment of lifetime and periodic caps for adjustable-rate residential loans. Our third and fourth chapters explain why either of those information defects can lead to errors of several hundred basis points in estimated sensitivity.

The fifth chapter describes several miscellaneous information items. These miscellaneous items produce model differences ranging from 0 to 100 basis points, and in many cases the model differences appear to be errors in the BA model. However, the available data indicate that the miscellaneous items would affect the on-balance-sheet estimates for relatively few banks.

The final chapter discusses some of the omitted issues, the most important of which are core deposits and off-balance-sheet instruments. We discovered that there is no market consensus about core deposits, and so no given treatment is clearly in error. Off-balance-sheet and mortgage derivatives are generally so idiosyncratic that small changes in the information inputs result in large changes in the estimated interest-rate sensitivities, but we have been unable to independently verify the existence of a consensus concerning the interest-rate sensitivity of any given instrument.

Those familiar with interest-rate-risk modelling might be surprised that, with the exception of core deposits and derivatives, we have generally been able to characterize the errors in the models with some precision. However, that precision is possible only after granting certain common assumptions. Among other commonalities, both models use the Bloomberg model of the market consensus for expected prepayments for residential mortgages. The models also share several crucial assumptions: (1) that fixed-rate instruments other than residential mortgages carry prepayment penalties that remove the relation between interest rates and prepayment incentives; (2) that the covariance between interest-rate movements and changes in credit quality is zero; (3) that rate changes take the form of instantaneous and parallel 200 basis-point shifts in the yield curve; (4) that balance sheets are not altered in response to that rate shock, and (5) (where relevant) the volatility of interest rates is constant. The apparent precision with which we quantify errors results from those common assumptions. In the real world, violations of those assumptions can be expected to produce divergences between model predictions and reality. That observation implies that interest-rate-risk modelling is an inexact science, despite the apparent precision of the model outputs.

Chapter One: The Two Models' Maturity-Aggregation Errors

Even if it were possible to perfectly model the interest-rate risk for a particular instrument, it is generally too costly to model each of an institution's instruments separately. Instead, most interest-rate-risk models aggregate--and treat identically--instruments that have similar but not identical characteristics. That aggregation causes estimation error.

In this chapter, we analyze the error that results from aggregating the maturities of the instruments of a given loan type, and calculate the errors that result from either the OTS' or the banking agencies' approach to aggregating maturities. We employ both the available data and the Law of Large Numbers to ensure that our estimated aggregation errors are representative for "real-world" portfolios.

We evaluate the maturity-aggregation errors only for assets. In practice, maturity-aggregation errors for liabilities will be negligible. About 50 percent of the median bank's liabilities are CDs, and the remaining 50 percent are core deposits. For CDs, the average maturity is about one year, so CDs have too little interest-rate sensitivity for aggregation errors to be large enough to substantially affect the estimated interest-rate sensitivity of portfolio equity. For core deposits, the contract maturity is zero, and the effective maturities are assigned by the modeller.
Ignoring the liability side will misrepresent the estimation errors for the minority of banks that have significant amounts of long-term CDs or nondeposit borrowing. For those banks, maturity-aggregation errors on the liability side will sometimes ameliorate and in other cases aggravate the maturity aggregation errors on the asset side.

I. The Two Regulatory Approaches to Maturity Aggregation

The two regulatory approaches to aggregating maturities represent alternative compromises between model accuracy and reporting burden. The banking agencies employ a "bucket" approach: For each portfolio of a given type of financial instrument, the individual instruments are aggregated into several maturity ranges, called buckets (seven buckets in the 1993 Notice of Proposed Rulemaking (NPR)). The maturity ranges are: 0 to 3 months, 3 to 12 months, 1 to 3 years, 3 to 5 years, 5 to 10 years, 10 to 20 years, and 20 to 30 years. The model assumes that the maturities of all of the loans in each maturity range equal the midpoint of that maturity range.

The OTS' interest-rate-risk model uses a "weighted-average maturity" (WAM) approach instead of buckets. For each type of financial instrument, each institution reports only the WAM for the entire portfolio of that instrument type. For example, the remaining maturities for each thrift's entire portfolio of Treasury securities are averaged into one WAM. The model then assumes that the maturity of each individual security equals the WAM of the subportfolio.

Either the bucket or the WAM approach misrepresents the relation between the interest-rate sensitivities and the maturities of an institution's individual financial instruments. The bucket misrepresents average maturities because it is unlikely that the WAM for the instruments in any bucket will equal the midpoint of that bucket. We label the estimation errors that result from that problem the "maturity-estimation error." Furthermore, even when the maturity-estimation error is negligible, the bucket approach produces what we label "within-bucket WAM-convexity error": averaging the maturities of a group of instruments implicitly assumes that interest-rate sensitivities are linear in maturities, but (as we will see) interest-rate sensitivities are highly convex in maturities (interest-rate sensitivity increases at a declining rate as maturity increases). We label the combined maturity-estimation error and within-bucket WAM-convexity error the "bucket-aggregation error."

The OTS model correctly assigns average maturities, so it has a zero maturity-estimation error. However, it produces a much higher "WAM-convexity error" than does the bucket approach. This is because the convexity error operates over the entire maturity range, rather than over the short subsets of that range used by the bucket approach.

The OTS used a bucket approach from 1984-1992. Since then, the OTS has used the WAM approach, which has two advantages. First, by using WAMs, the OTS requires thrifts to report each relevant datum for each type of financial instrument only once. In contrast, when using buckets, each relevant datum must be reported as many times as there are buckets. Therefore, for any given length of the reporting form, the WAM approach allows the OTS to collect much more information about each type of financial instrument.

The second advantage of the WAM approach is that it avoids the "within-bucket maturity-estimation error." However, because the WAM approach produces a much higher convexity error than does the bucket approach, there is a tradeoff that needs to be quantified.

II. The Bucket-Aggregation Errors.

In this section we analyze the within-bucket WAM-convexity errors and the within-bucket maturity-estimation errors that result from the banking agencies' proposed model (BA model). The 1984-1992 *Thrift Financial Reports* provide information on the distribution of instrument maturities across buckets, but we are unaware of any data on actual within-bucket distributions of maturities. Therefore, we rely on Monte Carlo simulations and what we believe to be reasonable assumptions to characterize the errors statistically. We build a reality that, to the extent that our assumptions characterize real-world portfolios, shows the extent to which the Law of Large Numbers can be relied upon to eliminate the bucket-aggregation errors. However, even if our assumptions correspond to reality, our approach has two major limitations.

The first limitation is that we must omit managerial responses to the (stochastically determined) interest-rate exposures. If managers have perfect knowledge of the outcome of that stochastic process, they can change their exposures in either of two directions. First, risk-averse managers that appear "match funded" using the bucket aggregations, but actually have significant (stochastically determined) exposures, might take steps to reduce their exposures even though the proposed BA model creates no regulatory incentives to do so. Conversely, risk-seeking managers that have negligible (stochastically determined) exposures might seek to increase their risk when they realize that such risk will elude detection by the regulatory model.

The second limitation is that the conclusions we reach, while otherwise robust to the assumptions about the within-bucket distributions of maturities, are not valid for degenerate or badly skewed distributions. To the extent that institutional factors produce such distributions, the errors are much larger than we estimate here. Since the data offer little insight into the prevalence of "bad" distributions, an important uncertainty remains that should be considered when evaluating the tradeoff between information costs (reporting burden) and model accuracy.

Feid (1993) analyzes the maximum bucket-aggregation error that can result from the proposed BA model. He demonstrates the theoretical possibility of "bottom-line" errors of several hundred basis points in the estimated sensitivity of portfolio equity, even for relatively short-term portfolios. In essence, we demonstrate below that such very large errors result only from deliberate managerial gaming or unusual portfolios, and are highly unlikely to arise from stochastic processes (see the Appendix to Chapter One for a brief discussion of Feid's techniques).

II.A. A Model of the Within-Bucket Maturity Distributions

We assume that the maturities of each institutions' instruments are uniformly but randomly distributed within each bucket. There are many reasons why real-life portfolios might violate the uniformity assumption, but whatever the true distribution of the maturities of a given type of instrument for a given institution, by the Law of Large Numbers the observed distribution of maturities within each bucket will tend toward uniformity as the number of buckets increases (as an interval shrinks, the difference between the maxima and minima over that interval also shrinks).[2] Since the sum of uniform distributions tends to a normal distribution, this tendency implies that the stochastically determined bucket-by-bucket WAMs are normally distributed. Hence, our assumption that the instruments' maturities are uniformly distributed implies that the WAMs within each bucket tend to a normal distribution.

For simplicity, we assume in this section that all instruments have nonamortizing payment structures. That assumption overstates the errors for amortizing instruments and understates the errors for zero coupon instruments. We assume that the instruments are distributed evenly across maturities.

We test both the seven-bucket model proposed for the BA model and the eight-bucket model used by the OTS from 1989-1992 (the OTS gains that extra bucket by dividing the 3 to 12 month bucket into a 3 to 6 month bucket and a 6 to 12 month bucket.) The latter produced only slightly smaller errors. The numbers we report are for the eight-bucket model.

For each bucket, we employ the SAS random number generator to draw a separate random number for the maturity of each instrument. The random number is drawn from the uniform distribution U[(0,1),0.289] (0.289 represents the standard deviation for a uniform distribution on

---

[2] While no single distribution would characterize all portfolios, a uniform distribution may be the most realistic globally as well as within buckets. An established institution that pursues a stable buy-and-hold strategy will come to hold instruments spread evenly across the maturity spectrum. As "old" instruments mature, they are replaced with new instruments at the opposite end of the maturity spectrum. This implies that the average maturity will tend to fall at the midpoint of the portfolio's maturity spectrum.

The tendency toward uniform distributions is greatly weakened by a number of real-world factors. For example, many instruments have amortizing payment structures, so that even for uniform maturity distributions the weighted-average maturity exceeds the unweighted-average maturity and hence the midpoint of the maturity spectrums. Obviously, there are many such factors that influence the global maturity distributions.

that interval). The resulting random number χ is then scaled up to occupy the interval corresponding to each bucket's maturity. The scaling employs the formula $(\alpha + \beta\chi)$, where α represents the lower bound of the bucket in days and β represents the bucket width in days (365.25 days per year). The daily yields are adjusted to correspond to bond-equivalent yields (BEYs) of 8 percent in the base case and 10 percent after the shock.

The resulting WAMs within each bucket are distributed $N([\alpha + 0.5\beta],[\{.289\beta\}/n^{1/2}])$, where n represents the number of financial instruments in each bucket.[3] We ran each of our simulations both with n= 10, to proxy a bank with a small number of instruments, and with n= 11,351 to proxy a bank with a large number of instruments.

Varying the number of instruments in this way produces a rough proxy for differing bank sizes. Suppose that the average instrument has a par value of $100,000. In an eight-bucket model, 10 instruments per bucket implies total financial assets of about $8 million, roughly representative of the smallest existing banks. At the other extreme, 11,351 instruments per bucket implies a bank with total financial assets of about $10 billion.

The number of instruments per bucket has different implications for the maturity-estimation error than for the within-bucket WAM-convexity error. The maturity-estimation error has a stochastic component, depending on the randomly determined within-bucket maturity dispersions. For n= 11,351 the standard deviation of the WAMs is only $.00271*\beta$, and the expected value of hte WAMs equals the bucket midpoint, so that within-bucket maturity-estimation error is negligible. For n= 10, the standard deviation is $0.0914*\beta$, large enough that the maturity-estimation error remains important. However, the expected value of the WAM-convexity error is independent of firm size, and so remains positive for the "large" bank.

The maturity-estimation error could be captured by first aggregating and then valuing the loans in each bucket, but capturing the within-bucket WAM-convexity error requires each loan to be valued before aggregating the loans in each bucket. We assume each instrument is at par at a level 8 percent BEY yield curve. We then calculate the value of each instrument after rates increase to 10 percent BEY, summing the values to find the total value of the loans in each bucket.

To conserve computer resources, our simulations are run over 400 banks. Experimentation showed that this sample size is large enough to ensure rough accuracy in our estimate of the average maturity-aggregation error. However, with a small number of simulations, the probability of producing outliers is reduced, so 400 simulations tends to understate the estimated maximum possible errors. We assume that the maturities for each bank's instruments are evenly distributed from zero through the portfolio's maximum maturity. We assume that banks choose

[3] That standard deviation is implied by the Central Limit Theorem applied to results from successive draws, with replacement, from the uniform distribution. To ensure that the product of the SAS random number generator corresponds to theory, we inspected several runs from the random number generator and found that the actual standard deviations varied over a range of roughly $0.27/n^{1/2}$ to $0.3/n^{1/2}$. For our purposes, relatively few draws (400) produce sufficient accuracy, but in some modelling applications a much larger number of draws is needed.

five different maximum maturities, corresponding to the five longest buckets in the BA model: 3 years, 5 years, 10 years, 20 years, and 30 years.[4]

II.b. Error Estimates

We express the total maturity-aggregation error as 1-(true value/BA value). Positive errors mean that the BA model has overstated sensitivity (understated the post-shock value of the instruments). The expected error is positive, because the within-bucket WAM-convexity error is always positive (i.e., the WAM convexity error represents an overstatement of the portfolios' true interest-rate sensitivity), and the expected maturity-estimation error equals zero.

As we increase the maximum maturity, the potential error increases because the instruments that are added to the portfolio become increasingly rate sensitive. For the "large" bank with 11,351 instruments per bucket, the errors are:

Distribution of large banks' estimated maturity-aggregation errors, as function of portfolio maximum maturity:					
Maximum maturity (years):	3	5	10	20	30
Smallest error (basis points):	0.2	0.7	4.3	11.6	10.4
Average error:	2.0	2.1	6.4	13.9	12.2
Largest error:	3.7	3.5	8.4	16.0	14.0

Even in the worst case, with maximum maturities at 20 years, the bucket-aggregation error does not exceed 16 basis points, and the mean error is only 14 basis points. The very tight range of errors results because the large number of instruments in each bucket drives the stochastically determined maturity-estimation error almost to zero. Evidently, provided that all large banks' portfolios have maturity distributions that "cover" the buckets, the eight-bucket model produces very small errors. However, the mean error remains positive even when the maturity-estimation error goes to zero, because of the within-bucket WAM-convexity error.

For "small" banks, the same conclusion holds for the average error, but there are significant outliers. For example, if the maximum maturity is 10 years, almost 25 percent of our

[4] We spread the maturities evenly across time by weighting the value of the instruments in each bucket as follows: 1-3 months and 3-6 months, 1/120 each; 6-12 months, 1/60; 1-3 years and 3-5 years, 1/15 each; 5-10 years, 1/6; 10-20 years and 20-30 years, 1/3 each. The assumption that the instrument maturities are evenly distributed across time rather than across the time buckets weights the long buckets more heavily, thus tending to overstate the interest-rate sensitivity of the portfolios. This probably biases against our conclusion that the bucket methodology produces small maturity-aggregation errors.

hypothetical small banks will have their portfolio sensitivity overstated by more than 25 basis points, while over 10 percent of the banks will have their sensitivity underestimated by more than 25 basis points:

Distribution of small banks' estimated maturity-aggregation errors, as function of portfolio maximum maturity:					
Percentile of errors (basis points)	Maximum maturity (years)/instruments per bank (with 10 instruments per bucket).				
	3/40	5/50	10/60	20/70	30/80
Minimum	-73.0	-54.7	-63.5	-66.8	-52.9
5th	-33.4	-29.0	-39.8	-34.1	-22.3
10th	-23.3	-18.1	-28.3	-24.1	-14.9
25th	-13.3	-7.5	-10.7	-7.1	-2.3
50th	2.7	2.4	4.5	11.8	11.5
75th	14.6	12.0	23.2	32.1	24.2
90th	26.0	21.5	38.8	47.6	35.8
95th	32.2	27.3	45.7	57.1	44.2
Maximum	53.4	42.3	87.1	94.3	75.8

For most portfolios, the bucket-aggregation errors will lie between those experienced with 10 instruments per bucket and those experienced for 10,000 instruments per bucket. We repeated the above simulation for a portfolio with 100 instruments per bucket. If each instrument has a par value of $100,000, such a bank would have total financial assets approaching $80 million, roughly representative of the median bank.

Distribution of median banks' estimated maturity-aggregation errors, as function of portfolio maximum maturity:					
Percentile of errors (basis points):	Maximum maturity (years)/instruments per bank (with 100 instruments per bucket).				
	3/400	5/500	10/600	20/700	30/800
Minimum	-19.0	-13.7	-15.7	-15.6	-8.6
25th	-2.5	-1.7	-0.7	8.1	8.1
50th	1.9	2.0	6.2	14.2	12.3
75th	6.1	5.5	11.8	19.5	16.6
Maximum	19.4	17.7	29.5	38.5	31.5

For these median-sized portfolios, the Law of Large Numbers causes sufficient shrinkage of the maturity-estimation error for the within-bucket WAM-convexity error to dominate, causing a significant positive bias in the total maturity-aggregation error. Hence, the average error is higher for the median-sized bank than for very small banks. However, despite the larger average error, the range of estimation errors is much smaller for the median-sized banks than for the small banks.

II.c. The Benefits of Alternative Bucketing Approaches

The results from our simulations suggest that the eight-bucket maturity-aggregation errors are generally small. However, we have assumed that within-bucket maturities are uniformly distributed. Our results hold for almost all distributional assumptions (since i.i.d. draws from covering distributions are expected to sum to a normal by the Central Limit Theorem). However, there will be cases where the within-bucket maturities tend to a degenerate or badly skewed distribution. Feid has shown that for those distributions the within-bucket maturity-aggregation errors can be extremely large.

Because of these and other concerns, many advocate doubling the number of buckets employed by the BA model. Each concern is at least partially mitigated if more buckets are employed. To see if using more buckets would reduce the estimation error, we redid the above simulations after doubling the number of buckets by splitting each of the eight OTS buckets in two. This also required that we cut the number of loans by one-half, so that there were 5 loans in each bucket for the smallest banks and 50 loans in each bucket for the median-sized bank. We found that doubling the number of buckets cut the errors by approximately one-half; and is helpful for small banks that may suffer a large measurement error under the eight-bucket approach. For example, the estimation errors for the small banks ranged from -34 basis points to 52 basis points with 16 buckets (the case with maturities ranging from zero to 20 years), compared to -67 to 94 basis points using 8 buckets.

While 16 buckets are more accurate than 8 buckets, employing WAMs within 8 buckets is more accurate than using bucket midpoints within 16 buckets. For the 10-instrument-per-bucket case with 8 buckets, but using WAMs in place of the bucket midpoint, the estimation errors range between 5 and 22 basis points.

The advantage of using within-bucket WAMs relative to doubling the number of buckets becomes even greater when our simulations are run with variable loan sizes. Varying the loan sizes increases the maturity-estimation errors inherent in the bucket approach, because even if the within-bucket distribution of maturities is uniform, the loans might vary in size. In our stochastic simulations, variable loan sizes increase the error that results when the average maturity differs from the bucket midpoint. For the small bank with 10 loans per bucket, randomly varying the loan sizes from $1,000 to $300,000 causes the estimation errors to increase by about 50 percent for those banks for which the bucket approach overstates sensitivity. (Varying loan size actually slightly reduces the error for those banks for which sensitivity is understated. In that case, the negative maturity-estimation error partially offsets the positive within-bucket WAM-convexity error.) However, if within-bucket WAMs are used, variable loan sizes have no effect on the estimation errors.

A disadvantage of the within-8-bucket WAM approach relative to the 16-bucket approach is that the former has a larger mean bucket-aggregation error than the latter. This is because the WAM approach always overstates sensitivity, while the replacement of actual maturities with the bucket midpoints can produce either positive or negative errors. Because of that bias, employing WAMs addresses only the maturity-estimation errors, not the WAM-convexity errors. Doubling the number of buckets addresses both errors.

On net, however, a positive but known bias with a small range of errors seems preferable to smaller positive bias with a much larger range of errors. Perhaps more importantly, within-bucket WAMs address the problems of degenerate/skewed distributions and possible management gaming much more effectively than does doubling the number of buckets. Of course, if the reporting costs are deemed negligible, within-16-bucket WAMs would be the preferred solution.

III. Estimation Errors Resulting from Replacing "Buckets" with Weighted-Average Remaining Maturities (WAMs).

The OTS model aggregates all maturities for each type of instrument by requiring thrifts to report their portfolio "weighted-average maturities" (WAMs). For example, each institution aggregates all of its fixed-rate 30-year residential together and calculates that portfolio's WAM. In this section, we show that for many instruments, this procedure results in a large estimation error, both in theory and in practice.

WAM aggregation was introduced in the 1993 (CMR) version of the OTS model; the 1984-1992 OTS models had employed the "bucket" approach proposed in the Banking Agencies' NPR. The OTS made this change because the 1984-1992 models omitted several pieces of information that the OTS believed essential to measuring the interest-rate risk in residential mortgages. The OTS replaced the buckets, which required eight line items for every datum, with weighted-average maturities (WAMs), which require only one line item per datum, in order to collect that additional information without greatly expanding the reporting form.

III.a. Why the WAM Error Occurs

The basic problem with the WAM approach is convexity. The interest-rate sensitivity of an instrument or portfolio increases in its maturity, but the rate of increase in that sensitivity declines as maturities increase. An 8 percent coupon Treasury bond with 7.5 years to maturity will decline in value by 10.38 percent if market rates go from 8 percent to 10 percent BEYs. If we double the maturity to 15 years, the decline in value increases by 5 percent, to 15.37 percent. However, if we increase the maturity from 15 years to 22 years, the decline in value increases by only 2.4 percent, to 17.74 percent.

The convexity error can be illustrated by considering several $300 million portfolios of financial instruments, each distributed differently across six five-year buckets, but each having a WAM of 15 years:

Bucket (years):	0-5	5-10	10-15	15-20	20-25	25-30	WAM
Years to maturity:	2.5	7.5	12.5	17.5	22.5	27.5	
Portfolio A	$50	$50	$50	$50	$50	$50	15
Portfolio B	95	4	11	90	46	54	15
Portfolio C	150	0	0	0	0	150	15
Portfolio D	0	0	150	150	0	0	15
Portfolio E	0	150	0	0	150	0	15
Portfolio F	59	24	42	76	81	18	15
Portfolio G	0	180	10	0	0	110	15
Portfolio H	0	40	110	110	40	0	15

For now, suppose that all of the instruments within each bucket have maturities equal to the midpoint of that bucket, so that no convexity or maturity estimation error is introduced by grouping subportfolios into only six buckets (as we have seen, that error is likely to be relatively small unless the bank has very few instruments in each bucket). For rate increases from 8 percent to 10 percent, the OTS estimates the loss in value for each portfolio at 15.37 percent (for nonamortizing Treasury Bonds), and at 8.39 percent (for a 1-4-family mortgage at a 6 percent CPR).[5] However, the actual decline in values for the portfolios are:

Portfolio:	As T-Bond (%)	As FRM (%)
A	13.60	7.50
B	13.02	7.22
C	11.48	6.44
D	15.23	8.32
E	14.08	7.73
F	13.72	7.57
G	13.52	7.43
H	14.93	8.16
OTS estimate:	15.37	8.39

[5] The CPR when the BEY is at 8 percent is irrelevant for calculating its value, because the mortgage is at par. However, in some prepayment models a high initial prepayment rate may remain relatively high even after a 200 basis point increase in market rates. Therefore, we also used a 12 percent CPR for the 8-percent fixed-rate mortgages at 10 percent BEYs, as all the models we have seen agree that the CPR will be less than 12 percent for such discount mortgages. If a 12 percent CPR is assumed instead of a 6 percent CPR, the mortgages decline in value by 6.82 percent instead of 8.39 percent when rates jump from 8 percent to 10 percent BEY.

For the Treasury Bond portfolio D, which has maturities that "bunch" relatively tightly around its WAM, the convexity error from replacing buckets with WAMs is only 14 bp (for FRMs, the corresponding error is only 7 bp.) However, for A, which is dispersed evenly across the buckets, the error is 177 bp for the bond and 89 bp for the FRM; for D, which is evenly divided between the two most extreme buckets (a "barbell portfolio"), the estimation error is 389 bp for the bond and 195 bp for the FRM. To the extent that real-world portfolios look like either A or D, aggregating maturities across buckets produces a very large error.

As a percentage of sensitivity, convexity error declines as the WAM increases. Expressing sensitivities as a percentage of par, as we do in this paper, the WAM convexity is greatest in the middle maturities; at short WAMs, the low interest-rate sensitivity dominates the high convexity error; at long WAMs, the low convexity error--combined with the low dispersion needed to attain a long WAM--dominates the high interest-rate sensitivity. At the extreme, as maturities increase past 40 years, interest-rate sensitivities (asymptotically) become constant, so that the convexity becomes irrelevant (e.g., a negligible WAM-convexity error results from using a 50-year WAM to represent a portfolio that has equal proportions of 40-year and 60-year instruments).

III.b. Characterizing the Data

Unfortunately, banks' call reports do not include maturity distributions. However, the Thrift Financial Reports (TFRs) included data on thrifts' intraportfolio maturity distributions buckets from 1984 through 1992. We assume that portfolios with given WAMs have the same bucket dispersions whether held by banks or by thrifts, so that we can use the thrift data to characterize the WAM-convexity error that would result if the current OTS model were applied to banks. To calculate the portfolio WAM, we assume that within-bucket WAMs equal the bucket midpoints.

For an arbitrary number of buckets, arbitrary WAMs, or arbitrary interest-rate scenarios, characterizing the WAM-convexity error requires a sophisticated and tedious mathematical treatment.[6] However, for the specific case of eight buckets, where we have a parallel shift in a level yield curve from 8 percent to 10 percent BEY, a much more simple and direct solution is available. We compare the errors from the WAM and bucket approaches by (1) valuing each bucket separately and then summing the resulting values, and (2) calculating the WAM for each loan type and then valuing the portfolio as if the WAM represented the actual maturity of each instrument.

---

[6] The linearization needed for a general solution can be achieved with a Taylor Series expansion to the nth order derivatives. However, the solution is computationally intractable, so we employed a polynomial expansion to characterize the WAM convexity error. The expansion fits a curve where (a) the dependent variable is the difference between the sensitivity at each bucket's maturity midpoint and the sensitivity at the portfolio-wide WAM and (b) the independent variables are the difference between each bucket's maturity and the portfolio WAM, raised to powers implied by the degree of the polynomial expansion. We found that a 9th-order polynomial, applied to the 8-maturity case implied by the 1990-1992 OTS Section MR, produced an R^2 of 1 and estimation of the WAM error that was accurate to the fourth decimal place.

We applied these calculations to the TFR data for the first quarter of 1990 and the fourth quarter of 1992. The conclusion is essentially identical no matter which period is used. However, the sample is about 50 percent larger for 1990 than for 1992 (2900 v. 1900 thrifts), so we report the numbers for the earlier period. We calculate the WAM-convexity errors for three different types of instruments: 1-4 family fixed-rate residential mortgage loans and MBS; Treasury and agency bonds ("investment securities type 1" on the TFR); and 5+ family and nonresidential real estate loans. Together, those three types of instruments are about 40 percent of the average bank's total assets, in roughly equal shares. We assume that the 1-4 family loans had 30-year original maturities, and amortize with a constant prepayment rate (CPR) that falls to either 6 percent or 12 percent per year after the 200 bp shock to interest rates. We assume that the other real estate loans and bonds are nonamortizing.

The average thrift reported that its fixed-rate 1-4 family residential loan portfolio had a WAM of 16.2 years in the first quarter of 1990 and 14.3 years in the fourth quarter of 1992. For the other real estate loans, the average maturity was nine years. Few thrifts hold bond portfolios with long maturities, with the average WAM at only about two years.

We calculate the global WAM-convexity "error" as [1-(OTS value/BA value)]. This term is a pure error term only under our assumption that the BA value contains no within-bucket maturity aggregation error, whereas we discovered above that even under the best of conditions that error ranges from 3 to 13 basis points. Because convexity overstates sensitivity, the OTS value is always less than or equal to the BA value.

The distributions of WAM convexity errors for the three types of instrument are:

Estimated errors from replacing eight buckets with WAMs, for thrifts in 1990 quarter four:				
Percentile of errors (basis points)	Instrument\number of thrifts with positive balances (1990 Quarter one)			
	Fixed-rate 1-4 family loans and MBS (2871 observations)		Other real estate (2724 observations)	Investment securities (2793 observations)
	12 % post-shock CPR	6 % post-shock CPR		
Minimum	0	0	0	0
10th	17.7	22.7	24.6	0
25th	24.8	31.3	65.7	0.5
50th	35.2	43.0	113.5	7.5
75th	54.8	63.4	173.7	49.0
90th	86.8	93.7	232.7	248.7
Maximum	230.9	236.1	522.9	564.0

This table probably overstates the errors in the current OTS model for FRM, because the 1993 OTS model segregates those instruments between 15-year and 30-year original maturity. With the 1993 reporting form, the average WAM for 30-year original maturity FRM is about 22 years, compared to the 14.3 years reported when the 15-years and 30-year original maturities were combined. Conversely, the table understates the errors for investments securities that would result if the OTS model were applied to commercial banks, because few thrifts but most banks hold intermediate-term investment securities. The average maturity of banks' investment portfolios is about twice that of thrifts' portfolios (four years compared to two years). To correct for those biases, we divide the sample into ranges of WAMs, ranging from 0 to 5 years to 20 to 25 years. The OTS model error is generally very high for Treasury portfolios but is generally relatively small for FRM:

Estimated errors from replacing eight buckets with WAMs, 1990 quarter four:			
Range for WAM in years	Median convexity error in basis points (1990 quarter one)		
	Fixed-rate 1-to-4-family mortgages and MBS (number of observations)	Other real estate (number of observations)	Investment securities (number of observations)
0-5	45.5 (39)	61.1 (498)	6.2 (2522)
5-10	92.3 (111)	136.4 (1137)	359.6 (163)
10-15	43.2 (925)	108.8 (884)	476.1 (62)
15-20	46.4 (1292)	135.9 (166)	369.5 (28)
20-25	30.9 (504)	56.2 (39)	70.9 (18)

The errors are highest in the intermediate WAMs, both because the convexity error is highest at intermediate maturities and because portfolio with intermediate WAMs tend to have the most widely dispersed instrument maturities. The errors are extremely large for investment securities, due to the frequency of barbell portfolios for thrifts. Barbell distributions may be more rare among banks; the call reports suggest that banks generally concentrate on intermediate-maturity Treasuries.

IV. Conclusion

From the OTS perspective as a thrift regulator, portfolios of fixed-rate amortizing instruments with more than 20 years to maturity, together with ARMs with less than five years remaining to repricing, are much larger proportions of balance sheets than are portfolios of nonamortizing instruments with intermediate WAMs. The information gained in the 1993 reporting change may be more valuable than the buckets that were sacrificed. However, even for amortizing instruments, the WAM-convexity error in the OTS model is significant in proportion to the banking agencies' proposed threshold sensitivity of 1 percent of assets.

For the average bank, long-term Treasuries and commercial real estate loans are more than 20 percent of assets, while 1-4 family fixed-rate mortgage instruments are less than 15 percent of instruments. For bonds and commercial real estate, the global WAM approach can produce large measurement errors. For example, if the WAM-convexity is 100 basis points for Treasuries and commercial real estate loans, and those loans are 20 percent of assets, the errors in estimated net-worth sensitivity will be about 20 basis points (less any WAM-convexity error relating to fixed-rate CDs and nondeposit borrowings plus any WAM-convexity error for the bank's other assets). And it appears that the WAM-convexity errors may approach 300 basis points for the commercial real estate loans and Treasuries held by a significant minority of the industry.

The bucket approach to maturity aggregation, in contrast, produces errors approaching 100 basis points only very rarely. Furthermore, those rare events can be prevented by using more buckets or weighted-average maturities within the current seven- or eight-bucket approach. Using within-buckets WAM would reduce the errors much more effectively than would doubling the number of buckets.

Appendix to Chapter One: Stochastic Processes and Feid's Error Estimates

Feid (1993) uses the seven buckets proposed for the banking agencies' IRR model, constructs hypothetical portfolios for which the interest-rate sensitivity is known with certainty, and calculates the maximum error in the estimation of the sensitivity of portfolio net worth that can result from assuming that the weighted-average maturity within each bucket equals the midpoint of that bucket. He does this by assuming that all of the assets within each bucket have the maximum maturity possible within that bucket, while all of the liabilities within each bucket have the minimum maturity possible for that bucket.

Feid finds that, even where the institution has no assets or liabilities of more than 3 years, the maximum error from bucket aggregation totals 1.2 percent of assets (given a 5 percent capital-to-asset ratio). Where the institution has assets and liabilities spread out evenly across the buckets, but still has no assets or liabilities of more than 20 years, the maximum error is 2.39 percent of assets.

Because such large errors call into question the usefulness of the model's results, we replicated Feid's paper (including the simultaneous valuation of both assets and liabilities), but replaced his deterministic maturities with stochastic maturities. In particular, we were interested in determining if random variation of within-bucket maturities could produce the same large errors that Feid proves can result from management exploitation. For all loan maturities, stochastic errors approach the size of the deterministic errors only when there are six or fewer financial instruments per bucket (42 instruments per institution). For the case with 10,000 instruments per bucket, stochastic processes can generate measurement errors of at most 20 basis points.

Chapter Two: Portfolio-Wide Coupon Levels

The OTS collects the weighted-average coupon for the portfolio of each type of instrument, while the banking agencies' (BA) model forgoes coupon information entirely. Coupon data have both instrument-specific and general importance. In this chapter, we analyze the general importance of coupon data for bottom-line accuracy, deferring the instrument-specific issues to the next chapter. To analyze the bottom-line importance, we simultaneously assess the errors on both the asset and the liability sides of the balance sheet.

I. Why the BA Approach Can Cause Errors

The quasi-duration approach used by the BA model actually uses coupons and discount rates as inputs for evaluating every instrument. However, rather than requiring banks to report their portfolio weighted-average coupons, the proposed model assumes coupons instead. The approach is to observe the banking system's "typical" net interest margin (NIM), taken to be 375 basis points. To choose a discount rate, flat term structures are assumed for both sides of the balance sheet, with all liabilities yielding 4.75 percent and all assets yielding 8.50 percent (except for FRM, where rates reflect current market rates of 7.5 percent for 20-to-30-year mortgages and 7.0 percent for shorter-maturity mortgages). Because the assumed discount rate equals the assumed coupons, all instruments are always at par.

If the BA model's explanation for a bank's NIM is inappropriate, or if a bank's instruments are not at par (coupons are not equal to discount rates), model errors result. While we can not determine how the errors from those two sources will interact, we can separately quantify the errors.

II. Errors That Result When the BA Theory of the NIM Is Wrong

When the BA model assumes flat yield curves, with all coupons on assets 375 basis points higher than all coupons on liabilities, it implies that maturity mismatching does not contribute to the typical bank's 375 basis point NIM. It is true that banks' practice of using asset yields to recapture administrative and default costs explains a significant part of the NIM, but for many institutions maturity mismatching also plays a role. In fact, for the thrift industry the match-funded NIM appears to be as close to zero as to the 375 basis points assumed in the BA model (the call reports do not include coupon-by-maturity information, and so are not adequate for estimating match-funded NIMs). Coupons for most of thrifts' short-term assets are in the 4 to 5 percent range, compared to 8 percent for long-term assets (coupons are substantially higher for credit-risky assets). Similarly, CD yields increase from 3 percent to 5 percent as CD maturities increase from 3 months to 36 months, with long-term liabilities yielding in the 7 percent range.

We quantified the error that might result from an inappropriate specification of the match-funded NIM by constructing a hypothetical bank with a 5 percent capital-to-asset ratio. The bank has $100 in assets and $95 in liabilities in each of the seven time "buckets" used by the BA model. This implies that the bank's maximum asset maturity is 30 years (we also construct banks with maximum maturities of both 20 years and 10 years), and that asset maturities equal the liability maturities. All instruments are initially at par. We assumed that the bank's asset coupons at each maturity are 250 basis points higher than the liability coupons (i.e., the match-funded NIM is 250 basis points instead of the 375 assumed by the BA model). We specified a yield curve that roughly corresponds to the present yield curve, rising from 3 percent for maturities of less than one year to 8 percent at the longest maturities:

Hypothetical banks' yields as function of maturities							
Maturity Bucket	1-3 months	3-12 months	1-3 years	3-5 years	5-10 years	10-20 years	20-30 years
Asset yields (%)	5.5	5.5	6.5	7.5	8.5	9.5	10.5
Liability yields (%)	3.0	3.0	4.0	5.0	6.0	7.0	8.0

Finally, we assume that all instruments are nonamortizing and options-insensitive.

If the average coupon differs between assets and liabilities, match-funding does not completely eliminate interest-rate risk. This is because the interest-rate sensitivity of an instrument's market values declines as the discount rate increases. Therefore, when interest rates rise, the value of our hypothetical bank's assets declines by a smaller amount than does the value of its liabilities, so its equity ratio increases. Conversely, when interest rates decline, the value of assets increases less than does the value of liabilities, so equity value declines. We report the results for the adverse declining scenario here.

For a bank that has assets and liabilities with maturities extending to 30 years, the 200 basis-point interest-rate decline causes equity to fall from 5.0 to 2.6 percent if the match-funded NIM is 375 basis points, but only to 3.8 percent if the match-funded NIM is 250 basis points. This means that assuming that the match-funded NIM is 375 basis points when the "true" match-funded NIM is 250 basis points produces a bottom-line estimation error of 120 basis points (3.8 percent minus 2.6 percent). Fortunately, the error is much smaller for banks with assets and liabilities of shorter maturities:

Post-shock equity ratio for hypothetical bank following a 200 basis point rate decrease (upsloping yield curve, 5% initial equity-to-asset ratio, all instruments initially at par):			
Maximum instrument maturity:	Post-shock equity ratios:		
	Match-funded NIM @ 375 bp (BA assumption)	Match-funded NIM @ 250 bp ("Truth")	Match-funded NIM @ zero
30 years	2.60%	3.77%	5.00%
20 years	3.82	4.30	5.00
10 years	4.55	4.70	5.00

For most banks, the maximum maturity of 10 or 20 years is probably most representative. First, for the bank with maximum maturities of 30 years, 3/7 or 42 percent of the assets have maturities of greater than 5 years (the three longest of the seven buckets are 5-10 years, 10-20 years, and 20-30 years). In contrast, the call reports show that the average bank has only 15 percent of assets at maturities exceeding 5 years. Hence, given our assumption of options-insensitive instruments, it appears that the BA coupon assumptions will probably only rarely result in errors approaching 100 basis points. However, our analysis to this point grants the BA assumption that all instruments are always at par.

We also repeated this exercise by comparing the bank' s sensitivity under various assumed match-funded NIMs and flat yield curves. The size of the error that results from assuming the wrong match-funded NIM is not materially affected by the assumed slope of the yield curve. Similarly, we found that error to be no higher for banks that are highly mismatched than for banks that have the same maturities for both assets and liabilities.

III. Instruments that Differ from Par

The BA assumption that all instruments are at par may be an excellent device given that the model forgoes coupon data, but will cause errors for instruments that are at either premium or discount. To see how large such errors might be in practice, we used the available data for banks and thrifts to indicate what the distributions of bank portfolio' s weighted-average coupons might look like. There appears to be substantial variation in those portfolio coupons. The range from the 10th percentile to the 90th percentile is as high as 500 basis points for such heterogeneous instruments as consumer loans, and about 150 to 200 basis points for homogeneous instruments such as 30-year original maturity FRM or Treasury securities. We use a range of plus-or-minus 100 basis points to represent the range across real-world portfolios.[7]

---

[7] Most of the coupon data is from the thrift industry' s Thrift Financial Reports. For banks portfolios of Treasury securities, we were able to use call report data to infer the interfirm coupon dispersions. To limit the sample to only one type of securities, we used only those banks that have more than 85 percent of their portfolios in Treasuries. From the set of

In principle, incorrect coupon assumptions produce only moderate sensitivity-estimation errors. Discounting a 25-year bond at an 8 percent BEY, varying the coupons from 7 percent to 9 percent causes the sensitivity to a 200 basis point shock to vary between 17.9 percent and 18.6 percent. That range is even more tight at shorter maturities.

Percentage Decline in value of Treasury Bonds at various coupons, for a discount-rate increase from 8 percent to 10 percent (BEYs):			
Maturity	7% Coupon	8 % Coupon	9% Coupon
5 Years	7.8	7.7	7.6
10 Years	12.8	12.5	12.2
25 Years	18.6	18.3	17.9

These sensitivity ranges characterize the error that results from violating the BA assumption that all instruments are at par. For a portfolio that is characterized by the 10-year instruments, the range of sensitivities is 60 basis points (12.8 percent minus 12.2 percent). Hence, provided that the BA model assumes a coupon that falls within the 10th-to-90th-percentile range of the industry's actual coupons, the error that results from incorrectly assuming that all instruments are at par appears unlikely to ever exceed 60 basis points as a percentage of total assets. For a portfolio that is characterized by 5-year instruments, that error appears unlikely to exceed 20 basis points.

It is difficult to interpret the significance of that apparently small error for individual banks. The BA error for not-at-par instruments may either compound or offset the error that results if the BA model inaccurately characterizes the match-funded NIM. When those two errors compound, the bottom-line estimation error approaches 40 basis points for banks with only short-term assets (15 basis points for the NIM-estimation error plus 20 basis points for the premium/discount error), and can approach 200 basis points for banks with long-term assets and liabilities. Unfortunately, we have been unable to devise a way to determine how often those errors will compound in practice.

---

banks that met that criterion, we chose only those banks that reported specific weighted-average maturities for their portfolios (we chose banks with portfolios with weighted-average maturities falling within specific ranges, e.g. 2.5 to 3 years.) For the banks that met both of those criteria, we observed the range for the banks' reported portfolio premiums. We then solved back for the range of coupons necessary to produce that range of premiums. This technique yields an estimated range of from 150 to 200 basis points between the 10th and 90th percentile of the banking' industry's coupons on Treasury portfolios.

IV. Conclusions

Deferring the relation between coupons and options sensitivity to the next chapter, it appears that foregoing coupon data will generally result in bottom-line errors that average less than 20 basis points. However, under particular circumstances, there may be bottom-line errors of more than 100 basis points.

We would prefer to have better data for assessing the frequency of those large errors. In particular, we would like to be able to better estimate the extent to which the potentially large errors on one side of the balance sheet (a) are prevalent, and (b) systematically cancel out potentially large errors on the other side of the balance sheet. Absent that data, we can not ensure that large errors (approaching 100 basis points) will not result from foregoing coupon data. However, it does appear that such large errors will seldom occur, except at banks with significant amounts of greater-than-10-year-maturity assets. (The call report data are inadequate for estimating how many banks hold such long-term assets.)

The lack of coupon data has provoked a great deal of criticism of the BA model. For example, Hugh Cohen of the Federal Reserve Bank of Atlanta (1994) estimates that a bottom-line error of (plus or minus) 335 basis points results from the BA approach to coupons and maturity (he does not decompose the source of that error into coupons versus maturity errors). Furthermore, he believes that those large errors will commonly result in practice, even for "conservative" banks. We have some analytical differences with Cohen, and do not endorse his conclusion. However, given the lack of data, it may be that the truth is somewhere between our optimistic assessment and his pessimistic conclusion.

Chapter Three: Coupons and Options-Sensitive Instruments

For assessing the importance of maturity and coupon data, we expressed errors as a "bottom-line" percentage of total assets, because those types of errors apply simultaneously to both assets and liabilities. For the remainder of this report, we analyze errors that apply only to specific instruments. These errors do not necessarily increase bottom-line errors; in some cases instrument-specific errors cancel other errors, leaving the bottom-line errors unchanged, while in other cases those errors compound each other, causing the bottom-line errors to balloon. However, regardless of the effect on bottom-line accuracy, instrument-specific errors will inappropriately penalize or reward portfolio choices that have different implications for "true" interest-rate risk than for the regulators' measure of interest-rate risk.

The two instruments for which coupons have special importance are fixed-rate residential mortgages (FRMs) and core deposits. For these instruments, the coupons help determine the strength of the incentives to prepay or withdraw early. By motivating prepayments, coupons help determine the instruments' effective maturities, which determine interest-rate sensitivity. This phenomenon is potentially important for any long-term fixed-rate instrument, but except for FRMs and core deposits the financial markets generally impose "prepayment penalties" that generally remove the relation between coupons and interest-rate sensitivity.

For FRMs, we analyze the importance of coupon data at two distinct levels of detail. First, we analyze the importance of knowing the weighted-average coupon for a given portfolio. We then consider the importance of knowing the dispersions of coupons within that portfolio, because any given WAC can result from many different combinations of coupons.

I. Portfolio Weighted-Average Coupon Levels (WACs).

I.a. Coupons and FRMs

To see how coupons can determine the interest-rate sensitivity of FRMs, consider the way that the OTS evaluated prepayments during the low interest-rate environment of mid-1993. Almost all FRM borrowers had a strong incentive to prepay, because interest rates were at the lowest levels in two decades. If a FRM had a coupon that was relatively high, the borrower's incentive to prepay was expected to weaken only slightly if rates rose by 200 basis points, because those relatively high coupons would still remain above market rates. However, for FRM with relatively low coupons, a rate increase of 200 basis points would cause prepayments to fall quite sharply, because market rates would then be higher than the mortgages' coupons. Hence, FRM portfolios' effective maturities were expected to increase when rates increased, and that effect was expected to be much more pronounced for portfolios with low coupons than for portfolios with high coupons.

This effect causes portfolios with low coupons to have longer effective maturities than do portfolios with high coupons. Because instruments with long effective maturities also have highly rate-sensitive market values, FRM portfolios with relatively low WACs have much more sensitivity than portfolios with high WACs. For a 30-year original-maturity whole-loan portfolio with an 8 percent WAC--roughly the thrift industry's 10th percentile of FRM WACs as of mid-

1993--the OTS estimates that a 7.6 percent decline in value would result for a 200 basis-point interest-rate increase. For the 90th percentile of the thrift industry's WACs (about 9.25 percent), the estimated decline in value is only 5.2 percent. Hence, interportfolio differences in the WACs cause a difference in FRM sensitivity of over 200 basis points in the OTS model.
Because the BA model assumes that the coupons on all FRMs equal the current market rate, it estimates the same sensitivity for all FRM portfolios of given maturity distributions. In the NPR, the assumed coupon for the portfolios described above is 7.5 percent, and the estimated decline in value for the 200 basis-point interest-rate increase is 9.4 percent.

We used a "constant prepayment rate" (CPR) model that we developed using Federal Home Loan Mortgage Corporation prepayment data to independently test for the importance of coupon information (Benston, Carhill and Olasov, 1992). The results from that model correspond to those of the OTS model concerning the importance of the portfolio WACs.

I.b. Coupons and Core Deposits

Portfolio coupons are also important in the OTS assessment of core deposits. As the coupon on the various types of core deposits is varied from the thrift industry's 10th percentile to its 90th percentile, the estimated sensitivities to the 200 basis point shock change by about 100 basis points.

We cannot independently replicate the OTS result for core deposits. There is as yet no consensus about the proper technique for evaluating the interest-rate sensitivity of core deposits.

II. Intraportfolio Coupon Dispersions.

For FRMs and fixed-rate nondeposit borrowings, the OTS augments the instruments' WAC with detailed information on the balances within each of several coupon ranges, which increase from "Less Than 8%" to "11.00% & Above" in increments of 100 basis points. The OTS requires this detail because, for options-sensitive instruments, aggregating coupons can result in estimation error.[8]

To see why coupon dispersions can be important, consider an example of two portfolios. Both have WACs of 8 percent, but the first consists only of mortgages with 8 percent coupons while the second is comprised of equal shares of 7 percent and 9 percent coupons. The market might expect that prepayments on mortgages with coupons below 8.5 percent would fall nearly to zero if interest rates rose by 200 basis points, while prepayments on 9 percent mortgages would fall only to 20 percent per year. Hence, even though the two portfolios have the same WACs, a rate increase of 200 basis points drives the expected prepayments on the first portfolio to zero, while the expected prepayments on the second fall only 10 percent (the 20 percent prepayment rate multiplied by the 50 percent of the portfolio with WACs at 9.0 percent, plus 0 percent prepayment multiplied by the 50 percent of the portfolio with WACs at 7.0 percent.)

---

[8] Aggregation generally produces estimation error, except for linear functions. Interest-rate sensitivities are linear in the coupon if and only if the payment structure is independent of the discount rate:

$PV = COUP((1-(1+i)^{-t})/i)$; $\delta COUP/\delta i = 0 \Leftrightarrow \delta^2(\delta PV/\delta i)/(\delta COUP)^2 \equiv 0$.

That example is illustrative but is also highly simplified. In practice, the effect of coupon dispersions on expected prepayments is highly complex. For some portfolios, coupon dispersions have a major effect on the estimated prepayments, while for other portfolios the effect is very small. This is reflected in the OTS' estimated market-value sensitivity to the 200 basis point changes in interest rates. For perhaps 50 percent of portfolios, the OTS model produces roughly the same results either with or without taking account of coupon dispersions. For most of the remainder, taking account of the dispersions changes the sensitivity by around 40 basis points. For a small minority, acknowledging coupon dispersions can change the estimated sensitivity by over 100 basis points.

When we attempt to replicate the OTS results for coupon dispersions, we obtain the somewhat stronger result that recognizing the effect of coupon dispersions usually changes the sensitivity estimates by 100 to 200 basis points. We discussed this issue with the OTS modelers. Their view is that the relation between prepayments and coupons varies systematically over time. In contrast, the Benston/Carhill/Olasov model treats that temporal variance as random. The OTS believes that, in the current environment, ignoring FRM coupon dispersions will produce errors of 100 basis points or more only for a minority of institutions. However, the OTS expects that, in other interest-rate environments, ignoring dispersions could produce those large errors for a majority of institutions.

For the nondeposit borrowings, the coupon dispersions had no effect on the estimated sensitivity in the OTS model. We were able to replicate that finding on our own models. Most thrift borrowings are from the Federal Home Loan Bank System, and most have prepayment penalties that remove the institution's incentives to prepay when market rates of interest decline. The coupon dispersions on nondeposit borrowings would become important only if a bank had substantial borrowings that are either callable or puttable.

III. FRM Errors and Bottom-Line Errors

Given that the BA approach to FRMs can produce sensitivity-estimation errors exceeding 200 basis points, it is useful to know how many banks have extensive FRM holdings. Including both MBS and portfolio loans in FRM, the median bank holds about 12 percent of its assets in FRM portfolios. About 2600 banks, or 25 percent of the banking system, have as much as 20 percent of their assets in FRMs, and 500 banks have as much as 30 percent of their assets in FRMs. (These numbers all increase if collateralized mortgage obligations (CMOs) are included among FRMs.) Given the BA model's large errors in measuring the sensitivities of FRMs, and the large number of banks with significant FRM holdings, it appears that forgoing coupons on FRMs will cause the BA model to improperly assess many banks' interest-rate sensitivity.

The importance of the problem for the bottom-line error depends of the share of assets in FRM. If a bank holds 12 percent of its assets in FRMs, and the sensitivity-estimation error is 200 basis points, then that error will equal 25 basis points as a percentage of total assets (200 bp x 12%). For a bank with 40 percent of its assets in FRMs, that error would be 80 basis points as a percentage of total assets. In some cases, those errors will offset other errors at the bottom line, but in some cases those errors would compound with other errors.

IV. Conclusions

Both interest-rate sensitivities and market values fluctuate considerably over the range of real-world FRM portfolio WACs, so that data on WAC levels appear indispensable for modelling the interest-rate sensitivity of FRM portfolios. The evidence is less clear with respect to FRM coupon dispersions. In the current environment, we know that errors of over 100 basis points will occasionally result if those dispersions are ignored, and that errors of over 40 basis points will be common. In other environments, errors of 100-200 basis points could be common if coupon dispersions are ignored.

For core deposits, the importance of coupon data is more difficult to rigorously document. Our judgement is that a better understanding of how to model the interest-rate sensitivities of core deposits is now evolving. Those new models rely on both current coupons and coupon histories.

Chapter Four: Evaluating Caps on Adjustable-Rate Instruments

In Chapter Three, we saw that the interest-rate sensitivity of FRM portfolios varies greatly with relatively small changes in their coupon distributions. In this chapter, we look at several information items that the OTS model uses in evaluating adjustable-rate residential mortgages (ARMs).

Estimating interest-rate sensitivity is much more complex for adjustable-rate instruments than for fixed-rate instruments. This greater complexity can cause larger estimation errors for adjustable-rate loans than for fixed-rate loans, even though the latter generally have greater interest-rate sensitivity. Hence, for any given error tolerance, modelling adjustable-rate loans requires the largest amount of information.

I. Information Differences Between the OTS and BA Models.

I.a. The OTS Approach

Because neither adjustable-rate commercial loans or consumer loans are a large part of thrift portfolios, the OTS focusses on adjustable-rate residential mortgages (ARMs). Thrifts segregate their ARM portfolios both by the index and by period used for the loans' "reset" (aka "repricing," the length of time between coupon adjustments). There are three categories of "current-index" (Treasury) ARMs: one-to-six-months reset period, seven-months-to-two-years reset period, and two-to-five-years reset period. There are two categories of "lagging-index" ARMs: One-month reset, and 2-month-to-five-year reset.[9] For each category the following items are collected: Balances at "teaser" (below-market) coupons; weighted-average margin above the index; weighted-average coupon, remaining maturity, and time remaining to "reset;" and the proportion of the portfolio that has coupons falling within various distances to the loans' lifetime and periodic interest-rate caps and floors. For adjustable-rate commercial and consumer loans, only a subset of that information is collected.

The original (1984-1989) OTS model collected only time to repricing and coupon information, essentially the same treatment as in the proposed BA model. At that time, it was widely believed that ARMs were a solution to the interest-rate risk inherent in FRMs.

The OTS' current understanding is much different. It appears that the 1984-1989 OTS model significantly understated the interest-rate risk of ARMs. This created incentives for thrifts to underprice ARMs relative to FRMs in their residential mortgage portfolios, and probably contributed to the widespread substitution of ARMs for FRMs in thrifts portfolios: ARMs were essentially zero percent of assets in the early 1980s, but increased to over 40 percent of assets by 1993, while FRMs were falling from about 70 percent of assets to only 30 percent. That

---

[9] The "lagging-index" ARMs are sometimes called "COFI" ARMs, because most are indexed to the thrifts' Cost-of-Funds Index developed by the Federal Home Loan Bank of San Francisco. Changes in that index usually lag changes in other interest rates.

substitution, in turn, is associated with a moderate increase in the thrift industry's rate of failure and with reduced thrift profitability (Benston, Carhill and Olasov, 1991; Getman, 1989).

To correct that situation, the OTS ARM model has been expanded twice, first in June 1989 to incorporate information about lifetime caps and ARM indices, and then in 1993 to its present form.

I.b. The BA Approach

In contrast to the detailed information collected for the OTS model, the BA model uses only the time remaining to coupon reset and reset margins.[10] This is potentially an important limitation of the BA model, because adjustable-rate loans are as important in the banking industry as ARMs are in the thrift industry. Adjustable-rate loans constitute over 50 percent of all bank loans, and about 28 percent of total assets. Adjustable-rate investment securities constitute about 12 percent of bank securities, and about 2 percent of assets. Thus, almost one-third of bank assets are adjustable-rate commercial, consumer, and residential instruments.

Over 70 percent of banks' adjustable-rate instruments have coupons that adjust instantly to changes in market rates of interest. In the jargon, such loans have zero "reset periods." The call report does not explicitly separate the adjustable-rate loans by loan types, but we believe that most commercial and industrial loans have zero reset periods. If that is true, then circumstantial evidence suggests that the remaining 30 percent that have nonzero reset periods are roughly evenly divided between ARMs, consumer loans (such as adjustable-rate second mortgages), and commercial real estate loans.

A disproportionate share of adjustable-rate instruments are held by the largest banks, as the median share of assets in adjustable-rate instruments is about 20 percent rather than the aggregate 30 percent. About 5 percent of banks hold more than 50 percent of their assets in adjustable-rate instruments.

We lack data on the share of banks' adjustable-rate loans that have either periodic or lifetime caps. However, interviews with various commercial lenders indicate that caps are not uncommon on adjustable-rate commercial loans. For thrifts, about 90 percent of ARMs have lifetime caps, and about 90 percent have periodic caps. The data on commercial real estate loans are incomplete, but indicate that a similar proportion of thrifts' commercial real estate loans have lifetime caps. Thrifts do not report caps for other commercial or consumer adjustable-rate loans.

II. The Relation Between Model Inputs and Estimated Sensitivities

The method we use is to begin with a very simple ARM, with no caps or floor, sequentially vary the information input, and observe the change in the OTS' estimated sensitivities. Because most of the information items used by the OTS are not collected at all by the BA, any changes in the

---

[10] In the BA model, ARMs within 100 basis points of lifetime caps are treated as fixed-rate loans. In our analysis, all of the ARMs are more than 100 basis points from the lifetime caps, and so would be treated as ARMs without caps by the BA model.

OTS sensitivity that result from changes in the information inputs represent model differences between the BA and the OTS.

Analyzing caps requires an explicit treatment of prospective interest-rate volatility, and most models employ a Monte Carlo simulation. We have not developed and published a Monte Carlo model. For an independent analysis of the OTS model for ARMs, we rely on the work of Schwartz and Tourus, who develop a Monte Carlo model that uses the same information inputs as the OTS (Schwartz and Tourus, 1991). The OTS and Schwartz and Tourus models roughly agree about quantitative marginal effects of the information inputs that we describe here.

II.a. Coupons and Interest-Rate Sensitivity

We varied the weighted-average coupons (WACs) on the portfolios evaluated by the OTS and found that, within the current range of interindustry variance in WACs, the portfolio WACs do not affect the estimated sensitivity to a 200 basis-point shock. Hence, coupon information does not appear to be important for estimating the market-value sensitivity of ARMs.

II.b. Lifetime Caps

Lifetime caps are crucial to evaluating ARMs. However, the effect of lifetime caps on interest-rate sensitivity varies with several other factors: the ARM's periodic caps and floors, its lifetime floors, its maturity, its coupon and reset margin, and the current interest rate environment. To focus on lifetime caps, we specified an ARM portfolio that had lifetime caps but not periodic caps, and was typical in other respects. This portfolio is useful for illustrating the effect of the interest-rate environment in determining the importance of lifetime caps.

In the mid-1993 interest-rate environment, the OTS estimated that an ARM portfolio with no lifetime or periodic caps would decline in value by 1.5 percent of par (150 basis points) in the up-200 interest-rate shock. The BA estimated that the same portfolio would decline in value by about 180 basis points. None of the information items that we discuss below would change that BA estimate, but all change the OTS estimates substantially. (In the BA model, ARMs within 100 basis points of lifetime caps are treated as fixed-rate loans. In the following analysis, all of our ARMs are more than 100 basis points from the lifetime caps, and so would be treated as ARMs without caps by the BA model.)

About 90 percent of all ARMs have lifetime caps. When the loans are initially issued, these caps are typically 500 basis points above the loan's contract rate. If rates subsequently decline, as has occurred over the last few years, the lifetime caps become progressively less important. Conversely, if market interest rates and the portfolio coupons begin to move upward, the caps become more important. The case of a given one-year ARM with lifetime caps but no floors or periodic caps, a 28-year remaining maturity, and otherwise typical characteristics illustrates that point:

OTS' estimated sensitivity of typical ARM with 28 years to maturity:					
Distance of current coupon from lifetime cap (basis points):	- ∞	-800	-600	-400	-200
(OTS') basis point decline in value for 200 bp rate increase:	170	180	220	400	780

As market rates rise above the cap (so that the ARM's coupon reaches the cap), the estimated sensitivity asymptotically approaches that of a 30 year FRM (about 10 percent for a 28-year remaining maturity, depending on expected prepayments).

For real-world portfolios with typical characteristics (as opposed to the single ARM presented in the table), the difference between the OTS and BA sensitivity estimates are about 50 basis points in the current environment (230 basis points in the OTS model minus 180 basis points in the BA model). Following an increase in interest rates, a lender might find that one-half of the same portfolio was within 300 basis points of its lifetime cap, while the other one-half was within 150 basis points of its lifetime caps. At that point, the OTS estimated market-value sensitivity to the 200-basis-point increase would be about 500 basis points. Since the BA estimate would remain at 180 basis points, the model difference at that point in the rate cycle would be 320 basis points.

The Schwartz and Tourus analysis is consistent with that of the OTS, and options-pricing theory in general suggests that lifetime caps will have a large effect on the interest-rate sensitivity of an ARM.[11] We conclude that the 50-to-320-basis-point difference between the OTS and BA models represent a BA model error for the case of ARMs with lifetime caps but no floors or periodic caps.

---

[11] Prices for 5-year interest-rate caps on 3-month LIBOR are reported regularly in *Swaps Monitor*. In the first six months of 1994, 3-month LIBOR increased from 3.35 percent to 4.80. Over the same period, the price of a newly issued 5 year cap with a strike price of 7.0 percent increased from 1.66 percent of notional to 4.14 percent of notional. Similarly, the Bloomberg reports showed that ARMs MBS fell from 3 to 7 percent in the first half of 1994. Though changing volatility estimates and the steep yield curve also contributed, the magnitude of the 1994 increase in caps prices is consistent with the OTS and Schwartz and Tourus predictions about interest-rate sensitivity.

Lifetime caps can be even more important for adjustable-rate commercial real estate loans (the only other adjustable-rate loan for which the OTS collects information on lifetime caps) than for ARMs. For commercial mortgages, adding a cap at a distance of 150 basis points from current market rates causes the sensitivity to rise from 0.3 percent to 12.1 percent. This extreme decline results because in that rate environment, lifetime caps essentially convert the adjustable-rate commercial real estate loans into fixed-rate loans. Since those loans often have long maturities and nonamortizing payment structures, their market values can be even more rate sensitive than the market values of FRMs.

II.c. Periodic Caps

We evaluated the importance of periodic caps both in a portfolio without lifetime caps and then in a portfolio with nearly binding lifetime caps. In an otherwise typical portfolio without lifetime caps, the OTS model projects that a 200 basis point rate increase would cause a decline of about 150 basis points in the value of a portfolio with no periodic caps, a decline of about 260 basis points in a portfolio with 200 basis point periodic caps, and a decline of about 500 basis points in a portfolio with periodic caps of 100 basis points. If the same portfolio has the nearly binding lifetime caps discussed above, the periodic caps increase the sensitivity by only about 50 basis points, to about 550 basis points. As before, the BA model projects a 180 basis point sensitivity for this ARM portfolio, so ignoring periodic caps creates model differences of between 30 and 370 basis points, depending on the lifetime caps.

Schwartz and Tourus generally focus on lifetime rather than periodic caps, but their limited analysis of periodic caps is consistent with the results of the OTS model, insofar as confirming that periodic caps have a significant effect on the sensitivity of ARMs. However, we have not independently replicated the OTS' specific quantitative assessment.

II.d. Reset Margin

"Reset margin" refers to the gap between an adjustable-rate loans' coupon and its index rate. For example, a floating-rate loan might have a coupon that equals the prime rate plus 100 basis points; the index is the prime rate and the margin is 100 basis points. The OTS collects the weighted-average margin for all types of adjustable-rate loans.

We varied the reset margin for several kinds of the adjustable-rate commercial-loan portfolios that the OTS evaluated. Varying the margin causes the estimated interest-rate sensitivity to vary by only 0-30 basis points. Subsequent investigation suggests that, in general, the reason for that change in sensitivity was that varying the reset margin permanently varies the instruments' coupons, which changes interest-rate sensitivity for the reasons described in chapter 2 above.

While unimportant in the absence of caps, the reset margin can interact with lifetime and periodic caps to have an important effect on the estimated sensitivity. For example, given a one-year Treasury ARM with both periodic and lifetime caps, increasing the reset margin from 100 basis points to 200 basis points can increase the OTS' estimated market-value sensitivity by as much as 350 basis points, depending on the ARM's other characteristics.

II.e. Remaining Maturity

For both commercial and residential adjustable-rate loans, the OTS collects both weighted-average remaining maturity and time remaining to reset, while the BA model collects only time remaining to reset. Remaining maturity can have significant effects on sensitivity under either of two conditions. First, if the instrument has a long reset period, the remaining maturity becomes a prime determinant of sensitivity. For example, if rates rise by 200 basis points, a 4-year-to-reset, adjustable-rate, options-insensitive, amortizing loan with a remaining maturity of 30 years will decline in value by 600 basis points. If the same loan has a remaining maturity of only 5 years, it will decline in value by only 400 basis points.

While that example suggests that ignoring remaining maturity can lead to large estimation errors, the effect of remaining maturity declines rapidly as the reset period shortens, becoming negligible for reset periods of one year or less. Both call report and TFR data indicate that only about 10 percent of adjustable-rate loans have reset periods in excess of one year.

The second condition under which remaining maturity becomes important is when the lifetime caps become binding or nearly binding. As that happens, an adjustable-rate loan begins to take on the characteristics of a fixed-rate loan, so remaining maturity becomes a key determinant of sensitivity. In the OTS model, if the current coupon on an ARM is 400 basis points below the lifetime cap, increasing the maturity from 20 to 30 years increases the sensitivity by about 20 basis points. If the ARM is 200 basis points below the lifetime cap, that increase in maturity increases the sensitivity by about 80 to 100 basis points. This result holds regardless of the ARM's time to reset.

This analysis suggests that in most interest-rate environments, the remaining maturity of adjustable-rate loans has little value as a datum, unless a bank makes adjustable-rate loans that have long reset periods. However, in interest-rate environments where lifetime caps are beginning to come into play, the remaining maturity becomes an important determinant of sensitivity for even short-term-to-reset adjustable-rate loans. In other words, as the probability that lifetime caps will become binding increases from zero to one, remaining maturity progressively replaces term to reset in determining interest-rate sensitivity.

III. Conclusions

The values of adjustable-rate instruments with caps are very sensitive to interest-rate changes. While conclusive data are not available, the available data suggest that banks issue caps on the majority of their adjustable-rate residential loans, and perhaps on their adjustable-rate commercial loans as well.

Unfortunately, information that is irrelevant in the absence of caps becomes crucial in the presence of caps. As caps come into play, every item that the OTS collects can have major effects on the interest-rate sensitivity of the values of adjustable-rate loans.

If the regulatory model fails to account for the importance of caps on adjustable-rate loans, there will be three major consequences. First, a strong artificial regulatory incentive will be created for risk-seeking banks to issue caps on their adjustable-rate loans, because such loans create considerable interest-rate risk but will not explicitly require capital funding. Second, even at banks that are risk averse, the regulators may appear to endorse the myth that adjustable-rate loans have no interest-rate risk. Third, because adjustable-rate loans are a large part of banks' assets, a substantial bottom-line error will exist in the regulatory interest-rate-risk assessment. At the median, adjustable-rate instruments are about 20 percent of bank assets; unless offset by other errors, an error of 300 basis points as a percentage of par would translate into a bottom-line error of 60 basis points as a percentage of total assets.

Chapter Five: The Effects of Miscellaneous Information Items

The preceding chapters analyzed four specific controversies about the information parsimony of the BA model. However, as we described in the introduction, there are several other pieces of information that are used by the OTS model but not by the BA model. In this chapter, we measure the model differences that result from those information items, by varying the portfolio characteristics within the range of the inter-firm variance reported in the Thrift Financial Reports.

I. Amortization Structure

Financial instruments can be fully amortizing, partially amortizing, nonamortizing, or (more rarely) negatively amortizing. (Partially amortizing or nonamortizing loans are sometimes referred to as "balloons.") Roughly speaking, the BA model assumes the consumer loans and residential mortgages are fully amortizing, while the various types of commercial loans are nonamortizing. In contrast, the OTS requires thrifts to segregate commercial real estate (CRE) loans between amortizing versus nonamortizing loans, though it assumes that all construction and all commercial and industrial (C&I) loans are nonamortizing.

It is usually necessary to know whether a loan is amortizing or nonamortizing in order to determine its interest-rate sensitivity. As the table below shows, a 200-basis-point upward shift in the yield curve causes declines in value that vary greatly, depending on whether the loan is amortizing or nonamortizing (we assume options-insensitive, zero-prepayment instruments, with semiannual payments):

Decline in value as percent of par, for rate increase from 8 percent to 10 percent BEYs:						
Remaining maturity or time to repricing:	1 year	2 years	4 years	7.5 years	15 years	25 years
Amortizing	1.4	2.3	4.0	6.4	11.1	15.0
Non-amortizing	1.9	3.5	6.5	10.4	15.4	18.3

The current call report does not distinguish between amortizing and nonamortizing loans. It does report that about 20 percent of banks' assets are in commercial lending, split roughly equally between relatively long-maturity CRE and relatively short-maturity C&I loans.

I.a. Commercial and Multi-Family Real Estate Loans

The Thrift Financial Reports indicate that, for thrifts, about 60 percent of CRE loans are fully amortizing, so if we assume that banks' CRE portfolios are similar to thrifts', we can comment on the significance of the BA model's assumption that all CRE loans are nonamortizing. Of the thrifts' amortizing CRE loans, about 70 percent have maturities or times to reset of 2 years or less, so we estimate that an average of about 4 percent of bank assets are in short-term amortizing CRE loans (70 percent of amortizing CRE, which are 60 percent of total CRE, which are 10 percent of total assets). For those loans, the BA model would overstate sensitivity by 0 to 120 basis points, an estimation error that would contribute only 0 to 5 basis points to the bottom-line estimation error as a percentage of total assets (4 percent of assets multiplied by the maximum 1.2 percent estimation error). If we suppose a four-year maturity/time-to-reset for the remaining 30 percent of amortizing CRE, for which the BA model would overstate sensitivity by 250 basis points, an additional 5 basis points of bottom-line estimation error would result.

These results suggest that, for the average bank, ignoring the payment structure of the CRE portfolio would make only a small contribution to the bottom-line estimation error. However, for banks that concentrate in amortizing CRE (or amortizing C&I loans, if there are such animals), the BA model would create a moderate disincentive for extending amortizing loans, since such loans have lower interest-rate risk but receive the same regulatory treatment as do nonamortizing loans.

I.b. FHA-VA FRM

One reason the OTS decided to forego detailed maturity information was to expand the detail devoted to loan types without lengthening the reporting form (see Chapter 1). One specific place that the OTS chose to increase the detail on loan type was to distinguish 30-year FRM between those guaranteed by the FHA-VA and so-called "conventional" guarantors.

The reason for distinguishing between FHA-VA and conventional FRMs is that the former are assumable, and so have different prepayment patterns than the latter. (As we saw in chapter 2, both the interest-rate sensitivity and base-case market values of FRMs are very dependent on their expected prepayments.) When interest rates rise, borrowers would prefer not to prepay, while lenders would prefer that their borrowers do prepay. With most conventional loans, borrowers who sell their homes must prepay regardless of the interest-rate environment; this baseline prepayment rate is about 5 percent per year. However, with assumable FRMs, that 5 percent need not prepay. Hence, in rising interest-rate environments, the effective maturity of assumable loans increases more rapidly than does the effective maturity of conventional loans, and this causes FHA-VA FRMs to decline in value by a greater amount than do conventional FRMs.

To test for the importance of this datum, we changed the percentage of FHA/VA mortgage-backed securities (MBS) in one of our hypothetical portfolios from 30 percent --the industry average-- to 100 percent. The OTS estimates that a portfolio with 30 percent share of FHA/VA, and otherwise typical characteristics, would decline in value by about 700 basis points if rates increased by 200 basis points. A portfolio composed entirely of FHA/VA MBS would decline by about 800 basis points. Hence, this information datum creates a model difference of about 100 basis points.

While the economic argument for the extra sensitivity of FHA/VA makes sense, we lack the data to independently verify that the effect is as large as the OTS model suggests. The OTS derives its prepayment projections from the Bloomberg system, which reports a purported consensus of the prepayment projections of a small number of Wall Street firms. Independent verification would require prepayment history for both conventional and assumable mortgages.

MBS comprise about 10 percent of the average bank's assets, so if banks' portfolios look like thrift portfolios, FHA/VA MBS average about 3 percent of bank assets. Thus, the one-percent-of-par-value model difference would translate into 3 basis points of "bottom-line" interest-rate sensitivity. For the thrift industry, about 10 percent of MBS holders specialize entirely in FHA/VA, and the bottom-line errors would be correspondingly higher to the extent that those specialists hold significant amounts of FHA/VA MBS. Only about one percent of portfolio lenders specialize in FHA/VA loans, apparently because it is difficult to focus one's marketing efforts entirely on FHA/VA-qualified borrowers.

It appears that ignoring the distinction between FHA/VA and conventional mortgages will create moderate artificial incentives for risk-seeking lenders to extend those loans. However, such loans will cause at worst moderate errors in estimating banks' bottom-line sensitivity, and those errors only rarely.

II. Basis Risk

Different interest rates change by different amounts at different times. For example, T-Bill rates can decline while rates on core deposits and CDs remain unchanged. Similarly, rates on long-term Treasury Bonds can increase while rates on Treasury Bills are unchanged. When either or both events happen, banks that own adjustable-rate loans or off-balance-sheet instruments indexed to the Treasury rate suffer economic losses. That risk is called basis risk; the first type of basis risk depends on the instrument used for the basis, while the second depends on the point of the term structure used.

To measure such risk, the OTS requires thrifts to report the index most commonly used for the various types of adjustable-rate loans. In contrast the BA model ignores the index, except that banks are required to assign all of their so-called "lagging-index" ARMs to the 3-5 year time bucket, regardless of the lagging-ARM's actual time to repricing.

We tested for the importance of this variable in the OTS model by varying the indices for a number of adjustable-rate loans. For most kinds of loans, varying the index made almost no difference in estimated sensitivity. The largest effect was on ARMs; lagging-index ARMs declined by about 20 basis points more than current-index ARMs, except when (nearly) binding lifetime caps came into play. In that case, lagging-index ARMs decline by 100 basis points less than do current-index ARMs. In contrast, the BA model assigns considerable significance to the index for ARMs. In their model, the values of all lagging-index ARMs decline by 300 basis points when rates increase. In the OTS model, lagging-index ARMs decline by about 150 basis points absent lifetime caps and by about 450 basis points with (nearly) binding lifetime caps.

We have not independently verified either model's results about the importance of basis risk. The BA treatment of lagging-index ARMs is admittedly *ad hoc*. The OTS has yet to publish a comprehensive description of its approach to basis risk.

Given that caveat about our inability to verify either model's results, we tentatively conclude that basis risk can be ignored for on-balance-sheet instruments without creating significant errors in estimating interest-rate sensitivity. However, it would be inadvisable to extend that conclusion to off-balance-sheet instruments, where the basis often determines the entire cash flow.

III. Original Maturity

The OTS collects data on original maturity for all FRMs and for CDs. Original maturity is supposed to affect the retention rate on CDs and the prepayments on FRMs. However, we found that varying the original maturity had negligible effects on the estimated sensitivity of CDs.

For FRM with given remaining maturity and coupons, the OTS expects higher baseline prepayments for higher original maturities. As a result, the OTS projects that a 7.5 percent coupon, 30-year original-maturity FRM with a 180-month remaining maturity would decline in value by 8.7 percent in the up-200 scenario. An otherwise identical FRM but with 15-year original maturity would decline by 9.4 percent in the same scenario.

It is not clear how to specify the relation between coupons on 15-year mortgages, coupons on 30-year mortgages, and current market rates. The OTS relies on the Bloomberg system, which in turn relies on a survey of market participants, who do not reveal their prepayment methodologies. Hence, the greater sensitivity that the OTS attaches to 15-year original-maturity FRM does not appear to be independently verifiable.

IV. Conclusions

All of the miscellaneous items appear to be relatively unimportant with regard to estimating the bottom-line sensitivity of most banks' on-balance-sheet instruments. However, either the payment structure of commercial loans or the assumability of mortgages might be important for a small minority of banks. Given a replicable source of data, we would anticipate verifying the OTS contention that the original maturity of FRM is an important datum.

Chapter Six: Caveats and Conclusions

For most issues, the analysis to this point has been able to use either third-party judgements or original modelling to discriminate between the two models. To conclude, we discuss two major areas in which such discrimination was not possible, and discuss what our work suggests about interest-rate-risk modelling.

I. Core Deposits

For financial intermediaries, determining the interest-rate sensitivity of "core deposits" is essential for modelling interest-rate risk. Core deposits fund an average of about one-half of all bank assets. The deposits have a contract maturity of zero, but it is universally recognized that the all-in cost of core deposits exhibit at least some stickiness with respect to market rates of interest, so that core deposits have positive effective maturity.

While all agree that core deposits have positive effective maturity, there exists no consensus on the actual maturity that should be assigned to any given type of core deposit. For example, to help lobby the regulators concerning the proposed BA model, the New York Clearing House surveyed its eight members concerning the interest-rate sensitivity of their demand deposits.[12] The estimates of the market-value decline that would result from a 200 basis-point rate increase were essentially uniformly distributed from 1.6 percent to 9.5 percent. We observed similarly wide ranges of estimates for other types of core deposits in the proprietary disclosures that banks make to the regulators as part of the supervision process.

The current lack of consensus on the rate sensitivity of core deposits may be reduced as banks devote more attention to interest-rate-risk modelling. One reason why present estimates show such a broad range is that most banks' core-deposit models focus on acquisitions rather than rate sensitivity. However, some banks attempt to directly model the interest-rate elasticity of their deposits. Most such efforts are highly proprietary, but Tempo Savings Bank has published its analysis, and the most sophisticated proprietary model we have seen produces conclusions that are very similar to those published by Tempo (Stroh 1993). This suggests that one reason for the lack of consensus on core deposits might be that different banks apply incompatible statistical approaches when measuring their deposits' interest-rate risk.

Recent academic work shows promise of rigorously documenting the rate sensitivity of deposits (Hutchison and Pennachi, 1993; Hutchison, 1993; O'Brien, Orphanides, and Small, 1994). That work suggests that sensitivities may be highly variable across institutions, though the evidence at this point is not sufficient to distinguish estimation error from true institution specificity. If core

---

[12] Letter from Jill M. Considine, President of the New York Clearinghouse, to Karen Carter, Office of the Comptroller of the Currency, dated October 28, 1993. The eight members of the clearinghouse are: The Bank of New York; the Chase Manhattan Bank, N.A.; CitiBank, N.A.; Chemical Bank; Morgan Guaranty Trust Company of New York; Bankers Trust Company; Marine Midland Bank, N.A.; United States Trust Company of New York; National Westminster Bank USA; European American Bank; and Republic National Bank of New York. The eight banks that participated in the survey were not identified.

deposits are shown to have highly institution-specific characteristics, the regulators will find themselves in a dilemma between imposing inappropriately generic core-deposit assumptions or encouraging endless appeals from banks concerning their measured interest-rate risk.

II. Mortgage and Off-Balance-Sheet Derivatives

Despite the extensive options-pricing literature, we have found few pieces that directly address the interest-rate sensitivity of derivative products. The BA model essentially ignores the idiosyncratic characteristics of given derivatives. The OTS does value derivatives, and our work with their model suggests (not surprisingly) that the interest-rate sensitivities of derivatives are extremely dependent on those idiosyncracies. Accordingly, for complex derivatives, the OTS requires institutions to report their own sensitivity estimates (for simple positions, the institution can report their own positions, but have the option of relying on the OTS model). Since derivatives can overwhelm the balance sheet in determining an institution's interest-rate-risk exposure, it appears that off-site measurement systems are inapplicable to institutions that hold complex instruments, and that the regulation or characterization of such banks will necessarily depend on the banks' own models. A similar conclusion probably holds for banks with significant foreign-exchange exposures.

III. Conclusions

Not surprising, there are significant differences between the estimates of the BA and OTS models. For basic on-balance-sheet instruments, we have been able to categorize those differences into three broad orders of seriousness. Almost all of the model differences we identified results from differences in information inputs. The most serious class, or "first-order differences," exceed 100 basis points as a percent of the instrument's par value and result from different information about: caps and floors on adjustable-rate loans; maturity distributions for long-term instruments; coupons, original maturity, and assumability for fixed-rate residential mortgages; amortization structures on commercial real estate loans, and the put option on core deposits. (Neither model deals with call options on securities, whether liabilities or assets, but ignoring call options and perhaps other miscellany could also create first-order errors.) "Second-order" differences, between 30-100 basis points, occur from dispensing with general coupon data and from the bucket approach to maturity distributions. Finally, third-order differences of 0 to 30 basis points can result from different treatments of almost any instrument characteristic.

While the existence of model differences is not surprising, it is surprising that we were able to discriminate between differences and errors down to the third order, for every (on-balance-sheet) item except core deposits. This is because the estimates of independent models repeatedly fell within 30 basis points of the estimates of the more information-intensive model. Though our analysis has hardly exhausted all possible information parsimonies, it seems safe to conclude that information parsimony in interest-rate-risk modelling generally produces measurable estimation error.

The fact that parsimony produces error does not imply that completeness precludes error. The apparent precision in our model estimates, and our discrimination between estimates, is possible only because we grant the model's underlying assumptions, as discussed in the introduction. Even where there is apparent consensus about the underlying assumptions, those assumptions can mischaracterize reality in important and unpredictable ways, causing false predictions.

An example is the prepayment functions for fixed-rate mortgages, one of the most important assumptions for modelling the risk of firms with significant involvement in that asset (portfolio holdings, originations, or mortgage servicing). The experience of the 1980s had indicated that the prepayment function was highly stable. For example, Benston et. al. used aggregated 1984-1988 prepayment-by-coupon data to achieve an R^2 of .7 in their prepayment function (Benston, Carhill, and Olasov, 1992). Wall Street firms, which use much more detailed data, presumably achieved an even greater explanatory power in their proprietary models.

That apparent stability of the prepayment function created great confidence among market participants that prepayments were highly predictable, but that predictability vanished in the early 1990s. For example, data provided the authors by the Federal National Mortgage Association reports that the annualized quarterly prepayment rate for mortgages with coupons 200 basis points above market has ranged from below 20 percent to above 60 percent since December 1990, instability that is clearly inconsistent with the .7 R^2 reported by Benston, even though the average 40 percent CPR at that coupon-to-market spread is consistent with the prior parameter estimates.

The breakdown of the historical relation between interest rates and prepayments caused the failure of several firms. A classic example is Coastal States Life Insurance Company, a $128 million company that had invested $120 million in a CMO portfolio that was supposedly immune to interest-rate risk. However, that immunity held only so long as actual prepayments were equal to those predicted in each given interest-rate scenario. When prepayments did not perform as expected, the company's losses produced deep insolvency (Jereski 1993).

Similar caveats hold for the relation between interest rates and credit losses, and any number of other underlying assumptions that interest-rate-risk models are forced to adopt. Yet, as a mathematical exercise, interest-rate simulations require such assumptions in order to fix the variables.

For these reasons, we conclude that complete information is necessary but not sufficient for accurate interest-rate-risk simulation. Even at the level of detail in the OTS model, and even granting its underlying assumptions, important inaccuracies remain (e.g., its maturity aggregation error described in Chapter One). And we know that the underlying assumptions should be questioned. Despite being an almost entirely mathematical exercise, interest-rate-risk modelling is demonstrably an art form rather than a science.

References

Benston, George J., Mike Carhill and Brian Olasov. "The Failure and Survival of Thrifts: Evidence From the Southeast." In *Financial Markets and Financial Crises*, edited by R. Glenn Hubbard. Chicago: The University of Chicago Press; 1991, p. 304-384.

Benston, George J., Mike Carhill and Brian Olasov. "Market Value v. Historical Cost Accounting: Evidence From Southeastern Thrifts." In *The Reform of Federal Deposit Insurance*, edited by James R. Barth and R. Dan Brumbaugh, Jr. HarperCollins Publishers, Inc; 1992, p. 277-304.

Cohen, Hugh. "Approximation Error: The Hidden Problem in Measuring a Bank's Interest-Rate Exposure." Atlanta: Federal Reserve Bank of Atlanta, unpublished manuscript; February 1994.

Feid, John J.; "Estimating the Measurement Bias in the Banking Agencies Proposed Interest Rate Risk Model." Washington, D.C.: Federal Deposit Insurance Corporation, unpublished manuscript; October 1993.

Getman, Paul; "The Last Temptation of Thrifts." *The Wall Street Journal*, March 23, 1989, p. A24.

Hutchison, David E. "Economics, Rents and Interest Rate Risk in Retail Financial Markets: the Case of Consumer CDs." Richland, WA: Washington State University Department of Finance; unpublished manuscript, November 1993.

Hutchison, David E., and George G. Pennachi. "A Framework for Estimating the Value and Interest Rate Risk of Retail Bank Deposits." Richland, WA: Washington State University Department of Finance; unpublished manuscript, July 1993.

Jereski, Laura. "Seized Insurer's Woes Reflect Perils of CMOs." *The Wall Street Journal*, Wednesday, May 12, 1993, p. C1.

O'Brien, James, Athanasios Orphanides, and David Small. "Estimating the Interest Rate Sensitivity of Liquid Retail Deposit Values." Washington, D.C.: Board of Governors of the Federal Reserve System; unpublished manuscript, May 1994.

Schwartz, Eduardo, and Walter N. Tourus. "Caps on Adjustable Rate Mortgages: Valuation, Insurance, and Hedging." In *Financial Markets and Financial Crises*, edited by R. Glenn Hubbard. Chicago: The University of Chicago Press; 1991, p. 283-303.

Stroh, Robert J. "The Key Role of Core Deposits in Interest Rate Risk Management and the Impact on Market Value." Trenton, IL: Tempo Bank, FSB, unpublished manuscript; October 1993.

