Application of Investment Models in Foreign Exchange Reserve Management in Eesti Pank

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This paper describes active investment strategy used in the central bank of Estonia and introduces model-based investment decisions as a component of that strategy. The first chapter of the paper describes the evolution of the investment process in Eesti Pank and outlines the framework of reserve management. It describes the role of several forms and styles of investing: active and passive management, qualitative and quantitative management, emphasizing the role of diversification for achieving better performance. The chapter concludes with the description of the investment strategy used in the central bank of Estonia.

The second chapter describes model-based investing as part of active management strategy. Three investment models are estimated and tested: a model for directional positions in the US, German and Japanese 10-year government bond futures, a model for cross-currency positions in ten major currencies, and a model for cross-country yield spread trades in eight major government bond markets. The models extend the framework developed by Ilmanen and Sayood (Ilmanen *et al.* 2002). After the model estimation the models are combined with a trend-following model and the whole set of diversified models is tested. Finally, correlation study of these results with the results of external asset managers and in-bank discretionary analysis is performed. The paper ends with a discussion on the possibilities for further development of the quantitative investment program and conclusions.

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The views expressed are those of the authors and do not necessarily represent the official view of Eesti Pank.

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Introduction

Active management poses numerous challenges for investors who invest their funds in global bond markets. Central banks form a distinct group among these investors, as they have an important role in directing monetary policy and maintaining the stability of the local currency. Forming an investment strategy for managing foreign exchange reserves requires careful consideration of the various functions of the central bank and priorities arising from that.

In practice, central banks use quite different approaches to achieve their goals. This applies to the role of active management in the overall investment strategy, involvement of external asset managers, their selection principles, risk management methods, structure of the investment process etc. A successful investment strategy should be able to serve the needs of a central bank and to be efficient in terms of investment performance.

Application of quantitative methods and development of investment models has been recognized today as an important tool for active investors to improve investment performance. Numerous questions, however, require more detailed attention. What are the financial market predictors that can be used in these models, how would the models have performed historically, how to incorporate them into a general investment framework and allocate risks – these are but a few problems that need to be solved.

This paper describes the active investment strategy used in the central bank of Estonia and introduces model-based investment decisions as part of the investment strategy. The first chapter of the paper describes the evolution of the investment process in Eesti Pank beginning with a general overview of the framework of reserve management. The chapter includes a discussion on active versus passive management and compares qualitative and quantitative approaches to active management. It also discusses the importance of diversification based on the Law of Active Management. The first chapter concludes with the formulation of the active investment strategy used in the central bank of Estonia.

The second chapter analyzes the models currently applied in active reserve management. Three models are estimated and tested: a model for directional positions in the US, German and Japanese government bond futures markets, a model for cross-country positions in ten major currencies and a model for cross-country yield spread positions in eight major government bond markets. The models extend the framework developed by A. Ilmanen and R. Sayood (Ilmanen *et al.* 2002). In addition, a trend-following model is added to the portfolio and the performance of the model program is compared with the performance of external managers and discretionary in-bank decisions.

The third chapter discusses some ways to improve the performance of the model portfolio and the paper ends with conclusions.

1. The Evolution of Investment Process in Eesti Pank

1.1. General Goals and Framework of Reserve Management

Estonian monetary system is based on the currency board arrangement (CBA). CBA was established in the course of the 1992 monetary reform, when the exchange rate of the kroon was fixed against the German mark (1 DEM = 8 EEK). Since 1 January 1999 the exchange rate of the Estonian kroon has been fixed against the euro, the currency of the European Economic and Monetary Union (1 EUR = 15.6466 EEK). CBA also sets the goals and framework for foreign exchange reserve management, because according to the principles of the CBA, the foreign exchange reserves must fully cover all Eesti Pank's kroon liabilities, including the banknotes and coins issued, and the accounts of commercial banks with Eesti Pank. The reserves serve as the means to ensure the stability of the kroon, and every kroon in circulation can be freely converted to all major currencies. Therefore, Eesti Pank observes strict constraints in reserve management, taking into account the primary objectives – preservation and liquidity of assets. Return comes third on the list of objectives.

These goals determine the framework for the managing and structure of foreign exchange reserves. Regarding the role of the reserves in backing the Estonian kroon, these consist of two parts: its major part serves as the cover for Estonian kroon liabilities, and the rest are excess reserves (the funds in excess of liabilities). Currently the excess reserves constitute about 17% of the total amount of foreign exchange reserves. Theoretically, the excess reserves are the funds that can be risked in the financial markets. In practice, risk limits are much smaller to avoid unnecessary volatility of the reserves.

For practical purposes, the reserves has been subdivided into two portfolios – the liquidity portfolio (the liquidity buffer) and the investment portfolio; a small part of the reserves is also held in gold. The purpose of the liquidity buffer is to cover the monthly foreign currency demand of the banking system. It consists of highly liquid assets required for operating the currency board system, which the central bank can use at any time for foreign exchange transactions with domestic credit institutions. It amounts to about 5% of the total foreign exchange reserves and is invested in the international overnight market.

The second and larger part of the foreign exchange reserves is the investment portfolio. The objective of the investment portfolio is to generate optimum earnings above money market interest rates during the global economic cycle. It is subject to various constraints regarding the list of permitted instruments and risk limits. The assets of the investment portfolio are mainly invested in the liquid government bond markets of major industrial countries. As to the currency composition, Eesti Pank holds EUR and USD-nominated assets, but the currency risk against EUR is hedged, since the liabilities of the bank (Estonian kroon) are in EUR. In practice, the investment portfolio is subdivided into a cash portfolio and two bond portfolios (USD and EUR respectively) that are managed separately. The duration of the investment portfolio is relatively low to reduce its volatility. Therefore, the bulk of assets are invested in money market instruments (cash) and the rest are bonds. This reflects the preferences of the Eesti Pank and follows the principles of reserve management (preservation of value, liquidity, and return) described above. Apart from internal portfolio managers, Eesti Pank has

employed two external managers[1]. In this paper, however, we deal primarily with the internal management of the foreign exchange reserves.

1.2. Combining Different Forms and Styles of Investing

1.2.1. Passive and Active Management

Since 1992, when the foreign exchange reserves were formed in Eesti Pank reserve management has undergone various changes. The size of the reserves has grown from EEK 718 million in 1992 to EEK 20 billion in 2004, influenced by foreign capital inflow resulting in growing cash emission and bank deposits. In 1995 benchmarking was introduced to reserve management. This enabled to separate investment decisions into passive and active management decisions and established the benchmark portfolio as a standard against which the efficiency of active investment decisions could be measured.

Passive management can be described as a "buy-and-hold" strategy, where the investor does not alter the structure of his portfolio very often, but aims at a return generated by simply buying and holding certain securities. Active management, in contrast, means relatively frequent changes in the portfolio in order to better utilize the opportunities, which might develop in the markets. These opportunities may be related to changes in the economic cycle, certain economic or market scenarios, events etc., which influence the prices of securities. An active investor attempts to predict these factors or reacts to them and adjusts his portfolio so that it would be more profitable than a simple buy-and-hold strategy, i.e. he tries to earn excess return over the passive management (i.e. the benchmark portfolio) return.

Combining passive and active investing in Eesti Pank has enabled to structure investment process in a more efficient way, as both types of decisions are independent of each other. Decisions related to choosing and modifying the benchmark portfolio affect the overall level of return and volatility of the investment portfolio. Currently the benchmark portfolio of Eesti Pank is based on the principle that it should produce non-negative return in a 3-month horizon with at least 95% probability. The duration of the benchmark portfolio thus depends on the yield level and volatility of the bond market. In 2004 the duration of the EUR portfolio was 1.04 years and of the USD portfolio 0.78 years.

The aim of active management is to take reserve management a step further from the passive strategy. Active management adds a layer of decisions, which enable to adjust the portfolio further to make use of the market opportunities that may arise during the economic cycle. In practice, active management means deliberate deviations from the benchmark portfolio. These deviations constitute both risk and opportunity for active managers. The major risk categories currently allowed in the Eesti Pank are the duration risk, yield curve risk, country risk, currency risk, and the credit risk. It would be unreasonable to manage the whole risk/opportunity set by passive management decisions, as these reflect long-term strategic preferences of an investor. Active management enables medium and short-term adjustments in the portfolio, and it is

[1] Agreement with the third manager is pending.

possible to monitor the performance of the decisions related to each risk category separately. The efficiency of these decisions depends on the skills of the investor and can be measured in monetary terms as profit or loss. Since 2002 Eesti Pank has been using the Value-at-Risk (VaR) methodology to measure and limit the investment risk in the listed categories[2].

Combining active and passive investing is undoubtedly a more demanding endeavor for an investor than relying only on passive management. Successful active management presumes that there are certain inefficiencies in the global money, bond and currency markets, which can be profitably exploited. Additional profits from active management have to be large enough to cover the increase in transaction costs and other outlays (mostly related to additional staff, software, etc.).

Sometimes it is argued that in global financial markets all inefficiencies are exploited very quickly by arbitrageurs and, consequently, there are no trading rules/models that would yield stable positive returns in excess of transaction costs. The supporters of this argument put forward relevant research. Usually the researcher takes one certain trading rule, adds transaction costs and compares it with a simple buy-and-hold strategy (i.e. passive investment)[3]. Often the results show that certain active trading rules do not yield statistically significant profits compared to passive strategy. In addition, there are papers, in which directional forecasts from some forecasting model (or from some certain forecasters) are compared to random (coin-flipping) forecasts[4]. Quite often the results indicate that the accuracy of such forecasts is statistically not significantly better than 50%.

The fact that some trading rules/models fail, however, does not prove that profitable rules/models do not exist. It is true that it is not easy to be consistently profitable in global financial markets and that depending on market conditions even historically profitable strategies can and do fail. Yet, in spite of the fact that many simple investment rules do not work, it is still possible to develop profitable investing rules. In chapter 2 we outline some quantitative methods, which have produced profit in historical testing and have continued to do so in real investing. It is indeed rather difficult to forecast the markets correctly and base successful investing on those forecasts. However, it is not necessary to predict the market levels correctly in long term to exploit market dynamics profitably. Success of the trend-following methods, which are based on reacting to the price dynamics instead of predicting them, are a proof of that[5].

Therefore, it can be concluded that although financial markets are highly efficient, they are not completely efficient. Due to numerous factors including the differences between investors regarding their risk/reward preferences, investing horizons, skill levels, etc., certain inefficiencies can develop, exist and disappear in the markets for shorter or longer periods. With proper skills these inefficiencies can be profitably exploited to

[2] Except the credit risk
[3] Examples of such papers are Fong *et al.* 2005, Neely *et al*. 2003 etc.
[4] For example Kolb *et al.* 1996 etc.
[5] The performance of major active investment styles applied by commodity trading advisors (CTAs), including the trend-following CTAs is monitored by CISDM (Center for International Securities and Derivatives market) at the University of Massachusetts.

make the active management meaningful[6]. This has been the philosophy behind combining active and passive investing in Eesti Pank.

1.2.2. Qualitative and Quantitative Approach to Active Management

One can distinguish between two major investment styles, which are both widely used by institutional investors – discretionary investing and systematic investing. Discretionary investing relies mainly on qualitative analysis of the economy and financial markets. It necessarily involves a certain degree of subjectivity, as it is based on the opinion of an investor regarding the future market dynamics. Systematic investing, in contrast, relies exclusively on quantitative analysis and attempts to quantify market behavior in relation to the factors which are supposed to influence it. These factors can be classified as technical factors, which are derived from the price dynamics (trend direction, momentum, volatility, etc.) and fundamental or economic factors (like CPI, economic activity, etc.); there are also various other factors that may affect the market (like investment flows, relationships with other markets, etc.). Systematic investing in its pure form means that investment decisions depend 100% on signals generated by quantitative investment models. It is possible to combine these styles of investing in various degrees, but usually one style is dominant. The matrix of major investment styles is presented in Figure 1.

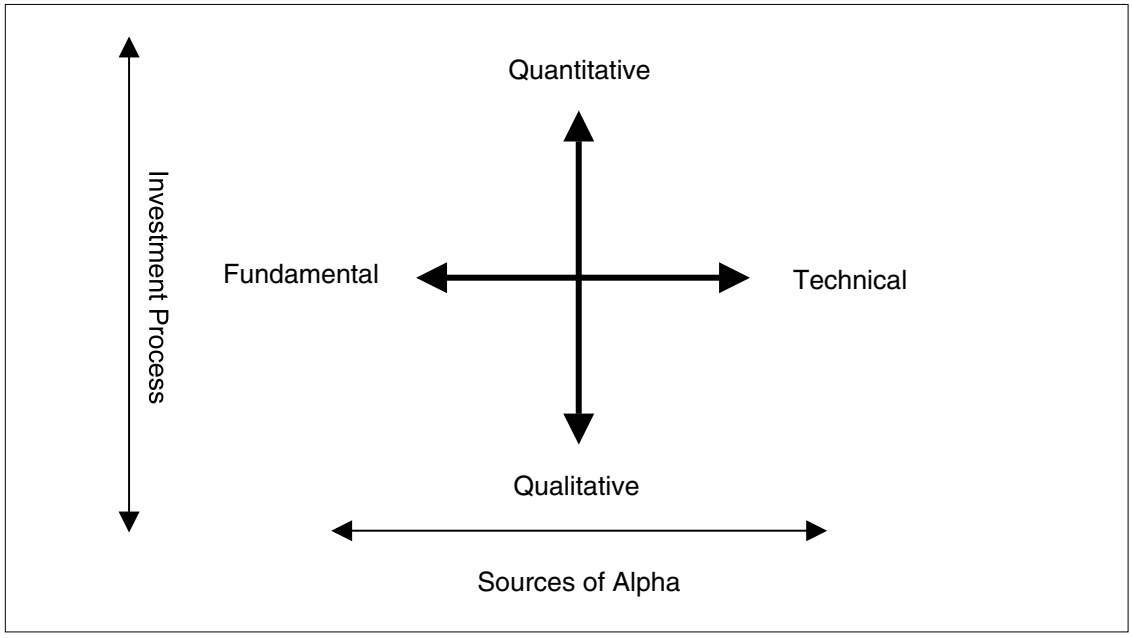

Figure 1. Matrix of investment styles

Both styles of investing are currently used by institutional investors as viable ways of making investment decisions. With the advent of computerized analysis of financial markets and special trading strategy back-testing software (like Tradestation, MetastockWealth-Lab etc.), as well as the expansion of managed futures and hedge

[6] The concept that investors should be (and are) rewarded for the cost of gathering and analyzing additional information with higher gross returns is known as "rational efficient markets formulation", see, for example Grossman and Stiglitz (1980).

fund industry quantitative analysis techniques and systematic investing have gained more ground at the expense of the discretionary style. According to some estimates, only 20% of managed futures accounts are predominantly managed by discretionary methods[7]. Long-term performance of these styles has varied over the years. Based on Barclay Trading Group data (CTA indices), in 1992–2004 the average yearly return of discretionary and systematic investors was 3.3% and 6.7%, respectively. In the last five years (2000–2004), the discrepancy in performance between the two styles has diminished, as these numbers were 5.4% and 6.8%, remaining slightly in favor of the systematic style.

Over the years, the investment process in Eesti Pank has undergone several changes resulting in combining both investment styles. Until 1995 the majority of investment decisions were individual discretionary decisions by portfolio managers in accordance with the general investment guidelines. In 1995 collective decision-making gained more importance, when a special body (investment committee) was established in the Financial Markets Department to make longer-term (also called strategic) investment decisions based on economic analysis and market views of the committee members. These decisions were collective discretionary decisions usually based on consensus between the committee members regarding the future market development. In the beginning the decisions were mostly based on qualitative analysis of the economy and financial markets. Later it was decided to add more elements of quantitative analysis to the investment decision-making by discretionary use of econometric models. In 2002 it was decided to separate quantitative investing from qualitative investing by forming a strategy group, which started to use investment models in a systematic way, and investment committee ceased its activity. The strategy group currently uses only investment models for making investment decisions. It operates within a fixed risk limit in VaR terms and uses derivative instruments[8]. At the same time the cash portfolio, USD bond portfolio, and EUR bond portfolio are managed by portfolio managers, who make discretionary decisions on the basis of qualitative assessment of market developments (tactical decisions).

Experience of the investment committee, which met once a month, indicated that it was quite complicated to reach a consensus between the members who relied on various sources of information and had different degrees of involvement in analyzing market developments. The decision to separate the two investment styles and combine them in reserve management, as it is currently practiced, was a natural outcome of the inherent differences between the two investment styles. The purpose of the separation was to increase the efficiency of the investment process by better utilization of the strengths of both styles described below.

Systematic investing and applying investment models enables investors:

- to eliminate emotional factors (greed, fear etc.) and related common mistakes from investing;
- to consistently take into account important factors that affect market dynamics;
- to incorporate risk management based on historical performance of the model;
- to back-test and analyze the consequences of altering the factors or parameters in the investment strategy.

[7] Barclay Trading Group data (2001).
[8] Similar approach is practiced by external asset managers.

Discretionary investing, on the other hand, enables investors:

- flexibility in selecting important information including unquantifiable information (like political events);
- often faster response to the change in market conditions, more flexible adjustment of risk/reward preferences which fits the personality of the investor;
- to choose such an investment horizon and trading time-frame which is more suitable for the investor;
- application of personal experience and skills in investment decisions.

Both investment styles can be used to gain edge over the market, but adhering to either style does not by itself guarantee that this edge can be easily developed and maintained. Combining both investment styles in reserve management, however, serves as a good way to diversify portfolio and gain from the strengths of these styles while reducing risk if correlation between their performance is weak.

It has to be noted that all markets are not equally suited to systematic investing (i.e. to successful application of investment models). For example, the performance of trend-following models depends on the trendiness, which varies with markets. Some markets (like interest rates and major currencies) exhibit more trendiness, which is due to the economic cycle and differences between major economic regions regarding economic growth, inflation, current account balance and other factors. Intraday trading models usually require a certain degree of intraday volatility and are therefore mostly used in S&P 500 index futures market, where profits justify the costs associated with relatively frequent trading. Similarly, certain fixed income classes lend themselves to the use of quantitative techniques better than other fixed income classes (SSGA 2003, p1). In general, markets that are sufficiently liquid, standardized and developed, have less event risk, and those prone to trend are more suitable for quantitative investing.

Quantitative analysis of financial markets is by no means a new field of analysis. Over the years a number of models have been developed to analyze and predict market behavior; their number and degree of sophistication continues to grow. It is impossible to count all the quantitative techniques which have been used for that purpose – from simple linear regression to neural networks and genetic algorithms. For the purpose of this paper, these models can be divided into the following three major categories.

1. Econometric "best fit" models. These models are mostly used to explain the past behavior of a particular financial market and usually contain several fundamental (economic) indicators as inputs. The purpose of such models is often not to predict market behavior, but rather to assess whether the price of a security is close to the estimated "fair value". These models have been developed by academic researchers for purely theoretical purposes, but they can also be helpful tools for institutional investors. A well-known example of such model is the "Taylor rule", which is used to explain the US fed funds rate dynamics by output gap and inflation dynamics. Other examples are Goldman Sachs World Interest Rate Equilibrium model (GSWIRE) for 30-year U.S. Treasury bond yield (Hatzius 1999), a term structure model of government bond yields (Diebold *et al*. 2002), and many others. As a rule, all major investment banks are involved in developing such models, and similar models have been developed and used also in Eesti Pank (Vesilind 2003). It should be noted, however, that while these models can be used as convenient tools to analyze and

explain the market dynamics, they are rarely directly applicable to active investing. The main reason is that although these models provide an indication of the "fair value" of exchange rates and interest rates, market prices can often significantly deviate from their theoretical "fair values" for a considerable time period. As a result, relying exclusively on such models would usually not yield satisfactory risk/reward profile for the investor.

2. Technical investment models. Models belonging to this category use primarily technical indicators derived from the price and they are designed with the purpose to provide profitable trading signals. A number of such models can be purchased as software. The performance of more than two hundred technical models (also called trading systems) is currently monitored by an independent institution Futures Truth Co.[9]. Several years of practical experience have shown, however, that the performance of such models widely varies. A large number of models, which have demonstrated positive performance in the past, fail to produce even remotely similar results in real trading. The main reason why such models fail is over-optimisation. With the help of powerful software packages (like Tradestation and Metastock), it is very easy to back-test investment ideas on historical price data and optimize parameters in the model. Overoptimized models perform poorly or fail completely in actual investing, as the markets are constantly changing and future price behavior does not usually replicate its past behavior. An example of such model would be a simple moving average crossover model, which gives a buy–signal, when the short-term moving average of prices crosses over the long-term moving average. It is easy to find an optimal and sometimes even very profitable combination of its parameters (the lengths of moving averages) for an in-sample period only to find out that this combination results in outright loss in the out-of-sample period. Nevertheless, there are also technical investment models, which have demonstrated robustness and continued to perform reasonably well in actual trading. These models are based on sound investment philosophy (like trend-following, pattern recognition etc.) and are not overoptimized[10].

3. Technical-fundamental investment models. These models do not rely only on technical analysis to generate trading signals, but may use a combination of technical and fundamental indicators as input variables. The algorithm of the model determines whether the security should be bought or sold. Such models for bond and currency markets have been developed in Citigroup[11], JP Morgan, State Street Global Advisors[12], Informed Portfolio Management[13], ABN AMRO Asset Management, and other financial institutions and these are successfully used in active investing. A simple example of such model is the forward bias model for major currencies developed in Deutsche Bank, which gives a signal to buy currencies of the countries with higher interest rates and sell currencies of the countries with lower interest rates (Deutsche Bank 2002, p 13). More often, however, such models combine several factors that influence price behavior. It is this combination of many weakly correlated inputs, which renders this category

[9] The results are published in Futures Truth Magazine.
[10] See Hill, J. *et al.* The Ultimate Trading Guide, p 185.
[11] Ilmanen *et al.* 2002.
[12] SSGA 2003, pp 2–8.
[13] Darnell *et al.* 1997.

of models sufficient robustness, so that they can be profitably used in active investing. Even if one input in the model may lose its significance temporarily or permanently due to changes in market behavior, it is unlikely that all inputs share the same fate simultaneously. An important factor of success for such models is rigorous out-of-sample testing in order to verify the stability of relationships between the inputs and the output. Yet it is possible that the risk/reward characteristics of these models may decline over time to the extent, which leads to overhaul or even abandonment of the model. Markets are ever-changing and it is nearly impossible to predict which relationships persist and which will weaken or disappear.

It has to be added that successful application of investment models does not depend only on selecting or developing one profitable model, which is applied in one or two markets. Better results in terms of risk/reward can be achieved by combining several weakly correlated models, which are applied to a variety of markets and trade a number of instruments. This underscores the importance of diversification in active model-based investing.

1.3. Forming a Diversified Investment Strategy

The efficiency of active management can be characterized by information ratio (IR), defined as expected active return divided by active risk. The relationship between the information ratio of a combined portfolio and its subcomponents has been summarized as the Law of Active Management (see Clarke *et al.* 2002, p 50).

$$IR \approx IC\sqrt{N},$$

where: IR is information ratio (ratio of average profit to its volatility) of the entire investment portfolio;
IC is information coefficient (average ratio of average profit to volatility) of each investment model/manager;
N is the number of independent investment decisions.

According to this law, the performance of an actively managed portfolio can be improved either by improving the performance of individual managers or models (i.e. by increasing their predictive power) or by increasing the number of independent (in practice, weakly correlated) investment decisions (managers) or models.

This relationship is illustrated by Figure 2, where the probability of cumulative profit is shown as a function of the number and the accuracy (percentage of correct directional forecasts) of positions[14]. It can be implied from the figure that in order to be profitable with 95% probability, the investor has to have at least 40 independent investment positions with 60% accuracy or over 180 investment positions with 55% accuracy. If we assume – perhaps more realistically – that the investor has 10 positions in a month (120

[14] Similar analysis is presented in an article by Central Bank of Norway (Highest Possible… 2004) outlining the bank's active management strategy. The following assumptions apply: 1) the positions have zero correlation, and 2) profits and losses are of equal size.

positions per year) with 53% accuracy then the yearly profit can be secured with 80% probability.

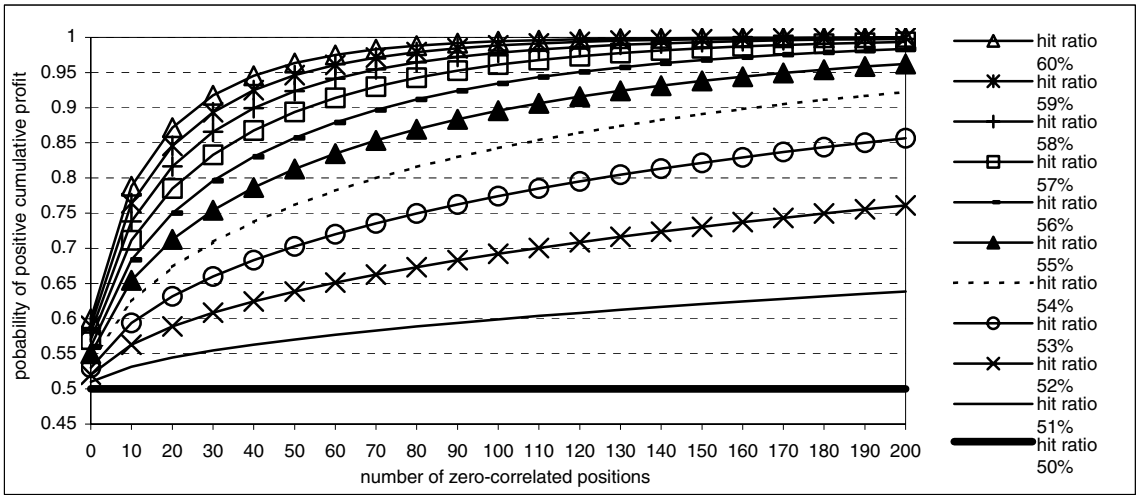

Figure 2. The probability of positive excess return in a year as a function of the number of independent positions and their accuracy

The main implication of the law of active management for reserve management is the importance of diversification. The idea that even if individual directional forecasts rarely beat random forecasts, there can be a minuscule added value, when we use a pool of forecasts is shown, for example, by Greer (2003). As global bond and currency markets are highly efficient, it is relatively difficult to find exceptionally profitable managers or to increase the performance of any single investment model. Therefore, in trying to achieve better performance with active management, it is important to increase N by adding more independent managers or models with a positive performance expectation, i.e. diversification.

The effect of diversification on reducing the overall portfolio volatility and improving its information ratio has been studied on the data related to performance of professional managers who invest in futures markets (CTAs). It has been demonstrated that even by combining a relatively small number of CTAs in a portfolio it is possible to achieve a significant degree of diversification. According to a relevant study, ca. 2/3 of the total risk reduction compared to the portfolio which includes all managers can be achieved by combining as few as four different managers in a portfolio and ca 3/4 of risk reduction can be achieved by combining five CTAs[15].

The same logic – it is possible to improve the reward/risk ratio by adding diversification – applies to reserve management. Diversification of active management can be achieved by hiring external managers who use different methods to earn excess return, and dividing risk between internal managers who rely on different investment styles (discretionary and model-based investing). The principle of diversification can be further extended to the quantitative investing itself. Diversification within a model-based investment program is possible by combining models, which focus on different risk classes (currency risk, curve risk, country spread risk, duration risk, credit risk etc.),

[15] Schwager, J. Managed Futures: Myths and Truths, p 225.

rely on different types of inputs (technical, fundamental etc.), and operate in different time-frames (long-term, medium-term, short-term).

The importance of diversification for improving investment performance cannot be over-emphasized. Diversification ensures that investment results do not rely on any one manager, investment style, market or model. This is important, because the performance of any investment manager/model or the dynamics of any single market is highly unpredictable. According to several studies, "past performance [of managers] is far less predictive of future performance than generally believed"[16]. It is, therefore important to combine various approaches in active management to improve the stability of results.

Active investment strategy of the foreign exchange reserves in Eesti Pank is summarized in Figure 3.

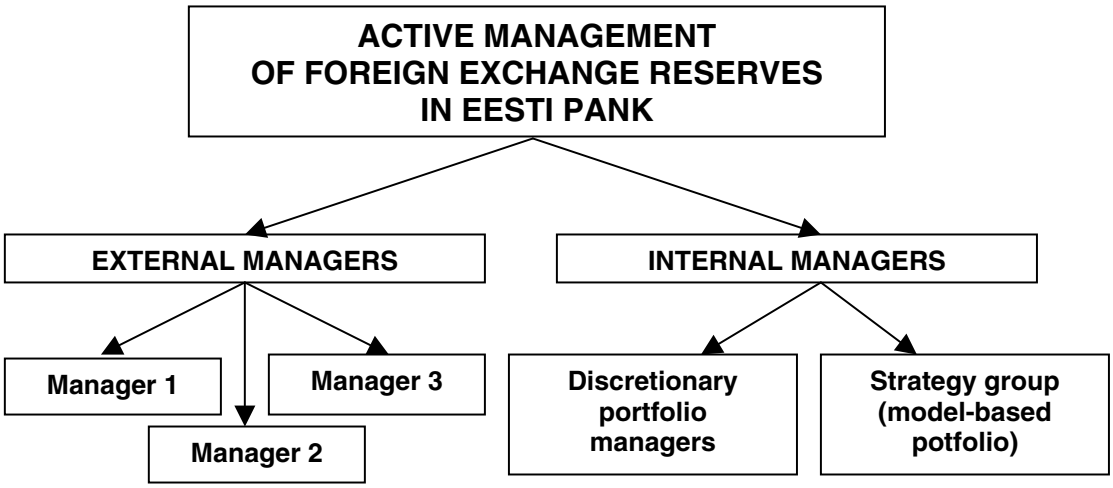

Figure 3. Diversification of active management of foreign exchange reserves in Eesti Pank

Based on the theoretical principles elaborated above, the active investment strategy in Eesti Pank is currently characterized by the following main features.

- In order to achieve better diversification and increase the number of independent active investment decisions, total risk budget has been divided between external and internal portfolio managers, who make investment decisions independently of each other. The risk budget is divided into ten risk units. Five units are distributed to internal[17] portfolio managers and five are meant for distribution to external managers[18].
- Within Eesti Pank risk is divided between two major investment styles: discretionary and systematic. The first style is represented by portfolio managers

[16] Ibid., p 282.
[17] Portfolio managers working at Eesti Pank.
[18] Global asset managers who invest according to risk mandates which are largely similar. Currently Eesti Pank has selected three external managers whose management fee is mostly dependent on their investment performance. Only minimal cash is allocated to external managers to fulfil margin requirements. Risk mandates allow investing in the bonds and currencies of the following countries: the euro area countries, the USA, Canada, Switzerland, the United Kingdom, Denmark, Sweden, Norway, Japan, Australia, and New Zealand.

who base their decisions mostly on qualitative analysis, and the second is represented by a strategy group, which bases their decisions mainly on investment models. The aim of such diversification is to achieve better risk-adjusted performance in long term.

- Active investment risk is measured and limited based on the Value-at-Risk (VaR) methodology. The VaR methodology is more universal and easier to apply than managing and estimating the duration, curve, etc. risk separately.
- With the exception of internal portfolio managers, who manage real funds, the majority of active investment decisions are implemented with derivative instruments (i.e. by using overlay strategies). This facilitates performance measurement and keeps real funds of the reserves always under the control of Eesti Pank.

Model-based investing as part of active reserve management strategy is described in more detail in the following part of the paper.

2. Model-Based Investment Decisions as Part of Diversified Active Investing

2.1. Formulating the Task

The starting point for searching models to be applied in active management was to identify the risk classes suitable for quantitative investing. To achieve better diversification of the investment portfolio, it was decided to focus on the major risk classes available for investors who primarily invest in global bond and currency markets – duration, yield curve, cross-country yield spread, and currency risk. Since the list of permitted instruments did not include suitable instruments to trade credit risk and volatility, these risk classes were excluded. As a result of further investigation, yield curve trades were also excluded, as it was difficult to find a well-performing model for yield curve positions implemented with derivatives. Finally it was decided to base the quantitative management research on the framework developed by Ilmanen and Sayood (Ilmanen *et al.* 2002). This choice was supported by strong theoretical background, the extent of diversification provided by the models, and availability of historically tested results. Further adjustments were then made to extend the list of markets and to use the models in overlay-style investing. The final set of models included a model for directional investing in 10-year government bond futures of the G3 countries (duration model), a model for trading yield spreads of eight major bond markets, and a currency model for trading ten major currencies. All these models are technical-fundamental models, which use both types of inputs.

In order to widen the range of models and diversify among the models, it was also decided to include technical models in the model portfolio. A trend-following model was a natural choice, as these models are quite widely used by both private and institutional investors and have proved their viability in practice.

With regard to combining different models into a model program there exist several ways to balance the risk. It is possible to use fixed or variable position sizing, and one has to decide whether to balance the risk between wider risk classes (like interest rate risk and currency risk), models, or even individual positions. In the beginning, risk

allocation on the basis of Value-at-Risk of individual positions seemed a logical choice. However, the actual results of such method hinted that the VaR-based position sizing underestimated the profit potential of individual positions leading to undesirable underweighting of well trending positions, which exhibited more volatility and were therefore "riskier". Thus, it was decided to abandon the VaR-based position sizing and combine models according to their long-term profit/loss volatility as measured by the standard deviation of monthly results. This method of combining the models implied fixed sizes for all positions. Accordingly, the size of positions was derived from the volatility of model results[19]. Within one model positions are equal in the currency model and roughly equal in the duration and cross-country yield spread model. Such method of position sizing demonstrated in historical back-testing its ability to balance risk in various categories leading to better risk-adjusted performance of the combined model portfolio. All models described below were tested in a 145-month period starting on December 31, 1992 and ending on January 31, 2005. Data sources were EcoWin and Bloomberg.

2.2 Duration Model

The duration model is a regression model that gives monthly signals for directional trading of 10-year government bond futures of the USA (TY), Germany (RX) and Japan (JB)[20]. The model is estimated using the following variables:

- **Endogenous variable**: Excess return of Citibank 7–10 year government bond index over 1-month deposit rate. Although the positions are implemented with futures and the results of the model are also based on trading futures, excess return of government bond index as endogenous variable gave better results in ex-post tests than the change in futures prices.
- **Exogenous variables**:
    - **Curve steepness**. The steeper the yield curve (measured as difference between 10-year yield and deposit rate), the higher the return of 10-year bonds compared to deposit rate. This is the result of yield difference and also the result of expected flattening of the curve.
    - **Real 10-year interest rate**. The higher real interest rate, the higher the probability of decline in interest rates and corresponding increase of return.
    - **Inverted momentum of stock market as a proxy of economic activity**. Inverted momentum is calculated as the ratio of six month rolling average of stock market to the last value of stock market. High inverted momentum indicates declining stock prices and slowing economic activity, which is positive for long-term bonds.
    - **Monthly change in nominal effective exchange rate (NEER) as the proxy of inflation**. First a combination of NEER and commodity price index (CRB index) was tried as a proxy of inflation[21]. Since the CRB index turned out to be insignificant, only NEER remained in the model. Rising exchange rate lowers inflation and is therefore positive for bonds.

[19] Due to the relatively large nominal size of Japanese 10-year government bond future, which does not enable exact scaling, the duration model was slightly underweighted compared to other models.
[20] Bloomberg symbols are used throughout the paper.
[21] Conventional inflation measures (CPI, etc.) could not be used, because they are published with a lag.

As all variables in the model have different dimensions and measures, they were normalized before estimation. In order to achieve higher robustness, the coefficients in the equations of three countries were restricted to be equal. The final model estimated included the following formulas (the description of variables can be found in Appendix 1):

EXCRET_GER_NORM = C(1)+C(2)*CARRY_GER_NORM(-1) + C(3)*VALUE_GER_NORM(-1) + C(4)*CYCL_GER_NORM(-1) + C(5)*FXCH_GER_NORM(-1) + C(6)*EXCRET_GER_NORM (-1)

EXCRET_US_NORM = C(1)+C(2)*CARRY_US_NORM(-1) + C(3)*VALUE_US_NORM(-1) + C(4)*CYCL_US_NORM(-1) + C(5)*FXCH_US_NORM(-1) + C(6)*EXCRET_US_NORM(-1)

EXCRET_JP_NORM = C(1)+C(2)*CARRY_JP_NORM(-1) + C(3)*VALUE_JP_NORM(-1) + C(4)*CYCL_JP_NORM(-1) + C(5)*FXCH_JP_NORM(-1) + C(6)*EXCRET_JP_NORM(-1)

The estimation period for each month was the preceding (rolling) 10-year period[22]. The forecasted 1-month *ex-ante* signals were tested using difference-adjusted generic futures prices. If the prediction for the next month had a positive sign, then the futures contracts were bought. If the prediction had a negative sign, the futures contracts were sold. All positions were kept for one month until the model generated new signals. No stops or target levels were used. Cumulative results of the model trading 20 contracts of TY futures, 20 contracts of RX futures and two contracts of JB futures is presented in Figure 4 and the performance statistics in Table 1[23].

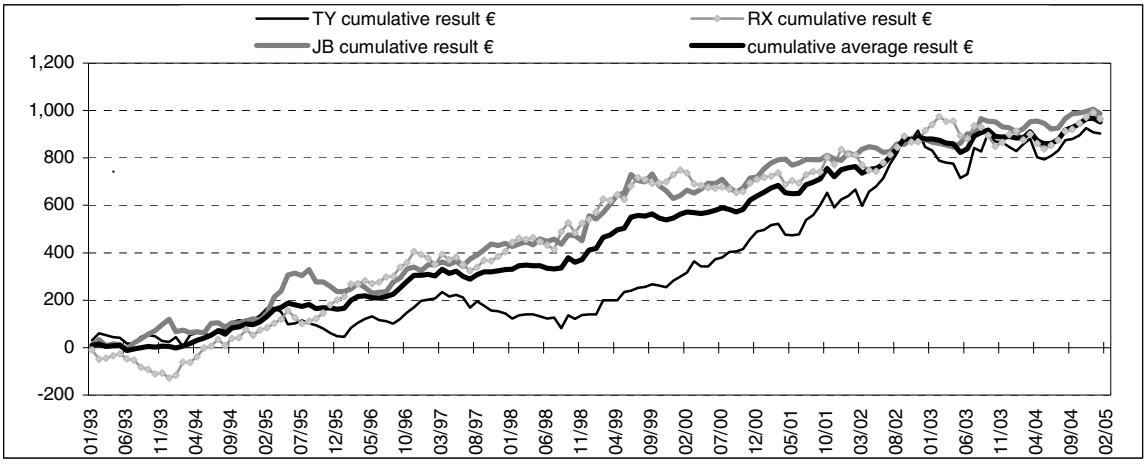

Figure 4. Simulated performance results of the duration model

[22] Due to data availability, a small number of first estimations were done with slightly shorter estimation period.
[23] Before 1999 synthetic euro was used as a proxy for euro. End-of month exchange rates were used for conversion.

Table 1. Simulated results and selected statistics of the duration model

Statistics	Total	RX	TY	JB
Cumulative return (€)	3,384,496	1,115,800	1,110,793	1,157,903
Average monthly return (€)	23,341	7,695	7,661	7,986
Standard deviation of average monthly return	59,465	30,562	35,371	28,196
Sharpe ratio, annualized[24]	1.36	0.87	0.75	0.98
Maximum monthly return (€)	174,654	85,000	121,273	120,458
Minimum monthly return (€)	-120,507	-64,200	-81,935	-70,341
Accuracy[25]	0.67	0.60	0.58	0.60
Profit factor[26]	2.83	1.81	1.71	2.13
Maximum drawdown (€)	-214,573	-237,400	-220,243	-120,458
Longest profitless period[27]	12 months	22 months	25 months	15 months
Average yearly return (€)	280,096	92,342	91,928	95,826

It can be concluded from the figure that the overall performance of the model was more stable than the performance of individual instruments. Only the US 10-year futures (TY) seem to have two clearly different sub-periods: good profitability in 1999–2002 and more moderate profitability before and after that period. Historical results indicate that the average monthly profit was €23,341 with the results ranging from €-120,507 to €174,654. The longest profitless period was 12 months, and the biggest drawdown €-214,573. Different efficiency ratios (Sharpe ratio, accuracy, and profit factor) clearly show the positive effect of diversification.

The model was also tested with variable position sizes, which were scaled according to the strength of the model signal, but it did not increase simulated profits.

2.3. Model for Currency Positions

The model for currency positions is a ranking model that produces monthly signals to trade three cross-currency positions of ten major currencies (USD, EUR, CAD, CHF, SEK, NOK, JPY, AUD, GBP, NZD). The signals were obtained by ranking the currencies according to the value of four input variables:

- **Deposit interest rate**. According to the interest rate parity, the forward exchange rate of a currency with higher deposit interest rate is lower than its spot rate. In reality, however, the interest parity often does not hold, i.e. currencies with higher deposit rates do not depreciate as much as predicted by the interest rate parity (Rosenberg *et al.* 2002, p 72).

[24] Calculated as $\sqrt{12}$ * (average monthly return)/(standard deviation of average monthly return). Original Sharpe ratio (see Sharpe 1994) uses both in numerator and for the calculation of standard deviation the difference between the return of active portfolio and the return of benchmark portfolio. As in our model all the positions are taken using derivative instruments, the return of the benchmark portfolio is constantly zero and this way cancels out from calculations.
[25] The number of positive months divided by the total number of months.
[26] Gross profit divided by gross loss.
[27] The length of period without the new equity high.

- **The ratio of exchange rate to its long-term average.** When currency is overvalued relative to its long-term average then it is expected to depreciate and vice versa.
- **Monthly change in 10-year government bond yield.** Rising interest rates tend to support exchange rates as can be implied from standard monetary model of exchange rate (see for example Frankel, Rose, p 1691–1692).
- **Trend** (measured as last 3 months' average return of the currency's exchange rate against USD). Technical momentum indicator.

After ranking the currencies by each input value the average rank is calculated for each major currency, and then the currencies are ranked by their average ranks[28]. Cross-currency positions are initiated with 1-month forward contracts according to the following rule:

- Buy 1st currency against 10th
- Buy 2nd currency against 9th
- Buy 3rd currency against 8th

In historical simulations deposit interest rates were used to calculate the one-month forward exchange rate. All positions were held for one month until next positions were generated by the model. There are no target or stop levels, and the parameters in the model are not optimized. Cumulative results of the currency model and individual currency positions (in percentage terms) are presented in Figure 5 and the performance statistics in Table 2:

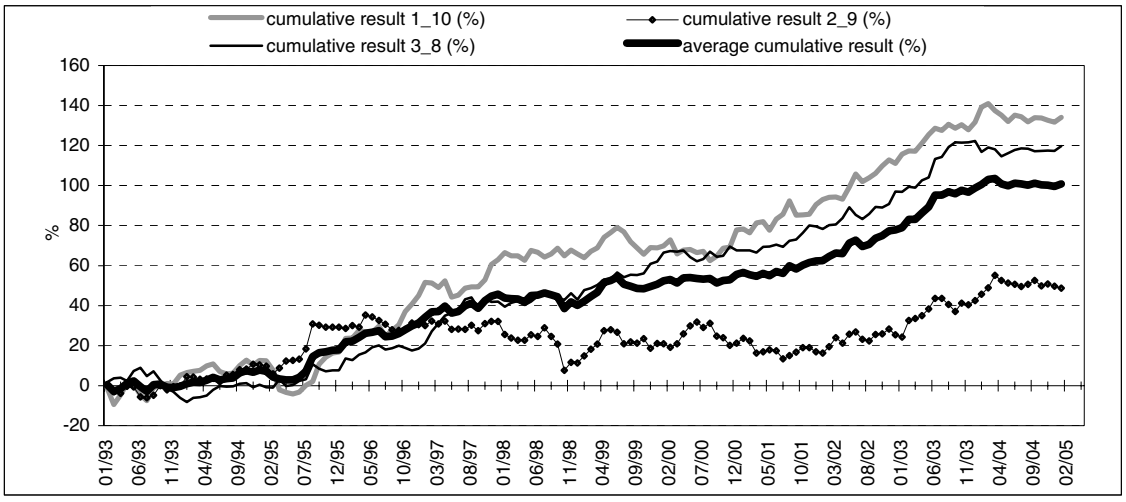

Figure 5. Simulated results of the currency model

As can be implied from the graph, the currency model had relatively good performance in 1995–1997 and 2001–2003, and more moderate performance in other periods. Compared to the duration model the statistics of the currency model are somewhat worse, but still remain within acceptable ranges. Monthly results of individual currency pair positions range from -13.2% to +12.6% and of the whole model from -6.1% to +7.3%. The average monthly return in simulations was 0.7%, the maximum drawdown -

[28] Average of each individual ranks. In case of parity "a tie breaking rule" was applied that gives more weight to higher individual ranks.

7.95%, and the longest profitless period 17 months. It is, however, difficult to explain why the third currency position has performed better than the second, which is slightly counter-intuitive.

Table 2. Simulated results and selected statistics of the currency model

Statistics	Average	1–10	2–9	3–8
Cumulative return (%)	100.85	134.07	48.80	119.69
Average monthly return (%)	0.70	0.92	0.34	0.83
Standard deviation of average monthly return	1.98	3.49	3.15	2.56
Sharpe ratio, annualized	1.22	0.92	0.37	1.12
Maximum monthly return (%)	7.32	8.67	12.59	9.29
Minimum monthly return (%)	-6.05	-9.81	-13.22	-5.47
Accuracy	0.66	0.63	0.54	0.65
Profit factor	2.92	2.68	2.67	2.91
Maximum drawdown (%)	-7.95	-17.01	-27.74	-17.17
Longest profitless period	17 months	20 months	84 months	25 months
Average yearly return (%)	8.35	11.10	4.04	9.90

The results of the currency model by single inputs (predictors) are presented in Figure 6. The results for each input are calculated as if this input was the only input in monthly ranking.

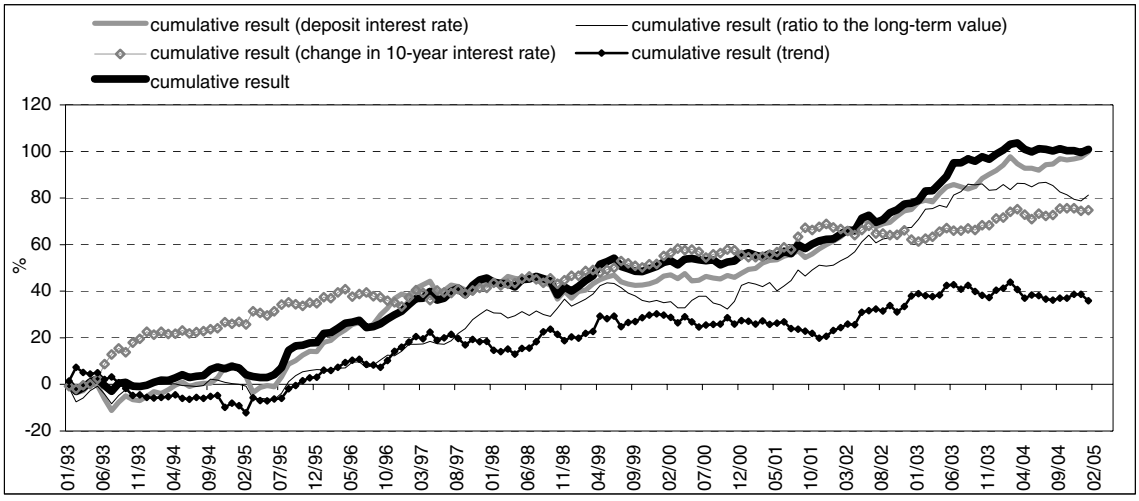

Figure 6. Simulated results of the currency model by different inputs

The results indicate that individually, the best predictor is the deposit interest rate. Cumulative profit for such single input model is almost as good as the result of the four-input model. Therefore, one could use this predictor as the only input to build a forecasting model similar to the Deutsche Bank's forward-rate bias currency trading model (Deutsche Bank 2002, p 13). The other inputs yield weaker, but still positive results when used individually, the weakest of the four being the trend indicator.

2.4. Model for Cross-Country Yield Spread Positions

The model for cross-country yield spread positions is also a ranking model that produces each month two cross-country spread positions in 10-year government bonds or corresponding futures. Out of eleven major bond markets (the USA, Germany, Canada, the United Kingdom, Japan, Sweden, Australia, New Zealand, Denmark, Switzerland, and Norway) eight markets were selected. Denmark was excluded because of high correlation with the German market (correlation of monthly changes in 10-year government bond yields is above 0.9); Switzerland and Norway were excluded because of high transaction costs. The final model thus included eight countries and two monthly positions. In six markets out of the eight futures were used, in two (Sweden and New Zealand) forward contracts were used, because liquid futures were not available. In historical backtests the duration of two positions in one cross-country pair was assumed to be equal; the currency risk was not hedged as it influences only final profits and is usually insignificant. Average bid-ask spread was deducted from the results[29].

At the end of each month the eight markets were ranked applying the same technique as was used in the currency model. The first three explanatory variables are the same as in the duration model and the fourth is trend reversal indicator:

- **Curve steepness** measured as a difference between the 10-year government bond interest rate and the deposit interest rate.
- **Real interest rate** measured as a difference between the 10-year government bond interest rate and the latest 10-year inflation forecast.
- **Inverted momentum of stock market** as the proxy of economic activity.
- **Ratio of 10-year government bond interest rate to its 6-month average**. This is a trend reversal indicator. The higher current interest rate level compared to its 6-month average, the higher the probability that reversal of trend may occur, raising the price of a corresponding bond/future.

All positions were held for 1 month. There are no target or stop levels and the parameters in the model are not optimized.

The results of the model and individual cross-country spread positions (in percentage) is presented in Figure 7 and the performance statistics in Table 3:

According to the backtest, the first cross-country pair has performed considerably better than the second pair. At the same time, most of the difference can be attributed to the first 1.5 years of the test period as later the performance of both pairs was relatively similar. The efficiency characteristics of the yield spread model are largely similar to those of the currency model. At the same time, the average profit and the volatility of performance in percentage terms are smaller. The average monthly return of the models was 0.4% and the results ranged from -3.5% to +4.68%. The maximum drawdown of the model was 4.74%, and the longest profitless period was 18 months.

The results of the cross-country spread model by single inputs are shown in Figure 8:

[29] Both the duration model and the currency model were tested without taking into account transaction costs, which were assumed to be insignificant given the liquidity of markets traded. In cross-country yield spread model, however, bid-ask spreads were included in the analysis, because of larger trade sizes and relatively less liquid bond and future markets in several smaller countries.

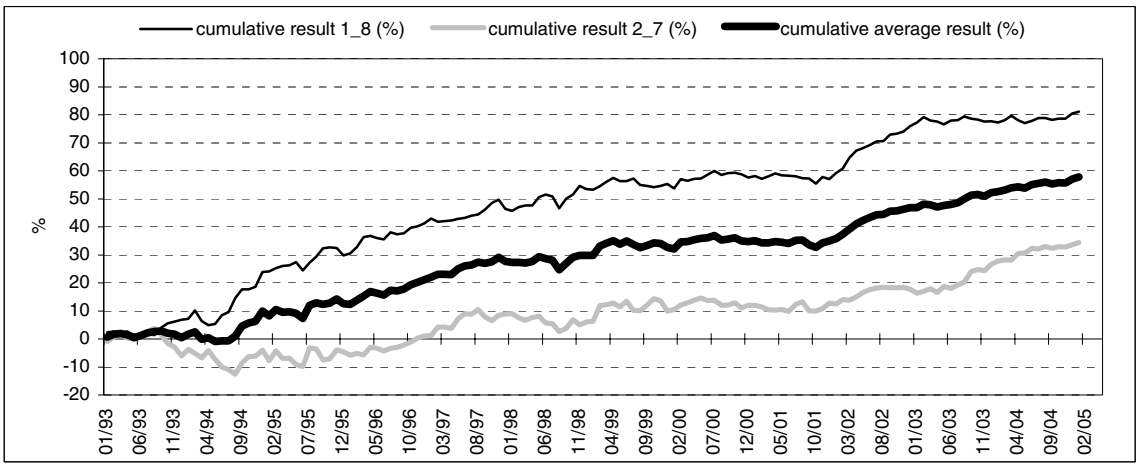

Figure 7. Simulated results of the cross-country yield spread model

Table 3. Simulated results and statistics of the cross-country yield spread model

Statistics	Average	1–8	2–7
Cumulative return (%)	57.77	81.10	34.45
Average monthly return (%)	0.40	0.56	0.24
Standard deviation of average monthly return	1.17	1.56	1.78
Sharpe ratio, annualized	1.18	1.24	0.46
Maximum monthly return (%)	4.68	5.21	6.59
Minimum monthly return (%)	-3.50	-4.20	-3.98
Accuracy	0.66	0.67	0.57
Profit factor	2.44	2.60	1.42
Maximum drawdown (%)	-4.74	-5.18	-16.44
Longest profitless period	18 months	18 months	41 months
Average yearly return (%)	4.78	6.71	2.85

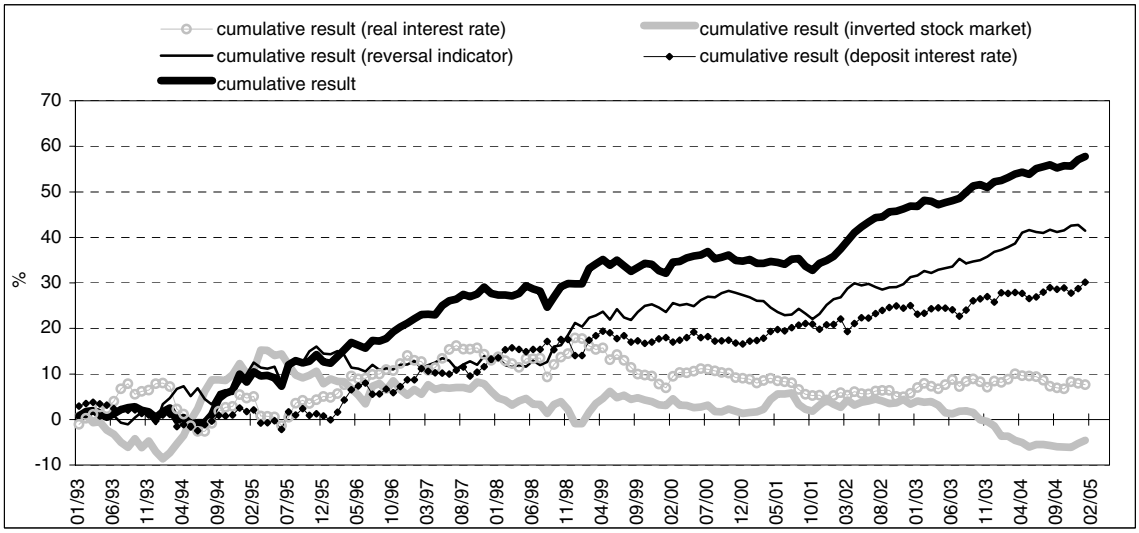

Figure 8. Simulated results of the cross-country spread model by different inputs

It can be implied from the figure that individually the trend reversal indicator is the best predictor and the inverted stock market performance indicator the worst. The model was also tested with three inputs leaving out inverted stock market, but the stability of monthly profits declined. Therefore all four inputs were retained in the model.

2.5 Trend-following Model

The trend-following model is the only purely technical model among the investment models currently used in Eesti Pank based on a proprietary algorithm[30]. Adding a trend-following model enabled to increase the breadth of the quantitative strategy, as it is based on different principles and is weakly correlated to the models described above. This decision was supported by the fact that trend-following is one of the oldest concepts in technically based investing that has been widely and successfully practiced by large global investment funds for many years. Trend-following method has several proven strengths; its major weakness is related to the fact that markets do not always follow the trend, but may spend considerable time in limited ranges or choppy conditions. This causes frequent losses, and the accuracy of trend-following models (measured by the ratio of profitable trades to the total number of trades) is usually below 50%. Usually a basket of several instruments is needed to get satisfactory results with these models

The trend-following model is actually a combination of two different models, which are applied to the same group of markets. The basket of instruments traded by the model includes two 10-year government bond futures (the U.S. and Germany) and two major currency pairs (EUR/USD and USD/JPY). All these markets have historically demonstrated sufficient trendiness making them suitable instruments for this type of model. These markets are usually not very closely correlated and display relatively low correlation of performance results. Cumulative results of the model are presented in Figure 9 and selected statistics in Table 4.

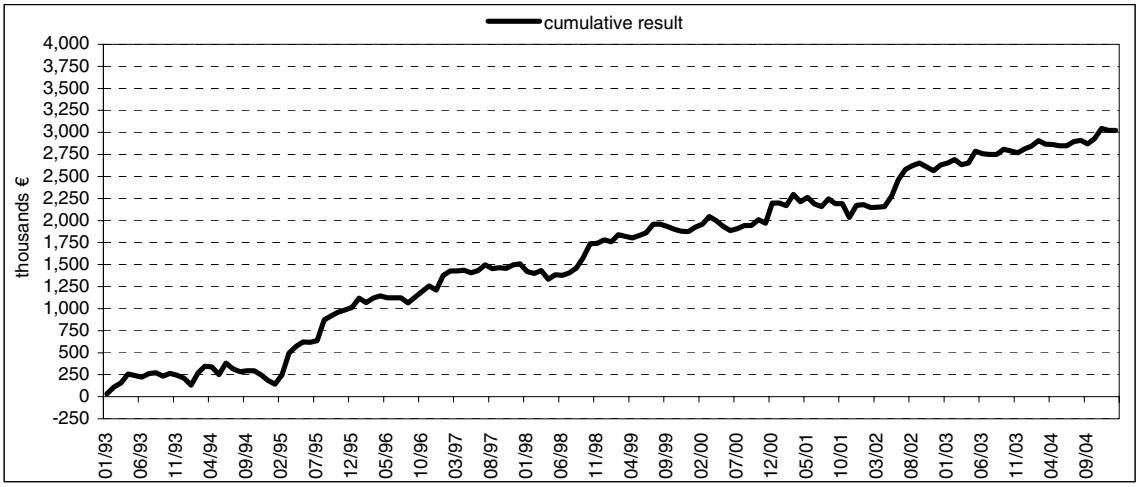

Figure 9. Simulated results of the trend-following model

[30] Due to the fact that developing robust technical models requires extensive work and special software to perform portfolio testing, it was decided to purchase the model from a professional model developer. The choice was based on a proper study of different trend-following models including necessary comparisons and historical backtests.

2.6. Results of the Combined Model Portfolio and its Comparison with the Results of Other Managers

The models described in the previous sections were combined according to their long-term profit/loss volatility measured as the standard deviation of monthly results. The combined portfolio included positions from four models. Three models (duration, cross-country yield spread, and currency model) had a total of eight positions each month. Depending on market conditions, the number of positions from the trend-following model varied from zero to four according to the number of markets traded. Consequently, the total number of open positions varied from 8 to 12.

The results of the combined portfolio are presented in Figure 10 and selected statistics in Table 4[31]. Simulated historical average monthly profit of the model strategy was 94,173 euros with standard deviation of 151,260 euros; 71% of months were profitable. Monthly results ranged from -204,281 to 592,573 euros. The length of the longest profitless period, which in the case of single models exceeded twelve months in most cases, was less than a year for the portfolio as a whole. The maximum drawdown of the portfolio was 327,140 euros.

In order to estimate the degree of diversification between the models correlation analysis of the model performance results was performed. The resulting cross-correlation matrix is presented in Table 5.

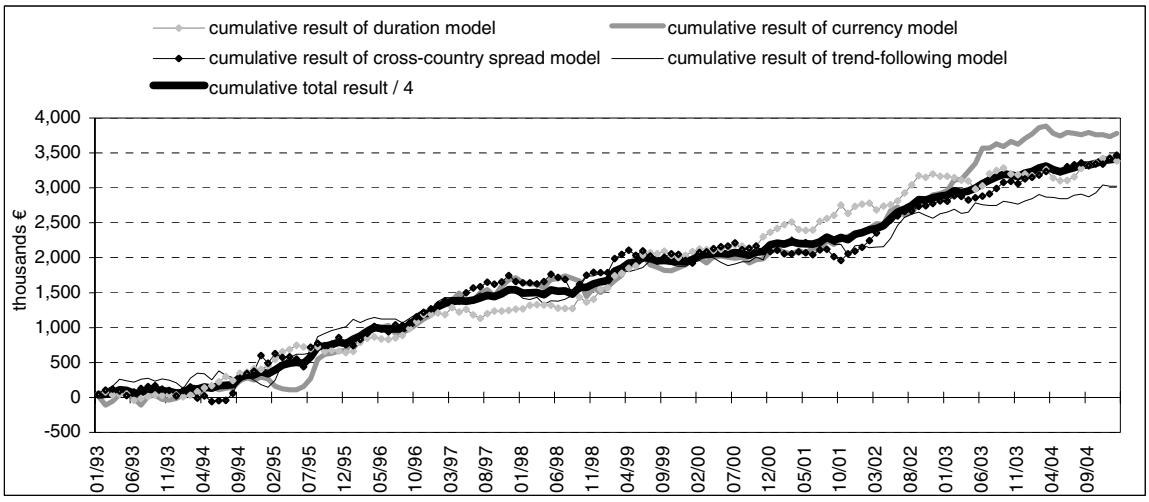

Figure 10. Simulated results of the combined model portfolio

[31] Position sizes in the combined model portfolio were as follows. The duration model: 20 contracts TY, 20 contracts RX and 2 contracts of JB futures; the cross-country yield spread model: € 3,000,000 per position in both countries; the currency model: € 1,250,000 per each currency pair. The trend-following model could have full or half position size depending on market conditions; full position was 10 contracts for TY future, 10 contracts for RX future, 10 contracts for the eurocurrency future, 10 contracts for the Japanese yen future.

Table 4. Simulated results and statistics of combined portfolio of models. Test period 31.12.1992– 31.01.2005 (145 months)

Results of combined portfolio of models (€)	Total	Duration	Currency	Cross-country	Trend
Cumulative return (€)	13,655,052	3,384,496	3,781,943	3,466,482	3,022,131
Average monthly return (€)	94,173	23,341	26,082	23,907	20,842
Standard deviation of average monthly return	151,260	59,465	74,215	70,380	66,426
Sharpe ratio, annualized	2.16	1.36	1.22	1.18	1.09
Maximum monthly return (€)	592,573	174,654	274,326	281,028	248,634
Minimum monthly return (€)	-204,281	-120,507	-226,732	-209,779	-154,494
Accuracy	0.71	0.67	0.66	0.66	0.59
Profit factor	5.27	2.83	2.47	2.44	2.35
Maximum drawdown (€)	-327,140	-214,573	-298,149	-284,437	-261,100
Longest profitless period	9 months	12 months	17 months	18 months	14 months
Average yearly return (€)	1,130,073	280,096	312,988	286,881	250,107

Table 5. Correlation matrix of the model performance results

	Duration	Currency	Cross-country	Trend
Duration	1.00	-0.02	0.08	0.20
Currency	-0.02	1.00	0.13	0.07
Cross-country	0.08	0.13	1.00	0.05
Trend	0.20	0.07	0.05	1.00

It can be seen from the table that the quantitative investing program is relatively well diversified. The highest cross-correlation between monthly returns is 0.20 observed for the duration model and the trend-following model[32]. The risk/reward characteristics of the combined model strategy (Sharpe ratio, accuracy, profit factor etc.) were better than these of single models demonstrating positive effect from diversification among the models and markets. While the Sharpe ratios of individual models were ranging between 1.09–1.36, the Sharpe ratio of the combined model portfolio was 2.16. However, since the risk characteristics of investment models are usually somewhat poorer in actual investing than hypothetical results, it is reasonable to be prepared for somewhat lower risk characteristics in the future.

In order to estimate the diversification of all active management decisions simple correlation analysis of different managers' investment results was also performed[33]. Table 6 provides a correlation matrix of actual model-based portfolio performance with other investment decisions in year 2004.

[32] Both duration model and trend-following model include the US and German 10-year bond futures in their respective portfolios.

[33] As mentioned before Eesti Pank's active management scheme includes both in-house managers (discretionary managers and the strategy group) and external managers.

Table 6. Correlation matrix of the model portfolio, external asset managers and in-house discretionary managers

	Model portfolio	External manager 1	External manager 2	Discretionary managers
Model portfolio	1.00	0.21	-0.12	-0.81
External manager 1	0.21	1.00	0.37	0.02
External manager 2	-0.12	0.37	1.00	0.22
Discretionary managers	-0.81	0.02	0.22	1.00

It can be implied from the table that the active reserve management strategy of the Eesti Pank is relatively well diversified. With each individual manager taking about 10 or more positions in each month there is relatively high probability of positive yearly return for the combined active management strategy.

3. The Need for Further Development of Active Model-Based Investing

In order to be successful in active investing constant effort to improve performance is needed. The first prerequisite for developing models with positive expectation is correct understanding of the market behavior. A well-known investor L. Williams has described the market as "a collision of random events, spiced with human emotions and fundamental realities" (Williams 2004, p 2). It means that along with identified and unidentified fundamental and psychological factors there is usually a large degree of randomness in market behavior. This degree is by no means stable, but fluctuates over time – at times markets may exhibit more randomness than at other times. The task of investment model developers is to identify important factors that influence market behavior and combine them into a model. The model or combination of models should also incorporate a risk management scheme to cope with unpredicted (including random) movements of the market.

An important factor influencing the performance of investment models is the constant tendency of the markets to "exploit away" existing inefficiencies. There is virtually no inefficiency (or predictor) which cannot be, in principle, exhausted by market participants. Competition between investors leads to changes in market behavior and reduces the performance of models (and managers who rely on them) by eroding these inefficiencies. For example, the performance of managers who extensively use various trend-following models shows how the performance of a model-based investment strategy can diminish over time. According to the CISDM data of 1983–1993, the average annual return of the trend-following CTAs was 19.1%, but in the next sub-period (1994–2004) it had decreased to 10%, i.e. almost by a half[34].

In recent years an important factor influencing market behavior has been rapid growth of hedge funds, which have increasingly exploited existing market inefficiencies. Compared to most other asset managers, hedge funds are often more effective tactical risk takers, because they are much more specialized and subject to fewer restrictions and constraints. According to some studies, the number of hedge funds increased fourfold

[34] Center for International Securities and Derivatives Market at the University of Massachusetts.

from 1990 to 2003 (from 2,000 to over 8,000), and their assets under management grew 20 times over this period, from $38 billion to $817 billion[35]. It is estimated that while hedge funds may control no more than about 3% of world assets, they make up a much bigger part of volumes of trading on financial assets, given the fairly high turnover of their funds compared to the traditional real money investors. JP Morgan estimates that hedge funds could account for a third of trading volumes on some financial assets, and anecdotal evidence suggests they can at times dominate trading in certain assets.

The growth of hedge funds has twofold implications for active investors. On the one hand, it has brought about intensification of global search for excess return (alpha) and diminished returns for active investors (including the hedge funds themselves). In 1995–1999 the average annual return of CSFB/Tremont Hedge Fund Index was 16.3%, but in 2000–2004 it was 7.5%[36]. On the other hand, increasingly sophisticated investment strategies used by hedge funds and other active investors have influenced the significance of factors, which have been used in investment models.

Broadly speaking, hedge funds returns come from two sources – from the exploitation of structurally high risk premia and from exploiting market opportunities over time. The study by JP Morgan found that in recent years many better-known market opportunities have been eroded in both categories and the majority in the areas where the hedge funds have been most active: equities and interest rate markets[37]. This process has been accompanied by declining volatility in some markets and also led to higher correlation between major financial markets that reduces the opportunities for cross-market trades. The foreign exchange market can serve as an example of that. According to the study, some factors that have been reliable predictors of forex market behavior in 1994–1999 (like carry, change in economic activity expectations etc.) have demonstrated lower information ratio for forecasting price dynamics in 2000–2004 when hedge funds activity became stronger. At the same time, some other factors have gained more importance (like portfolio flows, changes in speculative positions etc.) as measured by their information ratio.

Changes in market environment and the intensification of search for alpha thus prompt constant work aiming at maintaining a competitive edge in the market. Regarding model-based investing we can identify the following areas in which this work can be done.

1. Monitoring and improving old models. As mentioned before, there is constant pressure by market participants to erode the factors and models used to predict market dynamics. “Any strategy yielding above-average risk-adjusted return […] is, by the unshakable laws of human nature, under a sustained threat by other market participants seeking to correct this “inefficiency”.[…] This means that there is a limited shelf life for nearly any highly successful market approach.”(K. Grant, 2004, p10). In quantitative terms, the information ratio of any factor, which has demonstrated reasonable performance in the past, can decline. It is therefore necessary to monitor the performance models and input factors constantly and adjust the investment program if necessary (when the performance significantly declines). Even if a model has been developed without

[35] JP Morgan, Have Hedge Funds…, 2004.
[36] CSFB/Tremont data.
[37] JP Morgan, Have Hedge Funds…, 2004.

excessive optimization, quite often its actual performance results can be significantly weaker than the hypothetical historical results. In addition, there has to be considerable patience with regard to time horizon of the expected positive results. Depending on the length of backtest a single model may have profitless periods lasting for more than 12–24 months. Diversification between models may reduce profitless periods for the combined portfolio, but it is impossible to eliminate them completely.

2. Finding new predictors and developing new models. Since well-known factors may lose their significance for predicting market behavior, there has to be constant effort to develop new models trying to capture new predictors and attempt at maximizing the gains from the diversification of the model portfolio. While market participants tend to exhaust known predictors, changes in market environment may bring forth other predictors. Research in this area should indicate which important predictors are not yet captured by the existing models.

3. Better risk management and portfolio optimisation. Another area, which also requires attention, is portfolio optimization and risk management. Improvements in this area are important to achieve better risk adjusted returns, because the performance of the model portfolio depends not only on the performance of the individual models, but also on how these models are combined and how the risk is allocated between the models and individual positions.

Practical experience with the investment models described in section two of this paper have provided some insight regarding the avenues that can be explored in the future to improve the models applied in Eesti Pank. Some of these have been already mentioned in literature (Ilmanen 2002, p 50).

1. Revising predictors in the existing models. As mentioned above, the information ratio of predictors may vary over time, and some factors may lose their previous significance. An example of that is relative stock market performance as an input in the cross-country 10-year spread model. In an updated backtest this factor taken individually does not have predictive ability regarding the dynamics of the yield spread it used to have for a long period. It is possible that the stock market dynamics has lost its previous significance for 10-year yield dynamics. In addition, it may also be possible to find new predictors and incorporate them into the models. In some cases, however, information that may have predictive power, is not readily accessible. Such information is, for example, data about portfolio flows and speculative positions in forex market.

2. Identifying regimes related to the model performance. For example, it has been observed that the performance of carry trades may depend on investors' willingness to risk ("risk appetite"). Market behavior can also be influenced by factors of temporary nature (such as oil prices). Incorporating such factors, however, increases the risk of over-optimisation if the relationship proves to be unstable.

3. Improving model exits. Three models currently used in Eesti Pank (duration model, cross-country 10 year yield spread model, and currency model) are quite simplistic with regard to their exit mechanism (i.e. the method for closing open

positions). The only exit these models have is time exit – once a position is initiated, it is maintained for one month accepting all profit and loss fluctuations. The advantage of such approach lies in the fact that it is rather difficult to time the market and predict the extent of market movement. Closing positions before a month has expired runs the risk of underperforming the model. The disadvantage of the time exit is the resulting inability of these models to capture efficiently large open profit or cut the losses short. Further research should indicate if it is possible to improve performance of these models by modifying exit rules.

4. Improving the quantitative strategy breadth by adding new models and risk classes. Credit spreads and volatility are currently the markets (risk classes) not yet included in the model portfolio. Developing different models for the same risk class and instrument is limited by the predictability of price behavior. Successful models trading the same instruments and having similar time horizons are usually strongly correlated, which decreases their significance for diversification. Another dimension for diversification is the time-frame. Current models can be mainly categorized as medium-term models, which give signals for a one-month horizon (duration, 10-year cross-country spread, currency model), or varied horizon (the trend-following model). Adding a reasonably performing short-term model would allow investing in the same markets in a weakly correlated manner that would add diversification to the existing models.

5. Portfolio optimisation. Currently the models are combined on the basis of their profit/loss volatility. Since in some cases the instruments traded by the models overlap[38], portfolio optimisation would in theory help to achieve better risk-adjusted returns. However, given low correlation between the models, the positive effect from portfolio optimisation would not probably be very large. Nevertheless, this remains an area that can be studied further in the future.

Patient work in these areas should ensure the continuation of positive performance of the model portfolio and help to maintain its present diversifying role in the active investing strategy of foreign exchange reserves in Eesti Pank.

[38] For example, a position including the US 10-year future can be initiated independently by three models: the duration model, the cross-country yield spread model, and the trend-following model.

Conclusions

Application of investment models in active reserve management in Eesti Pank has evolved as a logical step in an effort to improve the efficiency of the investment process. It has been systematically practiced since 2002. Model-based investing has improved the diversification of investment decisions and reduced the reliance of investment success on single discretionary decisions. Due to positive results both in hypothetical backtesting and in practice, and low correlation of its results with the results of other portfolio managers (external and internal), model-based investing fits well into overall investment strategy. Model-based investing has thus increased the breadth of the strategy and enabled to incorporate a major investment style into the investment process, which is based on identifying proven quantitative relationships in the markets.

Currently the strategy group in the Financial Markets Department uses four models for making model-based investment decisions. The list of models includes a duration model for G3 10-year government bond futures markets, a cross-country 10-year yield spread model, a currency model for major currencies, and a trend-following model. The backtested results of these models (for 1993–2004) show that combining weakly correlated models improves significantly investment performance and reduces the volatility of results. If the accuracy of the best performing single model (in terms of positive monthly performance) ranged from 57% to 67%, then the accuracy of the combined program were 71%. Combining models has also reduced the time of profitless or negative performance and increased significantly the profit factor, which demonstrates improved risk and reward characteristics.

Due to the complicated nature of market behavior, ongoing changes in the market environment, and constant pressure by the market participants to reduce and eliminate the existing inefficiencies, model-based investing should be accompanied by appropriate research and development effort. This is aimed at improving the risk-adjusted return of the model program and stability of results.

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Appendix 1. Description of variables used in duration model

Variables:

EXCRET	Excess return of Citibank 7-10 government bond index over one-month deposit rate
CARRY	Difference between 10-year government bond yield and deposit rate
VALUE	Real interest rate calculated using 10-year government bond interest rate and 10-year inflation forecast from *Consensus Forecasts*.
CYCL	Inverted momentum of stock market. Calculated as a ratio of six month rolling average of stock market to the last value of stock market
FXCH	Monthly change in trade-weighted NEER

Country and other suffixes:

GER	Variable of Germany
_US_	Variable of the United States
_JP_	Variable of Japan
_NORM	Variable is normalized
(-1)	Variable at time t-1