Strategic Risk Management for Developing Countries: The Colombia Case Study[1]

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1. *Introduction*

Uncertainty makes economic and project management more difficult for any entity. This is especially true for sovereigns that have experienced substantial financial volatility and shocks throughout the nineties, especially those with substantial debt and commodity price exposures. Furthermore, the development of a strategic approach at the country level for the analysis of that uncertainty has lagged behind as most approaches exclude, for example, trade flows and fiscal dimensions. A World Bank research project undertook to rectify that situation. In this paper, we present a case study for Colombia of the tools developed in that research project. We only look at one small aspect of the issues in order to illustrate how these tools could be applied and what might be examined.

2. *Strategic approach to ALM is important, especially for developing countries.*

Global financial markets have been very volatile in recent decades with large changes in commodity, foreign exchange, interest rates, and capital flows. Many developing countries have large exposures to these risks. They often have large external debts and considerable foreign exchange reserves, exposing them to interest and exchange rates risks. Many developing countries depend on (primary) commodity exports for generating foreign exchange, or need to rely on imports for energy and to supplement basic food supplies. Adverse movements in international commodity prices can affect them greatly. All these risks have played a role in raising the debt burdens and negatively affecting economic performance of many developing countries.

Uncertainty makes economic and project management more difficult for any entity. This is even more so in developing countries. On the upside, developing countries have more difficulty dealing with the booms resulting from commodity prices increases. On the downside, external shocks, which appear small, have often created havoc in developing countries. A variety of reasons will continue to contribute to the greater impact of shocks in developing countries: companies in these countries have limited access to financing and hedging tools, and access may be cut off completely in periods of financial turbulence. In the mid-1990s, for example, private capital went into East Asia at about $40 billion per annum,

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with a peak of about $70 billion in 1996. In the second half of 1997, more than $100 billion in bank loans pulled out of these same countries. As financial integration advances while international capital markets remain volatile, emerging market economies will be exposed to many risks.

Improving ALM will thus be more important than ever before. During the last two decades, a broader range of financial tools (credit swaps, derivatives, etc.) has become available. The breadth of tactical risk management tools has expanded greatly and now includes many types of borrowings and assets, forwards, swaps, plain vanilla and exotic options, etc. Asset/Liability Management (ALM)-strategies have become more sophisticated and concepts such as value-at-risk are now commonly used. And developing countries have in recent years gained some access to risk management tools.

Yet, the development of a strategic approach for ALM at the country level has lagged behind. Typical approaches to country ALM are copied from approaches for firms and financial institutions do not incorporate country-specific factors and strategic interactions are missing. They often exclude, for example, trade flows and fiscal dimensions. Modeling flexibility is very limited, with country adaptation often happening through a piece-meal approach by basic analysis rather than optimization. More generally, their perspective is often the development of benchmarks. However, by requiring a benchmark, which is constant over time, they fail to incorporate the dynamic realignment of portfolios. The treatment of uncertainty is typically also very limited and constraints are typically not included in the optimization process itself, but rather through iterating around the solution

ALM for sovereigns in developing countries often has to consider risks on a much broader scale than well-established corporations in developed countries. It is also essential that they adopt a truly dynamic approach. Risks to include concern not only the government's own direct exposures, such as those arising from debt and reserves, but also those arising from contingent risks from the banking systems or state-owned enterprises. Approaches need to be related to measures of the government's earning potential, such as the sensitivity of fiscal revenues to global factors. Without these factors, approaches to risk ignore the existence of natural hedges in the external and fiscal sectors, limit the analysis to "on-balance" liabilities only, and ignore many important constraints. And approaches need to be dynamic: developing countries face, for example, many constraints in rapidly adjusting their asset and liabilities as transactions costs can be high. ALM strategies pursued for corporations in developing countries can thus clearly be less than optimal and may even add to risk for developing countries' sovereigns.

The events in East Asia have highlighted the complexities of ALM in a financially integrated world. East Asian countries had little of the traditional weaknesses in fiscal management: balances were general in surplus and public debts were low. Yet, East Asian countries did witness a buildup of financial vulnerabilities in the private sectors. These were mainly the result of macro-policies being pursued, particularly foreign exchange management, the sequencing of liberalization, and the poor process of domestic financial intermediation. But, a neglect of external asset and liability management was also an important factor in triggering the crisis in several countries. Affected East Asian countries are now trying to improve their asset and liability management. The lesson may be that proactive ALM can reduce the risks of currency and balance of payments crises.

The changing nature of reserve management risk (See De Beaufort, 2000) also highlights the need for more sophisticated risk management tools. There has been impressive growth in the level of total foreign exchange reserves of central banks, of which Asia and Latin America account for almost all the increase. This growth implies an opportunity cost so that central banks are considering more active investment strategies for a portion of their portfolio that has a low probability of being used for intervention purposes. The challenge then becomes how to apportion the portfolio between a liquid portfolio that could be used for intervention purposes and another for investment purposes while managing asset class risk, credit risk, currency risk, and interest rate risk. The objective becomes one of enhancing returns with sound asset and liability management and a solid public mandate while constraining risk to a suitable level.

3. The risk management issues facing the Central Bank of Colombia

Building on recent advances in technology and optimization techniques, it is feasible to address some of the weaknesses of existing ALM techniques.[5] To illustrate the techniques developed and their ease of application, we present the case of the foreign exchange reserve management of the Central Bank of Colombia (Banco de la Republica, BR). We first describe the ALM-problem as faced by the reserve managers and the government of Colombia, and then the approach currently taken by BR to managing its reserves.

In deciding on the way it wants to manage its reserves, BR faces a number of strategic objectives for holding reserves, as well as legal and other constraints. It also has to consider its relationship with the country's overall debt management and the budget. Moreover, BR has its own institutional structure for management, including reporting on reserve management, which need to be taken into account in the modeling.

Strategic Objectives. The management of Colombia's foreign exchange reserves is regulated by Law 31 of 1992, in which the responsibility of the Central Bank regarding the management of foreign reserves is defined in Article 14 as follows: "The Central Bank will administer the foreign exchange reserves in accordance to public interest, in support of the domestic economy and with the objective of facilitating the external payments of the country. The administration of the reserves involves its management, investment, custody and disposition of the assets. Its investment will follow criteria of safety, liquidity and return in assets denominated in freely convertible reserve currencies or in gold." From this, general objective follows a narrower objective on the desired size.

Size: The objective of BR is to hold sufficient foreign exchange reserves to intervene in the domestic currency markets, both to ensure normal volatility in the exchange rate of the Colombian Peso, to deter speculative attacks and to provide an adequate guarantee for foreign investment in the country. There is no clear policy regarding the optimal size of the reserves. Although, in light of the risks arising from rapid movements of capital and currency substitution, the ratio of reserves to months of imports and the ratio of reserves to financial liabilities in Colombia (M3, including bonds) is watched, there is no expressed desired objective for a minimum or maximum level. No factors regarding private sector behavior are taking into account.

[5] These results build on the earlier work reported in Claessens, Kreuser, Seigel and Wets, 1997, and 1995.

Constraints: The BR does face a number of constraints, some arising from legal factors, some for financial planning reasons, and yet others for historical reasons.

Asset classes. As administrator of the foreign exchange reserves, BR faces certain legal constraints. No borrowing is allowed, for example, except in the case of securities lending. All liquidity needs of the bank are to be met by the liquidity portfolio, and the investment portfolio can only invest in highly liquid assets such as government bonds or very short-term time deposits. It can execute derivative transactions, but only in order to hedge. In such cases, it is allowed to deposit part of its reserves assets to cover margin calls or guarantees, or to purchase instruments to hedge. And, by law BR cannot incur losses of principal, but currency gains and losses are not considered part of this constraint.

Policy, legal and other constraints. Expect for the limits on loss of principal, there are no policy constraints on realizing financial losses (or gains). Reserves are marked to market every day, thus directly affecting the profit and loss of the Central Bank. The legal limits of no principal losses, means that there is a policy constraint of avoiding negative returns within each currency over a given year.

Relationship with external debt management. Since there can be important synergies between the management of assets and liabilities, BR manages its reserves in coordination with the liability of the Republic of Colombia. There is a Risk Committee designed to coordinate reserve management policies with public debt policies. This leads to certain policy restrictions, which, to date, apply mainly to the currency composition of its reserves. In particular, the currency composition of foreign exchange reserves must match the composition of the outflows of the balance of payments in order to eliminate as much as possible cross-currency risks.

Institutional Arrangements. According to the charter of BR, the body responsible for defining the strategic objectives of reserves is BR's Board of Directors. The Reserves Committee makes strategy decisions on portfolio allocations monthly, as sub-committee of the Board. Most tactical and many strategic issues are addressed directly by the reserves department on a daily basis (tactical) and monthly (strategic) basis. However, if deemed necessary, a meeting of the reserve management committee can be arranged. The process for the review of strategic and tactical choices can also be revisited when needed.

Current Foreign Exchange Reserves Management Arrangements. Reflecting its objectives and these various constraints, BR has the following policies currently in place for the management of foreign exchange reserves.

Size: The reserves are divided into two portfolios: the liquidity portfolio, which is equivalent to around 10% of total reserves and is invested solely in US dollar denominated overnight investments, and the investment portfolio. The liquidity needs of BR are met by the liquidity portfolio (as the investment portfolio can only invest in highly liquid assets, such as government bonds or very short term time deposits, it can accommodate liquidity needs as well). The level of the liquidity portfolio is determined by an analysis of the historic behavior of outflows, with a current range of $500 million to $900 million. The rest of the reserves are invested in the investment portfolio. After deducting a reserve provision for future foreign exchange losses and the administrative expenses of BR, excess return is transferred to the Ministry of Finance at the end of each year.

Currency and duration: As noted, the currency composition of the investment portfolio is based on the balance of payments outflows by country of origin and mirrors the average composition over a rolling two year period, currently 80% US dollars, 15% Euros and 5% Yen. The interest rate exposure within each currency is set on an average two-year duration, achieved through a combination of 1 to 3 months money market instruments generally tied to LIBOR, and government bonds. Within each currency, the portfolio composition is set to ensure that the probability of negative returns over a given year is low. For the last three years, the asset allocation has been in the following, broad ranges: US$ portfolio: 20% 1-3 months money market instruments and 60% 1-5 years US Government Bonds; EURO: 3.75% 1-3 months money market and 11.25% German Government bonds; and Japanese Yen: 3% 1 –3 months money market instruments and 2% 1-10 year bonds.

Currently, all money market instruments no longer than one year have to be issued by governments with a minimum long term rating of AA, banks with a minimum long term rating of A+, or corporate bonds with a minimum long term rating of AA. For bonds, the benchmark only includes governments issued by the United States, Germany and Japan, although reserves can be invested in US agencies, eurobonds and supranationals with a minimum rating of AA. Derivatives are only considered for hedging purposes and so far, the central bank has only used foreign exchange forward contracts and futures on authorized instruments via recognized exchanges. The use of options has not been considered for reserve management.

Management: Almost 50% of the investment portfolio is invested passively, in accordance to a benchmark portfolio and evaluated at the end of each month. The other 50% are invested with active external managers, of which 5% is invested directly by the BR. Aggressive active strategies are rare, however, and strategies tend to concentrate on deviations from the index

Risk measurements. Market risk is measured by the modified duration of the portfolio and each of its components. Currency risk is measured by the difference between the benchmark and actual weights in each currency. Credit risk is measured by the rating of every issuer. Managers are evaluated against the benchmark on a monthly basis, separating deviations due to currency risk, duration risk and credit risk. On a yearly basis the performance of each administrator is reviewed by the Board of BR over a rolling three-year period compared to the tracking, benchmark portfolio.

4. Strategic analysis using integrated advanced tools for ALM[6]

The problem faced by the BR of managing its reserves while matching the currency composition of the outflows of the balance of payments and observing other constraints is an optimization problem under uncertainty. A general model for this type of ALM-problem has been formulated and solved as a dynamic stochastic programming problem by Claessens et al. (1997). Further discussion of the technology is beyond the scope of this paper (readers are referred to Claessens et al. 1997 and 1995 papers; Ziemba & Mulvey, 1998 provide a more

[6] These were originally developed at the World Bank. They are now available from The RisKontrol Group GmbH who continues to develop them in a package called RisKontroller. More detailed information on these tools and their use can be found at www.riskontroller.com.

general overview on asset and liability modeling). It is worth noting here, however, that the methodology is very flexible and allows for many different specifications of objective functions, stochastic behavior and constraints. Specifically, the model has the following characteristics: it is based on cash flows for all currencies and at all future dates, not just the next period; it incorporates stochastic volatility constraints on the liquid portfolio; it allows for choices among all asset classes at all future dates; it incorporates transaction costs; and its decisions are based upon maximizing a specific objective function (e.g., the expected value of the portfolio at the horizon in terms of a basket currency). Next, we show how these tools can be used by BR.

(i) The base case

For the asset choices, we include short maturity and long maturity assets in each of US dollar, Euro, and Yen. We also include a liquidity portfolio of short dollars. The model allows for the sale of long maturity assets and any currency transactions and includes transaction costs.

We make the following behavioral assumptions on interest and exchange rates:

- Expected values of interest rates are computed so that they satisfy statistically the interest rates implied in the term structure. In other words, in expected value sense, the rates of return on long maturity assets are indifferent from investments in short assets at any time.[7] We apply this principle to the current rates as well as to any future rates by calibrating the expected interest rates in the future to the forward rates implied today.
- We compute the volatility of and correlations among and between the interest and exchange rates from historical information. The variability of the short term rates is taken as the historical volatility over the last year and that of the long term rates over most of the nineties (we use a longer period to base the estimate on a statistically constant regime).[8]
- Going forward, we allow time-varying volatility to reflect the possibility of regimes over which the uncertainty is more or less stable and to incorporate the mean-reversion present in many asset prices. Consequently, the variance does not change exactly by time (and the standard deviation not by the $\sqrt{t}$) because the stochastic processes change over time.
- In terms of exchange rates, expected values are computed such that the Uncovered Interest Parity hypothesis holds, i.e., exchange rates are expected to appreciate or depreciate by the differential in interest rates.

These assumptions essentially mean that all assets have identical expected rates of return and the only difference is the variability of the various assets. Tables 1 and 2 provide respectively the expected values of the rates and the standard deviations of the various assets.

[7] As we have a finite horizon model, we make investments in long and short assets equivalent at the horizon.

[8] This estimate has been quite accurate to date. For more on regime matching, see RiskMetrics, *LongRun Tecnical Document*. In the next section, we will make some assumptions that reflect a change in the regime.

Table 1: Expected values of rates

Assets	*1999*	*2000*	*2001*	*2002*
Euro short rate	3.40	5.45	6.43	6.36
Euro long rate	4.99	8.57	9.88	9.04
Dollar short rate	5.23	6.41	6.73	6.20
Dollar long rate	6.28	7.99	8.52	8.07
Yen short rate	0.12	0.08	0.14	0.35
Yen long rate	1.11	1.48	1.74	2.22
Euro exchange rate	0.99	0.97	0.97	0.98
Yen exchange rate	102.20	97.24	92.10	87.03

Table 2: Standard deviation of rates

Asset Class	*2000*	*2001*	*2002*
Euro short rate	0.68	1.29	1.45
Euro long rate	0.99	1.64	1.63
Dollar short rate	0.35	1.15	1.61
Dollar long rate	0.44	0.89	1.05
Yen short rate	0.07	0.13	0.25
Yen long rate	0.37	0.54	0.77
Euro exchange rate	0.08	0.19	0.30
Yen exchange rate	6.83	8.99	12.39

We can represent the stochastic processes graphically. An example for the US dollar short rate is given in Figure 1. The degree of correlation between the US dollar short and the long rate can be assessed from Figure 2. Both of these figures are useful in understanding how interest rates might progress over time and in relation to each other.

Figure 1: US dollar short rate scenarios

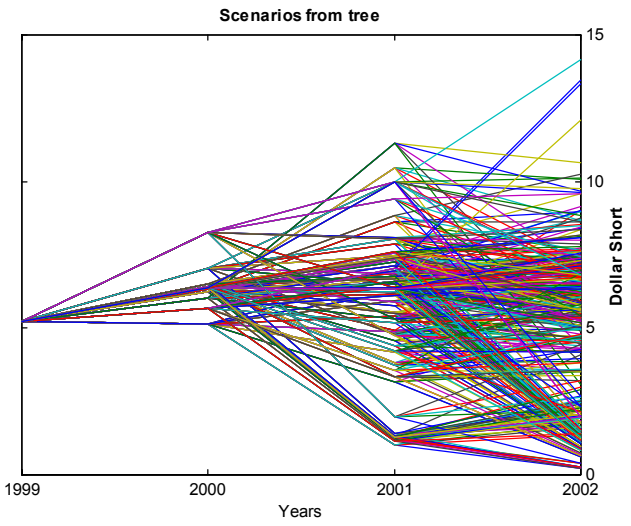
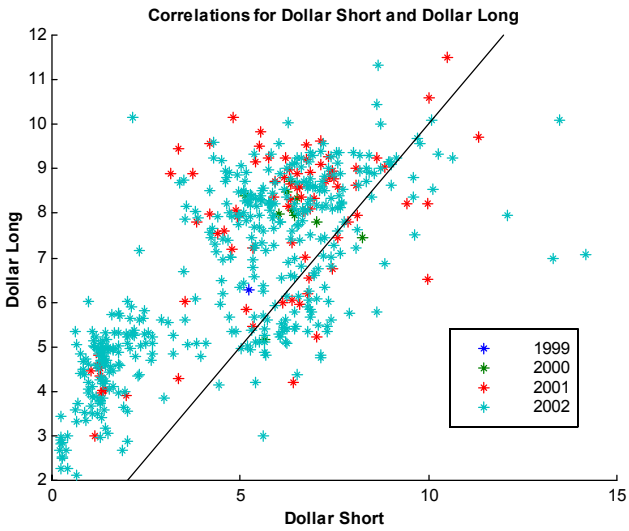


Figure 2: Short vs. long rates

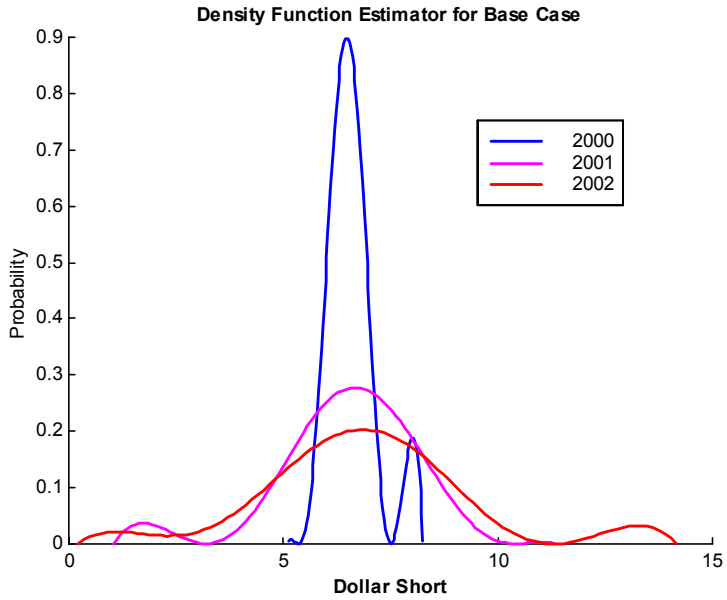


One must be careful in interpreting Figure 1, as the scenarios do not have equal probability of occurrence, i.e., the density of the tree is not depicted, but rather each scenario appears with equal likelihood, which is not what the stochastic process implies.[9] To better

[9] A single path along the graph from 1999 to 2002 is called a scenario.

understand how rates are distributed, we depict the density functions[10] over time in Figure 3 for the US dollar short rate. From this, it is easy to see that the interest rates are distributed over a smaller range in the first year, and, as time progresses, spread out.

Figure 3: Density functions of US dollar short rate



We can also use the densities to provide us with the cumulative distribution for certain cutoff levels, e.g., the probability of worst or best case interest rate outcomes (Table 3). The value "2.16" in the first row of the column "2001" means that in 2001 there is a 3% chance that the short term US dollar interest rate will be less than 2.16. Or, from the bottom of the column, the chance it will be greater than 9.06 is 3%. This can be used to identify "values at risk" measures.

Table 3: Probability distribution of dollar short rate

Probability	*2000*	*2001*	*2002*
3	5.79	2.16	2.02
16	6.10	5.25	4.96
50	6.54	6.69	6.91
84	7.01	8.03	8.87
97	8.04	9.06	13.06

Note: The probability (percent) that the rate will be less than the amount specified in the column, e.g., in the column "2000" and row "'50", half of the interest rates will be below 6.54 and half above.

With the distribution of rates, we can derive the optimal asset allocation for a given objective function. One of the considerations in BR reserve management is that the currency composition of foreign exchange reserves must match the composition of the outflows of the balance of payments to reduce as much as possible cross-currency risks. The resulting desired currency composition for reserves is currently 80% US dollars, 15% Euro, and 5% Yen. This

[10] We obtain explicit expressions for these (See Wets, 1998). This allows us to integrate them to obtain the cumulative distributions and to obtain inverse values to create tables like Table 3 for any probability values.

combination can be though of as a basket currency, implying that we can redefine the objective function to be the maximization of returns defined in the basket currency. This insures that any asset choices are evaluated relative to what is considered the most risk-reducing currency composition of assets. Table 4 provides a summary overview of the solution, on which we expand.

Table 4: Solution summary information
(All expected values except for 1999)

Item	*1999*	*2000*	*2001*	*2002*
% US dollar	80.00	80.00	80.00	80.00
% Euro	15.00	15.00	15.00	15.00
% Yen	5.00	5.00	5.00	5.00
Expected yearly return in USD		5.23	5.69	6.14
Standard deviation of return		0.53	0.82	1.09
Weighted average maturity	5.09	5.00	5.00	4.33
Probability of returns < 2.75%		0.00	0.00	0.02
Probability of returns < 5.5		100.00	48.20	30.34
Probability of returns < 7.5%		100.00	100.00	100.00

When we solve the model by optimizing our objective, we derive the percent asset allocation in each year (Table 5). In terms of currency choices, this is for year 1999 the exact same asset allocation[11] as currently suggested by the Central Bank of Colombia: 80% US dollars, 15% Euro, and 5% Yen. This is to be expected since, by construction, the expected rates of return on each asset (after currency movements) are identical and there are no bounds specified on any asset classes nor any other constraints imposed. We emphasize the point here to show the consistency of the model with the prior assumptions.

Table 5: Percent expected asset allocation

Asset Classes	*1999*	*2000*	*2001*	*2002*
Euro short	3.74	4.29	4.81	5.31
Euro long	11.26	10.71	10.20	9.71
Euro Total	15.00	15.00	15.01	15.02
US dollar liquid portfolio	7.13	6.90	6.47	5.18
US dollar short	10.00	13.95	17.87	22.51
US dollar long	62.87	59.15	55.64	52.29
US dollar Total	80.00	80.00	79.98	79.98
Yen short	3.00	3.02	3.05	3.07
Yen long	2.00	1.98	1.96	1.93
Yen Total	5.00	5.00	5.01	5.00

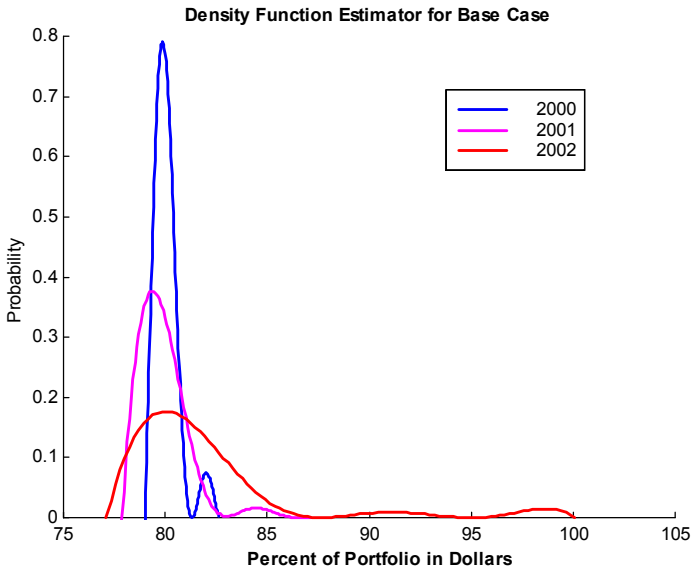
Table 5 suggests that the asset class proportions are (almost) constant over time. This is not necessarily the case as the asset allocation in Table 5 for the years beyond the first year are the percent allocations expected. As exchange and interest rate movements will occur, depending on the particular scenario which materializes, the portfolio manager may find that a composition is realized that deviates from the 80/15/5 split. In order to achieve the desirable mix at each future date, he will rebalance the portfolio in a certain way depending on the specific outcome in the year. As the outcomes themselves are stochastic, the allocation in the second year and beyond become stochastic as well. This element of dynamic

[11] With some latitude as to the assumption of the percentage in the dollar liquid portfolio.

rebalancing of the portfolio at every future event is a key part of the optimization technique. Different than most other ALM-models, the model explicitly allows at date zero (today) for the possibility of rebalancing at future dates, i.e., the possibility of rebalancing in the future plays a role in current allocation of assets. This way we obtain the correct estimates for the density functions of activities that depend on future decisions, such as total wealth.

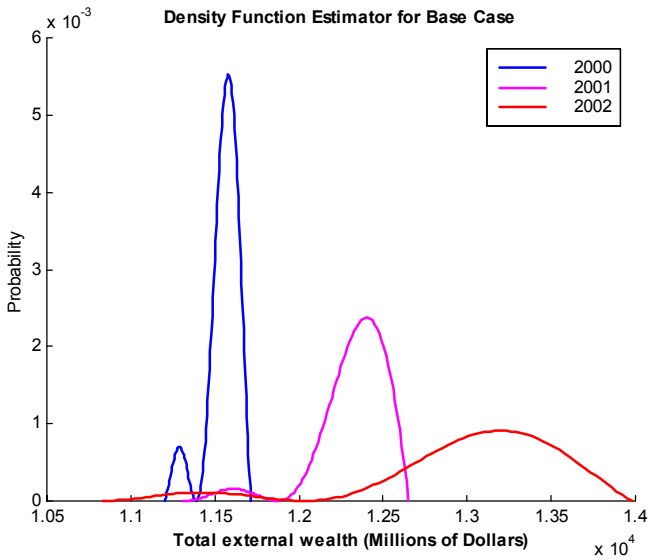
To illustrate, we plot the density functions of the proportions of dollars in the portfolio in Figure 5. We see that in the year 2000, there is little variability around the 80% proportion, but that the variability expands somewhat in 2001 and even more in 2002. In none of the years, however, is the variation very substantial. In 94% of the cases in the years 2000 and 2001, the fraction of US dollars is between 78-83%. Put differently, the optimal portfolio is quite stable over time and requires only modest rebalancing.

Figure 5: Density functions of the percent of $US in the portfolio



The modeling technique allows us to get the density functions of any decision and outcome variables at every date in the future. Following the portfolio allocation, Figure 6

Figure 6: Density functions of total external wealth in millions of $US



gives the density functions of wealth at different points in time. The figure shows that the densities for total wealth widen as time progresses, a reflection of the increase in uncertainty.

Using the densities, just as we did for the interest rates, we can generate a table of the distribution of wealth derived, which is given in Table 6. The distribution of wealth is quite narrow, 94% of the density mass is between $11,401 and $13,796 at the end of 2002 and 68% between $12,662 and $13,544. This is partly due to the relatively low volatility measures used and the fact that there were no other constraints imposed on the problem.

Table 6: Probability distribution of wealth in millions of $US

Probability	*2000*	*2001*	*2002*
3	11,282	11,658	11,401
16	11,488	12,182	12,662
50	11,571	12,371	13,134
84	11,638	12,519	13,544
97	11,679	12,599	13,796

Note: In analyzing the wealth in dollars at the horizon (year 2002), we must be careful to keep in mind that we are actually maximizing wealth measured in the basket currency. This is almost dollars but not exactly. The expected wealth at 2002, for example, in millions of $US is 13,134 and the maximum expected wealth in millions of the basket currency is 14,735.

(ii) An alternative scenario

The assumptions of the last section were based on an investment neutral assumption, that is, we assumed that all assets were expected to yield the same rates of return. This is only one of the many possibilities. Specifically, typically three possible choices for predicting future rates are being used. First, the assumption we used above that current market data embedded in the yield curve and in forwards and options contain the most accurate information on how future rates will move. Second, the assumption that rates behave as they have in the (recent) past and base the future stochastic processes on the basis of estimation using historical data. Lastly, one may use expert judgement. Our techniques allow for the use and integration of all three approaches.[12]

To explore the sensitivities of the outcome of the ALM model to the assumptions on rate movements, we conduct a test and alter the model by increasing the Euro appreciation. Specifically, we assume that the Euro appreciates at twice the rate indicated by the Uncovered Interest Parity assumption over the year 2000 and that the volatility of all the processes almost doubles. The new volatilities are given in Table 7. Everything else is assumed to remain the same. We call this case the *stronger Euro*.

Just as before, we present the summary solution information in Table 8 first. Comparing this with Table 4 we notice the wider dispersion in returns. On the downside, there is a 20% probability that the compounded return will be less than 3.75% in 2002. However, on the upside there is a 2.7% probability that returns will be greater than 13.5%. Looking at the standard deviation of returns, we see that they are much higher than before,

[12] The latter, integration, is an extension of the technique proposed by Fischer Black and Robert Litterman, Global Portfolio Optimization, *Financial Analysts Journal*, September-October, 1992.

with the possibility of substantial negative returns. However, the expected value of total wealth is higher, as the rate of return on the Euro is higher.

Table 7: Standard deviation of rates for stronger Euro

Asset Class	*2000*	*2001*	*2002*
Euro short rate	0.89	1.88	2.23
Euro long rate	1.39	2.91	3.27
Dollar short rate	1.10	1.65	1.93
Dollar long rate	1.31	2.41	2.79
Yen short rate	0.16	0.30	0.39
Yen long rate	1.48	1.79	1.63
Euro exchange rate	0.38	0.49	0.62
Yen exchange rate	19.80	22.53	27.07

Table 8: Optimal solution with stronger Euro

Item	*1999*	*2000*	*2001*	*2002*
% Euro	92.83	92.71	92.74	92.76
% US dollar	7.17	7.29	7.26	7.23
% Yen	0.00	0.00	0.00	0.01
Expected yearly return in USD		6.87	6.36	6.72
Standard deviation of return		11.10	11.63	11.92
Weighted average maturity	5.80	5.48	5.25	4.99
Probability of returns < 3.75%		52.00	18.95	20.85
Probability of returns < 7.5		54.00	56.98	42.28
Probability of returns < 9%		54.00	71.22	65.69
Probability of returns > 13.5%		6.00	2.23	2.70

Table 9 provides more detail of the effects of this stronger Euro assumption on the optimal asset allocation. It is no surprise that the modified solution produces a large position in Euro (89% in Euro long assets).

Table 9: Percent expected asset allocation for stronger Euro

Asset Classes	*1999*	*2000*	*2001*	*2002*
Euro short	3.77	7.82	11.89	15.88
Euro long	89.06	84.89	80.85	76.89
US dollar liquid portfolio	7.17	5.30	4.85	3.75
US dollar short	0	1.99	2.41	3.48
US dollar long	0	0	0	0
Yen short	0	0	0	0
Yen long	0	0	0	0

As noted, volatility was assumed to almost double, thus raising the riskiness of the rates of return, including the possibility of negative rates of return. In order to examine solutions with less volatility in returns, we use the techniques for restricting the density function of returns. We adopt an objective function[13] that weighs not only the expected value of the wealth, but also the uncertainty surrounding the distribution. We will also include, as

[13] The objective is a piecewise linear-quadratic preference function of total final expected wealth. It tends to push the probability mass into a region defined by function parameters determined exogenously.

required by the central bank, a constraint on negative returns. As noted, the central bank faced the legal restriction that there should be no loss of principal. We will apply a no-negative-returns constraint to the total returns on the basket currency. This is most natural in our setting since it captures all currencies at once. The solution, which we call the *constrained* solution, is given in Table 10.

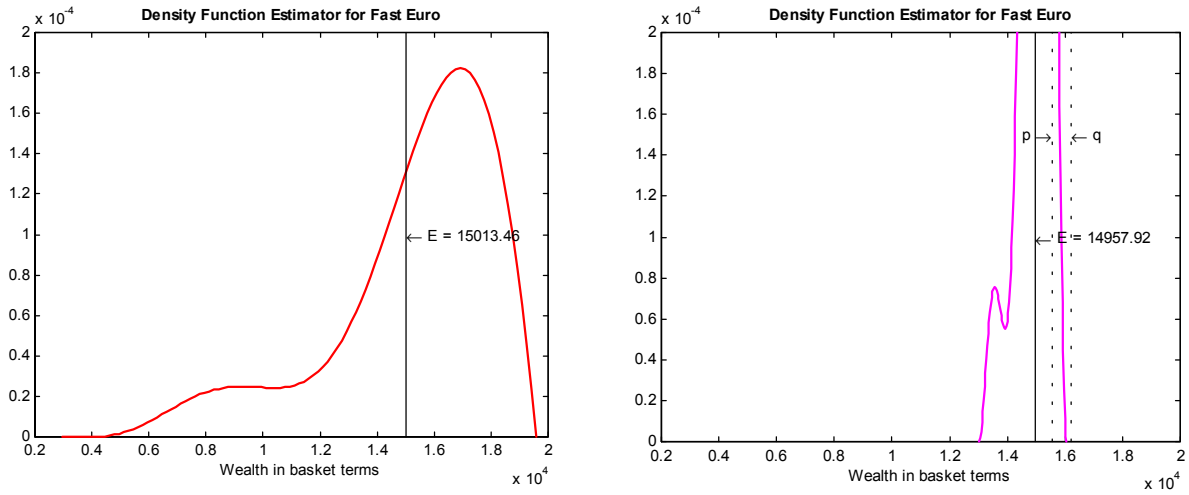
Table 10: Optimal solution of stronger Euro with constrained density

Item	*1999*	*2000*	*2001*	*2002*
% Euro	19.31	19.14	18.87	18.89
% US dollar	75.69	75.88	76.24	76.22
% Yen	5.00	4.97	4.88	4.89
Expected yearly return in USD		5.54	6.41	6.74
Standard deviation of return		2.18	2.69	3.05
Weighted average maturity	5.18	4.86	4.58	4.34
Probability of returns < 3.75%		4.00	5.66	5.03
Probability of returns < 7.5		98.00	100.00	99.74
Probability of returns < 9%		100.00	100.00	100.00

Now the asset allocation proportions are closer to the 80/15/5 split for USD/Euro/Yen as given in the Base Case. Moreover, on the downside, the probability of returns being less than 3.75% is now only 5% as compared to 20% before. However, on the upside there is now only a 0.3% probability that returns will be greater than 7.5% whereas before the probability was 58%. All in all, the standard deviation of returns has dropped considerably, at a cost of lower rates of return.

In order to get a better understanding of what is happening, we examine various density functions. The first graph of Figure 7 is the wealth in basket terms. The second graph in Figure 7 shows the dramatic "squishing" of the density function of returns, leading also to a lower variability of wealth. Whereas wealth varied from 4 to 20 billion in the basket[14] currency, it now varies between 13 and 16 billion. This comes at a cost, as noticed, however, in the expected value of wealth of about 56 million.

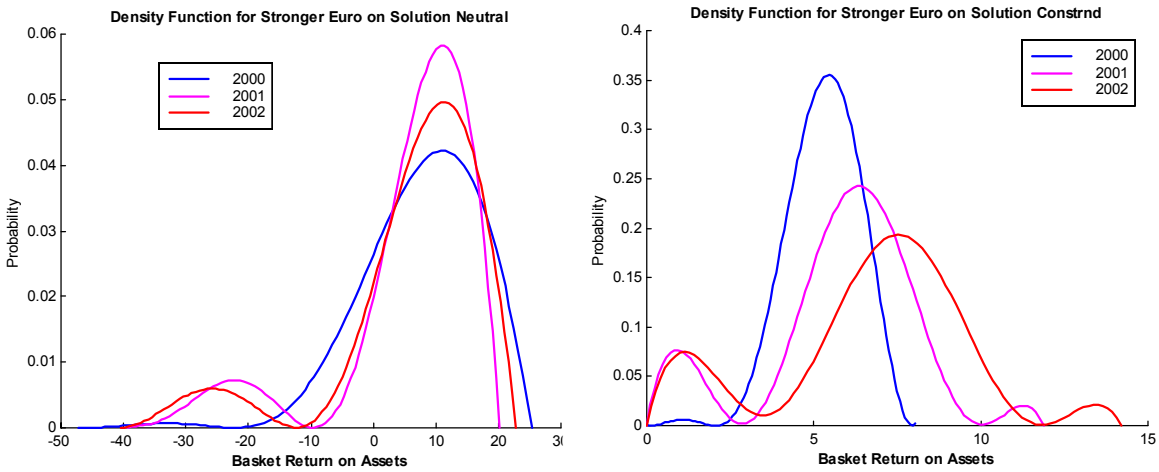
Figure 7: Density functions of wealth in 2002 – stronger Euro versus constrained



[14] We could have also graphed the returns in $US but these are not much different.

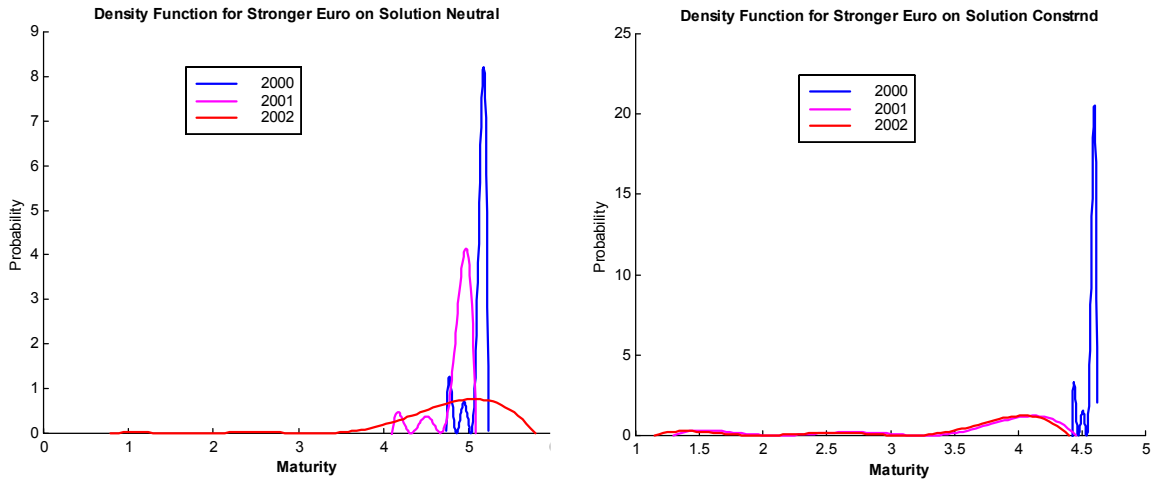
Figure 8 presents the densities of the returns on the assets. The base case basket returns vary from -50% to 20% in all years whereas under the constrained solution the densities of the rates of return vary from 0 to around 10%. This then maintains the no-negative-return requirement.

Figure 8: Densities of percent returns - stronger Euro versus constrained



We also examine the maturity structure of the portfolio. Comparing Tables 8 and 10, we see that the average maturity of the constrained solution is less in every year than the base case. This is consistent with a portfolio with less volatility. Moreover, the average maturity decreases in each future year within each solution under the constrained solution. To examine these phenomena, we plot the graphs of the densities of the average maturity of the portfolio in Figure 9.

Figure 9: Densities of average maturity – stronger Euro versus constrained



We notice that the densities are very narrow in both cases in the year 2000. However, in 2001 and 2002 the densities are much wider. Also, the average maturity decreases over time. One way to examine these issues is to look at the expected cash flows over time, given in Table 11. We see that, to obtain a lower maturity, the model suggests selling some long assets and purchasing short. We see in Table 11 that the main sale of assets (135 million

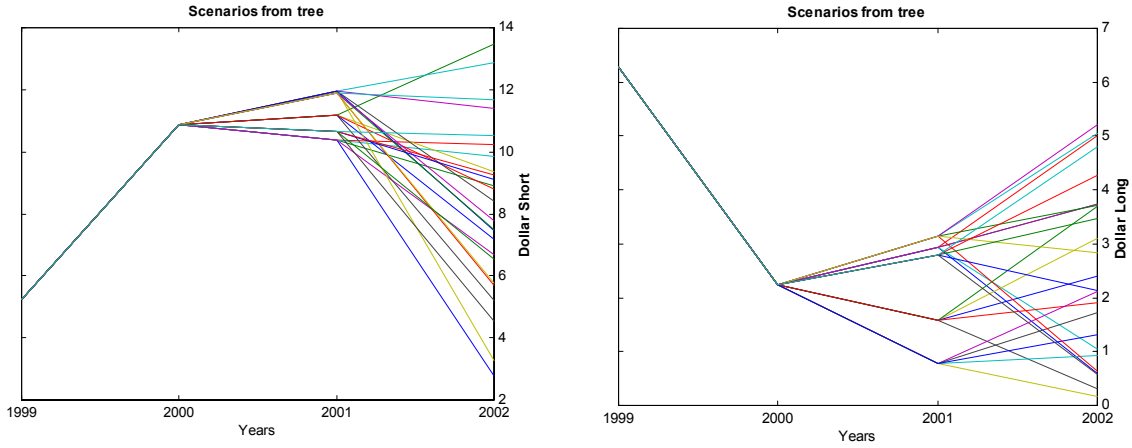
$US) takes place in the year 2001. A further breakdown[15] of the line items of the cash flow statements for the sale of assets and for new assets acquired shows that the main sale of assets takes place in long dollars and the main purchase is in short dollars.

Table 11: Expected cash flows for the constrained case
(Expected Sources of Funds in Millions of $US)

Category	*1999*	*2000*	*2001*	*2002*
Liquid assets matured	1,100.00	821.19	655.31	640.17
Other matured assets		1,714.35	2,522.15	3,373.37
Return on assets		569.55	638.60	701.80
Sales of assets	159.50	10.29	134.90	0.11
Total sources	**1,259.50**	**3,115.38**	**3,950.96**	**4,715.45**

The question is why does this happen. If we look at Figure 9, we notice that the density of the maturity in year 2001 has a long tail. What we would like to know is what the scenarios look like corresponding to that long tail, i.e., under which interest rate scenarios did the model suggest to sell long and purchase short. For this, we examine all scenarios with average maturity less than 3, which is given in Figure 10.[16] The chance that these scenarios will occur is only 1.8%. From the figure, it is clear that these scenarios correspond to states of the world where there is a yield curve inversion. In this case, it makes perfect sense to sell long dollars and purchase short.

Figure 10: Scenarios for maturity < 3 for constrained case



iii) A combined scenario

One other scenario of interest is the one where we constrain the densities, yet still wish to allocate currency in the ratios 80/15/5. Moreover, suppose we will always rebalance the portfolio to maintain the same ratios. How do the solutions compare? There is much less

[15] We omit the details of that table and we omit the table of applications of funds.
[16] Within RisKontroller, we have the facility to specify a slice of any density function. That slice can then be used to generate scenarios, cash flow statements, new densities, or any or any other functions for those scenarios.

left to optimize but there is still freedom to choose the maturity. Figure 11 graphs the densities of wealth lost due to the policy decision to adopt an 80/15/5-currency composition instead of that suggested by the constrained case. In looking at these densities, we note that the distribution is almost centered on 0 with a potential for losses of up to 800 million compared to the constrained solution. However, the probability of such losses is small. Nevertheless, there are opportunity costs to having additional constraints imposed.

Figure 11: Densities of wealth lost in millions of $US for policy decision to enforce 80/15/5 ratios

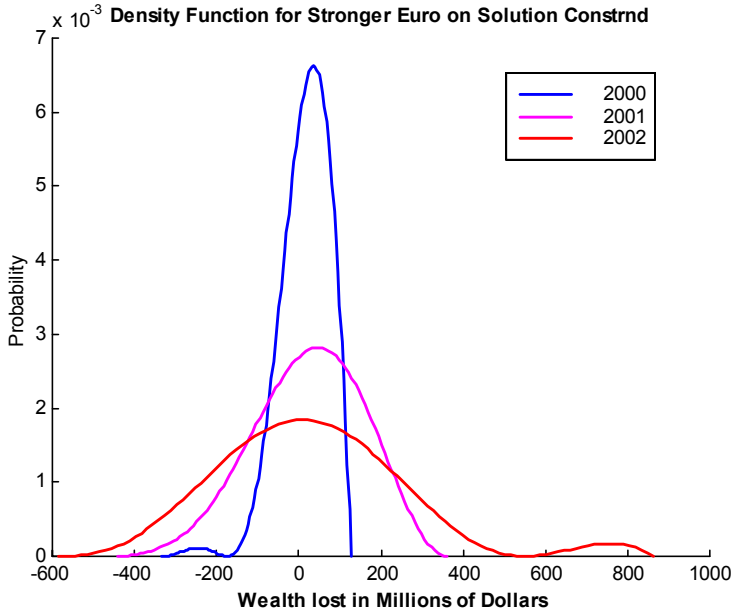


Table 12 provides a more precise answer of the distribution of costs. The expected loss varies from 16 to 24 million. In 2002, there is a 3% probability that the loss due to the difference is beyond 399 million. On the other hand there is a 3% probability that that the 80/15/5-currency composition will give a 290 million-dollar gain over the solution suggested by the constrained solution.

Table 12: Probability distribution for losses due to policy decision to enforce 80/15/5

Probability	*2000*	*2001*	*2002*
3	-94	-206	-290
16	-39	-103	-157
50	16	20	24
84	67	137	193
97	95	219	399

5. Conclusions

(i) ALM-modeling

The analysis demonstrates how to make informed decisions under uncertainty for debt and asset management. It showed that a rigorous process of analysis and the structured framework provide significant gains in modeling and insight. It also showed that one needs

to investigate the whole spectrum of distributions of asset returns, exchange rate returns, and their effects on uncertainty of wealth currency composition, maturity, and asset composition to understand the reasons for their volatility or lack thereof. While many have used simpler measures—such as value-at-risk, standard deviations, partitions of the densities, or probabilities on achieving specified intervals—these are most often only partial measures and less informative than the full density measures.

Applying the model to the problem of risk management for a reserve manager, we can analyze in more depth the currency composition and maturity choices. Using various "cuts" of the solution and different sensitivity analysis, we find robust support for the preferred choices. We also show the tradeoffs of making other policy choices and provide statistical measures for different choices. We also investigated the sensitivity of the solution to the stochastic processes used. We found that the results were very stable. More generally, the dynamic stochastic optimization approach leads to solutions that are quite robust to assumptions on underlying stochastic processes. The theoretical foundations for this model actually guarantee the stability of the proposed solutions under (not excessive) perturbations of the underlying stochastic processes.

The model can be extended to address more complex issues with active reserve management. One extension is the problem of liquidity portfolio size and the allocation of part of reserves to active management. The model could be used to determine levels of reserves to go to active management either in-house or through external managers with pre-specified risk profiles with a desired overall risk profile of the portfolio. The model can also be extended to analyze disaster scenarios (with low probability and high impact).

(ii) More complex ALM models

The application to the management of a central bank's foreign exchange reserves shows both the ease of usage as well as some of the gains to be obtained from using this approach compared to approaches that are more traditional. It is easy to extent the model to more general problems and thus bring out all the features and advantages of using a dynamic stochastic programming approach. One such more complex problem is that of a sovereign debt manager, for which the approach can be expected to be even more useful. A debt manager is likely to have to consider a much broader range of objectives and constraints than a reserve manager is. She will, for example, have to incorporate the evolution of fiscal revenues and the relationship between these revenues and external risk factors. She will also have to consider the risks coming from contingent liabilities, including government guarantees to state and/or private enterprises and other contingent liabilities (most often these are not even budgeted or evaluated). In addition, the range of legal and policy constraints is likely greater. Furthermore, liabilities, be they loans from banks or bonds, are generally less easily altered than reserves where short-term assets are generally liquid and can be easily marked-to-market and sold. The market for altering long-term liabilities is much less liquid, and, while they can be swapped in principle, this can often only be done at large costs.

(iii) Implementation

As with all models, their values depend on their application and the context of usage. It is clear from many experiences with debt and reserves management that a proper institutional framework is key. This needs to involve the availability of good personnel, data,

reporting and accounting procedures, and accountability. Second, proper ALM requires a very careful analysis of the real, underlying objectives and constraints. Often such an analysis will indicate underlying problems, which need to be fixed first before any ALM can be undertaken. And the analysis, as well as institutional weaknesses might well suggest that the best way forward is to use very simple models to analyze specific areas of concerns.

This does not mean necessarily that most countries should not pursue an ALM-approach as laid out here. There are undoubtedly some countries, which have addressed most of the pre-requisites. For those, a strategic ALM-approach may be a useful tool. And even for those countries that do not yet have all the prerequisites in place, a strategic ALM-approach allows them to evaluate the opportunity costs of the existing approaches. Regardless of the level of institutional development, the elements of a strategic approach provide a conceptual framework against which managers may wish to compare their existing approaches and assess whether they can be expected to address the underlying objectives and constraints. All too often, managers will "buy" very expensive technology or advice, which only addresses a sub-set of their problems. It can then well be that the proposed solutions are far from optimal or even suggest a totally inappropriate position! It will often be more important to go through a rigorous process in the government and debt and asset management agencies of identifying risks, constraints and objectives, than to adopt a technology for a sub-set of the overall problems.

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