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Strategies for Managing Sovereign Debt
A Robust Decision Making Approach

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This document was submitted as a dissertation in September 2014 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Steven Popper (Chair), Robert Lempert, and Zvi Wiener.
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Abstract

Sovereign debt portfolios are affected by financial and economic factors that are themselves deeply uncertain. Building on methodological developments for policy making under deep uncertainty, this dissertation examines and demonstrates how the Robust Decision Making (RDM) methodology could be applied to the problem of selecting the government’s debt portfolio. Using a large set of non-probabilistic simulations coupled with data mining tools, the analysis identifies and characterizes bond issuance strategies that appear to perform well across a large set of possible assumptions and scenarios. This approach introduces a new framework for assessing funding strategies based on varying assumptions regarding the government’s liquidity buffer. This proof-of-principle analysis illustrates possible improvements to debt management practices, both in government and in the private sector.
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Finally, I dedicate this dissertation in memory of my late mom, Rachel Abramzon. Her love, strength, foresight and wisdom are what made me who I am. Though she passed away before I began my doctoral studies, if I had to pick one person to thank on this occasion she would be the one.
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<td>Autoregressive</td>
</tr>
<tr>
<td>BOI</td>
<td>Bank of Israel</td>
</tr>
<tr>
<td>CRI</td>
<td>Consumer Price Index</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>PDM</td>
<td>Public Debt Management</td>
</tr>
<tr>
<td>SDM</td>
<td>Sovereign Debt Management</td>
</tr>
<tr>
<td>RDM</td>
<td>Robust Decision Making</td>
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<tr>
<td>USD</td>
<td>United States Dollar</td>
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The European sovereign debt crisis which began in earnest in 2008 brought the governments of several advanced counties to the verge of insolvency. Eurozone members Greece, Ireland, Portugal, Cyprus and Spain all had to seek third-party financial assistance to repay their government debts. At the same time, countries such as Germany and the U.K., while also severely affected by the global slowdown, have been mostly able to contain investors’ fears of not paying their debts.

What could explain this difference? Among other explanations, one key factor that rarely gets the attention of the general public (but is seldom overlooked by investors and credit rating agencies) is the debt structure of these governments. Not only the size of debt matters, but also its repayment profile. The case of the U.K. could provide a good example. Though its total debt to GDP ratio was higher than Spain’s by more than 15 percentage points (77% vs. 60%), its debt refinancing needs as share of GDP in 2010 were almost one third of Spain’s. U.K.’s favorable debt maturity profile that resulted in relatively low refinancing needs enabled its government to enact an exceptionally strong countercyclical policy, with budget deficits higher than those of Spain, Portugal, France, Greece and Italy. (see figure P.1).

Figure P.1: Maturing Debt and Budget Deficit of Selected Advanced Countries (% GDP), 2010

Though government debt in general has intrigued many scholars, from historians to financial experts, the policy question of how to actually manage and allocate the government’s debt

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1 The importance of the structure of debt has manifested itself throughout history. For example, Niall Ferguson (2009) argues that the origins of the French revolution are connected to high levels of short-term debt, creating an exceptional burden on the French public to finance the government’s debt repayment needs.
profile remains largely unanswered. Only in the past two decades has this question received more attention, backed by the work of practitioners in national debt offices and international institutions. Perhaps the most novel policy innovation was the introduction of stochastic simulation techniques into this field.

However, and especially since the recent global recession, there has been growing dissatisfaction with these methods. Their core weakness is connected to the reliance on unverifiable and simplifying assumptions, especially with regards to the likelihoods they assign to possible futures. Concerns have been raised that debt managers who rely on these assumptions are susceptible to improper risk perceptions.

This challenge is not by any means confined to sovereign debt management. It is shared with many other fields of policy analysis that operate under conditions of deep uncertainty. The need to address this difficulty has triggered the development of alternative methods which allow for a policy analysis that permits exploring the implications of different assumptions. In this study I demonstrate how such approaches could help debt managers in their task to design and select strategies for issuing sovereign debt.

Using the Israeli case, the study’s findings imply that some of the debt portfolio choices made by the government might be suboptimal across an array of assumptions and decision criteria. In other words, governments’ debt managers seem to end up choosing instruments that are not best suitable to support their objectives. The framework suggested in this study helps examine these choices and possible alternatives in a systematic and meaningful way.
1. Introduction and Background

Sovereign Debt and Its Challenges

Government debt is one of the basic instruments, together with taxation, for financing public expenditures. Borrowing by governments, as well as by any other entity, comes with both costs and risks. Costs consist of interest and indexation payments which the borrower is required to pay periodically. Risks are related to the possible economic burden of servicing and repaying the debt which could distort other fiscal needs or at extremes, lead to default.

A debt payment crisis could not only threaten the stability of financial markets but could lead to a generalized slump in the real economy. Numerous historical incidents of sovereign debt crises and defaults have been found to negatively affect a country’s economic and political systems (Borensztein and Panizza, 2009; Sturzenegger and Zettelmeyer, 2007). They often damage the borrower’s reputation, hampering its ability to engage in future financial transactions; severely affect the ability to trade internationally; trigger a domestic financial crisis and destabilize the political system. Hence, when planning ahead governments try to avoid a situation in which the debt service and repayment plan strains the economy or even signals that this situation is likely to happen.3

Up until the 2000s, well-established research and guidelines on policies for sovereign debt portfolio management were remarkably sparse. Since then, government debt management offices in several countries and international economic policy institutions (World Bank, IMF and OECD) have been engaged in developing tools and approaches to address it. Still, as stated time and again, there is no fully established set of tools for the practical management of risks associated with sovereign debt (Missale (1999), Chan-Lau and Santos (2010)).

The Debt Manager’s Policy Problem

The government debt manager is in charge of issuing and managing a public debt portfolio, in light of the government’s borrowing requirements (deficit) and debt refinancing needs. Debt managers usually face a few objectives related to 1) minimizing debt service costs over the

---

2 Indexation refers to changes in the value of obligations due to their linkage to market indicators, such as CPI and the foreign exchange rate.

3 This does not rule out that defaulting on debt might be a rational decision at a time when the costs of paying the debt are even higher than the consequences of defaulting. However, a priori default cannot be optimal since in this case a government would not be able to borrow. Instead, defaults are associated with unexpected shocks such as wars and severe recessions which may have not been fully internalized by lenders at the time of lending. For a recent in-depth discussion of these issues, together with rich historical evidence, see Sturzenegger and Zettelmeyer (2007)
medium and long run; (2) minimizing risk, which could be measured in various ways and taking into account a wide array of risk factors; and (3) supporting the development of capital markets, which is manifested in maintaining liquid bond markets (Missale, 1999). Since tradeoffs between these objectives exist, debt managers are usually expected to primarily determine and sustain a prudent level of risk and only then focus on lowering costs (in other words, the cost minimization objective is subject to maintaining an acceptable level of risk). The IMF and the World Bank have also offered general guidelines and best practices to manage sovereign debt in light of these objectives (International Monetary Fund and World Bank, 2005).

The debt profile chosen is a mixture of debt obligations that differ in various aspects: their maturities, interest payment schedules, indexation, and denomination in foreign or local currency. The choices of some these instruments could have competing influence on the debt management objectives. For example, shorter maturities are usually associated with lower debt service costs but can also increase rollover risk since they require repayment of larger amounts of principal in a given time.

The debt management question could also be analyzed in a broader context of managing the whole sovereign “balance sheet”. Such a prism, sometimes termed as Sovereign Asset and Liability Management (SALM) takes into account all the assets and liabilities of the general government, out of which government debt is only one part.

The policy problem of debt managers could be described as one that is made under deep uncertainty, a situation in which decision makers do not know, or are not able to agree on, the probability distribution of future states of the world, though they are aware of the set of these possible states (this situation is sometimes referred to as ambiguity, severe uncertainty or Knightian uncertainty). Especially in recent years, it has become widely acknowledged that many financial and economic phenomena are characterized by this type of uncertainty. In the context of government debt, deeply uncertain financial and economic factors affect the outcomes of sovereign debt management (SDM) decisions. As a result, debt managers who traditionally focus on what they perceive as quantifiable risks are susceptible to employing improper risk management practices.

In light of these gaps, this research suggests a path for answering what are the best strategies for issuing and managing sovereign debt. It demonstrates how recent methodological advances in policy decision making and risk management, backed by increases in computational power, provide new avenues for supporting SDM practices and especially their ability to address deep uncertainties. This work demonstrates how one of these methods, Robust Decision Making (RDM), could support sovereign debt managers in examining and selecting strategies for issuing

---

4 The availability of choices for debt instruments varies across countries according to the level of development and characteristics of their financial markets. For example, countries with underdeveloped local markets might effectively have no other choice than issuing at least some foreign currency debt.

5 See, for example, Taleb (2004))
sovereign debt. The endeavor will also constitute the first major application of RDM methodology to a macroeconomic and financial policy issue.
2. Existing Approaches to Sovereign Debt Management

Background

Up until recent years, the literature that provided practical policy insights for debt management was surprisingly rare. Originally, the academic literature on public debt was centered on the role that debt management plays in the macro economy, in particular, whether the size and structure of the debt placed constraints on monetary and fiscal policy. Barro’s (1974) seminal work laid out one of the major cornerstones of public debt management (PDM) theory - the concept of PDM neutrality. Based on a set of Ricardian assumptions that: (a) agents have infinite planning horizons (complete information); (b) markets are complete; (c) taxes are non-distorting, it is shown that debt issuance should not have real effects compared to taxation and therefore debt management would be irrelevant for the real economy. Although the theoretical investigation of the Ricardian Equivalence is conceptually valuable, it is clear that the strong assumptions behind it do not hold in practice and prudent debt management is indeed important (Missale, 1999). The following sections will discuss how such analysis is conducted in practice.

The Scope of Analysis: Asset and Liability Management (ALM) Considerations

The debt management question is part of a broader context of managing the whole sovereign “balance sheet”. Such a prism, sometimes termed as Sovereign Asset and Liability Management (SALM) takes into account all the assets and liabilities of the general government, of which government debt is only one part of them. Such an approach enables a more comprehensive view of the government’s net exposure to risks in a fashion that is similar to the accounting of a private firm’s financial position.

There are several approaches by which assets and liabilities may be included in such an analysis (Das et al., 2013). In general, assets under this framework include: the tax base (which generates future tax revenues); holdings of state-owned enterprises; non-financial assets (e.g., land) and financial assets, notably the foreign reserves (see table 2.1). On the liabilities side, public debt could include not only the government’s liabilities but also those of the central bank. Other major liabilities include non-discretionary spending commitments and contingent claims, which could be explicit (e.g. loan guarantees) or implicit (e.g. a safety net for the banking system). Policy making under SALM is associated with the need to maximize long term social
welfare while reducing risks, taking into account specific conditions of the balance sheet. In this sense it is similar to the more narrow debt management practice that focuses solely on liabilities.

Table 2.1: Components of a Sovereign Balance Sheet (Total Government, including Central Bank)

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>The tax base: expected tax revenues</td>
<td>Government debt</td>
</tr>
<tr>
<td>Tangible assets (e.g. land, state-owned enterprises)</td>
<td>Explicit liabilities, including contingent liabilities (e.g. state worker pensions, social security allowances)</td>
</tr>
<tr>
<td>Foreign reserves</td>
<td>Non-explicit liabilities (e.g. support in case of disasters)</td>
</tr>
<tr>
<td>Monetary assets (e.g. banking sector loans)</td>
<td>Monetary liabilities (e.g. banking sector deposits)</td>
</tr>
</tbody>
</table>

Though conceptually desirable, accounting for assets and a wider range of liabilities is challenging. It is an overarching task that requires careful compilation of data and estimations of the value of public assets and liabilities, many of which are hard to evaluate or even define. Also, since different (sometimes competing) institutions are usually responsible for these assets, it is unlikely that one coherent policy could be adopted in reality with regards to all assets and liabilities. This is especially true for the case of the government’s debt portfolio which is managed by a designated debt office while revenue and expenditure policies are decided separately by other government entities. Moreover, foreign reserves are often managed by the central bank or an independent sovereign wealth fund, serving goals that are frequently different or even conflicting with the debt manager’s interests. Cassard and Folkerts-Landau (2000) point out, for example, that central banks’ policy of increasing the interest rates in the face of growing inflation concerns could hamper the government debt manager’s policy of lowering debt costs.

For this reason government debt offices rarely take a comprehensive SALM approach when deciding on debt policy. At the same, even if a full SALM approach cannot be taken, it might be desirable to incorporate some aspects or segments of this approach. Especially, it could be useful to take into account both the size of the foreign currency debt and of foreign reserves in order to assess the net exposure to foreign currency risk and its expected borrowing costs. In addition, quantifying debt costs in percent-of-GDP terms helps maintain cognizance of the tax-base, a major government asset which is strongly correlated with GDP (International Monetary Fund and World Bank, 2005). By doing so, we can more easily assess the debt policy’s alignment with larger fiscal objectives related to tax-smoothing or deficit-smoothing.

Analytical vs. Numerical Approach

Evaluating current debt positions and identifying desirable policy actions for affecting them are at the heart of the practice of sovereign debt policy. The way these questions are tackled in
the literature and in practice can be divided roughly into two methodological approaches: an analytical approach and a numerical (computational) approach.\textsuperscript{6} The relevant economic and financial academic literature mainly takes an analytical approach, while the numerical approach is associated with the actual practice of debt management offices as influenced by the field of applied mathematics. The following sections will describe and provide examples of both approaches, but since this dissertation offers an improvement to the numerical approach for evaluating debt management policies this latter area will receive emphasis.

\textit{The Analytical Approach}

An analytical approach has been applied both for evaluating current debt positions and for outlining general guidelines for debt instrument choice.

One of the primary areas of focus of this literature was characterizing the concept of debt sustainability, which is regarded as a basic requirement for sound debt management and fiscal policy. If lenders believe that a country will not be able to fulfill its financial obligations in the future, they will not lend in the present. The country will then face difficulty in rolling over its debt and debt markets could meltdown. In theory, the fundamental requirement for debt sustainability is that the present value of future expected government balances is greater than current indebtedness. In reality, a more lenient criterion widely used in the literature for assessing debt sustainability is whether the government deficits/surpluses are at a level required to keep the debt-to-GDP ratio constant, i.e. a situation in which the government rolls over its debt infinitely (Silva, Carvalho and Medeiros, 2010). The analytical discussion on debt sustainability was supplemented by empirical research that tried to assess, based on historical evidence, levels of sovereign indebtedness where lenders become intolerant (Reinhart, Rogoff and Savastano, 2003) or when economic activity is negatively affected (Reinhart and Rogoff, 2010).

When dealing with the more specific question of choosing the allocation of debt instruments, studies that take an analytical approach are usually associated with achieving fiscal policy objective(s), such as minimizing the budgetary cost or risk of government debt. In particular, a main line of research has focused on supporting the fiscal goal of tax-smoothing through debt management (for a survey of this literature, see Missale (1997)).

Barro (1999) famously suggested a strategy of issuing contingent perpetual bonds which offer repayments that are correlated with the government’s tax revenue. This idea is theoretically optimal in terms of the goal of tax smoothing but has not found much actual implementation. In practice governments do not issue state-contingent debt but instead issue instruments with various maturities (not perpetuities) that are either nominally fixed or inflation-indexed and which could be denominated in various currencies (Missale, 1999).

\textsuperscript{6} This distinction between analytical and numerical approaches is influenced by Melecky (2012) who used it in the context of deciding on the currency structure of sovereign debt.
A number of papers have looked at how conventional debt instruments could support fiscal policy. The general understanding is that although nominal debt is less risky from the government’s risk-management perspective, some inflation-indexation is justified in order to ameliorate the moral hazard concerns stemming from government’s ability to inflate its currency and so reduce its debt (Missale and Blanchard, 1994). Similar arguments are commonly used to justify issuance of foreign currency debt, which is in general exposes the government to higher risks than local currency debt.

The need to account for actual market prices of debt instruments remains debated. For example, the costs for the government to issue long term local currency debt is usually higher compared to short-term or foreign currency denominated debt, but it is reduces the rollover and market risk (Arbelaez et al., 2005). Despite these higher costs, Missale (2012) argues that if imperfections and informational and credibility problems (incentive problems) were not to exist, debt managers should abandon the goal of minimizing costs and focus on risk reduction, since the higher price of less risky instruments should be seen as an insurance premium.

As can be seen from the examples above, though analytical frameworks give important guidelines for debt managers, they usually do not provide exact policy instructions and need to be further adjusted and calibrated to reflect the specifics of a given economy. Applying these approaches could be very much sensitive to the different metrics and assumptions used. Therefore, as concluded by Melecky (2012): “from a policy perspective, the analytical approaches are likely more useful for forming strategic guidelines for debt management rather than for determining strategic benchmarks for optimal debt portfolio allocation.”

**The Numerical Approach**

The numerical approach is employed by government debt managers in several developed and developing countries in both evaluating the current debt position and choosing strategies for future actions. The numerical approach uses computational power to quantitatively characterize scenarios for the debt profile. These approaches have been pioneered by several government debt offices in the late 90s, in particular those of Denmark and Sweden, that have adjusted applied mathematical methods and common investment methods (such as Value at Risk) to the debt management policy question. They often are connected to the adoption of numerical strategic benchmarks for the debt portfolio, especially among debt offices in Europe, Central Asia, Latin America and the Caribbean (Melecky, 2007). Well documented efforts are those of Canada (Bolder and Deeley, 2011), U.K. (Pick and Anthony, 2006), Sweden (Bergström, Holmlund and Lindberg, 2002), Turkey (Balibek and Memis, 2012) and Brazil (Silva, Carvalho and Medeiros, 2010). The World Bank and the IMF have also recently developed a computational toolkit to support debt management in developing countries, the Medium Debt Management Strategies (MTDS) Toolkit.

The common path of the numerical approaches for debt management, as described in general by Velandia (2002), consists of a few typical steps:
- First, projection of expected debt service costs under base case assumptions of the funding strategy and future market rates.
- Then, new projections of debt service costs under alternative assumptions, using statistical techniques, historical analysis, worst case scenarios, etc.
- Next, assessment of risk based on the difference between the cash flow or present value of the base case and the alternative scenarios.

If the focus is on assessing the current portfolio and current policy, rather than choosing among alternative strategies, the analysis can stop here. However, when we are interested in evaluating possible policies, these steps are repeated for all alternative funding strategies and cost-risk tradeoffs are assessed. It is common to graph the cost and risk of each strategy as a single point defined by x-y coordinates, and if enough data points exist, presenting an efficient frontier of strategies (see figure 2).

**Figure 2.1: Illustration of an efficient frontier of strategies**

Source: Velandia (2002)
Deterministic vs. stochastic models

The analysis above could be done using either deterministic or stochastic models (Risbjerg and Holmlund, 2005), ranging from simple scenario-based models to more complex ones (Organisation for Economic and Development, 2005). Deterministic models generate only a limited number of scenarios, usually reflecting adverse financial and macroeconomic shocks, without assigning probabilities to them. They are relatively easy to understand, interpret and communicate and hence might be appealing in a political decision making setting. The risk quantification that such stress tests provide, however, lacks a solid connection to likelihoods.7

Stochastic models, on the other hand, can generate a continuum of scenarios for each strategy that often enable us to assess a probability distribution of the outcomes. When using stochastic simulations, the risk assigned to candidate strategies can be similar to the common method of Value at Risk (VaR) which expresses risk as the n-percentile of the a distribution. In the context of debt management, this kind of analysis could for example specify the the maximum debt service payments that a given debt strategy yields with n = 95 per cent likelihood. This measure could then help guide policies that try to cope with what is perceived to be 95% of the best performing cases. If the same analysis is repeated for several strategies, it can also be used to rank them according to their perceived level of riskiness. Applications of this method to the debt-management point of view are sometimes referred to as Cash-Flow-at-Risk (CFaR), Debt-at-Risk (DaR), Cost-at-Risk (CaR) and the Budget-at-Risk (BaR) measurements.8 Given that the choice of the threshold in a VaR-style analysis is usually subjective and somewhat arbitrary, recent studies have tried to propose methods to evaluate and choose these quintiles (Gaglianone et al., 2011).

As mentioned beforehand, the probabilistic and parametric assumptions that are used for stochastic modeling are often debatable, leading to criticism of these methods. Some of these shortcomings are discussed later in this study.

Outcome Measures

The main outcomes of interest for debt managers are those that measure costs and risk, adhering to the two top policy objectives of costs and risk minimization. In addition, debt managers would want to track how strategies support market development, mainly by evaluating liquidity in key benchmark debt instruments.

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7 An example of a deterministic model is the World Bank’s Medium Debt Management Strategies (MRDS) Toolkit, that illustrates the costs and risks of several debt management strategies under a limited set of adverse scenarios.
8 An example of studies using VaR and similar approaches to evaluate debt position is Garcia and Rigobon (2004)
Cost Measures

Measuring the cost of debt service is fairly straightforward – it should sum up all the payments, beyond the repaid principal, that are paid by the issuer. Primarily, this consists of cash-based interest payments as well as indexation on CPI-linked bonds and foreign currency bonds (nominal face value of principal payments is ignored). In order to provide meaningful comparisons, values should be denoted in real terms, either using a base year price or as share of GDP. The latter option has advantages as it corresponds with an asset-liability framework (see earlier discussion). In some cases, when government accounting standards do not record all costs, adjustments are required to provide an accurate analysis.

Risk Measures

Various measures of risk have been used in the debt management practice and literature, addressing different dimensions. Risk measures could be divided into two broad categories. The first category includes those that describe the structure of the debt portfolio, often used to indicate the risk of the portfolio at a particular time period. The second category includes those that summarize the result of scenario simulations over time. Naturally, one can combine the two approaches by measuring the trajectory of the debt stock structure over time.

Debt Structure Metrics

Some of the most common risk metrics are those that describe the structure of the debt stock at a given point in time. These indicators provide meaningful standards especially when used to compare to other alternative portfolios or to strategic portfolio benchmarks that the debt managers are trying to achieve (which might be arbitrarily chosen). The comparison between the actual values of these metrics and the strategic benchmarks provides an indicator for the excessive risks existing in the portfolio.

Some of these metrics include:

- Average term-to-maturity (or duration) of the debt portfolio
- Portion of debt maturing within 12 months (or a different time period)
- Average time to re-fixing (ATR). This is the average time until all the principal payments become subject to a new interest rate. This measure more strongly reflects the risk associated with variable rate bonds.
- Composition of the debt portfolio, including
  - Currency composition of debt stock

---

9 Sweden’s debt office has recently proposed a new cost measure that instead of counting the cash flow at the actual time of payment equally spreads out the costs over the entire time to maturity.
Currency composition of foreign exchange-debt stock
Share of variable rate debt in the debt stock

Simulation-based Risk Metrics

When various debt trajectories are simulated, risk could be measured as a summary of these outcomes. Notable examples include:

- **Variability of interest payments.** For example, standard deviation over time.
- **Covariance between the budget balance and the debt-service costs.** Maintaining a positive correlation supports a budget-smoothing objective.
- **Breaching a liquidity buffer.** This measure summarizes the amount or severity of periods in which rollover and debt service needs exceed a predefined level. Maintaining a liquidity buffer prevents financial distress and improves borrowing conditions.
- **The upper threshold of the cost distribution.** In line with a cost-at-risk methodology, this measure equals the value of an upper percentile (say 95th percentile) of the cost distribution. The larger this value is, the higher the risk within the government debt portfolio. This risk measure can be further enriched to include the expected costs that occur in the tail of the probability distribution ("Conditional/Tail Cost-at-Risk") rather than a single value in the confidence threshold.

Market Development Measures

An objective that is occasionally overlooked is capital market development which the government achieves by ensuring liquidity in key benchmark debt series that provide a basis for pricing transactions in the financial markets. In practice, a good measure for this objective would be the stock in key benchmark series. One could measure either the outstanding stock or the stock of those securities recently issued.

However, in liquid and more highly developed domestic bond markets issuance into benchmark series by the government is of smaller importance. In these cases, private players can generate liquid benchmarks through derivative transactions.

Time Span of Analysis

The time horizon for which the analysis is conducted has major influence over the results. Since debt objectives typically relate to the medium and long run, most developed countries focus on outcomes with a time horizon of several years. That said, for some purposes, especially for short term budgeting, there might be interest in analyzing more immediate periods.

Focusing on earlier time periods gives more weight to the initial debt portfolio. In addition, immediate time periods might exclude costs related to indexation on the principal of bonds that are paid at maturity. Therefore, there might be value in providing results for different time periods.
horizons, including a “steady state” which represents a long term picture that is detached from the current debt portfolio. This approach is carried out in our analysis.

Current Shortcomings

Though conceptually appealing, in many cases the implementation of the numerical methods has shown some shortcomings. In some cases, such as in Sweden and Israel, these shortcomings have led to abandonment of such methods for decision making. We will discuss three categories of such deficiencies.

Narrow definition of strategies – benchmarking instead of policies

In many cases, the “strategies” that are evaluated for issuing debt are in fact long-term “benchmarks”. Portfolio benchmarks are typically expressed as numerical targets for key portfolio characteristics, such as the share of short-term to long-term debt, the desired currency composition or interest rate duration of the debt. In many cases, the simulations are run separately to identify benchmarks for currency composition and run separately to identify the optimal maturity, which leaves out important information each time the analysis is conducted.

In these cases the selected “strategy” in the model is seen as the optimal long-term debt structure, and debt managers are expected to devise a way to achieve this optimal portfolio through short term actions. However, the benchmark itself does not offer a clear path or strategy for achieving the desired profile; and hence its practicality for actual policy is limited. As noted by the Brazilian Debt Office:

Currently, the benchmark model works with just one optimal debt structure (when the economy has reached the steady state) without considering the nature of the transition between the two (the current situation and the steady state). […] the transition is within an operational framework that differs from the one used in the benchmark model. Therefore, this study needs to be expanded to consider how the convergence from the current scenario to the long-term scenario (stationary state) would occur, as well as to explore what the speed should be in the change from the current federal public debt profile to the one desired in the long term (Silva, Carvalho and Medeiros, 2010).

The possibility of adopting the benchmark as a policy prescription by issuing debt periodically according to the same assigned weights is highly questionable. Both in theory and in practice, decision makers would tend to adjust their policies according to market and fiscal conditions and especially in light of changes in their risk perception. Hence, a richer framework that evaluates flexible, adaptive strategies is needed.

Strong model assumptions

Simulations require a clear underlying modeled system that enables the generation of scenarios. These modeled systems include a set of links, interactions and correlations between
various elements, in our case financial and macroeconomic variables, that determine the system’s path. In addition, stochastic analysis usually requires assumptions regarding probability distributions of some of these elements. This is often done based on historical data and structural hypotheses. The system outcomes, in turn, are strongly influenced these underlying assumptions.

The reliance on historical likelihoods and other strong assumptions in order to project future paths has proven misleading many times. One reason is that many of the structural links between economic variables are evolving, sometimes substantially.\textsuperscript{10} Melecky (2012) illustrated, for example, how the choice of the estimation period for exchange rate standard deviations used for debt modelling alters results substantially.

In many cases, structural assumptions (e.g. normal distribution of probabilities) are merely a guess. Methods used for parameter estimation are usually geared towards capturing averages, or “equilibrium” levels, but fall short of providing an adequate quantification of extreme, highly consequential cases.\textsuperscript{11} The IMF/World Bank Debt Management Guidelines (2005) provided a warning on this issue:

> Data constraints may significantly impair the usefulness of the models, and the results obtained may be strongly model-dependent and sensitive to the parameters used. For example, some parameters may behave differently in extreme situations or be influenced by policy responses.

At a more basic level, Blommestein and Hubig (2012) criticize the standard micro portfolio approach for making two unrealistic assumptions that do not hold in reality, especially at times of crisis. First, an assumption that portfolio choices do not affect borrowing costs (government is a “price taker”) and second, that budget policy is independent of debt management. Relying on these assumptions to predict debt trajectories might be highly misleading, especially in “abnormal” times.

International experts interviewed for the purpose of this research suggested that indeed some country models proved to be too restrictive or complicated, either by forcing strong assumptions on structural relationships or parameter estimations. The more recent Turkish debt model (Balibek and Memis, 2012) provides an encouraging path. It provides flexibility to users by enabling them to choose among different modeling assumptions, including: normal distribution scenarios, fat tail scenarios, asymmetric shocks, yield curve shifting scenarios and bootstrapping. However, even here, the set of possible assumptions is fairly limited and there remains no systematic way to choose or compare the results of various modeling assumptions.

\textsuperscript{10} For an overview of some of the methods used to estimate covariances of macrovariables for the purpose of debt simulation see Melecky (2012).

\textsuperscript{11} This is the problem discussed at length by Taleb (2004)
Insufficient Support for Strategy Selection

Another area that remains weak is the method for strategy selection. Even if strategies can be compared to each other using one or two metrics (e.g. cost, risk) this does not necessarily provide adequate information for selection. In particular, even if one strategy proves to have lower risk level when all simulated scenarios are considered, from a policy perspective we still might want to focus on a subset of futures of interest (e.g. cases of extreme conditions) in which a different strategy outperforms all the others. In other words, there is need for a method that systematically enables us to divide the futures span into sub groups of interest for the purpose of strategy comparison. Another question that remains open is finding a coherent way of combining multiple metrics (especially regarding risk) into one coherent selection criteria.

This dissertation explores the promise RDM provides to tackle these shortcomings.
3. Incorporating Robustness into Debt Management Practices

Decision making under deep uncertainty

Definition and applicability to debt management

Deep uncertainty (also referred to as ambiguity, severe uncertainty or Knightian uncertainty) is a situation in which decision makers do not know, or are not able to agree on, the probability distribution of future states of the world, though they are aware of the set of these possible states. Sources of this deficiency lie in models, i.e. our representation of reality, being inaccurate or incomplete and the data supporting them noisy and erroneous. Models, as a result, end up being inherently uncertain themselves, both in parameters and in their structural forms. This all leads to our sheer inability to accurately predict the future or its likelihood. Many years of policy making have proved that this is in fact the rule rather than the exception.

Conditions of deep uncertainty hinder policy maker’s aptitude to employ the tradition tools of policy decision making, which could be dubbed as “predict-then-act” (Lempert, Popper and Bankes, 2003). In particular, utility maximization that relies on a probabilistic understanding of the future cannot be relied upon. Acknowledging that no agreed-upon probability distribution, including a subjective one, exists also makes Savage’s (1951) endorsement of subjective utility maximization inapplicable.12

The origins of modern-era research on decision making under conditions of deep uncertainty go back to Knight (1921), who is credited with the distinction between risk and uncertainty, the latter being a case with poor understating of likelihoods. Ellsberg (1961) later popularized a paradox which shows that individuals facing ambiguity act in a way that is inconsistent with the theory of subjective expected utility. Decision making under ambiguity has regained interest among economist in recent years, both from a normative perspective (Barlevy, 2011; Manski, 2011) and from a descriptive perspective serving as an explanation for macroeconomic phenomena (Hansen and Sargent, 2008). Still, systematic treatment on a wide scale of economic and financial policy problems under these conditions is extremely scarce and almost nonexistent.

This research is based on the notion that SDM requires decision making under conditions of deep uncertainty. The outcomes of the government debt manager’s decisions are affected by deeply uncertain factors, in particular financial market and macroeconomic conditions. Not only are we limited in our knowledge of the distribution of these factors, their effect on the debt

12 Even if policy makers would compromise on a subjective probability distribution, there is much debate whether indeed Savage axioms adhere to rational choice.
portfolio is rather complex. 13 Using Taleb’s (2010) terminology, sovereign debt management seems to be positioned close to (or even inside) the “fourth quadrant”, an epistemological domain in which both knowledge about distributions is scarce and payoffs are complex. Taleb deems general risk management, finance and economics all to be in this quadrant, and warns against the effort to quantify the risks in these fields. Similarly, SDM policy decisions should not be carried out under the set of tools that assume good knowledge of risk. Instead, tools for decision making under deep uncertainty should be applied.

Decision criteria

Decision making in general requires criteria for evaluation of policies. For situations in which probabilistic knowledge is absent or scarce, decision criteria that do not rely on such knowledge, or use only partial knowledge of likelihoods of it, are required.

Max-Min

Perhaps the most famous criterion that could be suitable for situations of deep uncertainty is Wald’s max-min concept: pick the policy with the least bad possible performance. This yields a precautionary approach that ensures the highest minimal level of performance. Mathematically, max-min means choose strategy \( s_i \in S \) that optimizes the following function across all futures \( F \):

\[
\text{Max}_{s_i \in S} \text{Min}_{f_i \in F} \left[ \text{Performance}(s_i, f_i) \right]
\]

Min-Max Regret

An alternative criterion for decision making under deep uncertainty is min-max regret, which was introduced by Savage (1951) and more recently endorsed as a criterion for economic policy (Manski, 2011). Regret is defined as the difference between the performance of a strategy in some future state of the world and that of what would be the best-performing strategy in that same future state. Mathematically, regret (R) of strategy \( s_i \in S \) in future state \( f_i \) is defined as:

\[
R(s_i, f_i) = \text{Max}[\text{Performance}(s', f_i)] - \text{Performance}(s_i, f_i)
\]

Where \( s' \) is used to denote all the alternative candidate strategies.

A min-max regret criterion, hence, chooses a strategy \( s_i \in S \) that has the lowest regret across all futures:

\[
\text{Min}_{s_i \in S} \text{Max}_{f_i \in F} [R(s_i, f_i)]
\]

---

13 Whether the payoffs from debt management are in fact “complex” depends on ones definitions and point of view. In our modeling framework, we use some outcomes measures that could be seen as “simple” – including recording whether interest or principal payments are above some level. However, as we will see, this level itself is uncertain and moreover the implications of high levels of debt burden are themselves unknown.
Criteria assuming partial knowledge of likelihoods

Other decision criteria have been developed for cases where decision makers have some limited amount of probabilistic information. If we acknowledge a limited set of possible distributions, one might want to maximize minimum expected utility (Gilboa and Schmeidler, 1989) or minimize maximum expected regret across all possible distributions and futures. A smooth ambiguity approach would assign weights to the set of priors and maximize their possible expected utility based on judgment (Klibanoff, Marinacci and Mukerji, 2005).

Robustness

Several approaches developed in recent years have used the term robustness to evaluate and choose policies. Though varying definitions of robustness exist, they all represent an idea of satisficing over a large set of futures. Non-probabilistic Robust Optimization methods, mainly used in the engineering context, apply Wald’s min-max decision criteria (Ben-Tal, El Ghaoui and Nemirovski, 2009). Somewhat similarly, Info-Gap theory (Ben-Haim, 2001) defines a robust policy as one that can withstand the highest level uncertainty and still achieve a minimum desired level of performance.

Some robust approaches do not offer a single solution, but instead help the policy maker apprehend the possible tradeoffs between policies. Included in these decision approaches are: trading some optimal performance for less sensitivity to assumptions; satisficing over a wide range of futures; and keeping options open, which generally support similar policy choices (Lempert and Collins, 2007). Another related approach seeks to identify thresholds for some uncertain future conditions beyond which a proposed design is no longer favored. In this latter case, policy makers are directed to assess their perceptions of likelihoods of futures rather than characterize strategies.

The selection of decision criteria for situations of deep uncertainty is a choice made among many reasonable options, none of which guarantees optimality. Policy makers and analysts would need to choose among them depending on their subjective preferences and available, even if only partial, knowledge of the problem and the environment. In all cases, policy planners should not seek to hide lack of knowledge under unwarranted assumptions but rather use these policy tools and approaches to help cope with what we do not know.

The Robust Decision Making (RDM) Approach

RDM is an analytic framework that uses computational, multi-scenario simulation methods to identify policies that are robust, characterize their vulnerabilities to assumptions and scenarios, and evaluate tradeoffs among them. RDM applies an approach termed exploratory modeling (Bankes, 1992)—instead of developing a system model to consolidate information and provide
predictions it uses the modelling effort to explore implications of varying assumption and hypothesis. It does not aim at predicting the future but rather focuses on creating and reasoning over comprehensive sets of plausible ones. By taking such an approach, we are able to overcome much of the justified criticism regarding the inaccurate modeling assumptions used to predict debt outcomes (see section 2.). When parametric or models uncertainty is present, we are able to explore implications of varying assumptions.

Once a policy problem is identified and regarded as one that is under deep uncertainty, the basic steps of an RDM analysis could be summarized as:

1. Construct a simulation model that relates actions and external conditions to consequences;
2. Generate a large set of possible futures for evaluation over the uncertain input parameters and varying model assumption;
3. Identify initial candidate robust strategies for evaluation under these possible futures;
4. Identify scenarios in which the strategies are vulnerable;
5. Characterize vulnerability of strategy performance to assumptions and scenarios, and characterize trade-offs among strategies;
6. Repeat steps 2 to 4 by considering improved strategies that include hedges against vulnerabilities.

An analysis of this type provides value because the policy decisions of greatest concern are actually brought within the analytical framework rather than remaining implicit and beyond the main analytical tasks. This is what then allows the analysis to characterize uncertainties not in terms of probabilities, themselves yet another form of assumption when there is insufficient certainty about frequency and causation, but rather in terms of the actual choices requiring decision. RDM provides a means for policymakers to clarify what they would need to believe was true in order to follow one policy path over another. This, in turn, allows more informed modification and hybridization of strategic courses that may themselves be defined by a series of adaptive, rules-based policies.

In the context of sovereign debt management, an approach informed by RDM would examine available alternatives for debt issuance and management despite our inability to reliably predict future financial market conditions and future government financing needs. For this analysis I generate a wide set of plausible future states of the world by varying assumptions about future financial market and macroeconomic conditions. Candidate robust strategies are then be evaluated according to their ability to achieve strategic goals in light of these futures.

Although RDM does not necessitate the use of a specific evaluation criteria for robustness, planners using RDM often define a robust strategy as one that has low regret compared to alternative strategies across the wide set of futures of interest. The use of the concept of regret helps detect not only the strategies with the best performance, but it also identifies the states of
the world in which one strategy performs much better than another.\textsuperscript{14} The definition of what exactly constitutes “low” levels of regret remains subjective, leaving room for the decision maker to apply his or her own, often case-dependent, preferences. However, if one wishes to have categorical decision criteria, she can opt to minimize maximum regret.

When compared to the Info-Gap method, RDM was found typically to generate similar (but not identical) insights. It differs from Info-Gap in its treatment of loses and gains, takes different approaches to imprecise information and arranges its analysis in different orders (Hall et al., 2012). Its relative advantage for policy makers lies, among other things, in its provision of a richer description of strategy performance over the vulnerable scenarios.

RDM can be characterized as a type of deterministic analysis since it does not assign probabilities to the handful of scenarios it eventually focuses on. However, by its virtue of initially scanning a very large possible set of perceivable futures, RDM can be seen as a systematic way to hybridize the approach of both stochastic and deterministic models. In this sense, it provides a new methodological advancement for currently used quantitative methods for SDM.

\textsuperscript{14} For a broader discussion of the advantages of the concept of regret for choosing strategies see Lempert, Popper and Bankes (2003) and Lempert et al. (2006).
4. The Analysis

Model Overview

The underlying system model developed for the analysis is in line with the general framework of existing government debt simulation models as described by Risbjerg and Holmlund (2005). The general structure contains inputs such as the initial debt portfolio, assumptions about future borrowing requirements and the funding strategy; a scenario generator that creates various paths for macroeconomic/financial variables; and a computation engine that calculates the issuance amounts and cash flows of the instruments.

The data used for the analysis is that from the State of Israel’s government debt profile. Israel provides a compelling case for analysis of government debt management -- it has a substantial level of indebtedness (above 70% GDP as of 2014), with varying types of maturities and bond types, and is susceptible to substantial macroeconomic and financial risks, some of which could be a result of its geopolitical environment. Nonetheless, the analysis described herein, including the simulation debt model, could be easily applied to most other countries.

Since the focus of this dissertation is on demonstrating the advantages that RDM can provide for analyzing debt policy and not to illustrate complex modeling techniques, a fairly simple model of the debt system is used. This means that when logically acceptable, variables are treated as exogenous and strong assumptions on model relations and likelihoods are avoided. This is in line with the exploratory modeling approach which does not attempt to actually predict the future but rather enable us to generate a large set of relevant plausible futures. It is also in line with the experience of sovereign debt planners showing that structural macroeconomic or financial models may impose too rigid and stylized relations within the model (Risbjerg and Holmlund, 2005) and make simulation tasks much less manageable. A detailed description of the model and experimental design appears in Appendix 2.

Using RDM’s framework of uncertainties (X), policy levers (L), relationships (R), and measures (M) – XLRM – the main pillars of the analysis will be characterized as follows:

Exogenous Uncertainties (X)

Exogenous uncertainties are factors outside the control of the decision makers that affect the success of their strategies. In our case these are mainly financial and macroeconomic variables. The choice to treat most financial and macro variables as exogenous, even if in fact some of them might be affected by funding decisions, is a practical choice and is also in line with the environment in which debt managers make funding decisions in reality. In principle, future research could expand the analysis to consider different possible relations between these factors.

The uncertain exogenous factors are:
- **Government financing needs.** This is the budgetary deficit, net of other competing financing methods such as privatization. This figure is the amount, net of rollovers, that the debt manager needs to issue each period.
- **Government interest rates.** Three different yield curves present the government’s borrowing costs: domestic nominal currency interest rates, domestic real interest (CPI-Linked) rates and the USD-denominated interest rates. Only one foreign currency (USD) is used in this analysis, but it could easily be expanded to include other currencies. For simplicity the term structure of interest rates will be a linear extrapolation between two stochastic variables: the short term interest rate and the long term interest rate, similar to the approach taken in the Swedish model (Bergström, Holmlund and Lindberg, 2002). The interest rate term structure will determine the coupon level of newly issued debt and in the case of variable interest rate would determine the interest payments for each period.
- **The USD Exchange rate.** This will determine the actual payments made, in domestic currency, on USD denominated debt.
- **Inflation rate (CPI).** This will adjust the principal of CPI-indexed debt for each period, affecting the respective interest payments.

In addition, the model will receive the *initial debt portfolio* as an input.

### Policy levers (L)

Policy levers are the choices available to the decision makers in each relevant period. These choices comprise the alternative strategies decision makers want to explore. In our case, the policy levers are the choices of debt to be issued, by type of debt and by maturity. Types of debt include: domestic-currency nominal bonds, domestic-currency CPI-linked bonds, domestic-currency variable rate bonds and foreign currency nominal bonds. Maturities span yearly intervals from 1 to 30 years, but the model could be easily adjusted to support longer and more frequent maturities.

In our simulation, the strategies, choices of policy levers, will include two layers:

1. **Baseline bond-type strategies:** A regular pattern of types of bonds issued each period, as percentage of the total funding requirements.
2. **Baseline maturity strategies:** A regular pattern of bond to be issued, by maturities, as percentage of the total funding requirements.
3. **Adaptable policies:** Adjustments to the baseline strategies in cases of an exceptional macro and financial environment. For example, if financing needs are above some threshold, the debt increases the issuance of long-term debt.

### Model Relationships (R)

Relationships describe the ways in which the system factors relate to one another based on the decision maker’s choices and the manifestation of the uncertainties. The relationships in the

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15 Later, it would be possible to adjust the yield curve model, for example, by adding a curvature factor as in Diebold and Lei (2006).
model are reflected in a dynamic process in which each year the debt manager is required to issue new bonds to cover current government financing needs as well as to roll-over old debt. Borrowing terms are determined each period by existing market interest rates for each type of bond. The debt stock, as well as future interest payments are reevaluated according to fluctuations in exchange rate, inflation and interest rates.

**Evaluation Measures (M)**

Measures are the performance standards used to rank the desirability of strategies after accounting for scenarios’ outcomes. The two main areas of measurement of debt management outcomes, as observed in the literature, are cost and risk. The debt manager, in general, seeks to minimize both, but a tradeoff typically exists between the two.

The modeling workhorse includes a feature that also enables predefining a fixed percentage of annual issuance into key benchmark series, which fulfills the third, often-overlooked, goal of financial market development. Hence, a measure for market development is not necessary.16

For the base case analysis, I examine evaluation measures for cost and rollover risk. The measure for cost equals the average annual cash flow on debt instruments from coupon payments and indexation of the principal value. Rollover risk is counted as the average annual principal payments (or, similarly, principal refinancing needs) over the time horizon. All measures are denoted as percentage of GDP, which helps maintain real values and supports an ALM perspective.

Given the non-probabilistic approach utilized in this study, value-at-risk type measures cannot be applied. I also chose to avoid measures describing the structure of the debt profile since they seem to be hard to grasp in themselves, especially when they lack a predefined clear benchmark. Instead, when analyzing the stochastic non-probabilistic simulations, I use a measure that describes breaching the liquidity buffer (both in regret and absolute terms) over time, as discussed below.

**New Risk Measure: Breaching of Liquidity Buffer Under Deep Uncertainty**17

Maintaining a level of available liquidity is key in avoiding a debt repayment crisis. Measuring this level across multiple scenarios could therefore provide valuable insights for policy makers. This measure equals the sum of overall periodic debt financing needs (principal and interest payments) that are above a specific level, as measured by percentage of GDP. However, the required level of liquidity is itself subject to deep uncertainty as policy makers

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16 For the case of Israel, I decided to ignore this aspect in the analysis and not predetermine specific benchmark issuance. For a developed country it is plausible to expect the private sector to generate liquid benchmarks through financial derivatives if needed.

17 One anonymous participant in a seminar at the World Bank suggested I use the term “total debt service needs beyond limit”. Another possible term could be “total excess debt service requirements”.

22
cannot predict what level of financing needs will actually trigger a crisis in a possible future.\(^{18}\) For this reason, unlike an analysis that predefines this level a priori, the RDM-type analysis here examines the performance of strategies across varying possible levels of threshold. This measure is examined both in “absolute” terms and in regret terms.

This single unified metric captures both rollover risk and cost, as it relies on both principal and debt service levels. For policy makers, providing one single metric may be also easier to grasp, and hence preferred, over multiple ones.

**Time Horizon**

As explained before, simulation outcomes are influenced by the choice of the time horizon considered. In order to account for possible differences related to such choices, the analysis is done twice separately. First, it is conducted on the first 30-years, referred to as the “transition period”. In addition, I inspect the results during the consecutive 30-years (i.e. years 31 to 60). This far ahead time horizon represents a period during which the initial portfolio is completely repaid and therefore it has no influence on outcomes. This latter period is referred to as the “steady state”. The focus in this monograph is on results for the transition period, but full figures for the steady state are presented in Appendix 3. When steady state analysis yields noteworthy differences they are explained in the main analysis.

**Candidate Robust Strategies for Sovereign Debt Managers**

The choice of strategies in an RDM analysis starts by evaluating a set of archetypical strategies that a policy maker would like to consider. The set of these initial strategies should preferably consist of a wide range of different elements, which could help us understand the tradeoff between the possible policy options. In our case, we consider 20 strategies, each of which is a combination of two basic elements as detailed in table 4.1: 1) one out of five basic bond-preferences; and 2) one out of four basic maturity-preferences. A richer technical description may be found in Appendix 2.

\(^{18}\) It is plausible to expect that this level also depends on the specific circumstances.
Table 4.1: Components of Candidate Robust Strategies

<table>
<thead>
<tr>
<th>Denoting Letters</th>
<th>Basic Bond Preference</th>
<th>Denoting Letters</th>
<th>Basic Maturity Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>“Nominal Heavy”: 70% of issuance is allocated into nominal bonds, and rest is equally distributed among other types (^{(1)}) (10% each)</td>
<td>S</td>
<td>“Short Term”: All bonds are issued with maturities of 1 to 15 years, in equal shares to each maturity</td>
</tr>
<tr>
<td>C</td>
<td>“CPI-linked Heavy”: 70% of issuance is allocated into CPI-linked bonds, and others equally distributed among other types (^{(1)}) (10% each)</td>
<td>L</td>
<td>“Long Term”: All bonds are issued with maturities of 16 to 30 years, in equal shares to each maturity</td>
</tr>
<tr>
<td>U</td>
<td>“USD Heavy”: 70% of issuance is allocated into USD-denominated bonds, and others equally distributed among other types (^{(1)}) (10%)</td>
<td>B</td>
<td>“Benchmark Focused”: 30% of bonds are issued with 5-year year maturities, 40% into 10 year maturity and 30% carry 30 year maturities.</td>
</tr>
<tr>
<td>V</td>
<td>“Variable Rate Heavy”: 70% of issuance is allocated into Variable Rate Bonds, and others equally distributed among other types (^{(1)}) (10%)</td>
<td>EQ</td>
<td>“Equal weights”: The issuance is allocated equally (1/30) into each of the terms to maturity</td>
</tr>
<tr>
<td>EQ</td>
<td>“Equal weights”: The issuance is allocated equally (25%) into each of the fours bond types (^{(1)})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:

\(^{(1)}\) The types of bonds included in the candidate strategies are: Nominal Bonds, CPI-linked Bonds, USD-linked bonds and Variable rate bonds (VRIs). GDP-linked bonds are introduced only later in the analysis.

Many of the figures in the rest of this document use combinations of these letters to specify the strategies used. For example, a strategy that is “USD-Heavy” and “Long-Term” is denoted “U-L”.

Describing Strategy Performance

*Expected Cost-Risk Tradeoff (A Classical Analysis)*

Classical expected-utility style of policy analysis would examine the expected performance of debt strategies, weighted by the likelihood of the possible scenarios. Knowledge of likelihoods would also enable us to present a probabilistic risk measure, such as standard deviation of performance. This is most often the approach used by debt offices when stochastic numerical analysis is conducted (see above).

Since our analysis assumes that the drivers of sovereign debt performance are deeply uncertain, i.e. likelihoods are unknown, we refrain from using weighted-averages to quantify outcomes. Instead, we start by understanding the basic tradeoffs among the candidate strategies under a base-case scenario, which is shown in Figure 4.1. The tradeoff presented is between average costs, measured as the sum of coupon payments and indexation values, and between
average annual rollover needs, which provides a measure of rollover risk – a major source of risk of default.

The base case scenario used in this initial analysis is the one that assumes zero values for the periodic shocks of the exogenous variables in the model. This means that the values of the macroeconomic and financial factors remain in their “equilibrium”/long-term levels, or if the initial levels are different they gradually move there.19

Figure 4.1: Average Annual Rollover and Costs of Candidate Strategies under a Base-case Scenario, Transition Period

Notes:
(1) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).
(2) Rollover needs include only the nominal value of principal paid at maturity. Indexation of the principal is counted within costs, which include also the cash-value payment of the coupons.

19 For example, the base case assumes: no volatility in the exchange rate over the period of analysis, Inflation is curbed at the long-term target and the currently low short term interest rate moves gradually to its long-term level.
The results indicate that in the base-case scenario, average annual rollover needs are determined solely by the maturity strategy where shorter maturities are associated with higher rollover needs. Average costs, on the other hand, are determined both by maturity choice and bond-type choice. Longer maturities are costlier, which should be attributed to the upward sloping of the yield curve. Consistent with this fact, variable-rate bonds, which pay short term interest, are the least costly on average. Nominal bonds, which do not provide any hedge to investors against market risk are the most expensive on average. The ranking of USD and CPI-linked bonds interchanges if the analysis is done for the steady state, as can be found in Appendix 3.20 Since the indexation on CPI-linked bond principal is paid only at maturity, an early or short term time-span of analysis underestimates their costs compared to the steady state.

For convenience, we can also sketch an “efficiency frontier” that connects strategies “V-S”, “V-B”, “V-EQ” and “V-L”. This set of points represents all the Pareto-optimal strategies, in the sense that no other available strategy outperforms them both from a cost and a risk perspective (simultaneously). Available strategies that are not located on this frontier could be seemingly improved at no added cost and no added risk. Hence, decision makers that choose seemingly non-optimal strategies should be required to well justify their choices.21 In the particular case of Israel, the government debt office has chosen to refrain from issuing variable rate bonds, which seems to be contradictory to the Pareto efficient frontier sketched in figure 4.1. Several reasons might serve as explanations for such a decision. In particular, the government might be concerned with other risk and cost aspects that are not reflected in the figure. For example, it might be concerned with a suddenly strong spike in interest payments, positioning a VRI-heavy strategy as relatively inferior (as will be seen in the rest of the analysis, see for example figure 4.4). Governments could also be driven by other considerations such as fear of crowding out private sector funding and preference to issue conservative and simple benchmark instruments.

To summarize, if the decision maker cares only about average levels of rollover risk and cost, and assumes that the base-case indeed represents the expected-level of consequences, they should be able to choose the best strategy among these options using the above analysis.

However, this is rarely the case. Policy decisions, especially when done under deep uncertainty, require a richer understanding of the possible set of outcomes. Further, identifying the scenarios in which strategies perform poorly could help devise a more robust policy. For this, a more detailed visualization is necessary, which is provided in the figures below.

20 However, the ranking of maturity profiles does not change in the steady state.
21 A justification of a seemingly sub optimal strategy choice could directly refer to the quantifiable deviation of cost and risk. For example, choosing strategy C-S over strategy V-S costs 0.55% GDP more on average, which could be seen as a premium that is either worth or not worth paying.
Visualizing Possible Outcomes

Next, I turn to explore the outcomes of candidate strategies across multiple possible futures, using both the breach of liquidity buffer measure and the average cost measure, in regret terms. This is carried through a set of stochastic simulations that apply the 20 candidate strategies to 1000 possible trajectories for the exogenous uncertain, thus generating 20,000 cases for consideration. For these simulations, a Latin hypercube sampling method is applied to all the periodic “shocks factors” of the exogenous model variables, as explained in appendix 2.

The results, as shown in Figure 4.2, show that the maturity base strategy is the predominant factor that determines the sum of rollover and debt cost when bundled together, both from a maximum regret and a median regret perspective. The figure provides a ranking of maturity strategies, where long-maturity strategies yield relatively fewer cases of high regret compared to all other strategies. The second in ranking are the strategies that have a fully diversified maturity profile. The ranking of strategies by maturity is similar when the analysis is conducted for the steady state (see Appendix 3), and is consistent when assuming different liquidity thresholds (note that Figure 4.2 present results for a wide range of thresholds).

Within a maturity policy, bond-choice makes a difference. While the dispersion of the regret among nominal bonds and equal-weight strategies is relatively even, issuance of variable-rate and USD bonds have a more dispersed pattern, which gives evidence to the possibility of extreme highly-consequential scenarios. This should not come as a surprise, since the costs of these instruments might be strongly affected by extreme values of the financial factors they are linked to. A more comprehensive analysis of bond-type choice will be presented later.
Figure 4.2: Distribution of Regret for Total Breaching of Liquidity Buffer of Initial Candidate Strategies, Transition Period

Notes:
(1) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).
(2) Outcomes are calculated for the entire 30-year period.
(3) The box plots divide outcomes by quartiles, where the whisker covers the top quartile. The horizontal line between the dark and light grey rectangles represents the median value.
(4) The figure presents results for liquidity thresholds between 3% to 19% of GDP, by intervals of 2%.
(5) Colors of the points represent different maturity preferences, as reflected in the strategy notations.

Though the ranking of bond-types by average costs is not unequivocal, Figure 4.3 shows that the choice of bonds and not maturity largely determines the distribution of average costs. The cost of nominal and CPI-linked bonds is usually subject to less extreme levels and appears to be less dispersed, while USD and variable-rate bonds could carry the largest costs. Notably, the possibility of extreme values does not necessarily translate into higher median values. For example, strategy “C-L”, which focuses on CPI-linked bonds and long maturities, appears to have the second lowest median regret, while its maximum level of regret is higher than nine...
other candidate strategies. USD-linked bonds have lower median outcomes than VRIs, but their maximum regret is higher. To better illustrate this point, Appendix 5 replicates Figure 4.3 but sorts the strategies by median regret. A policy maker that seeks to understand the sources of extreme outcomes could utilize a scenario discovery analysis as demonstrated later in this chapter.

Figure 4.3: Distribution of Regret for Average Costs of Initial Candidate Strategies, Transition Period

Notes:
1. Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).
2. Outcomes are calculated on an annual basis.
3. The box plots divide outcomes by quartiles, where the whisker covers the top quartile. The horizontal line between the dark and light grey rectangles represents the median value.
4. Colors of the points represent different bond-type preferences, as reflected in the strategy notations.

For simplicity, I will now move to a more comprehensive account of the tradeoffs among bond-types within a specific term-to-maturity policy. It is reasonable to assume that policy makers would prefer to focus on a maturity strategy that resembles the candidate strategy which fully diversifies the maturity structure (denoted “EQ”).

29
The “EQ” maturity strategy appears to usually perform better than maturity strategies denoted “B” and “S” both from a cost and risk perspective (using maximum and median regret criteria). In comparison to a strategy that issues only into long-maturity strategies (denoted “L”), the “EQ” strategy appears to be more risky though in most cases it is superior to it from a cost perspective. At the same time, issuing only into long maturities is unlikely. If the government ignores market demand for short maturities, debt costs are likely to increase, reflecting an even higher “regret” than specified in the figure. Hence, the rest of the analysis will examine the tradeoff between bond choices within the equal-share maturity base strategy. These strategies are denoted as “U-EQ”, “V-EQ”, “N-EQ”, “C-EQ” and “EQ-EQ”.

For our purposes, the “EQ” strategy should be seen as an “archetypical” baseline maturity strategy, but not one that needs to be followed literally at all times. In reality, the choice of maturity should be more nuanced and connected also to market demand over the entire yield curve. Debt managers could also consider adjusting the maturity profile in light of changes in the risk perception, as will be seen later.

**Sensitivity To Threshold Levels**

One substantial limitation of the analysis thus far is the uncertain threshold level over which the risk criterion (“breaching of liquidity buffer”) is calculated. Policymakers should also be interested in understanding how results are sensitive to this threshold level. Naturally, higher liquidity threshold levels result in less breach (in absolute terms) of those liquidity buffer levels, all things equal.

Figure 4.4 displays the tradeoffs between bond-base strategies, using the maximum regret criterion. It serves as an example of how RDM could help examine performance against varying assumptions.

A similar analysis using the median regret criterion and the absolute maximum value appears in Appendix 4. As explained earlier, criteria choice for decision making under deep uncertainty is inherently subjective and depends on the decision maker’s preferences and beliefs. I chose to focus on the maximum regret over other criteria since it is not only independent of probabilistic assumptions but it also reflects the policy maker’s aim to minimize bad choices within each and every possible future. In contrast, median or expected regret imply an underlying probabilistic model, and the max-min criterion might ignore the potentially substantial difference a strategy choice could make in the particular future we end up experiencing.

The figure illustrates that while nominal, CPI-linked and equal-weight strategies have similar levels of maximum regret at threshold levels below 15%, for higher threshold levels CPI-linked

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22 The model assumes that interest market conditions are independent of issuance choices. This assumption was made on methodological and practical grounds, since this relationship is deeply uncertain, however in reality it is clear that this assumption doesn’t hold and that increasing supply of one type of debt should increase its cost to the issuer. Future research could model possible values of such relationships.
bonds seem to perform better. This visualization enables policymakers to choose their bond-type strategy based on their subjective assumptions regarding the threshold level. Policymakers that are willing to assume that Israel’s liquidity buffer is above 15% of GDP, would be advised to issue CPI-linked bonds more heavily. A CPI-linked strategy under such assumptions could lower the regret levels over the first 30-year period by more than 10% GDP (i.e. an average regret of more than 0.3% GDP per year).

One advantage of CPI-linked bonds which could explain their favorable performance is their correlation with government asset values, and specifically with GDP levels. When inflation spikes CPI-linked payments grow but so do government assets, including the tax base. Since our outcomes are measured as share of GDP, the effect of inflation is partially subdued. Further discussion of the advantages of asset-linked debt appears when I introduce GDP-linked bonds.

**Figure 4.4: Maximum Regret for Total Breaching by Liquidity Buffer, Transition Period**

Notes:

1. Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter, EQ, means that the strategy issues into different maturities equally.

2. Total Breaching is the sum of debt service costs and principal repayments beyond the threshold, calculated over the period’s 30 years.

However, this observation does not hold when the analysis is done for the steady state, as shown in figure 4.5. In this case, though CPI-linked bonds have an improved performance at higher threshold levels, they never record the lowest levels of maximum regret compared to other strategies. At the steady state, a strategy that focuses on issuing variable rate bonds could
lower the maximum regret by almost 40% GDP compared to the second-best option (nominal-heavy strategy), which roughly equals an average annual regret of 1.3% GDP.

One possible reason for this inconsistency is that in the short run we do not fully account for the indexations of CPI-linked bonds since it is paid only at maturity. On the other hand, the price of variable rate bonds might fluctuate considerably in the short run due to changes in the short term rate. In the long run, however, changes in short term interest rate are more fully reflected in the price of other bonds, so variable rate bonds do not seem to underperform.

**Figure 4.5: Maximum Regret for Total Breaching by Liquidity Buffer, Steady State**

In summarizing results from the two time horizons, we find that a strategy that focuses on issuing nominal bonds seems to perform relatively well, usually second-best, among the five candidate strategies regardless of the threshold level assumed. Strategies that “bet” on CPI-linked or variable linked bonds are prone to lower levels of performance dependent on the time span of analysis and assumptions regarding liquidity threshold levels. But if we are indeed
concerned with the long-term steady state costs, adding a strong variable rate component appears to be a promising choice.
Understanding Sources of Strategy Failure

In order to further improve decision-making, the analysis next aims to identify and characterize one or more clusters of future states in which the candidate strategy perform poorly. By doing so, we will be able to identify the leading sources that could cause a debt repayment crisis and adjust policies accordingly. Such an analysis, called “scenario discovery”, uses statistical or data-mining algorithms to find regions of interest in the space of uncertain input parameters (Bryant and Lempert, 2010).

Following Bryant and Lempert (2010) I employ Friedman and Fisher’s (1999) “patient rule induction method” (PRIM) to identify and characterize the values of external factors in which the strategy “N-EQ” (Nominal bond heavy & equally spread maturities) performs worst, i.e. breaches the liquidity buffer the most or carries the highest costs. This data mining algorithm generates a set of “boxes”, containing regions in which the risk value is large compared to its value outside these boxes. A further discussion of this method can be found in Lempert et al. (2006) and Bryant and Lempert (2010). We use nine candidate drivers as possible determinants of scenarios, which are the exogenous variables of the model: GDP growth, cumulative GDP gap, budget deficit, exchange rate, exchange rate expectations, inflation, inflation expectations, short term nominal interest rate, long-term real interest rate.

Scenario discovery, when conducted over dynamic multi-period simulations, is sensitive to the time spans over which outcomes are calculated and to the time spans used to determine the trajectory of the drivers. For this reason, the scenario analysis is run in three separate rounds: the first looks at the average values of outcomes and drivers across the entire 60 years. Second, I divide the drivers into 15-year long “bins” and repeat the analysis. Finally, I focus on what drives dire annual performance by examining how drivers behave in the 5, 10 and 15 years before that year. These alternative specifications enable us to observe possible differences among them.

The results of the scenario discovery, as seen on Table 4.2, show that the main drivers of bad performance are those connected to macroeconomic external factors rather than financial market indicators: cumulative GDP gap\(^{23}\); GDP Growth, and budget deficit levels. Except for one run that indicated a possible significant role for exchange rates, financial indicators did not serve as strong drivers of failure.

\(^{23}\) Cumulative GDP gap equals the actual GDP in excess of the expected GDP level, with \(t=0\) serving as the baseline year:

\[
GG_t = GDP_{t=0} \times \prod_{i=1}^{t} (1 + G_i)(1 + \pi_i) - GDP_{t=0} \times \prod_{i=1}^{t} (1 + 3.5\%)(1 + \pi_i).
\]

Long term real growth is assumed to be 3.5%. See appendix 2.
Table 4.2: Boundaries of Parameter Values Corresponding to the PRIM-Generated Rules that Define a Scenario of Severe Failure for Strategy “N-EQ”^{(1)(2)}

<table>
<thead>
<tr>
<th>Outcome Time Span</th>
<th>60 years</th>
<th>60 years</th>
<th>Annual</th>
<th>Annual</th>
<th>Annual</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver Time Span</td>
<td>60 years</td>
<td>15 year “bins”</td>
<td>5 year prior</td>
<td>5 and 10 years prior</td>
<td>5, 10 and 15 years prior</td>
<td>10 years prior</td>
</tr>
<tr>
<td>Driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative GDP Gap</td>
<td>&lt;-0.52243</td>
<td>&lt;-0.52303 (30);</td>
<td>&lt;-0.465</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.01258 (15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real GDP Growth</td>
<td>&lt;0.0374</td>
<td>&lt;0.065</td>
<td>&lt;0.065</td>
<td>&lt;0.045</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Budget Deficit</td>
<td>&gt;0.02208</td>
<td>&gt;0.02352 (15)</td>
<td>&gt;0.045</td>
<td>&gt;0.045</td>
<td>&gt;0.045</td>
<td>&gt;0.045</td>
</tr>
<tr>
<td>Exchange Rate</td>
<td>&gt;1.58813 (30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coverage^{(3)}</td>
<td>0.7</td>
<td>0.825</td>
<td>0.02973</td>
<td>0.3207</td>
<td>0.9448</td>
<td>1</td>
</tr>
<tr>
<td>Density^{(4)}</td>
<td>0.77778</td>
<td>0.71739</td>
<td>0.96104</td>
<td>0.287</td>
<td>0.10788</td>
<td>0.07819</td>
</tr>
</tbody>
</table>

NOTES:
(1) A severe failure corresponds to 7.5% of total cases in which strategy “N-EQ” generates the highest levels of breaching of the liquidity buffer.
(2) The results record the top four (or fewer) drivers that determine a failure scenario. The values in the table represent the borders of the “box” that captures the cases of failure. Where cells are blank, the drivers do not appear to be among the top four leading determinants.
(3) Coverage is the share of failure cases that are contained in the scenario.
(4) Density is the share of failed cases out of total cases captured within the scenario.

These results could indicate to debt managers that an effective debt policy should respond to changes in the macroeconomic environment, specifically GDP and budget figures, but not necessarily to financial market indicators. This insight helps better illuminate the deeply uncertain debt policy environment. It implies that there is less benefit in trying to respond to changes in financial indicators and effectively “bet” on their future values. On the other hand, addressing real macroeconomic downturns is more likely to be a robust policy.

Addressing adverse macroeconomic conditions could be done either by issuing debt instruments that provide hedges or by adjusting policies in response to the external environment (or both). These possibilities will be examined below.
Examining the introduction of GDP-linked bonds

In recent years there have been growing calls to issue sovereign financial liabilities that are contingent on the values of economic indexes, such as commodity prices (Becker et al., 2007) and GDP (Barro, 1999; Shiller, 1994; Borensztein and Mauro, 2004). GDP-linked bonds, or variations of such, have been only rarely issued in practice – with the recent GDP-linked warrant issued by Greece in 2012 being a rare exception. Though conceptually appealing, as with other financial innovations, these instruments still suffer from market skepticism and carry a considerable premium (Chamon, Costa and Ricci, 2008).

The rationale behind these instruments is directly related to the SALM approach. Linking liabilities to asset values helps insulate the government from large unexpected increases in budget deficits, since a drop in the government’s revenues is matched with a drop in its debt payment requirements. For the case of GDP-linked bonds, a drop in GDP would lower tax revenues (as the tax base shrinks) but would also lower government’s interest payments. These securities are especially appealing given the insights from our scenario discovery analysis, where slumps in GDP levels have been found to be of the major drivers of excessive debt payments.

In this study, I simulate the possible implications of an issuance strategy in which 10% of the annual financing needs are allocated to GDP-linked bonds. As explained in detail in Appendix 2, these securities are assumed to pay an annual coupon that is equal to the real GDP-growth rate plus a constant spread, which is priced based on a no-arbitrage condition. The remaining 90% of issuance resembles the nominal-heavy strategy and the maturities of the bonds are equally spread out. In this sense, the GDP-linked bond strategy that is simulated is an adjustment of the “N-EQ” strategy.

The simulation results as shown in Figures 4.6 and 4.7, demonstrate that the GDP-linked bond strategy could further improve the robustness of the nominal bond strategy. It could lower the maximum total breaching (over the 30 years of analysis) by over 10% GDP and lower the maximum regret levels by over 3% GDP. Note that these figures are for a strategy that issues only 10% of its totals in GDP-linked bonds. Increasing the share of GDP-linked bonds could further improve performance. In the steady state, a GDP-linked bond strategy shows a decrease of the maximum total breaching by 18% GDP compared to a nominal bond strategy, but seems to slightly underperform in maximum regret terms (by 3% GDP, see figure AP3.4).
Figure 4.6: Distribution of Sum of Breaching of GDP-linked bonds vs. Alternatives, Transition Period

Notes:
1. All strategies have an equal weighted maturity policy (previously denoted “EQ”). Letters denote bond based strategies Variable Rate (V), CPI-Linked (C), Nominal (N) and GDP-Linked (G).
2. Sum of total breaching is the sum of debt service costs and principal repayments beyond the threshold, summed over the period’s 30 years.
3. Threshold levels range from 3% GDP to 23% GDP, with intervals of 2% GDP.

Figure 4.7: Maximum Regret of GDP-linked Bonds vs. Alternatives, Transition Period

Notes:
1. All strategies have an equal weighted maturity policy (previously denoted “EQ”). Letters denote bond based strategies Variable Rate (V), CPI-Linked (C), Nominal (N) and GDP-Linked (G).
2. Total Breaching is the sum of debt service costs and principal repayments beyond the threshold, summed over the period’s 30 years.
As explained above, contrary to the non-arbitrage assumption, in reality GDP-linked bonds are expected to carry a substantial premium. Therefore, the results in figure 4.6 and 4.7 do not necessarily reflect accurate levels of possible performance. They could, on the other hand, help the issuer, i.e. the government, to assess what premium level is justifiable in light of the potential hedge that these instruments provide.

As an illustrative hypothetical example, if we assume on average that strategy G-EQ will issue GDP-linked bonds amounting to 1% GDP annually, then the maximum annual “savings” of roughly 0.3% GDP in figure 4.6 (10% divided by 30) could be justifiable only if the premium amounts to no more than 30 percent of annual interest.24 Since this simple example takes into account only the “worst-case” scenario, decision makers also would want to weigh less severe outcomes in the calculation. Weighted outcomes could then be used to more accurately determine a fair premium from the government’s point of view.

Incorporating Adaptive Policies

It is often acknowledged that successful strategies should be able to respond to changes in the environment. However, as noted before, government debt offices have generally refrained from modeling strategies that adapt to changes and instead focused on static long term benchmarks. In this final stage of the study I demonstrate how simulating such adaptive elements could help guide debt manager’s choices.

Figure 4.8 depicts the outcomes of adaptive strategies across 500 different scenarios, using both absolute value and regret values of the “sum of breaching the liquidity buffer” metric. The adaptive strategies examined contain two adaptive elements to the strategy that thus far proved to be most robust – strategy G-EQ, which issues 10% of its bonds in GDP-linked securities and otherwise heavily focuses on nominal bonds, and issues equally into maturity profiles. The first adaptive policy examined, termed “Inflationary Caution”, is one that increases its CPI-linked bond shares in face of deflation, i.e. when annual inflation is less than zero. This is essentially a bet on inflation maintained at low levels. The second adaptive policy, termed “Recession Risk Aversion” is one that increases the maturity of new issuances in light of high budget deficits (above 5% GDP), representing a macroeconomic crisis. The first adaptive strategy lowers the issuance of non-CPI-linked bonds by 50%, while the second adaptive strategy does the same for bonds with time-to-maturity of less than 15 years.25 I also examine a combination of the two adaptive strategies (appears as “Inflationary Caution & Recession Risk Aversion” in Figure 4.8). These adaptive strategies are contrasted with to the non-adaptive baseline option, i.e. Strategy “G-EQ”.

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24 This is a very rough back-of-the-envelope calculation. An accurate calculation
25 Future research could examine varying levels of triggers and varying levels of decreasing/increasing bond type issuance.
The simulation results in Figure 4.8 show that an adaptive strategy that increases maturities at times of large deficits lowers maximum breaching levels by about 15% GDP across the 30 years of the transition period. The median scenario shows a similar drop. Maximum regret for this period, when comparing to the other alternatives, is lowered by 24.5% GDP.

On the other hand, the adaptive strategy that increases CPI-linked issuance in light of deflation proves to be risky and increases both the absolute values of total breaching, as well as their regret values. When combining the two adaptive elements, results are worse than using only the maturity-increasing policy alone.
In this final chapter I summarize the main insights revealed in the analysis, discuss the methodological choices taken and their implications, and discuss what debt managers should remember when utilizing the proposed RDM framework.

Particular Insights

The analysis provides some important insights for debt managers which could help guide particular policies. Below are the main policy implications as they arise from the findings, using Israel’s government debt portfolio as a case study:

1. **The choice of the term-to-maturity of government debt should be guided primarily by the perceived ability to absorb high rollover and debt service costs.**

   Within a given macroeconomic and financial future, maturity choice is the factor responsible for determining rollover needs. Together with bond-type choice it also influences debt service costs. Hence, the choice of the term-to-maturity profile should consider the maximum rollover and debt service costs an issuer could absorb at times of crisis.

   Short term maturities increase rollover levels, but at the same time contribute to lowering costs. On the other hand, long term maturities generate lower rollover needs but carry higher costs on average. A reasonable choice is thus a combination of long and short maturities which could potentially generate debt rollover and service requirements that are absorbable. Policy makers could also consider adjusting maturity choice over time when their perception of the risk levels of the environment changes.

2. **The choice of bond-type should be guided by the perceived ability to absorb high debt service costs.**

   Within a given macroeconomic and financial future and given a debt maturity strategy, bond-type choice determines service costs. Hence, the choice of a bond-type strategy should take into account its potential effect on debt service costs, and in particular, how they contribute to the breaching of the country’s liquidity buffer at times of crisis.

3. **Debt policy would benefit from maintaining a substantial available liquidity buffer.**
The severity of a debt crisis could be determined by the liquidity available to a government to absorb debt payment shocks. For this reason, it is advisable for a country to secure high levels of available liquidity. Sources of this liquidity could be comprised of:

- **Deep local market demand for government bonds.** In developed countries, local investors are usually the main source of demand for government bonds. A functioning system of institutional investors that enjoy a constant influx of funds from the public, and hold substantial reserves, could provide a liquidity buffer to the government.

- **Foreign Demand.** Developing countries often rely on foreign capital to finance their government debt, which repeatedly proved to be unreliable in times of crisis. A government that relies on foreign funding should find ways to secure this channel at all times. One option is to rely on foreign governments or international institutions, such as the IMF, to provide emergency funding when needed. However, this creates a negative signal to investors.

  Israel has been able to secure foreign funding through two major unique channels: the first are “Israel Bonds” (http://www.israelbonds.com/) which are non-tradable bonds that are mainly held by the Jewish diaspora and other international parties that support Israel. In times of economic hardship, such as in the 2002-2003 downturn, Israel was able to rely on this source of funding. In many ways, Israel bonds resemble a credit line for the government.

  The second source that secures foreign funding to Israel are US government loan guarantees. The US government enables Israel to issue bonds backed by US government guarantees, which provide it with readily available and inexpensive sources of funding.

- **Credit Lines.** Governments, just like businesses and individuals, can engage in an agreement with financial institutions for providing funds that can be readily tapped at the borrower's discretion.

- **Liquid Reserves:** Governments often hold funds in separate accounts for use in times of crisis. Common examples are sovereign wealth funds, which among their various objectives, could also provide funding to the government at times of need.

Deciding what exactly constitutes a “substantial” or “adequate” level of a liquidity buffer remains a subjective call dependent on the decision maker’s risk preferences. At the same time, the tools developed in this research might be able to help decision makers decide on what they deem to be such level. For example, if the Israeli debt manager seeks to ensure that the median of future liquidity breaching scenarios is equal to zero, he or she would need to secure a liquidity

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26 These phenomena popularly referred to as the “original sin”, a term coined by Eichengreen and Hausmann (1999).

27 Neither the academic literature nor policy practitioners have been able to reach a consensus on what constitutes an adequate level of liquidity for a country. For an overview of this debate and country practices see (International Monetary Fund, 2011a)
buffer of at least 15% GDP (see Figure AP4.2).

4. **Focusing on issuance of nominal bonds appears to be a robust choice.**

Regardless of time horizon considerations and assumptions on the available liquidity buffer, nominal bonds carry relatively low levels of risk compared to other alternatives, even if it they don’t provide the best outcomes at all times. In the current analysis, it has been found that a strategy that focuses on nominal bond issuance performs only second to a CPI-linked strategy in the short run, and in the long run it appears to be only second to a VRI strategy. It is therefore advisable for governments to anchor their issuance strategy on a large share of nominal bonds.

5. **Increasing the issuance of variable rate bonds appears to be a reasonable bet for Israel for the long run.**

Though in the short run it might expose the government to higher debt cost, in the long run issuing variable rate bonds appear to perform better than the alternatives. Therefore, the Israeli government should consider re-issuing variable rates, which their issuance has been halted in recent years. The currently low interest environment might be a particularly good time to reintroduce variable rate bonds, as some investors might be looking to hedge themselves against future interest rate hikes.28

6. **Issuing CPI-Linked bonds might be especially appropriate to governments that are primarily concerned with risks in the short run.**

Governments that are especially concerned about the short run should consider increasing the share of CPI-linked bonds. In the longer run, though, the cost associated with these instruments might prove to be higher than the alternatives, so caution is necessary.

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28 Similarly, the US Treasury has recently begun to issue floating rate notes. See: https://www.treasurydirect.gov/indiv/products/prod_frrs_glance.htm
7. **Issuing GDP-linked liabilities will lower the risk of the government’s debt portfolio.**

As argued in the analytical literature, issuance of GDP-linked bonds is expected to improve the resilience of the government debt profile to shocks. Governments should therefore seek to issue liabilities that are linked to GDP, or possibly to the value of other sovereign assets. For Israel, examples of possible indexations are to real estate prices (since the government owns large amounts of land) or securities that are negatively correlated with longevity (to hedge against possible spikes in social security, pension and health costs). Similarly, governments that hold foreign currency reserves could match these assets with foreign currency bonds.

8. **Increasing the maturity profile in times of budgetary hikes could be a good policy to tackle downside risks, while betting on financial indicators is hard to justify**

The analysis has shown that increasing maturities in times of budgetary crisis would lower the downside risk (in absolute and regret terms) as compared to not doing so. On the other hand, increasing the issuance of CPI-linked bonds at time of deflation might prove to be a costly bet. This could indicate that adjusting the type of bonds issued in light of market conditions might be unadvisable. On the other hand, lengthening maturities decreases risk and should be considered favorable in times of budgetary crisis.

**General insights and discussion of methodological choices**

On a more general and methodological level, this study demonstrated how a large set of non-probabilistic simulations could inform decision making on government debt policies. Given the deep uncertainty of the debt management environment, it was shown how adopting a RDM approach could help identify and outline strategies that perform relatively well compared to alternatives across the possible futures. This methodological approach tries to avoid the strong, often misleading, assumptions that guide much of “traditional” financial risk management.

The particular insights described above have been derived from a model using Israeli data, and therefore are specifically applicable to the Israeli case. Though it is safe to assume that many of the derived conclusions could hold for other countries as well, an accurate account should repeat the analysis using country specific data.

The set of tools devised for this research are well suited to be individually tailored to any country’s particular situation and circumstances. Future research on sovereign debt management that applies these tools to new cases could help generalize our insights and at the same time
provide country specific policy guidance, which will be useful both for decision makers and external parties who monitor these policies.

Avoidance of strong, unverifiable, parametric assumptions in the analysis is achieved by examining large sets of possible values for the driving factors in the system, rather than using a limited set of values or probabilistic distributions. At the same time, it is difficult to fully escape all assumptions, especially those that relate to underlying structural model relations. It is important, however, to acknowledge these methodological choices. Understand their implications could improve the accuracy of the insights and provide basis for future improvements. Perhaps the strongest assumption made in this analysis is that pricing conditions are independent from government policies and macroeconomic indicators (such as the overall debt and GDP levels). Blommestein and Hubig (2012) have already pointed out that using such assumptions could be highly misleading in an SDM context. A possible solution could be to model the relationships between these elements (what is often called in the literature a “penalty function”). If these relationships are deeply uncertain, one can examine alternative possible parametric and structural specifications. At the same time, I would argue that this criticism is less applicable to the RDM framework used in our research. The reason is that since we already examine very wide sets of values for both pricing conditions and macroeconomic factors, the simulations inherently include possible penalty functions, themselves deeply uncertain.

Another underlying assumption to note is that the governments can borrow at all times. One could argue that this assumption is invalid since governments might reach situations in which investors are not willing to fund their needs at all. A way to reconcile this debate is by interpreting very high issuance costs as situations where the government de-facto cannot borrow. A government would then seek alternative non-debt funding mechanisms such as rapid asset-sales, a solution that is effectively very costly. This extreme situation is also addressed in the analysis from a different angle: by examining acceptable levels of liquidity buffers, we basically assume that borrowing might be impossible beyond some threshold.

One other notable methodological assumption is that the pricing of GDP-linked bonds does not carry a premium compared to nominal bonds (a non-arbitrage condition). Past experience with issuance of similar instruments proves this to be highly unlikely. The analysis of GDP-linked bonds issuance is therefore less helpful in describing actual possible futures, but can instead be used to understand what could happen if such non-arbitrage conditions hold, and help debt managers evaluate what is an acceptable premium to pay for the hedging these instruments provide. This approach is discussed in the relevant section.

Finally, even though the RDM experimental design generates a large set of possible values for the financial and macroeconomic factors, these values are constrained by predefined bounds that are selected based on the analyst’s judgment. For example, as shown in appendix 3, annual real GDP growth was assumed to be bounded between -10% and 10%, and its annual shock
factor bounded between -5% and 5%. This specification is merely a guess that depends on the analyst’s perceptions of what constitutes plausible futures.

The way forward – what debt managers need to remember when using RDM

Robust decision making does not provide a silver bullet for government debt managers to find an optimal solution to their policy problem. Neither does it aims to do so. What it does provide is an ability to acknowledge, highlight and better understand what strategies could perform relatively well across many possible futures. It also helps understand what could be critical in causing failed performance, and help devise hedging options in light of these risks.

RDM will still require debt managers to make cautious assumptions and methodological choices. Some of these choices have been discussed in the previous sections and can be well justified. But possibly the most sensitive area of decision is the one that determines the range of plausible values of financial and macroeconomic variables. These choices are what determine the set of possible futures under consideration. Debt managers will have to look carefully at historical values for these factors, but also consult with experts, stakeholders and other decision makers in order to decide on which financial and macroeconomic scenarios and parameters need to be taken into account.

In addition, debt managers will have to give thought to the decision criteria that guides the analysis. The choice of decision criteria should depend on debt manager’s preferences and take into account the financial, economic, political and institutional setting in which they operate.

Not less important than making these choices, clear acknowledgment of them is what could substantially upgrade government debt management. When facing deep uncertainty or when categorical methodological choices are still hard to make, the RDM approach could be an effective aid to tackle these challenges.
## Appendix 1: Examples of Sovereign Debt Modeling Efforts

### Table AP.1.1: Examples of Country Debt Modeling Efforts

<table>
<thead>
<tr>
<th>Country</th>
<th>Modeling Approach</th>
<th>Risk Measures</th>
<th>Source</th>
</tr>
</thead>
</table>
| Canada  | • Macroeconomic and financial variables follow a reduced form based on historical data  
          • Strategies consist of constant issuing weights over time  
          • No foreign Currency Bonds  
          • Price adjustment for excessively large or small issuance amounts, based on a penalty function  
          • Includes an optimization framework  
          • Examine 5 different model specifications | • Variance of the government’s budget & debt charges  
          • Absolute, relative and tail cost-at-risk and budget-at-risk  
          • Conditional debt-charge and budgetary volatility  
          • Refixing share of debt  
          • Daily and quarterly rollover  
          • Maturity profile | Bolder and Deeley (2011) |
| Japan   | • Financial factors follow a model that uses data from the present yield curve and historical interest rate volatility  
          • Use the most recent government issuance plan and assume same annual issuance amount and maturity in future  
          • Examine only alternative maturity profiles | • Relative Cost at Risk | Internal conference background paper, citing prohibited |
| Sweden  | • Macroeconomic and financial variables follow a reduced form, usually AR(1), based on historical data  
          • Strategies include nominal foreign-currency and CPI-linked bonds, and three maturity profiles | • Average Variability of costs across scenarios and over time, counting the relative distance between 95th and 50th percentiles of the cost distribution | Bergström, Holmlund and Lindberg (2002) |
| Turkey  | • Macroeconomic and financial variables follow a reduced form based on historical data  
          • Financial scenario generator based on data from 2002  
          • Macroeconomic variables rely on government’s medium term program  
          • 5 options for scenario generation methods: normal distributions, fat-tail scenarios, asymmetric shocks, yield-curve shifting shocks and bootstrapping. | • Interest risk metrics: average time to re-fixing; share of CPI-indexed bonds in the TRY denominated debt stock and —share of TRY debt stock with interest re-fixing period of less than 12 months, excluding CPI-indexed bonds.  
          • FX risk measures:  
            • Currency composition of debt stock (local vs. foreign);  
            • Currency composition of FX-debt stock | Balibek and Memis (2012) |
| UK      | • Includes a comprehensive macroeconomic and financial model (with inter-related equations),  
          • Debt strategies include only nominal bonds, but maturities vary | • standard deviation of the debt cost ratio  
          • Cost at Risk | Pick and Anthony (2006) |
Appendix 2: Model Description

The system model used for the analysis describes a country’s debt portfolio over time, which is affected by the macroeconomic and financial environment and issuance policy choices. The model was programmed in Analytica©, a software that is suited for creating, analyzing and communicating quantitative decision models. It supports stochastic simulations, visualization of influence diagrams, and can be easily adjusted to incorporate alternative modeling assumptions.29

Below is a detailed description of the model’s components. In most cases, the assumptions used can be easily changed using the available software.

The Debt Portfolio

A debt portfolio of a country is the entirety of the expected payment obligations of that country at a given time. These obligations are split between various types of bonds and expected time of payment, and include three components:

- The Principal is the face value amount excluding interest and indexation that needs to be paid at the time of maturity. We assume all bonds are issued at-par.
- The Interest is the amount of the interest (“coupon”) to be paid.
- The Principal Adjustment Component, when applicable, is the change to the principal repayment requirement as a result of changes in the economic or financial environment, such as changes to the exchange rate (in the case of foreign currency obligations) or inflation (in the case of CPI-linked bonds).

It could be useful to illustrate the debt portfolio in time $t$ as shown in table AP2.1.

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29 The updated model can be downloaded at https://drive.google.com/folderview?id=0B9U0TNDNbbPvVTBwaDlyN3pxOE&usp=sharing.

A free software package for viewing models in Analytica© can be downloaded at http://www.lumina.com/
Table AP2.1: Example of a Debt Portfolio in a Selected Period (t=2013)

<table>
<thead>
<tr>
<th>Period (Year)</th>
<th>Nominal Bonds</th>
<th>CPI-Linked Bonds</th>
<th>USD Bonds</th>
<th>VRIs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Principal</td>
<td>Interest</td>
<td>Principal</td>
<td>Interest</td>
</tr>
<tr>
<td>2013</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>2014</td>
<td>90</td>
<td>5</td>
<td>80</td>
<td>9</td>
</tr>
<tr>
<td>2015</td>
<td>90</td>
<td>5</td>
<td>80</td>
<td>6</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>2042</td>
<td>150</td>
<td>10</td>
<td>120</td>
<td>0</td>
</tr>
</tbody>
</table>

Types of Bonds

For this analysis, I assume 5 types of bonds: Nominal, CPI-Linked, USD-linked\(^{30}\), Variable Rate Instruments (VRI), and GDP-Linked Bonds. Nominal bonds pay a fixed coupon that is determined at time of issuance and equal to the nominal market interest rate. CPI-linked bonds pay a fixed-rate coupon that is equal to the real market interest rate at time of issuance. The effective value of the coupons is linked to changes in the CPI, as well as the principal.\(^{31}\) USD-linked bonds also pay a fixed-rate coupon that, together with the principal, are subject to changes in the exchange rate. VRIs pay a coupon that is equal to the short term interest rate at the time of payment. The maximum time to maturity for all bonds is assumed to be 30 years.

GDP-linked bond are modeled to pay an annual coupon that is equal to the payment year’s real GDP growth rate\(^{32}\) plus a constant spread that is determined at the time of issuance. The constant spread is set assuming a no-arbitrage condition between nominal bonds and GDP linked bonds. We also assume that the market reflects rational expectations of future GDP following the same equation used to determine GDP growth in the model: \(g_t = 0.7\% + 0.8g_{t-1}\) (see table AP2.2).\(^{33}\)

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\(^{30}\) A more comprehensive analysis could include bonds denoted in other currencies beyond USD.

\(^{31}\) The coupon rate equals a constant percentage of the principal. Since the principal is linked to CPI, the coupon value changes accordingly.

\(^{32}\) For simplicity we assume that annual GDP growth rate is known during that same year, though in reality it is published by the statistical authorities on only ex-post.
The Dynamic Process

In each period t:
1) The debt portfolio is readjusted according to changes in the macroeconomic and financial environment. Changes in the CPI and exchange rate lead to an adjustment of the principal and coupon value of the CPI-Linked bonds and USD Bonds (respectively). Changes in the short term interest rate determine the changes to the payments on VRIs.
2) The government has to repay its existing obligations for this period, which include principal, principal adjustment and interest (coupon) payments.
3) The government issues new debt which its principal is equal to the sum of that period’s budget deficit and the principal value of debt that matures at this period. Existing market conditions for that period (see “yield curves” below) determine the expected interest payments which the issuer is obligated to pay in the future.

Macroeconomic and Financial factors

Influenced by the modeling approach other debt offices, in particular the Swedish debt office (Bergström, Holmlund and Lindberg, 2002) we use a stationary first-order autoregressive process (AR(1)) to determine the values of the majority of the exogenous macroeconomic and financial factors, as shown in Table A2.1. This process can be written, in general, as:

\[ y_t = \alpha + \gamma y_{t-1} + \varepsilon_t \]

Where \( \gamma \) is the autoregressive parameter, \( |\gamma| < 0 \), and \( \varepsilon_t \) is a periodic shock factor.

\( \varepsilon_t \), being a stochastic factor that is re-sampled across all periods and repeatedly through all the multiple runs, enables the generation of a wide set of scenarios. Technically, \( \varepsilon_t \) is modeled to follow a uniform distribution with mean zero, leading to an expected value of \( y \), \( E(y) \), to equal \( \frac{\alpha}{1-\gamma} \). However, the uniform distribution should not be perceived as a descriptive supposition but rather a modeling instrument that helps explore possible futures, in line with the exploratory modeling perspective. The bounds of the uniform distribution are a choice of the policy analyst

---

33 The spread \( S \) of GDP-linked bonds with time to maturity \( T \) is derived from equating the present value of a nominal bond and a GDP-linked bond. It equals:

\[ S_T = c_T - \frac{E_0[GDP_1]}{1 + r_1} + \frac{E_0[GDP_2]}{(1 + r_2)^2} + \cdots + \frac{E_0[GDP_T]}{(1 + r_T)^T} \]

Where \( E_t[GDP_i] \) equals the expected level at time \( t \) of real GDP growth in year \( i \); \( r_t \) equals the spot rate at \( t=0 \) for time to maturity of \( t \); and \( c_T \) is the coupon paid on at-par nominal bonds with time to maturity \( T \).

34 I use Median Latin Hypercube sampling.
that should reflect what she believes is a reasonable range of plausible trajectories which the debt manager should consider.\textsuperscript{35}

The existence and value of the constant $\alpha$ would depend on whether we indeed expect a specific long term average value for that same factor. For example, in the case of real GDP growth it is common to assume a long term average that reflects the economy’s fundamentals. If we indeed assume a long term average value, the value of $\alpha$ is set to be $E(y)^*(1 - \gamma)$.

The value of the autoregressive parameter $\gamma$ is based on prior literature or is estimated using historical data using a least-square estimation. The inclusion of a constant and propagation factor should be seen as stylized feature that helps smooth the shock affects in a way that resembles a reasonable reality when shocks are absent. Future research could examine the robustness of the results to alternative parameter values of these factors.

In cases where we assume that a longer term average value is unknown, $\alpha$ is set to equal zero and $\gamma$ to equal 1. This is a simple symmetric random walk model that could be written as:

$$y_t = y_{t-1} + \epsilon_t$$

The two exceptions that do not follow AR(1) or random walk processes are foreign exchange rate expectations and the budget deficit. Foreign exchange rate expectations are set to be an average of current period’s exchange rate and next period rate. This reflects a level of prediction, enabling some smoothing given that there is no predetermined long term value for the exchange rate.

$$X_t^e = 0.5(X_t + X_{t+1})(1 + \epsilon_t)$$

\textsuperscript{35} In practice, this choice should be communicated to the decision maker clearly and ideally, chosen together with them.
Table AP2.2: Modeling of the Macroeconomic and Financial Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Long Term Expected Value</th>
<th>Autoregressive Coefficient</th>
<th>Final Equation</th>
<th>Shock Factor Distribution Bounds</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP growth</td>
<td>3.5%</td>
<td>0.8</td>
<td>( G_t = 0.7% + 0.8G_{t-1} + \varepsilon_{1,t} )</td>
<td>-5%...5%</td>
<td>Possible value capped between -10% and 10%</td>
</tr>
<tr>
<td>Inflation</td>
<td>2%</td>
<td>0.4</td>
<td>( \pi_t = 1.2% + 0.4\pi_{t-1} + \varepsilon_{2,t} )</td>
<td>-25%..25%</td>
<td>Lowest value capped at -5%</td>
</tr>
<tr>
<td>Inflation Expectations</td>
<td>2%</td>
<td>0.2</td>
<td>( \pi^e_t = 1.6% + 0.2\pi^e_{t-1} + \varepsilon_{3,t} )</td>
<td>-10%..10%</td>
<td>Lowest value capped at -2%</td>
</tr>
<tr>
<td>Foreign Exchange Rate</td>
<td>n/a</td>
<td>n/a</td>
<td>( X_t = X_{t-1} \ast (1 + \varepsilon_{4,t}) )</td>
<td>-20%..20%</td>
<td></td>
</tr>
<tr>
<td>Short Term Nominal Interest Rate</td>
<td>3%</td>
<td>0.7</td>
<td>( i_t = 0.9% + 0.7i_{t-1} + \varepsilon_{5,t} )</td>
<td>-10%..10%</td>
<td>Possible value capped at the bottom at 0</td>
</tr>
<tr>
<td>Country Risk and Liquidity Premium</td>
<td>0</td>
<td>n/a</td>
<td>( CR_t = CR_{t-1} + \varepsilon_{6,t} )</td>
<td>-2%..2%</td>
<td></td>
</tr>
<tr>
<td>Real Long Term Interest Rate</td>
<td>3.75%</td>
<td>n/a</td>
<td>( R_t = 3.75% + CR_t )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal Long Term Interest Rate</td>
<td>5.75%</td>
<td></td>
<td>( I_t = R_t + \pi^e_t )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreign Exchange Rate Expectations</td>
<td>n/a</td>
<td>n/a</td>
<td>( X^e_t = 0.5(X_t + X_{t+1})(1 + \varepsilon_{7,t}) )</td>
<td>-10%..10%</td>
<td>See explanation in text</td>
</tr>
<tr>
<td>Budget Deficit</td>
<td></td>
<td></td>
<td>( B_t = 1.05% - 0.3 \ast GDPGrowth_t + \varepsilon_t )</td>
<td></td>
<td>See explanation in text</td>
</tr>
</tbody>
</table>

Notes:
2. The median of Bank of Israel's inflation target band.
3. Simplifying assumption used to generate values higher than the current low interest environment, which is unlikely to hold in the long run.
4. Based on Stein (2011)
5. Estimated using the least squares method on historical data.
6. Short term interest rates equal one year nominal spot rates.
7. Long term interest rates equal the coupon rate on bonds issued for the maximum term to maturity (in this analysis, 30 years).
The budget deficit is a periodical political decision affected by various factors which are impossible to predict. We assume that budgets are not directly dependent on previous period value, but are correlated with GDP growth levels and over the long run are kept at a sustainable level.

The general form of this equation is:

$$B_t = \alpha + \gamma GDPGrowth_t + \varepsilon_{9,t}$$

Where $\alpha$ is a constant set to generate a sustainable level over the long run, $\gamma$ is the anti-cyclical policy coefficient and $\varepsilon_{9,t}$ is a periodic shock. A sustainable deficit level is defined as one that keeps the debt/GDP ratio, on average, constant, which equals to:

$$B^* = LongTermGrowth \times \left( \frac{Debt}{GDP} \right)^*$$

Where $\left( \frac{Debt}{GDP} \right)^*$ is the long term debt to GDP target, equaling 60%.\(^{36}\)

The anti-cyclical policy coefficient $\gamma$ is estimated using a least squares method over historical data from 1991-2012, equaling (-0.3). The constant term $\alpha$ is calculated assuming absence of periodic shocks and therefor equals:

$$\alpha = B^* - \gamma LongTermGDPGrowth.$$

Using Israeli data, the final equation for the budget deficit equals.

$$B_t = 1.05\% - 0.3 \times GDPGrowth_t + \varepsilon_{9,t}$$

The periodic funding shock incorporates latent factors such as political considerations. We assume that these factors take the following distribution, which reflects a wider downside range but still maintains a mean of zero:

$$P[-2\% < \varepsilon_t < 0] = 0.5, \text{ Uniformly distributed}$$
$$P[0\% < \varepsilon_t < 1\%] = 0.475, \text{ Uniformly distributed}$$
$$P[1\% < \varepsilon_t < 20\%] = 0.025, \text{ Uniformly distributed}$$

Yield Curves

Yield curves represent the market interest rate that the issuer is required to pay, and therefore determine the coupon payment on the bonds. For simplicity the term structure of interest rates is modeled as a extrapolation between two stochastic variables: the short term interest rate and

\(^{36}\)This result is a simple mathematical transformation of the equation

$$\frac{Debt_t}{GDP_t} = \frac{Debt_{t-1} + B^*}{GDP_{t-1}(1 + \text{growth})} \text{ where } \frac{Debt_t}{GDP_t} = \frac{Debt_{t-1}}{GDP_{t-1}} = \frac{Debt^*}{GDP} = \text{ constant}$$

For example, for a long term debt/GDP target of 60% and long term real GDP growth of 3.5%, the long term average deficit should be sustained at 2.1% GDP.
the long term interest rate, similar to the approach taken in the Swedish model (Bergström, Holmlund and Lindberg, 2002). For simplicity the term structure of interest rates is assumed to be a linear extrapolation between two stochastic variables: the short term interest rate and the long term interest rate, similar to the approach taken in the Swedish model (Bergström, Holmlund and Lindberg, 2002). Later, it would be possible to adjust the yield curve model for example by adding a curvature factor as in Diebold and Lei (2006).

The nominal yield curve is a linear combination of the short term nominal interest rate (see table AP.2.1) and the long term nominal interest. The latter equals the real interest rate plus the periodic long term inflation expectations.

The real yield curve is a linear combination of the short term real interest rate and the long term real interest rate (see table AP.2.1). The former equals the short term nominal interest minus the current period inflation.

The foreign currency yield curve for the first year equals the nominal short term interest rate. For the third year and beyond it equals the nominal yield curve multiplied by the expected change in the exchange rate (i.e. nominal yield curve x long term exchange rate expectations / current exchange rate). For the second year it equals the nominal yield curve multiplied by half of the expected change in the exchange rate.

The VRI effective yield curve is the future materialized short term nominal interest rate plus a constant spread. Based on a non-arbitrage condition, this analysis assumes that the spread is equal to zero. Future modeling efforts could consider including a stochastic spread.

**Strategies**

Strategies in the model are a combination of basic preferences regarding type and maturity of bonds, as well as adaptive policies. These are explained in detail in the body of the monograph (see table 4.1).

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37 From a non-arbitrage perspective, nominal interest rates incorporate all the future expected changes in the short term interest rate, such that investors would be indifferent between investing in a nominal bond and an FRN. This could be proved easily by equating the present value of nominal bonds and FRNS, while substituting future one year forward rates at time m with 
\[
\frac{(1+r_m)^m}{(1+r_{m-1})^{m-1}} - 1.
\]
Appendix 3: Additional Results of the Steady State Analysis

Figure AP3.1: Average Annual Rollover and Costs of Candidate Strategies under a Base-case Scenario, second 30 years

Notes:
(1) The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).
(2) The Analysis above relates to the first 30 years of analysis. A figure for the second 30 years appears in Appendix 3, and provides a similar ranking of maturities, except for CPI-linked bonds which appear to have a higher ranking of costs across all maturities, especially for longer maturities. One reason for this difference is that a large portion of the costs of CPI-linked bonds is the indexation of the principal, which is paid only at the time of maturity.
(3) Rollover needs include only the nominal value of principal paid at maturity. Indexation of the principal is counted within costs, which include also the cash-value payment of the coupons.
Figure AP3.2: Distribution of Regret for Total Breaching of Liquidity Buffer of Initial Candidate Strategies, Steady State

Notes:

(1) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).

(2) Outcomes are calculated for the entire 30-year period.

(3) The box plots divide outcomes by quartiles, where the whisker covers the top quartile. The horizontal line between the dark and light grey rectangles represents the median value.

(4) The figure presents results for liquidity thresholds between 3% to 19% of GDP, by intervals of 2%.

(5) Colors of the points represent different maturity preferences, as reflected in the strategy notations.
Figure AP3.3: Distribution of Regret for Average Costs of Initial Candidate Strategies, Steady State

Notes:

(1) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N).
   The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).
(2) Outcomes are calculated on an annual basis.
(3) The box plots divide outcomes by quartiles, where the whisker covers the top quartile. The horizontal line between the dark and light grey rectangles represents the median value.
(4) Colors of the points represent different bond-type preferences, as reflected in the strategy notations.
Figure AP3.4: Distribution of Sum of Breaching of GDP-linked bonds vs. Alternatives, Steady State

Notes:
(1) All strategies have an equal weighted maturity policy (previously denoted “EQ”). Letters denote bond based strategies Variable Rate (V), CPI-Linked (C), Nominal (N) and GDP-Linked (G).
(2) Sum of total breaching is the sum of debt service costs and principal repayments beyond the threshold, summed over the period’s 30 years.
(3) Threshold levels range from 3% GDP to 23% GDP, with intervals of 2% GDP.
Figure AP3.5: Maximum Regret of GDP-linked Bonds vs. Alternatives, Steady State

Notes:
1. All strategies have an equal weighted maturity policy (previously denoted “EQ”). Letters denote bond based strategies: Variable Rate (V), CPI-Linked (C), Nominal (N) and GDP-Linked (G).
2. Total Breaching is the sum of debt service costs and principal repayments beyond the threshold, summed over the period’s 30 years.
Notes:
(1) The baseline strategy underlying all alternatives is “G-EQ”, one that issues 10% in GDP-Linked bonds, 67.5% into Nominal Bonds and 7.5% into CPI-linked, USD and VRI bonds.
(2) “Inflationary Caution” strategy is one that increases the issuance of CPI-linked bonds by 50% when annual inflation is less than 0%.
(3) “Recession Risk Aversion” strategy is one that increases the issuance of bonds with terms to maturity above 15 years by 50% when the annual deficit is larger than 5% GDP.
(4) Total Breaching is the sum of debt service costs and principal repayments beyond the threshold.
(5) Threshold levels range from 3% GDP to 23% GDP, with intervals of 2% GDP.
Appendix 4: Analysis using Median Regret and Maximum Value

Figure AP4.1: Maximum Total Breaching by Liquidity Buffer, Transition Period

Notes:
(1) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter, EQ, means that the strategy issues into different maturities equally.
(2) Total Breaching is the sum of debt service costs and principal repayments beyond the threshold, calculated over the period's 30 years.
Figure AP4.2: Median Regret of Total Breaching by Liquidity Buffer, Transition Period

Notes:

(1) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N). The second letter, EQ, means that the strategy issues into different maturities equally.

(2) Total Breaching is the sum of debt service costs and principal repayments beyond the threshold, calculated over the period’s 30 years.
Appendix 5: Additional Figures

Figure AP5.1: Distribution of Regret of Average Costs, Transition Period, Sorted by Median Regret

Notes:
(1) This figure replicates Figure 4.3, sorting strategies by median regret.
(2) Strategies are denoted as a combination of bond and maturity basic preferences. The first letter on each label denotes the bond-type strategy: Variable Rate (V), CPI-Linked (C), Equally Allocated (EQ), USD-Dollar (U) or Nominal (N).
   The second letter on each label denotes the maturity-type strategy: Short-Term (S), Benchmark-Focused (B), Equally Allocated (EQ), Long-Term (L).
(3) Outcomes are calculated on an annual basis.
(4) The box plots divide outcomes by quartiles, where the whisker covers the top quartile. The horizontal line between the dark and light grey rectangles represents the median value.
(5) Colors of the points represent different bond-type preferences, as reflected in the strategy notations.
References


