MODELS OF INTEREST RATE RISK

Analysis of Net Interest Income Sensitivity

Measures of interest rate risk (IRR) require reliable information on the amount and timing of the cash flows generated by an institution's assets, liabilities, and off-balance-sheet instruments. Because we do not always know this information with certainty, we make assumptions to perform the analysis. Depending on the type of analysis, these assumptions may include how:

- Market interest rates will change (over the period of analysis).
- Mortgage prepayment rates, deposit decay rates, and mortgage commitment "fallout rates" vary with interest rate changes.
- Management will administer interest rates that are under its control (such as loan rates and rates on retail deposits), when the general level of interest rates changes.
- Management will reinvest interest and principal cash flows.

Institutions commonly use two types of models to estimate the interest rate sensitivity of net interest income (NII): maturity gap models and NII simulation models. Likewise, there are two types of models commonly used to estimate the sensitivity of net portfolio value (NPV):

- Duration gap models.
- NPV simulation models.

Maturity gap and simple duration gap models are similar in that they implicitly make assumptions about the way interest rates and cash flows behave. Perhaps the most serious shortcoming of these models is that they assume that cash flows do not change in response to interest rate changes. For example, the model assumes that adjustable-rate loans do not reprice again after their next reset and that mortgage prepayment rates and deposit decay rates do not vary. The result is that the estimated change in NII or the change in the NPV of the institution is the same for a given increase in rates as it is for an equivalent decrease. However, in reality, the prepayment option embedded in mortgage assets results in asymmetric price changes for mortgages. That is, price increases when rates fall tend to be less than price declines when rates rise. The value of most thrift portfolios shows a similar sensitivity. We cannot accurately estimate this sensitivity by gap or duration models that assume that cash flows are the same in all interest rate environments.

NII and NPV simulation models, on the other hand, permit these assumptions to vary, but necessarily rely more heavily on the analyst to make choices about certain behavioral relationships incorporated into the model. Even though these models rely more heavily on parameters set by analysts, NII and NPV simulation models can be much more accurate than their less sophisticated counterparts, if we use appropriate assumptions. When assessing any measure of the IRR of an association, you should carefully evaluate the reasonableness of the assumptions used in the analysis.

Maturity Gap Models

Maturity gap is relatively easy to calculate, compared with other measures of IRR. During the 1980s, "gap" was the most commonly used measure of IRR in the thrift industry.

Maturity gap analysis measures the difference between the dollar value of assets and liabilities maturing or repricing during a given time period. We often express the dollar gap as a percentage of assets. When multiplied by a hypothetical change in interest rates, the dollar maturity gap gives a rough estimate of the effect of such a rate change on net interest income.

To calculate the maturity gap, principal balances of interest-earning assets and interest-bearing liabilities are categorized by maturity/repricing intervals or "buckets" (for example, under one year, one-to-three years), depending on when the institution receives the principal cash flows or when they adjust the interest rate. In more sophisticated gap models, the institutions adjust timing of the principal cash flows by incorporating the effects of loan amortization, mortgage prepayments, core deposit decay, and the effects of off-balance-sheet hedging instruments.

As an example of a maturity gap calculation, assume that an association with $10 million in assets estimates that $3 million of those assets will "reprice" during the next year (by having principal mature, prepay, amortize, or having the coupon adjust). Further, the model estimates that $6 million of liabilities will reprice during this time. This institution has a "one-year gap" equal to negative 30% [($3m - $6m) / $10m].

$$\text{GAP} = \frac{(\$\text{Assets Repricing}) - (\$\text{Liabilities Repricing})}{\$\text{Total Assets}}$$

To estimate the effect a change in interest rates has on an institution's interest margin, multiply the hypothetical rate change by the gap as a percent of assets. For example, the estimated effect of a one percent rise in interest rates on net interest income over the next year would be approximately 0.30 percent or 30 basis points (1.0% x -30% = -0.30%). Given assets of $10 million, this decrease in interest margin would translate to a reduction in NII of $30,000 over this period.

Although maturity gaps are relatively easy to measure and provide a rough measure of NII sensitivity, they have a number of well known shortcomings, including the following:

- Maturity gap models typically focus exclusively on near term NII. This focus hides the risk to NII of longer term repricing mismatches.

- The repricing intervals chosen for analysis are arbitrary, and there may be significant mismatches within a repricing interval that will be ignored in the analysis. The most common repricing intervals analyzed by thrift institutions are the one-year gap and the one- to three-year gap. A cash flow to be received in one year should have a different effect on interest rate exposure of an institution than an identical cash flow received in two and one-half years. Yet the one- to three-year gap model would treat these two cash flows as equivalent in terms of their effect on the IRR of the institution.

- Using maturity gaps to estimate the change in NII resulting from a change in interest rates assumes all interest rates change by the same amount – an unlikely occurrence. When the general level of interest rates increases by one percent, for example, some interest rates, such as those paid on passbook savings accounts, typically increase by a smaller amount, if at all.

- It is not possible to properly incorporate the effect of exchange-traded options or the options embedded in many financial instruments, such as early withdrawal options on CDs, the caps and floors in ARMs, and mortgage prepayment options. These options have a significant effect however, on the rate sensitivity of a financial instrument; neglecting to incorporate them into the analysis will misstate the IRR of an institution.

NII Simulation Models

NII simulation models project interest related cash flows of all assets, liabilities, and off-balance-sheet instruments in an institution's portfolio to estimate future net interest earnings over some chosen period of time. Analysts often refer to these models as "dynamic" NII simulation models. This is because you can build into the model changes in operating strategies, relative interest rates, early withdrawal of deposits, and prepayments.

Analysts calculate NII sensitivity as follows:

- Project base case NII for the current interest rate environment.

- Project cash flows for each instrument using assumptions about amortization characteristics, prepayment rates on mortgages, and deposit decay rates.

- Make assumptions about how to reinvest the principal and interest cash flows received during the period.

Next, run various simulations under alternative interest rate scenarios. For example, many models estimate the value of NII over the next year, if interest rates were to increase or decrease by one, two or three percent. As in the base case scenario, interest cash flows are projected over the period of analysis, and will depend on assumptions about deposit decay rates, prepayment rates, and on how we assume rates on adjustable-rate loans and deposits change in each interest rate scenario. To project how the coupons on adjustable-rate assets will change, analysts need information on the time to first reset, reset frequency, and the presence of any rate caps or floors.

The larger the differences in projected earnings between the base case and the alternative interest rate scenarios, the higher the level of IRR.

NII Simulation offers the following advantages:

- NII simulation models can provide more accurate estimates of the effect of changing interest rates on the future interest income of instruments with embedded options by varying prepayment rates according to the interest rate scenario being simulated. We similarly assess the value of other embedded options (for example, lifetime caps on ARMs) and off-balance-sheet instruments in institutions' portfolios.

- We can assume interest rates on different instruments change by different amounts when there is a change in the general level of interest rates. For example, we can assume changes in rates on core deposits lag behind changes in other rates.

Simulation analysis also has this disadvantage:

- NII models that project NII over long periods should take the time value of money into account. Like gap analysis, NII simulation models typically measure the effect of a change in interest rates over only short periods of time such as one year. Models that do project NII over longer periods of time sometimes aggregate these future cash flows in a manner that implies that cash flows received in the distant future are as valuable as those received in the near future. For example, a model may indicate that if rates increase by one percent an institution will lose $100 during the next year but will gain $100 in year two of the analysis. In fact, the present value of the $100 received in two years is less than the value of $100 received in year one.

Analysis of the Sensitivity of Net Portfolio Value

The net portfolio value N, equals the estimated present value (or economic value) of assets, A, less the present value of liabilities, L, plus or minus the present value of all off-balance-sheet items, O.

Net Portfolio Value

$N = A - L + O$

Analysts commonly use two types of models to analyze the sensitivity of net portfolio value, the duration gap model, and the NPV sensitivity model. Both models require detailed information on the amount and timing of all future cash flows deriving from all financial instruments in the portfolio as well as the specification of appropriate discount rates.

Duration Gap Analysis

Duration gap is the difference between the weighted-average duration of assets and liabilities, adjusted for the net duration of all off-balance-sheet instruments. It is a measure of the percentage change in the NPV expected if interest rates were to change by one percent. This measure is a point estimate, and is accurate for only small changes in interest rates.

To calculate the duration gap, analysts separately calculate the duration of each item in the portfolio. Analysts weight the duration, D, of each instrument by the ratio of its market value to the net value of the portfolio, and net the weighted durations of all assets, liabilities, and off-balance-sheet instruments as follows:

Duration Gap

$D_N = D_A(A/N) - D_L(L/N) + D_O(O/N).$

There are several different forms of the duration measure including simple (or Macaulay) duration and modified duration. Modified duration is the measure most often used to calculate the duration gap, and because it requires calculation of simple duration, we describe both measures below.

Simple Duration

Simple duration was developed to provide a measure of the average time to receipt of the cash flows of a financial instrument. It measures the weighted-average time until payments are received, where the weights are the proportion of the total present value of the instrument received in each period.

Calculation of the simple duration of an instrument requires three steps. First, calculate the present value of each cash flow (principal and interest) by discounting them by the instrument's required yield. (The sum of these present values equals the estimated price or market value of the instrument.) Second, multiply each present value by the number of years until it occurs, and sum these time-weighted present values. Third, divide the sum of the time-weighted present values from step two by the sum of the unweighted present values from step one.

Modified Duration

Modified duration is a measure of the interest rate sensitivity of an instrument, and obtained by multiplying simple duration by -1/(1+r). Modified duration indicates the expected percentage change in an instrument's price for a given change in the required yield of the instrument.

$$\% \Delta P = (-D/1+r) \times \Delta r$$

where D = duration of the instrument

P = price of the instrument

r = required yield of the instrument

Δ represents "the change in."

For example, if a liability had a modified duration of 4, we could expect the price of the liability to decline by .04 percent (.0004) for each basis point increase in interest rates. After calculating the duration of each item in the portfolio each instrument's duration is weighted by the ratio of the market value of that instrument to the NPV, and netted.

Drawbacks of duration gap analysis include the following:

- Duration gap can be difficult to calculate. The problem lies in obtaining economic values for each instrument. If the analyst cannot obtain market price quotes, they may calculate the economic values using present value analysis, described in the next section on the NPV sensitivity model. Sometimes analysts use book values to calculate the duration gap when they cannot get or easily estimate market values. When economic values diverge significantly from book values, the use of book values may result in significant error in the estimation of the interest rate sensitivity of portfolio value.

- Duration gap analysis provides accurate estimates of price sensitivities of instruments only for small changes in interest rates, say, less than 100 basis points. Modified duration assumes the percentage price change due to a rate change of a given magnitude will be the same when rates rise or fall (although opposite in sign). This is not true, however, when rates change by a large amount.

For a simple bond with no embedded options (such as a noncallable Treasury security), a large decrease in rates will result in a larger percentage increase in price than the percentage decrease in price that would result from an equal increase in rates. We call this phenomenon convexity. The analysis is further complicated when analyzing financial instruments with embedded options such as mortgage loans. Because borrowers tend to prepay their loans when refinancing rates fall below the coupon on the loans, the value of the loan will not rise as much as it would have had borrowers not prepaid (negative convexity).

- Duration does not take the shape of the yield curve into account. Analysts usually calculate the present values in the modified duration computation using the same discount rate (the required yield) for each future cash flow irrespective of when that cash flow will occur. This causes the model to overvalue long maturity cash flows and undervalue short maturity cash flows, biasing the estimated duration.

NPV Sensitivity Analysis

The measure of IRR deemed most important by OTS is the sensitivity of the NPV to changes in interest rates. We define an institution's NPV as the present value of assets minus the present value of liabilities plus the net market value of off-balance-sheet contracts. The sensitivity of NPV is the change in an association's NPV that would result from a shift, or shock, in the term structure of interest rates, say, by plus or minus 100 basis points.

Unlike simple duration gap, we use this measure to estimate the change in economic value for substantial changes in interest rates, like 100 or 200 basis points or more. These larger changes in interest rates allow the measure of IRR to depict the thrift's economic exposure across a wider range of possible outcomes.

We devote the remainder of this section to a brief overview of NPV sensitivity analysis. In particular, we discuss two methods of measuring the economic value of financial instruments. For more details on this type of analysis, see *The OTS Net Portfolio Value Model* manual.

Items Included in the NPV Measure

NPV should include the estimated present value (or economic value) of all existing assets, liabilities, and off-balance-sheet items in an institution's portfolio. For example, it does not include the value of new loans the management estimates it would make under the various interest rate environments, or the value of new deposit accounts they believe they would attract. It does include, however, the value of all existing off-balance-sheet instruments.[1]

[1] Most off-balance-sheet instruments will be included on the balance sheet in the future with the adoption of FASB 133.

For their internal use, institutions can produce estimates of the interest rate sensitivity of their portfolios on a going concern basis, taking into account future business. For TB 13a purposes, however, NPV should include only the value of existing instruments.

Measuring NPV: Static Discounted Cash Flow Approach

We estimate the value of a financial instrument by projecting the amount and timing of the future net cash flows generated by the instrument, and discounting those cash flows by appropriate discount rates. We commonly refer to this procedure as discounted cash flow analysis, or present value analysis. The basic formula for the present value of a financial instrument is as follows:

$$PV = CF_1/(1+i_1) + CF_2/(1+i_2)^2 + \ldots + CF_m/(1+i_m)^m$$

where CF_1 is the estimated amount of the first cash flow generated and i_1 is its discount rate. The discount rate used for each projected cash flow is the yield currently available to investors from cash flows resulting from alternative instruments of comparable risk and duration.

The accuracy of any valuation derived from the discounted cash flow analysis depends on the accuracy of both the cash flow estimates and the discount rates used. We must estimate these cash flows and discount rates not only for the current scenario, but for each of the alternate interest rate scenarios being estimated.

1. Estimating Cash Flows

The institution must estimate cash flows of all instruments separately for each interest rate scenario. The cash flows of many financial instruments held by institutions change depending on the course of interest rates. It is not acceptable for institutions to estimate the cash flows of these instruments for the base case and assume the instruments will realize those same cash flows in the alternate interest rate environments. NPV models should take account of the fact that coupons on adjustable-rate loans and deposits, mortgage prepayment rates, and core deposit decay rates will change depending on the interest rate scenario. Institutions should document the mortgage prepayment rates and deposit decay rates assumed in each interest rate scenario.

To the extent possible given their data systems, institutions should use disaggregated data to estimate the market value of the instruments in their portfolio. If sufficient information were available, institutions could value each loan, deposit, etc., separately by using information on amortization, coupon, maturity, and any options embedded in the instrument to estimate future cash flows. While it is usually not practical or necessary for institutions to disaggregate to the level of individual loans and deposit accounts, institutions should disaggregate instruments to the extent practical, grouping similar instruments together. OTS's NPV model and Schedule CMR guides the institution as to the minimum acceptable level of disaggregation.

Examples:

- Stratify fixed-rate mortgages into several coupon ranges (for example, seven to eight percent, eight to nine percent, etc.).

- Segregate adjustable-rate mortgages by index type, adjustment frequency, and distance to the lifetime cap. For example, value loans very close to their lifetime cap separately from loans with rates two percent from their cap.

- Segregate deposits by type, such as fixed-maturity deposits, MMDAs, transaction accounts, and passbook accounts. This stratification permits the application of appropriate parameters (prepayment rates, decay rates, etc.) to each type of instrument and will result in more accurate economic value estimates.

Under each interest rate scenario, we assume a single path of future interest rates based on future rates implied by the current term structure of interest rates. (In fact, analysts refer to this analysis as "static" cash flow analysis, because each scenario depicts a single hypothetical path of interest rates, as opposed to the numerous paths used in the option-adjusted spread [OAS] analysis described below.) The model calculates cash flows within each scenario based upon the assumed path of interest rates depicted in that scenario.

Cash flows may differ across scenarios for two reasons. First, loan prepayment and deposit attrition rates will differ, since borrowers and depositors will make different decisions about these actions under different interest rate environments. We model such differences in customer behavior by specifying a relationship between the interest rate scenario and the rates of prepayment and attrition, thereby changing the magnitude and timing of principal and interest cash flows. Second, the magnitude of interest cash flows differs across scenarios as adjustable-rate instruments (such as ARMs or MMDAs) reprice in future periods and receive different future coupon rates under different scenarios.

2. Discount Rates

The rate used to discount a cash flow should represent the yield obtainable in the market for a cash flow of similar maturity and risk.

There are two common methods for arriving at the discount rates for a particular instrument. The simpler method is to discount every projected cash flow by the yield of comparable instruments. In this case, each "i" in the previous equation would equal the current market yield of the instrument whose cash flows are being discounted.

A more complex, and more accurate method is to use non-constant discount rates based on the yields of zero-coupon instruments with maturities equal to those of each respective cash flow. In practice, analysts calculate for each cash flow a discount rate that has two components, a risk-free component, represented by the zero-coupon Treasury yield for the same maturity, and a fixed spread, which compensates investors for prepayment, credit, and liquidity risk. Analysts calculate the fixed spread as that increment to each of the risk-free components that causes the sum of the discounted cash flows to equal the observed market price of the instrument.

For either of the methods used, analysts typically adjust the discount rates in the alternate interest rate scenarios by adding or subtracting the amount of the interest rate shock (for example, for a plus 100 basis point scenario, add 100 basis points to each discount rate).

Measuring NPV: Option-Based Pricing

An option-based pricing approach is a more sophisticated approach to valuing assets (and, less frequently, liabilities) that contain embedded options. OTS uses this approach in the Net Portfolio Value Model to value mortgages and related assets.

The most important options in thrifts' portfolios are the prepayment options in mortgages and mortgage-related securities and the caps and floors in adjustable-rate mortgages. When mortgage rates fall, mortgage prepayments typically accelerate, forcing associations to reinvest the proceeds at lower yields. Interest rate caps and floors prevent the coupon rates of adjustable-rate loans from moving above or below a certain level when interest rates change. Both of these types of options can have a significant effect on the interest rate sensitivity of the instruments in which they are embedded.

In large part, the values of these options depend on the volatility of interest rates. When mortgage rate volatility increases, homeowners are more likely to prepay their mortgages. Higher volatility means there is a greater chance that mortgage rates will fall sufficiently below the rates on existing mortgages so as to induce prepayment. Likewise, the greater the volatility of the index on which adjustable-rate loans is based, the more likely that any rate cap or floor will constrain the coupon.

Option-based pricing models use an interest rate simulation program to generate numerous (hundreds or thousands) random interest rate paths that, in conjunction with a prepayment model, are used to estimate mortgage cash flows along each path. The model then discounts these cash flows and averages to arrive at a single mortgage price.

OAS models provide more accurate estimates of the value of these embedded options (and, therefore, of the mortgages themselves) than static discounted cash flow models. In a static cash flow analysis, the option has no value unless it is in the money (that is, the holder will exercise the prepayment option because rates have fallen and the homeowner chooses to refinance, or the rate cap or floor is effective). In fact, like exchange-traded options, these options have value even when they are not in the money, because it is possible they will be in the money at some future date. Market participants will, therefore, pay more or less for the instrument containing the option depending on the likelihood of exercise.

The sensitivity of NPV is a valuable measure of IRR, because it estimates how the economic value of an institution changes when interest rates change. In addition, the results are easy to interpret. It is, however, a complex measure that requires extensive modeling, and, as with any measure of IRR, the results are sensitive to the assumptions used.

OTS developed a computer model, called the Net Portfolio Value Model, that produces estimates of NPV sensitivity for each institution on a quarterly basis, as part of their Interest Rate Risk Exposure Report. Institutions with less than $1 billion in assets may use these estimates to comply with TB 13a. In addition, OTS uses these estimates to assess an association's IRR and to determine their compliance with TB 13a. For more detail on OTS's Net Portfolio Value Model or NPV sensitivity analysis in general, see *The OTS Net Portfolio Value Model* manual, or call the IRR contact person in your region.