Value at Risk of a Bank's Balance Sheet

by

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Through the application of a VaR analysis to the balance sheet of a hypothetical bank this paper will address several issues important to Bank managers. We will establish which balance sheet accounts lend themselves to meaningful VaR measures and the kind of information needed for input to these measures. We explain how depositor and borrower behaviors are captured in the risk measures. We also address the accuracy of the measures, and how the bank can use the VaR information for actionable decisions.

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Value at Risk Analysis of a Bank's Balance Sheet

A. Background

Value-at-Risk (VaR) has been widely used for banks' trading portfolios and for risk management purposes. Using VaR, a bank can monitor the business risks that arise from a wide range of sources, including yield curve movements, liquidity of the market, and currency fluctuations. As a result, the bank can use VaR for line-of-business, regulatory compliance, budgeting, and many other corporate decisions. Recently, Katerina [1996] provided an overview of the applications of VaR to risk management of banks.

But VaR has not been widely applied to structural balance sheets. Banks recognize that their risk has to be managed across the scope of their activities, that is, by integrating both the trading portfolio and the bank's balance sheet. In principle, the trading portfolio is structured to implement hedging of the risks of the asset and liability categories found on the balance sheet. Therefore, it is an incomplete, if not erroneous, exercise to measure the risk of the trading portfolio in isolation to the structural balance sheet.

However, extending the VaR framework from securities in a portfolio to the balance sheet is not straightforward. Many technical and conceptual issues have to be resolved. The trading portfolio consists of positions that explicitly entail the cash flow characteristics of typical securities: specified principal amounts, known or forecasted cash flows, and defined maturities. Account balances of the balance sheet, on the other hand, are point in time snapshots of the dynamic process of lending and account gathering. For example, a particular loan has a known term, and determinable cash flows. However, the balance sheet has non-determinant maturity customer accounts.

VaR application to balance sheet accounts must address the following issues: What accounts on the balance sheet lend themselves to meaningful VaR measures? How is depositor and borrower behavior captured in the risk measures? Does the bank have all the information needed as input to VaR measures? Are the VaR measures accurate enough to be useful? How can the bank use the VaR information for actionable decisions?

This study addresses these questions through the advancement of a VaR analysis applied to the balance sheet of a hypothetical bank. We will treat the stylized balance sheet shown in Figure 1.

Our purpose is to describe the steps undertaken to derive the Value at Risk for the bank's surplus, and then to discuss the managerial application of the VaR results.

Figure 1

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Balance Sheet for Bank, Aug. 31, 1996
(in millions)

PRIME RATE LOANS	**3,100**
BASE RATE LOANS	**2,100**
VARIABLE RATE	**600**
FIXED RATE LOANS	**1,200**
BONDS	**3,000**
	=========
TOTAL ASSETS	**10,000**

BASE RATE TIME	**2,000**
PRIME RATE TIME	**300**
FIXED RATE TIME	**500**
DEMAND DEPOSITS	**5,400**
LONG TERM MARKET	**1,200**
	=========
TOTAL LIABILITIES	**9,400**
SURPLUS	**600**

B. Methodology

Value-at-Risk (VaR) methodology can contribute vital managerial information when it is integrated into the bank's on-going risk management. As such, the VaR process is far more than the simple invocation of an encapsulated mathematical formula to measure risk. The VaR method depends upon a process of information monitoring and analysis. An integral part of the VaR methodology is data analysis and modeling of the individual items that will be subject to the VaR analysis. Accordingly, we will first describe the preliminary requirements for data analysis and modeling. These are the aspects of the process that require expert judgment and experience.

This process has four parts, which involve economic modeling and expert experience and judgment in the modeling validation and evaluation. The process is also an integral part of on-going, day-to-day management procedures. Indeed, GAT proposes a VaR methodology that is part of the bank's risk management process. The four parts are:

1. Modeling the Structural Balance Sheet
2. Modeling the Risk Sources
3. Determining the Value at Risk (VaR) Measure
4. Establishing the Organization of Risks

Each of these activities is described below.

1. Modeling the Structural Balance Sheet

The balance sheet items are, of course, book values. Within each category, individual components have different maturities as well as different payment terms. In general, the book values are different than their market values. Market values must be developed for each category to enter the VaR calculations.

The account balances, with the attendant detail of each, is the fundamental data requirement for applying VaR to the balance sheet, because those data define the magnitude of the cash flows. The loan or deposit amounts, the payment or servicing rates, amortization, and the formulas or conditions by which rates are reset are all found in the basic balance sheet accounts. The basic balance sheet data is sufficient to determine fixed rate cash flows. However, banks typically will originate variable rate loans, and traditionally offer deposits with variable rates.

The bank's balance sheet shown in Figure 1 has two major classes of variable rate items: those tied to *Prime* rate, and those tied to an *administered* rate. Each index differs in the degree of control that the bank has over the reset, and by the frequency of reset. Prime Rate is set by the bank in response to market rate levels and competitive forces, providing a high degree of control over the rate. There is no internal control on loans and deposits that are tied to an externally administered rate. In this analysis, there are items tied to two different administered rates: cost of funds index and a "Base" rate, assumed to be determined by the Central Bank. We assume that adjustable rate mortgages (ARMs) depend upon a 3-year cost of funds index. Further, there are loans and deposits which have rates that are spread off of the Base rate.

a. Modeling Prime Rate, Base Rate and the Cost of Funds Rate.

A plausible basis for variable rate models is to model them as discrete responses to the continuous changes in an open market rate. Arguably, the Libor rate best represents the competitive market for deposits and short term funds. Therefore, both the Prime rate and the Base rate models reset in response to the changes in the Libor rate, which is termed here the *Reference* rate.

The models must replicate the observable reset behavior over time. Accordingly, the models must have lagged response, to account for the indexes changing in response to *persistent* changes in rate levels of Libor, but not changing continuously. Further, the reset behavior must be asymmetric, with different behavior for up and down movements, to account for the observed fact that Prime and Base rates do not respond similarly in rising and falling markets.

The general framework for the models is an algebraic function of recent Reference rate levels. In general, this can be a complex function of the time series of values. However, research indicates that very good fit to the observed behavior can be accomplished with models that incorporate simple lagged moving averages. Those simple types of models are used in this study.

The parameters of each reset model are estimated so as to replicate the rate's *Normalized Spread.* This means the typical spread that one would observe between the administered level and the Libor rate, given that the latter had been, and is expected to remain, constant. Next, we define and determine reset thresholds, both for instances of rising and falling rate levels. When Libor changes so as to exceed one or the other of the threshold levels, then the model resets the level of the administered rate to the Normalized Spread. The graphs of the fit of the models to past rate levels is provided in Appendices A1 and A2.

b. Modeling Depositor Option Models.

Except for circumstances where principal repayment scheduling is influenced by a loan's rate level, the level of a variable rate is assumed to have no effect on the volume of the loan or deposit balance. However, in general, the relationship between alternative rate indexes is not static over time. Both borrowers and depositors have an option to move funds among alternative loans or kinds of deposits, in response to the relative attractiveness of one type over another.

Since movement of balances from one balance sheet item to another will directly affect the cash flows, they must be modeled. We refer to these models as *behavioral*. These model the changes in the size of account balances and substitution among different types of accounts that occur when customers perceive changes in the relative value of one kind of account over another.

2. Modeling the Risk Sources

The fundamental source of risk explored in Value at Risk analysis are changes in the levels of market rates. These directly affect the bank's capital position, in market value terms, by affecting the present value of the cash flows on both sides of the balance sheet, as well as the market value of the positions themselves. Rate changes also affect the undiscounted size of the positions, due to the optional transfer of deposits and loans from one type to another.

GAT uses an arbitrage-free interest rate model. An overview of the interest rate model can be found in Ho [1995]. The interest rate model provides a consistent framework in which any specified cash flow is fairly valued relative to any alternatively specified cash flow. Using the arbitrage-free specification, the Linear Path Space (*LPS*) method is applied (See Ho[1992]). LPS provides an arbitrage-free framework for the valuation of balance sheet items that have cash flows depending upon rate levels: a so-called "path dependent" series of cash flows. (See Bruno[1996] for an overview of sampling approaches that are efficient alternatives to the Monte-Carlo simulations.) On the modeled balance sheet, the accounts subject to customer options and the variable rate items are both sensitive to the paths taken by future rates.

3. Determining the Value at Risk (VaR) Measure

a. VaR as a Risk Measure

Value at Risk, or VaR, gives a threshold market value of the surplus over a defined time horizon, with a specified level of confidence that the surplus' value will be greater than or equal to that threshold level. VaR is often expressed by the incremental amount; that is, management is provided with the maximum adverse change in surplus, in market value terms, that can be expected over the time horizon. The level of confidence is directly interpreted as a probability or relative frequency number. In this analysis, we assume a one tail 99% confidence level over a one month horizon.

The underlying assumption of VaR is that the changes in market value of the surplus is the result of changes in the rates used to discount the bank's interest income and principal repayment on its assets, net of the cost of servicing its deposit base and other liabilities. Accordingly, the underlying assumptions governing VaR calculations relate to the future movements of market rates across the time horizon.

Fixed income securities use effective duration as the fundamental measure that links percentage changes in present value to the causative change in rates used to discount the cash flows. In the most simple formulation, one may produce a VaR number as follows: First, one determines the effective duration of each security or category of account. Next, one determines or predicts the volatility of the rate for the effective duration specification. The required confidence level, holding period, and the standard deviation of the rate change implies the threshold value of rate change. That level of rate change is then translated, via the effective duration, to the induced amount of value change in the security.

There are three general approaches to modeling of rate movements in common usage to determine the VaR measure: historical simulations, Monte-Carlo simulations, and parametric approaches.

We advocate the use of the parametric technique, based on rate movement theory and Linear Path Space as described in section 2. Our advocacy of this approach is grounded on the belief that it is theoretically the most sound and also the most internally consistent method.

The alternatives should be briefly summarized. The historical simulation approach uses a set of historical changes in market movements as a proxy of the future, and captures the changes in value of the balance sheet accounts across that set of rate changes. This is, in effect, a "look-back" method, and entails an implicit assumption that history repeats itself. Beyond that assumption, this method lacks any predictive power. Further, there is no probabilistic aspect to the method; that is, there are no alternative scenarios of future rates.

Monte-Carlo simulations address the latter criticism of the historical approach; they produce large numbers of alternative future scenarios, and assess value across each different scenario. As such, Monte-Carlo can be very extensive in identification and assessment of risk. Since the scenarios are chosen subject to a probabilistic (random) model of rate changes, measures of confidence are possible from this method. However, the methodology requires significant work and intensive computation to obtain reasonable levels of accuracy. The approach is not readily related to portfolio management by traders due to the insensitivity of the risk measure nor to general portfolio management because of the lack of precision in standard error. For these reasons, GAT does not favor this approach, and views it as inappropriate for the task at hand.

b. Parametric Approach

As indicated above, effective duration is the methodology that translates changes in rates to changes in value, and leads subsequently to the VaR number. Ho [1990] pioneered the concept of decomposing the "parallel" shift of discount rates employed in the definition of effective duration so the effect of a change in the discount rate of a particular term may be investigated directly. For example, one can envision a change in the rate of the one year term, while the rates for all other terms up to the maturity of the security are constant. The change in value induced by this change in the one year rate is referred to as the "one year Key Rate Duration" or "KRD". KRD's give management insight into the effect of the rate change of a particular term of maturity, (whether within the bank's control or not) in a way not possible with simple effective duration.

For GAT's Value at Risk purposes, rates for terms out to 30 years are represented by eleven points along the yield curve. In this case, where there was but one source of rate sensitivity, i.e., a parallel movement of rates, there are now eleven sources of risk.

The added complexity is easily managed. Each key rate has its own volatility. Furthermore, changes of each key rate are correlated with changes of every other key rate. Accordingly, a set of key rate changes combine to determine a change in value via the multivariate generalization of the naïve, one factor procedure: the key rate durations are used instead of just the effective duration, and the volatility of the sum of correlated random variables is used rather than the volatility of one, overall, parallel shift in rates. The volatilities and correlations may be estimated from the historical data. The statistical validity of this approach is explained in Hendricks [1996].

By concentrating on the effect on value determined by the Key Rate Durations, GAT's approach to VaR analysis is unique in identifying managerially significant risk sources individually, while maintaining the ability to combine them into one meaningful measure of capital exposure.

4. Establishing the Organization of Risks

The distinctive power of VaR lies in the ability of managers to identify levels of risk on an itemized level, and then to easily aggregate them until the overall risk is apparent. The two most important inferential statistics provided in the VaR results are the VaR numbers themselves, and the GAT $Beta statistic. Both of these are calculated and presented for each component item on the balance sheet. Ho, Chen, and Eng [1996] provides more details on the formulation and applications of $Beta. (Also, see Appendix B.) The application of risk contributors for risk management in a trading portfolio is discussed in Litterman and Winkelmann [1996]. This paper focuses the analysis more on the structural balance sheet.

The $Beta is the dollar contribution of each item to the VaR of the surplus. The $Beta of an account is the decomposition of the total risk (the VaR of the Surplus) and the attribution of that risk to each of the balance sheet items.

For the balance sheet, there is a fundamental offsetting hedge of value in the sense that the bank is “long” its assets and “short” its liabilities. The ratio $Beta/VaR, called the diversification effect, quantifies the impact of this hedge or any diversification effect upon this item. When the diversification effect is close to one, then there is little hedging or diversification impact on that balance sheet item. When an item has diversification effect close to zero, then the item's risk is mostly diversified away.

Typically, the sum of VaR for each category is greater than the total VaR. The major balance sheet category contributions to total VaR can be identified. Looking deeper within each category, specific holdings can be pinpointed which contribute most to the total VaR. Similarly, those categories or items that help reduce the total VaR through diversification can be identified.

The ratio of $Beta/total VaR depicts the percentage contribution of the risk by each item as a proportion of the total risk. We can order this ratio for balance sheet items, from largest to smallest. This graphic depiction, termed a *Pareto char,* enables risk managers to immediately identify the major contributors of risk. In so doing, one may easily formulate the most effective way to manage the total risk, by concentrating on those positions that are the major risk contributors. The ratio of $Beta/market value is the marginal risk contribution. This ratio represents the incremental increase in risk with the incremental increase in the balance. For example, if the marginal risk contribution is 0.1%, then for every $100 increase, there is an increase of $0.1 in the total risk of the surplus. For risk management purposes, this ratio enables us to identify the effective way to manage risk and to formulate the risk and return tradeoff with respect to marginal changes of the balance sheet positions.

C. Analytical Results

Exhibits A and B provide market value and VaR analytics for each summary group of balance sheet accounts considered in this analysis. There are a number of interesting results, conclusions and implications, summarized here.

The market value of the surplus is found to have been $1,078 million. In terms of the bank’s asset market value, of $10,166 million, this implies a substantial capital ratio. However, it should be noted that these figures implicitly include reserves against default, implemented by using the same discount rate for assets and liabilities.

The largest single contributor to the Value at Risk is Demand Deposits, with a $Beta of $36.89 million or 348% of the total risk of $10.59 million. As a result, items that correlate positively with Demand Deposits among the liabilities will increase total risk to the surplus, while positively correlated items among the assets will tend to provide natural hedges to the risk, causing a reduction in the total VaR of the surplus.

The analysis shows that the Demand Deposit risk is least diversified. The diversification factor is 0.827. This implies that only 17.2% of its VaR risk is reduced by other items on the balance sheet.

As discussed above, $Beta enables the bank to analyze the profitability of each product. $Beta is the risk contributed to the bank's total risk. By comparing the profits of the products along with their $Beta, we have a risk and return analytical framework to determine the profitability adjusted for risks. Further, by analyzing the marginal contribution of risk, $Beta/MV, and the profit margin of each product, we can formulate a business strategy that maximizes returns while minimizing the marginal contribution of risks. At the margin, fixed rate time deposit contributes the most risk with $Beta/MV at 2.16%, which is the highest. Fixed-rate loans provides the best hedging in that the $Beta/MV is -1.83%, meaning that an increase of $100 million in the fixed-rate loan position would reduce the total risk by $1.83 million.

D. Conclusions

This paper develops a prototype of the VaR model for a hypothetical bank. This prototype model has given answers to the following questions.

What are the items on the structural balance sheet that are appropriate for VaR measures?

All the items on the balance sheet can and should be considered in the balance sheet VaR analysis, with the exceptions of some fixed assets. Specifically, a bank's buildings and infrastructure, accounting goodwill, and net worth are not included. In VaR analysis, business risk is isolated from market risk. While in practice it is often difficult to separate the two types of risks, it is important in prototyping risk models. By isolating business risk, the analysis can be kept relatively straightforward. Clearly, office buildings have value, and that value is subject to risk. But it is not clear how one might value the property on an ongoing basis, because the building may have special value to the bank. Since office buildings are highly related to the operations of the bank, we should consider such risk as part of the business risk.

Growth in the size of the balance sheet items is not explicitly taken into account. Growth assumptions in the liability items would imply assumptions regarding investment and line of business strategies. These, in turn, would necessitate simulation of the balance sheet. However, future investments or borrowing do not affect the value of the bank today, when the investments and borrowing are taken at their market values. Therefore, much of the simulation would not affect the market value of the firm. Growth only affects today's value when the growth affects the future profit. For this reason, it is more practical to measure the market values for today's balance sheet and then adjust these numbers to reflect future growth.

How is consumer behavior captured by the risks?

Using the tax exempt and taxable items on the balance sheet, we exemplify how customer behavior affects the value of these items on the balance sheet. The model captures the option of depositors to change from one form of deposits to another. As a result, the bank's potential profit margin is lowered. VaR measures takes the motivating interest rate movements into account and therefore captures the expected loss in profit across alternative interest rate scenarios to measure this expected loss in value.

Does a bank typically have all the information available for VaR measures?

VaR framework should be considered a linchpin of the process of managing the interest rate exposure of a bank's surplus position. To maximize VaR's contribution, the accuracy and completeness of the data should be continually maintained and improved. Importantly, this prototype example shows that even the basic balance sheet information is adequate to provide essential input information to the VaR system.

Are the VaR measures accurate enough to be useful?

The accuracy and usefulness of a VaR system depends on the scope of the actionable decisions that the bank is required to make. The prototype model presented in this project suggests that we can use the results along with the trading portfolio to analyze the bank's combined risks.

How can a bank use the VaR information for actionable decisions?

We have shown that the surplus risk is $10.59 million, at a 99 percent level of confidence. The bank should make the decision whether such a risk is acceptable. If not acceptable, management must then decide how the bank should hedge the risks. It is important to recognize that optimal corporate strategy does not simply seek to minimize the VaR number. The goal would be to take profitable and manageable risks at acceptable levels.

The $Beta of each product can be used to quantify the risk of the product. As a result, we can compare the profitability of the products relative to each other on a risk adjusted basis. Furthermore, by analyzing the tradeoff between profit margin and the marginal contribution of risks to the bank, we can formulate an optimal business strategy that maximizes return while minimizing marginal contribution of risks to the bank. In short, this VaR framework can enable the bank to analyze profitability and future business strategies on a risk adjusted basis.

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The VaR framework proposed in this paper enables the bank to manage risk on a firm-wide basis. A bank can handle its risk more effectively when the risk measures are centralized. In a decentralized organization, the treasury department acts as an internal bank providing hedging services to each business unit. We have shown that VaR framework here allows the bank to analyze the firm-wide risk on a consolidated basis leading to a more effective management system. Lentinen [1996] shows the importance of this firm-wide approach.

Ho[1995] describes a risk management process, called the quality based investment cycle, which ties four phases together. The four phases are:

Requirement Phase - monitoring profits and establishing goals
Design Phase - analyze market opportunities and formulate strategies
Test Phase - test the validity of the proposed strategies
Implementation Phase - execution of the strategies and reporting the results

These four phases demand separation of functions and responsibilities. The organization of risk described in this paper enables the bank to integrate risk measurements with its organizational structure within the context of a quality-based cycle that has a well defined business control.

Given a consistent risk measurement system within a bank, Turner [1996] presents a procedure for allocation of risk capital and the measure of profitability on a risk adjusted basis.

What enhancements would increase the utility and efficacy of the VaR approach?

Behavioral models explain the movement of funds among the liability accounts; this can have a substantial effect on the cash flows, and thereby the market values of these account items. As the models evolve from studying customer behavior, the efficacy of VaR is enhanced. However, behavioral aspects of administered rates are also important in order to accurately forecast the cash flows of both assets and liabilities. As major contributors to the bank's total Value at Risk, they too deserve careful attention.

One of the powerful aspects of VaR is the ability to integrate off-balance sheet and Structural Balance sheet items' risk contributions. This integration was beyond the scope of this example, but is an important goal of the VaR analysis.

Finally, the process of integrating Value at Risk information into overall Risk Management needs to be pursued and formulated. Its inclusion can only enhance the flow of vital managerial information, both with respect to the risks of the Bank's core business of deposit taking and lending, and with respect to the investment and trading functions as well.

The purpose of this paper is to illustrate the use of VaR as a measure of risks on a balance sheet and to demonstrate how the VaR methodology may lead to actionable decisions. For the sake of clarity in exposition, we have focused our analysis on interest rate risks. The VaR framework can be extended to include model, liquidity, credit, and currency risks. It is beyond the scope of this paper to discuss those issues. Further, we have used a delta-normal approach for this analysis. In the case where option risk is significant, the delta-gamma procedure (see Rouvinez [1996]) can be implemented.

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Exhibit A. Aggregation of Risks to Portfolio (VaR Table)

Asset Portfolio	Market Value ($million)	VAR	VAR / MV	$Beta	$Beta / VAR
PRIME RATE LOANS	$3,286.00	$11.31	0.34%	$0.56	0.049
BASE RATE LOANS	$2,170.00	$4.92	0.23%	$3.99	0.811
VARIABLE RATE MORTGAGES	$625.47	$5.47	0.87%	$5.20	0.951
FIXED RATE LOANS	$1,231.46	$30.49	2.48%	$30.45	0.999
BONDS	$2,854.00	$33.46	1.17%	$32.79	0.000
TOTAL	$10,166.93	$72.99	0.72%	$72.99	1.000

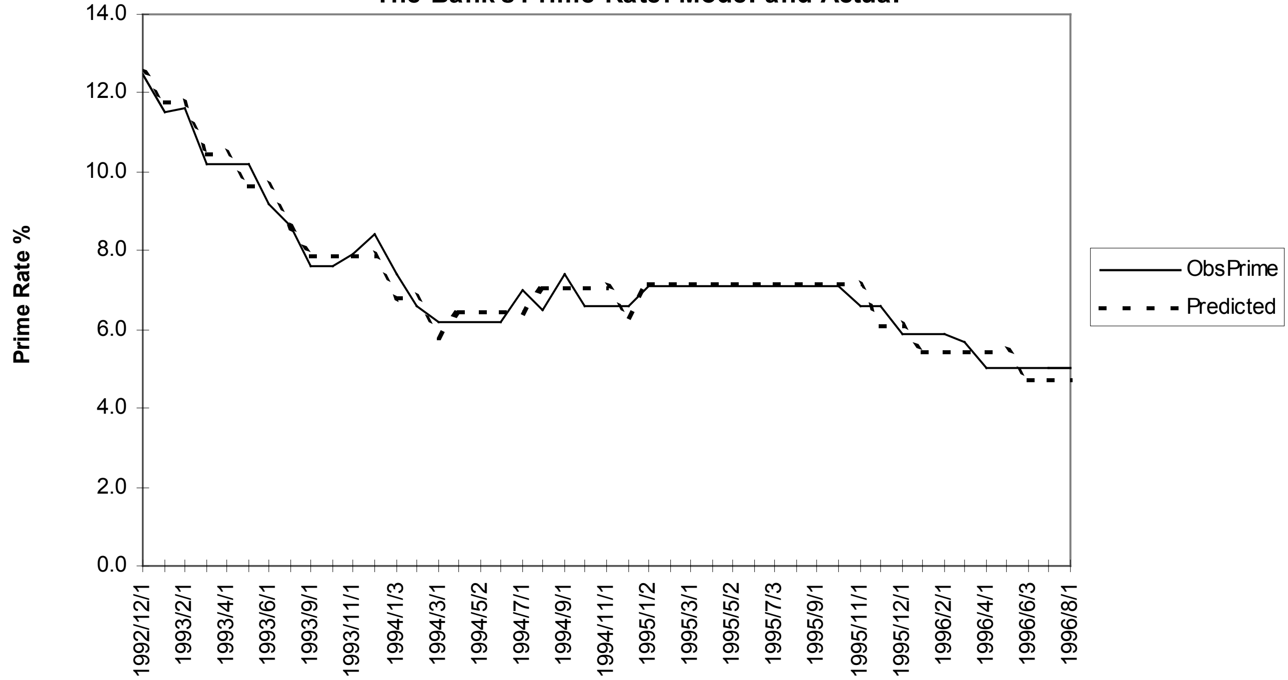
Liability Portfolio	Market Value ($million)	VAR	VAR / MV	$Beta	$Beta / VAR
BASE RATE TIME DEPOSITS	$1,959.94	$5.83	0.30%	$5.27	0.904
PRIME RATE TIME DEPOSITS	$289.00	$1.56	0.54%	$0.12	0.077
FIXED RATE TIME DEPOSITS	$443.08	$11.69	2.64%	$11.68	0.999
DEMAND DEPOSITS	$5,250.00	$44.62	0.85%	$44.48	0.997
LONG TERM MARKET FUNDING	$1,146.00	$19.85	1.73%	$19.75	0.995
TOTAL	$9,088.02	$81.30	0.89%	$81.30	1.000

Exhibit B. Aggregation of Risks to Surplus (VaR Table)

Portfolio	Market Value ($million)	VAR	VAR / MV	$Beta	$Beta / VAR
PRIME RATE LOANS	$3,286.00	$11.31	0.34%	$4.52	0.400
BASE RATE LOANS	$2,170.00	$4.92	0.23%	-$4.28	-0.870
VARIABLE RATE MORTGAGES	$625.47	$5.47	0.87%	-$4.79	-0.877
FIXED RATE LOANS	$1,231.46	$30.49	2.48%	-$22.54	-0.739
BONDS	$2,854.00	$33.46	1.17%	-$28.15	-0.841
BASE RATE TIME DEPOSITS	$1,959.94	$5.83	0.30%	$3.24	0.555
PRIME RATE TIME DEPOSITS	$289.00	$1.56	0.54%	$0.98	0.630
FIXED RATE TIME DEPOSITS	$443.08	$11.69	2.64%	$9.55	0.817
DEMAND DEPOSITS	$5,250.00	$44.62	0.85%	$36.89	0.827
LONG TERM MARKET FUNDING	$1,146.00	$19.85	1.73%	$15.16	0.764
Surplus	$1,078.91	$10.59	0.98%	$10.59	1.000

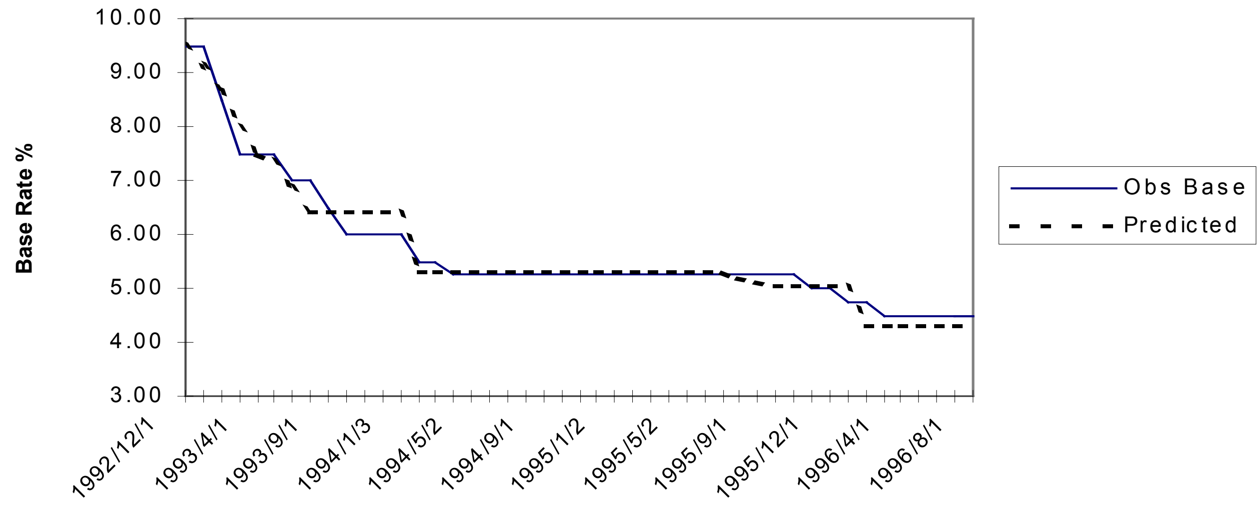
Appendix A1

The Bank's Prime Rate: Model and Actual



Appendix A2

Central Bank's Base Rate: Model and Actual



Appendix B: An Overview of BARRA's Value at Risk (VaR)

Section I: Terminology and Fundamental Constructions

A. The Change in Value Equation

Fixed income securities use effective duration as the fundamental measure to relate the percentage change in present value that arises from a change in rates used to discount the cash flows. The basic equation of effective duration is:

Equation 1: The Effective Duration Equation

$$\Delta P / P = -D\Delta r \qquad (1)$$

where,

P = the value of the security
D = the effective duration
Δr = a change in the discount rate applied uniformly to all cash flows.

Thomas Ho pioneered the concept of decomposing the "parallel" shift of discount rate employed in the definition of effective duration so as to directly investigate the effect of a change in the discount rate of a particular term. For example, one can envision a change in the rates around one year in term, while the rates for all other terms up to the maturity of the security are constant. The change in value that induced this change is referred to as the "one year Key Rate Duration" or "KRD".

For BARRA's Value-at-Risk purposes, the 30 years of the yield curve is represented by ten key rate shifts. Users of other BARRA applications may note that the "25 year" KRD has been equally allocated between the 20 and 30 year KRD's.

The sum of key rate durations, by construction, is identically equal to effective duration, as defined above. That is, the proportional change in present value can be written as:

Equation 2: The Key Rate Duration Equation:

$$\Delta P / P = -(KRD_1 \Delta r_1 + KRD_2 \Delta r_2 + \ldots + KRD_{10} \Delta r_{10}) \qquad (2)$$

where,
P = the value of the security
Δr_i = a change in the discount rate applied uniformly at the i-th KRD term, and i has terms according to:

i	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Term	*3mos*	*1 yr*	*2 yrs*	*3 yrs*	*5 yrs*	*7 yrs*	*10 yrs*	*15 yrs*	*20 yrs*	*30 yrs*

B. Key Dollar Duration.

The "dollar change" in a security induced by a Key Rate change is simply determined by multiplying both sides of the Key Rate Duration Equation by the basecase value, P. This yields:

Equation 3: The Key Dollar Duration Equation:

$$KD_i = KRD_i P, \quad i = 1,...10. \qquad (3)$$

C. Standard Deviation of the Key Rate Equation

Key Rate Duration measures the effect on value of a change in the "causative" variable, the rate used to discount the cashflows that occur around the time of KRD_i. In the future, rate changes are modeled as random variables, so we define the standard deviation of each of the key rate shifts as σ_i. This factor can be interpreted as follows in the VAR context. Consider, e.g., the fifth KRD, of five-year term, and assume that the current five-year spot rate is six percent. Say that one asserts that the volatility, V_i, of the five-year rate is 10 percent. This means that, a year from now, the five-year rate will be within the interval [5.40 to 6.60] with a "one sigma probability" of about 0.68. Similarly, the chance is about 95 in 100 that the rate will be within the "two sigma probability" interval: in this case, [4.80 to 7.20].

From the example, one can see that the probability interval points are derived from the quoted volatilities by the equation $\sigma_i = V_i r_i$. V_i is the quoted volatility (10 percent in the example), r_i is the rate level (6 percent above), and σ_i is the i-th *Key Rate Standard Deviation* (60 basis points in the example).

D. Key Dollar Duration Standard Deviation.

To express probabilities of the effects of key rate changes on value, the Key Rate Standard Deviations are simply multiplied by the Key Dollar Duration. That is:

$$\sigma\, KD_i = |KD_i|\, \sigma_i \qquad (4)$$

Note that the absolute value of the Key Dollar Duration is employed in this definition, reflecting the symmetry of the random movements being modeled.

E. The VaR Equation.

This equation defines the potential market loss, which is at the core of VaR. It provides a measure of potential market value loss, under a given level of confidence and a defined holding period term which can be attributed to key rate movements. Whereas the Key Dollar Duration shifts are presented individually, rates typically change along the entire range of maturities. In other words, a shift at the i-th Key Rate term is correlated with shifts at the other Key Rate terms. The well-known relationship of the standard deviation of a sum of correlated random variables is used to relate the change in security value with the probabilities of change in value, to give:

$$VaR = \alpha \sqrt{\sum_{I=1,10} \sigma\, KD_i \left(\sum_{I=1,10} \sigma\, KD_I * \rho_{i,j}\right)}\ \sqrt{t} \qquad (5)$$

Where,

α = a normal distribution confidence level, (e.g., α = .99 corresponds to a movement of $2.33\sigma_i$);
$\sigma\ KD_i$ = the Key Dollar Duration Standard Deviation;
t = the horizon of the analysis.

F. BARRA's $Beta Equation

$$\$Beta = cov\ (P_i, P) / \sigma(P) \qquad (6)$$

Where,
P = the Market Value of a portfolio
P_i = the Market Value of one sector in Portfolio P.
$Beta = the dollar contribution of each item to the VaR of the surplus.
$Beta/Total VaR = the contribution of the risk by each item as a proportion to the total risk.
$Beta/Market Value = the marginal risk contribution. This ratio represents the incremental increase in risk with the incremental increase in the balance.