



Innovative Applications of O.R.

## A multi-objective multi-period stochastic programming model for public debt management

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## ABSTRACT

While raising debt on behalf of the government, public debt managers need to consider several possibly conflicting objectives and have to find an appropriate combination for government debt taking into account the uncertainty with regard to the future state of the economy. In this paper, we explicitly consider the underlying uncertainties with a complex multi-period stochastic programming model that captures the trade-offs between the objectives. The model is designed to aid the decision makers in formulating the debt issuance strategy. We apply an interactive procedure that guides the issuer to identify good strategies and demonstrate this approach for the public debt management problem of Turkey.

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### 1. Introduction

Public debt management (PDM) is concerned with meeting the funding requirements of a country that arise from budgetary and other financial liabilities of the government. More specifically, it can be defined as the “process of establishing and executing a strategy for managing the government’s debt to raise the required amount of funding, pursue its cost/risk objectives, and meet any other public debt management goals the government may have set, . . .” (International Monetary Fund – The World Bank, 2003, p. 5). Public debt managers have a range of financial instruments, securities, at their disposal and have to form a specific portfolio, in terms of maturity, currency and interest types, that would suit the government’s objectives. Given the exposure of public sector balances and the country’s financial stability to public debt, the overall structure of public debt portfolio is fundamentally important for a country’s macroeconomic stability. Once a government is in a financial problem, i.e. facing difficulties in fulfilling fiscal liabilities or having to pay excessive costs when issuing debt, this has spill-over effects on the entire economy, as demonstrated by a number of recent macroeconomic crises in several emerging countries. Therefore, the financial liability portfolio of the government must be effectively managed.

Given its importance, the problem of designing the public debt management strategy, in terms of setting the composition of financing, draws attention of both practitioners and academicians from various perspectives. Alesina et al. (1990) elaborate on the choice of maturity of public debt and argue that issuing debt at long maturities that is evenly concentrated in time will boost public confidence and reduce perceived likelihood of confidence crisis about debt default. Missale and Blanchard (1994) claim that government can use the maturity of debt to show her commitment to anti-inflationary policies and thus should prefer short-maturity or indexed debt. The tax smoothing approach assumes that the main reason for the government to change taxes is to meet the long-term financing constraint, and the objective is to smooth taxes by choosing the optimal composition of debt with respect to maturity and contingencies. There is uncertainty about macroeconomic variables such as public expenditures, tax base, etc. and therefore, the composition of debt matters (Barro, 1995, 2003). The argument is that debt can serve as a buffer against tax rate changes if the government can issue debt with costs that are lower when net tax receipts are lower. A good review of theoretical and practical concepts regarding public debt management can be found in Dornbush and Draghi (1990) and Leong (1999).

Debt management authorities take a practical point of view and apply concepts and tools derived from those employed by private financial institutions. The simulation models of PDM offices are generally derived from the “Value at Risk” (VaR) concept widely used by banks

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and other financial firms. For sovereigns, this approach is modified into “Cost-at-Risk” or “Cash-Flow-at-Risk” simulation models by which the cost and risk performances of alternative debt management strategies are tested under various macroeconomic simulation scenarios (see Danmarks Nationalbank (2005) and Bergström et al. (2002) for two country examples). Bolder (2003) explains the simulation model for debt strategy analysis in Canada. More recently, Bolder and Rubin (2007) try to combine simulation and optimization approaches in debt strategy analysis. Countries also apply other methods like stress testing or scenario analysis to compare different PDM strategies (see International Monetary Fund – The World Bank (2003) and OECD (2005) for discussions on debt management practices of selected countries).

The general aim in these applications is to quantify costs and risks associated with policy choices. On the other hand, there is a need for providing support to decision makers (DM) to find efficient solutions. To the best of our knowledge, this is the first study that explicitly considers multiple objectives and guides the DM towards desirable strategies. In this paper, we model the PDM problem as a multi-period stochastic program with multiple objectives. We formulate the problem as a deterministic equivalent linear programming model, in which the decision variables are the amounts of different types of bonds to be issued, accounting for the cash-flow constraints for the government. We develop our approach as a decision aid tool in analyzing the trade-offs between alternative courses of action. In this context, we identify efficient solutions based on different preferences and apply an interactive Multi-Criteria Decision Making (MCDM) approach to guide the DMs in developing the debt strategy. We demonstrate how sovereign DMs can experiment with such a tool in a practical setting, drawing on the case of Turkey.

The following section defines the public debt management problem and discusses its main features. We then present our multi-stage stochastic programming (SP) model, developed to guide issuance decisions. Section 4 discusses how we employ the SP model to obtain efficient solutions and use an interactive algorithm by which the DMs can experiment to explore alternatives. The proposed methods are illustrated in Section 5.

## 2. Characteristics of the PDM strategy formulation problem

Governments often announce auction schedules or financing programs to publicize the amounts and dates with regard to planned bond issuance schedules. These issuance programs are prepared in line with the government’s debt management objectives and describe the types of bonds the government is planning to issue to meet the projected financing requirement in a certain period. Early announcement of issuance strategies leaves time for market participants, i.e. potential investors to absorb the information revealed and to adjust their cash-flow schemes.

The common aim in PDM is to minimize the cost of debt. It will be tax payers who will be paying back the debt and one of the main objectives of debt management offices is to find the necessary funds at the lowest possible cost in line with the expectations of citizens. Even though the relevant cost definition may differ for each country, the most common measure of cost in borrowing funds is the interest rate requested by lenders. When a government issues debt, the cost of borrowing is reflected in the national budget in terms of interest expenditures. For countries that issue debt in foreign currencies, the change in the value of the debt, measured in the local currency, due to fluctuations in the exchange rate also adds to the cost of debt. Debt management offices that engage in frequent secondary market activities such as debt buybacks or bond exchanges may also follow the marked-to-market value of their debt portfolios. When costs are distributed over a number of years, they can be measured in a present value basis. They can also be normalized with respect to a macroeconomic magnitude or the size of debt portfolio to allow period-wise comparisons.

A well-known characteristic of financial markets is that there is a trade-off between return and risk. Generally, the higher the returns from an investment, the higher are the associated risks. Considering the fact that an investor’s return on a financial instrument is a cost for the issuer, the “risk/return trade-off” concept has its mirror image for the government as the “cost-risk dilemma”. The recent financial crises, accompanied by the increased volatility of international fund flows and the complexity of financial instruments highlighted the importance of risk-related criteria, in addition to cost, while raising public debt. Most public debt managers are now concerned with the risks and associated macroeconomic issues as well as cost. The public debt management objective in the United Kingdom, for example, is “to minimise, over the long-term, the costs of meeting the Government’s financing needs, taking into account risk, ...” (HM Treasury, 2007).

An important characteristic of the multi-objective PDM problem is that decisions are made under uncertainty. Debt managers are not faced with choices that have deterministic outcomes. Their decisions are concerned with future actions of the government and while making strategy decisions, debt managers are not certain about the future states of nature for the relevant macroeconomic variables. There is a degree of uncertainty associated with the evolution of economic factors such as interest and exchange rates that drive the cost of borrowing. The actual outcomes of the decisions made while formulating the issuance strategy are contingent on realizations of macroeconomic variables that exhibit different types of stochasticity. In fact, it is this uncertainty that raises the need to consider risk objectives.

The major risks public debt managers face are the market risk, which is defined as the risk of an increase in the cost of debt service as a result of unfavourable movements in market conditions and the liquidity (re-funding) risk that indicates the possibility of having insufficient funds in order to make debt repayments.

The cost and market risk objectives are generally conflicting by their nature, as short-term interest rates are usually lower than longer-term rates. This is also true in an economy where interest rates tend to decline. In such a context, it would be less costly for the government to issue short-term debt to make use of lower or declining interest rates. The aim in issuing short-term bills or longer-term variable rate bonds indexed to short-term interest rates is to shorten the interest rate fixing period of the debt stock. This policy will expectedly serve for cost minimization purposes. However, in case of a sudden surge in market interest rates, the cost on a major portion of the government’s debt will have to increase. This is the market risk in public debt management, which is different from the market risk perceived by investors. Short-term bonds which have short duration are less sensitive to price changes, therefore expose less risk of market value movements for investors. However, for a government short duration means a short interest fixing period, i.e. higher risk of volatility in interest costs. Therefore, everything else being the same, “Short-duration debt (short-term or floating) ... is usually considered more risky than long duration (long-term, fixed-rate) debt” (OECD, 2005, p. 41).

For countries that have liabilities denominated in foreign currencies, the volatility of exchange rates also constitute a major market risk. The Mexican Crisis at the end of 1994 is partly attributable to the 29 billion United States Dollar (USD) tesobonos maturing in 1995, with 10

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