CHAPTER 1

Hedging Potential Liabilities of Foreign Reserves Through Asset Allocation

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1.1 Introduction

The purpose of this chapter is to explore further the topic of asset-liability management (ALM) for foreign reserves. Although several central banks use ALM to determine the asset allocation of the foreign reserves, mostly they do so in order to cover defined liabilities such as government or central bank debt. However, most countries hold foreign reserves as a buffer for a substantial shock to the balance of payments, which includes private and public sector flows. For instance, foreign reserves may help reduce the impact of large, potentially disruptive portfolio outflows from the equity and bond market on the rest of the economy. Therefore, in our opinion, ALM for foreign reserves should take into consideration all of the relevant macroeconomic vulnerabilities that might affect the balance of payments.

This chapter proposes an approach to quantify and to hedge those liabilities, using data from Colombia as an illustration. The chapter seeks to contribute to the ALM discussion by defining the liabilities of foreign

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reserves and their volatility, not only to determine the size of the liquidity tranche but also to find the portfolio that most appropriately hedges those liabilities. As a result, both the currency composition and the allocation of the portfolio across different asset classes depend on their ability to hedge the unique liabilities of each country. In the same fashion as Bonza et al. (2010) and Alhumaidah (2015), this chapter proposes a two-tranche approach. For the asset-liability tranche, a country-specific reserve adequacy measure is used to proxy for the liabilities of reserves, and the objective of portfolio construction is to hedge those liabilities. Hence, the size of the asset-liability tranche should be roughly the same as that of the liabilities. For the long-term investment tranche, whose size is determined by the excess of total reserves over liabilities, a traditional asset-only approach aims for wealth maximization, given that the likelihood of liquidating this tranche in the short term is theoretically low.

The next section summarizes relevant literature on ALM for international reserves portfolios. The third section reviews the work on reserve optimality and reserve adequacy and explains in detail the measure chosen to quantify the liabilities of foreign reserves. The fourth section explains the methodology and the fifth section describes the data and the sources. The sixth section shows the results. The seventh section concludes.

1.2 Asset-Liability Management in International Reserves Portfolios

The last two decades have seen a growing trend in international reserve accumulation in most countries around the world (Berkelaar et al. 2010), which has caused a great interest in strategic asset allocation (SAA) for international reserve portfolios, considering that SAA is the main source of return and risk for any kind of portfolio (Brinson et al. 1986).

There are two widely-used approaches to asset allocation: asset-only optimization (AO) and ALM. In the former, the purpose is to obtain the highest possible return for an acceptable level of risk, regardless of the liabilities (outflows of future money, both expected and unexpected, if they exist). By contrast, the ALM approach explicitly takes into account future cash flows or obligations and constructs portfolios that reduce the volatility of the difference between the present value of the liabilities and that of the assets.

Cash flow matching is the most traditional and conservative ALM methodology (Fabozzi 2007). It attempts to match liability cash flows with coupon and principal payments of fixed income assets in the portfolio. Risk matching or immunization is the other traditional ALM methodology. Its objective is to match the interest rate and liquidity risks of liabilities with those of the assets. Immunization outperforms cash flow matching when it is not possible to find assets in the financial market that pay cash flows identical to those of the liabilities.

The ALM approach is extensively used in defined-benefit pension plans, whose objective is to cover future pension cash flows through contributions and returns from the pension portfolio and to maximize the surplus once the projected liabilities are funded. Banks also apply ALM to construct a portfolio that replicates the duration of their liabilities.

In the case of foreign reserves management, the choice between AO and ALM depends on the specific objective of the central bank. When a central bank has a broad mandate such as reducing the probability of occurrence of balance of payments crises or when the liabilities are difficult to estimate, the AO approach is preferred. On the other hand, when the central bank has well-defined liabilities that it wants to hedge, for instance, government or central bank debt, the preferred approach is ALM.

In recent years, there have been a number of studies applying ALM to the construction of foreign reserve benchmarks and an increasing number of countries have adopted this approach. In the case of Canada (Rivadeneyra et al. 2013), international reserves are managed using an ALM framework that requires currency and duration matching of international reserves and foreign currency liabilities issued. The model jointly optimizes the mix of assets and liabilities across currencies, instruments, and tenors that maximize the return of the portfolio subject to duration and currency matching. Canada's foreign exchange reserves are financed by the federal government. Further, the primary objective of foreign reserves in Canada is to help to promote orderly conditions for the Canadian dollar in currency exchange markets and provide foreign currency liquidity to the government. Thus, the appropriate liability is defined by the debt instruments issued to finance the reserves account. As a result, applicability of the ALM approach is straightforward.

According to Bhattacharya et al. (2010), the Reserve Bank of India incorporates an ALM model that consists of a balance sheet for each currency separately, allowing for currency transfers and incorporating transaction costs. The market prices of the assets come from a dynamic stochastic optimization model with a tree-based uncertainty structure, where the central bank can hold or sell the assets in any future rebalancing period. The model also incorporates the liabilities and risk preferences of the central bank as Conditional Value-at-Risk (CVaR) constraints. The liabilities are factored into the optimization problem by including (1) a lower limit on the size of reserves, (2) a lower limit on the ratio of Net Foreign Assets (NFA) to the sum of NFA and Net Domestic Assets (NDA), (3) an upper limit on the percentage fall in value of reserves in any period, (4) a lower bound on the expected mark-to-market value of reserves, (5) an upper limit on the Liquidity at Risk[1] of the assets, (6) a constraint that foreign currency assets should exceed the amortization of external debt over the next 12 months (Greenspan-Guidotti rule), and (7) a constraint that the ratio of short-term external debt to reserves should not exceed a pre-set level.

For the Latin American case, Bonza et al. (2010) approach SAA by balancing short-term liquidity needs and real capital preservation for central banks, considering robust optimization techniques. A contingent claim analysis is used to estimate short-term liquidity needs. They also estimate a distance-to-liquidity-crisis indicator. The SAA attempts to preserve real capital, assuming that reserve requirements will grow at the same rate as real GDP. Under this proposal, the investment objective of excess liquidity reserves is to obtain a real return equal to the growth rate of real GDP, considering that the estimated probability of a liquidity event is quite low.

Alhumaidah (2015) proposes the standard two-tranche approach for reserve management for the Saudi Central Bank, which separates the portfolio into liquidity and investment tranches. He defines the level of the liquidity tranche as the equivalent of predicted reserve outflows, exogenously derived from a forecasting equation. The proposal allocates excess reserves to an investment tranche, which is managed with the objective of maximizing a utility function that incorporates the amount and likelihood of stochastic outflows as a liability, while also allowing for variable trade sizes by specifying that liquidation costs grow in a non-linear way. Although this chapter takes into account the liability by including the liquidation costs in the investment tranche's utility function, its aim is not directly to hedge potential outflows through asset allocation.

1.3 Measuring Reserve Adequacy

The liquidity required during periods of balance of payments crises represents the potential liabilities of foreign reserves. Academic approaches on the liquidity needs of central banks have had two methodological perspectives: the optimal level of reserves and the indicators of reserve adequacy.

Calculating an optimal level of reserves requires a cost-benefit analysis. Among the benefits of maintaining international reserves is the reduction in the probability of an external crisis, which is costly due to foregone production or consumption. In this sense, an optimal level of reserves makes the economy more stable and less vulnerable to external crises (Gerencia Técnica 2012). On the other hand, there is an opportunity cost of holding foreign reserves, which comes from the fact that they are invested in low-risk liquid assets which have a lower expected return than other alternatives such as developing local infrastructure or, in the case of emerging markets, paying down external debt. The models used to determine the optimal level of international reserves have followed this sort of analysis since the pioneering work of Heller (1966). Ben-Bassat and Gottlieb (1992) formulated a model where international reserves reduce the probability of a balance of payments or a currency crisis. In this framework, the level of international reserves is optimal when the accumulation of additional foreign currency reduces the expected cost to a lesser extent than the opportunity cost incurred to hold them. Jeanne (2007) and Calvo et al. (2013) have proposed the most recent methodologies on optimal levels of reserves. Jeanne proposes a model for a small open economy, where a sudden stop prevents access to international financing to meet payments on foreign debt. International reserves mitigate the negative impact on output and stabilize the consumption pattern of households. Meanwhile, Calvo et al. (2013) propose a similar model to that of Ben-Bassat and Gottlieb (1992), including the possibility that reserves can reduce both the likelihood of a foreign crisis and its cost.

Despite their enormous contribution to the academic literature, the application of optimal reserves models has several limitations (García-Pulgarín et al. 2015). The most obvious are the sensitivity of the results to small changes in the parameters and the assumption of constant external liabilities. These limitations undermine the utility of optimal reserves models to guide policymaking (Gerencia Técnica 2012).

Unlike the optimal reserves approach, reserve adequacy measures seek to determine an appropriate level of reserves, using several macroeconomic variables that might explain the outflows of the balance of payments during a crisis. The International Monetary Fund (IMF) was the first to conduct a study on reserve adequacy (International Monetary Fund 1953). The IMF staff argued that reserve adequacy was not a matter of a simple arithmetical relationship but rather that it depended on the efficiency of the international credit system, the realism of the existing pattern of exchange rates, the appropriateness of monetary and fiscal policies, the policy objectives, and the stage of development of countries. Five years later, the IMF (1958) proposed a less qualitative approach, arguing that reserves should be compared with a country's trade figures, as foreign trade was the largest item in the balance of payments. The data analysis showed that countries in general appeared to achieve annual reserve-to-imports ratios between 30 and 50%. This ratio was a preliminary indicator of adequacy. Triffin (1961) criticized this minimum benchmark (30% or 4 months of imports), arguing that it would be too low given the specific economic circumstances of countries. Triffin found that the ratio of monetary gold to imports in 1957 was the same as it was in 1913 and 1928 but, at 35–36%, this ratio was low relative to historical standards. From an examination of the distribution of the ratio between reserves and imports across countries and over time, Triffin (1961) concluded that a 40% reserve-to-import ratio could be deemed adequate for the stability of the balance of payments.

In a similar way, Greenspan (1999) cites the proposal of Pablo Guidotti, the then-Deputy Finance Minister of Argentina, who suggested that countries should manage their external assets and liabilities in such a way that they are always able to live without new foreign borrowing for up to one year. That is, usable foreign exchange reserves should exceed scheduled amortizations of foreign currency debts during the following year. This is the famous Guidotti-Greenspan rule, which states that a country's reserves should equal short-term external debt, implying a ratio of reserves to short-term debt (STD) of one. The rationale is that countries should have enough reserves to resist a massive withdrawal of short-term foreign capital.

Since these measures of reserve adequacy are unaffected by a set of strong assumptions, they become a reliable and robust indicator (García-Pulgarín et al. 2015) and therefore they are preferred by central banks for the design of economic policy (Gerencia Técnica 2012). Despite their advantages, the most important challenge raised by standard reserve adequacy measures is that an adequate level of reserves depends on rules of thumb (e.g., one in the Guidotti-Greenspan measure) and not necessarily on the particular characteristics and vulnerabilities of each country.

The IMF (2011), aware of the limitations of optimality models and the issues that arise when considering isolated indicators of reserves based on individual metrics (e.g., GDP or M2), proposed a methodology that identified four sources of vulnerability for the balance of payments. First, exports could diminish severely due to an unexpected drop in foreign demand or due to a negative terms-of-trade shock. Second, a reduction in external financing may hinder debt roll over. Third, foreign investors might retreat from domestic capital markets. Finally, there might be unforeseen domestic capital outflows from residents.

Having determined the sources of risk and vulnerability of the balance of payments, the IMF takes four variables to quantify each of those risks: exports, STD, portfolio liabilities (net international investment position minus foreign direct investment and STD), and money supply. The IMF (2015a, b) estimates a formula that takes into account all of these variables and their relative importance. To this end, they calculate the distributions of changes in each variable in periods of stress in the foreign exchange market. To identify these periods, the IMF used the methodology proposed by Eichengreen et al. (1996). The adequate level of reserves is the sum of the tenth-percentile drop in each variable over periods of stress. The IMF estimates two standard formulas whose application depends on the exchange rate regime of each country (fixed or flexible).

Gomez-Restrepo and Rojas-Bohorquez (2013) acknowledge the merits of the IMF methodology but argue that using standard weights for all countries may not accurately capture the importance of each variable for any specific country. For instance, countries that depend heavily on foreign trade and have a relatively closed capital account may need to place a higher weight on exports than on portfolio liabilities. The authors estimate the weights of the specific variables using Colombian data and find that the optimal weights for Colombia are different from those under the standard IMF formula.

García-Pulgarín et al. (2015) improve the country-specific approached proposed by Gomez-Restrepo and Rojas-Bohorquez (2013), taking into account the correlations between the variables in the formula. They incorporate the calculation of implied correlations among the variables considered, which typically results in a less conservative measure, since the worst-case scenario of each variable does not materialize simultaneously in a period of pressure in the foreign exchange market. In addition, García-Pulgarín et al. (2015) discuss some changes that could enhance the calculation of the metric. First, they replace M2 by M3, since it is a broader monetary aggregate that includes information that M2 might not capture, such as increase the risk of a bank run. Second, the authors include foreign direct investment as an additional variable because those inflows might suffer in the middle of an external crisis. Finally, they consider the dependence on remittances of some Latin American economies and include this variable to improve the calculation of the metric for the Colombian case. This methodology is explained below in more detail.

The first step is to calculate the index of pressures in the foreign exchange market according to the methodology proposed by Eichengreen et al. (1996). Accordingly, the changes of the following variables during periods of pressure in the foreign exchange market are calculated: STD, other portfolio liabilities (OPL), M3, exports (X), foreign direct investment (FDI), and remittances. The percentage of each variable that could be needed during periods of stress is estimated according to the following equation:

$$\omega_t = \left[\rho_{jt}\right] * \frac{1}{\sum_{j=1}^{6} \rho_{jt}} \tag{1.1}$$

where ω_t is the vector with the percentage of each variable that could be needed in times of crisis at time t, where ρ_{jt} is the value of each variable j. $j = 1$ corresponds to STD, $j = 2$ to OPL, $j = 3$ to X, $j = 4$ to M3, $j = 5$ to FDI and $j = 6$ to remittances.

With this, a product of the associated vectors to the percentage of each variable and the percentage changes in each variable during periods of market pressure (MP) is computed (this is done for each period considering the same sample periods of pressure), as shown below:

$$\%NARI_t = MP * \omega_t^T \tag{1.2}$$

$\%NARI_t$ is the ratio of adequate international reserves to total reserves for period t. After this, the percentiles for each period (of the resulting set product vectors) are calculated, and then multiplied by the aggregate level of the variables for each period:

$$NARI_t = P_{(10,5,1)}\left\{\%NARI_t\right\} * \sum_{j=1}^{6} \rho_{jt} \tag{1.3}$$

$NARI_t$ represents the adequate level of reserves. This methodology takes into account the implicit correlations between the variables in periods of pressure, making it less conservative compared to the IMF methodology (which is of linear combination of the value of each variable needed in times of stress).

In this chapter, the contingent liabilities of foreign reserves are defined through the reserve adequacy measure, proposed by García-Pulgarín et al. (2015). This measure defines the liquidity that a central bank should hold against possible shocks that affect the outflows of the balance of payments. Additionally, based on historical information, it is possible to estimate the past behavior of this measure and, more importantly for the purpose of this chapter, its volatility.

It is worthwhile to notice that the required level of foreign reserves changes over time. Factors such as financial development, greater access to capital markets, a greater degree of openness of the capital account, and growth of world trade have resulted in higher reserve requirements, reaching annual growth rates above 12%. From an ALM perspective, it is not possible to construct a portfolio that achieves that level of return consistently. As shown in Fig. 1.1, most traditional asset classes have returns lower than 12% in the long term. Consequently, the asset-liability exercise in this chapter focuses on the variability of the potential liabilities and not

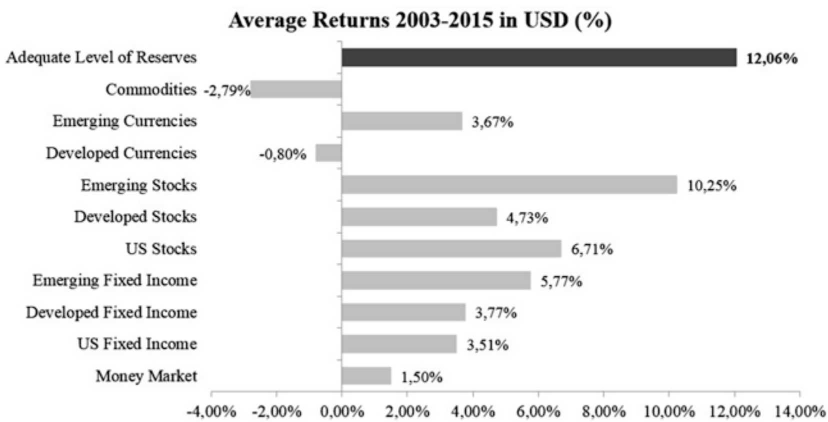

Fig. 1.1 Average annual growth of adequate level of reserves and returns of various asset classes

on their absolute level. When SAA is not sufficient to cope with increases in the level of the liabilities, it is necessary to accumulate foreign reserves, for example, by intervening in the domestic foreign exchange market, or by liquidating part of the long-term investment tranche. Building an optimal intervention rule that is consistent with the asset allocation of the portfolio is beyond the scope of this chapter.

1.4 Methodology

In order to determine the asset allocation that is most appropriate to hedge the liabilities of foreign reserves, it is important to understand what explains the behavior of the liability. Therefore, the first step in this process is to use a multi-factor risk model in order to identify the systematic factors that explain the liability. Although it is possible to work directly with asset classes in order to find the asset allocation that approximates most closely the behavior of the liability, the use of a multi-factor risk model allows the identification of the most important themes or macro variables that need to be considered when building a portfolio under this approach.

The multi-factor risk model used for fixed income is Wilshire's Axiom. This model provides historical factor returns for yield curve movements, sector allocations, inflation, and currency, among others, in the most important fixed income markets. The Appendix shows the list of factors from Axiom used in this analysis. For equity and commodity, some widely used indices are included. Through cross-sectional regression, it is possible to identify the factors with the best explanatory power.

Once the most relevant market factors are identified, the asset classes to construct the portfolio are chosen. For factors with positive coefficients, the related asset classes are included. Conversely, for factors with negative or non-significant coefficients, the related asset classes are excluded.

With the choice of eligible asset classes, portfolio construction is possible through the minimization of the squared error of the difference between the liabilities and the portfolio. Thus, portfolio construction attempts to find a linear relationship between the liabilities and various asset classes. Two portfolio alternatives were evaluated, unrestricted, and restricted. The former alternative permits a portfolio with leverage and short exposures. The latter intends to find a portfolio that is both investible and liquid. For both of them, a n asset and T periods system was used.

Year-on-year changes of liabilities and annual returns were used. The problem to solve is to find a coefficient vector w, such that:

$$\min \sum_{t=12}^{T} \left(r_t^L - \sum_{i=1}^{n} w_i r_t^i \right)^2 \tag{1.4}$$

Subject to:

$$\sum_{i=1}^{n} w_i = 1 \quad i = 1, \dots, n \tag{1.5}$$

where r_t^L refers to annual factor returns at period t. The solution to this problem is a coefficient vector w. Under this approach, each coefficient w_i represents the weight for asset class i in the portfolio. Equation 1.5 ensures that the entire portfolio is fully invested.

Without additional restrictions, the solutions to the problem are able to take any value in $\mathbb{R}$. A value above one for one asset class in vector w requires leverage either through derivatives or short exposures in other asset classes. By contrast, a negative value for a specific allocation implies a short position either through derivatives or by borrowing and selling the securities. Although both leverage and short positions can in theory contribute to replicate better the volatility of the liabilities, it may be infeasible to do so, because of either the non-existence of certain derivatives or the unwillingness of counterparties to trade in the amounts required, particularly considering the average size of international reserves portfolios. Moreover, it is important to note that some asset classes might be relatively illiquid for large allocations, which requires the inclusion of a liquidity constraint in order to make the portfolio investible. Thus, the second portfolio alternative evaluated includes the following restrictions, where c_j is the maximum allocation to currency j:

$$0 \leq w_i \leq 1 \qquad \forall i \in [1, n] \tag{1.6}$$

$$\sum_{k=1}^{n_j} w_k^j \leq c_j \qquad \forall j \in [1, m] \tag{1.7}$$

Here, n_j represents the number of assets in currency j included in the exercise, superscript j in the coefficient characterizes each currency, and m denotes the number currencies included. Equation 1.7 is the liquidity constraint, which imposes an upper limit on the participation of the portfolio in the government fixed income assets of currency j. For this chapter, the maximum participation allowed in the government fixed income market of any given currency is 3%, since it may be difficult to liquidate a larger allocation in a short period. The government fixed income market was used to proxy for total liquidity in a given currency, considering that it is the largest asset class available in most cases.

For the long-term investment tranche, which represents the tranche of the portfolio that aims to maximize returns, asset-only optimization is a convenient choice. The optimization allows for a broader range of asset classes and a longer investment horizon. García-Pulgarín et al. (2015) developed a methodology to create the benchmark of the long-term investment tranche. The methodological approach follows the Black and Litterman (1991) framework with enhancements in the estimation of the covariance matrix.

The main purpose of the optimization of the long-term tranche is to maximize a utility function that considers the first two moments of each portfolio return distribution, as well as the specific risk aversion of the investor. García-Pulgarín et al. (2015) allow a broad asset space, representing most of the market, which provides a good estimate of Black-Litterman equilibrium returns. Besides, they define a non-linear constraint, which restricts the portfolios within the efficient frontier to those that do not result in losses with a 95% confidence level in a time horizon of ten years, which corresponds to the approximate period in which a crisis event happens, assuming a time homogeneous Poisson process and a sudden stop probability of 10%.

1.5 Data Description

As described in Sect. 1.2, the variables used to estimate the liquidity needs of international reserves are M3, exports, STD, OPL, FDI, and remittances. The goes back to December 2003. Data periodicity is monthly and the variables are denominated in US dollars. The data source for the chosen Colombian macroeconomic variables is Banco de la Republica.

The source of factor returns for fixed income and currency is Axiom (Wilshire Associates). For equity and commodity indices, the source is Bloomberg.

The assets classes evaluated for portfolio construction were:

1. Government bonds from one to ten years from the United States, Germany, the United Kingdom, Switzerland, Sweden, Canada, Japan, Australia, New Zealand, and Norway. A bond index of other developed countries is also included.

2. Inflation-linked government bonds from one to ten years from the United States, Germany, and the United Kingdom.
3. Corporate bonds from one to ten years in the United States and Europe.
4. Supranational bonds of developed markets from one to ten years.
5. US mortgage-backed securities.
6. Equities from the United States, from developed countries excluding the United States, and from emerging markets.
7. The following currencies: Euro, British Pound, Swiss Franc, Swedish Krona, Canadian Dollar, Japanese Yen, Australian Dollar, and New Zealand Dollar.

The returns of fixed income assets are obtained from the Intercontinental Exchange (ICE) Data Indices. Data on the returns of stocks and currencies are obtained from Bloomberg. All of the series start in December 2003 and end in December 2015, since all the data necessary to estimate the liabilities are only available from the last month of 2003 onwards. Price and return data of the selected assets are denominated in US dollars, because the liability is also denominated in that currency as intervention from central bank of Colombia is always made in US dollars.

1.6 Estimation and Results

Figure 1.2 shows the set of factors from Axiom's multi-factor model that best explains the liabilities of Colombia's foreign reserves.

The factors with the highest positive coefficients are European corporate and duration in Australia and in the United States. It is important to remember that, since we are dealing with factors and not with asset classes, in the case of the European corporate factor, it is necessary to hold exposure to this type of debt isolated from European duration, which it may be difficult to implement in practice. In the case of the exposure to United States duration, it shows that interest rates in the United States move in the opposite direction of the liabilities. One possible explanation of this observation is that increases in interest rates in the United States cause outflows from emerging markets, which could cause decreases in monetary aggregates such as M3 or OPL, thus decreasing the reserve adequacy measure used in this chapter. This finding is consistent with the high participation of US Treasuries in foreign reserves portfolios.

Additionally, in order to hedge the liability better, it would be necessary to take short positions in duration in Japan and Switzerland and in inflation

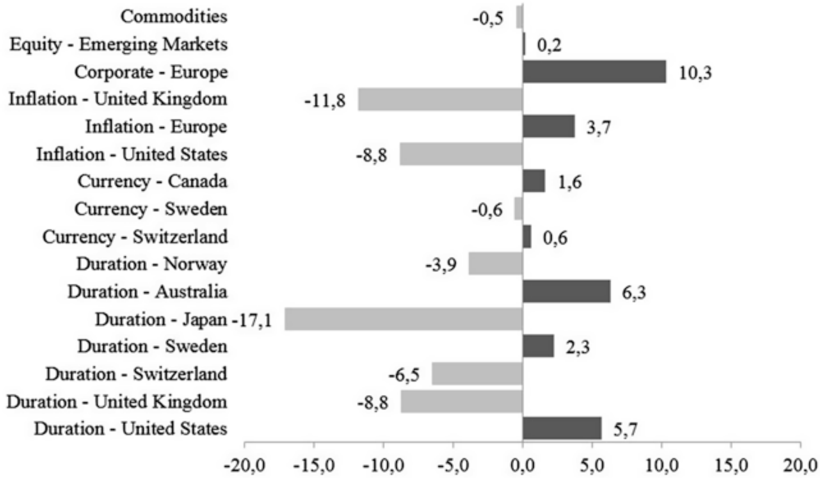

Fig. 1.2 Explanatory factors for the liability (reserve adequacy measure)

in the United Kingdom and in the United States. Although it may be difficult to implement short positions in those markets, particularly in the case of the inflation factors, the results indicate that certain traditional reserve assets may not be the best choice for the investment of foreign reserves of certain countries, once its correlation with the liabilities is considered.

One limitation of the current approach is that it is not possible to understand all of the reasons that explain the positive and negative relationships between the liabilities and the market factors, which should be the subject of further study. Notwithstanding, the factor analysis of the liabilities allows the identification of asset classes that are related to foreign reserves from an ALM perspective.

Figure 1.3 shows a comparison between the liabilities (reserve adequacy measure) and the combination of factors shown in Fig. 1.2. Both series have a similar behavior, with a 68% coefficient of determination.

Although the information on the most relevant market factors helps in portfolio construction, it is difficult to come up with an investible portfolio that has exposures to the factors matching those in presented in Fig. 1.2. Nonetheless, the information obtained from the exposure to factors is useful to narrow the universe of eligible assets to those that best explain the behavior of the appropriate level of reserves.

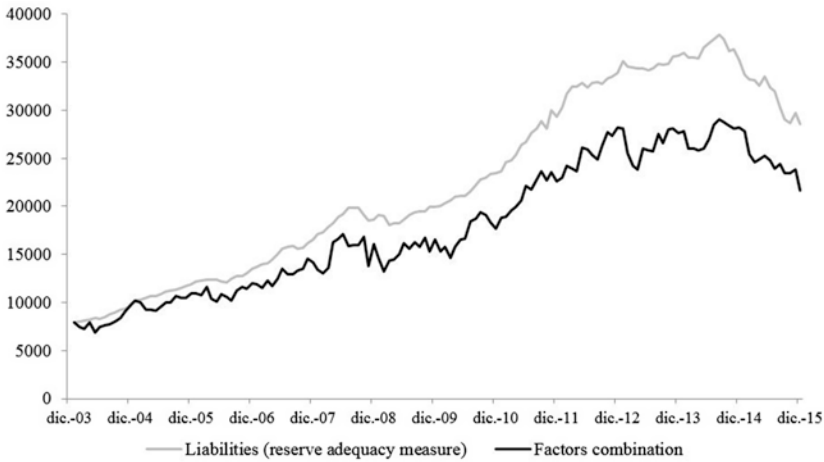

Fig. 1.3 Liabilities (reserve adequacy measure) and combination of factors with highest explanatory power (in US dollars million)

Figure 1.4 shows the unrestricted portfolio that minimizes the squared error of the difference between the liability and the portfolio; in other words, it is the solution to Eqs. 1.4 and 1.5. Ten asset classes are significant in the model with a 72% R^2. The asset with largest allocation in the portfolio is US mortgage-backed securities with 242% of the portfolio invested and the asset with the most negative allocation is US corporate bonds, with −391%.

There are five asset classes with an allocation over 100% in this portfolio and there are six asset classes with negative allocations. Figure 1.5 shows the currency allocation of the unrestricted portfolio. The largest allocation (271%) is to the US dollar and the most negative allocation is to the Australian dollar (−87%). This unrestricted portfolio has such large requirements in terms of leverage and short exposures that it is infeasible for a foreign reserve portfolio worth billions of dollars.

In order to obtain an investible portfolio, the restrictions in Eqs. 1.6 and 1.7 maintain the allocation to any asset class in a range from 0% to 100% and avoid concentrations in relatively illiquid currencies. Figure 1.6 presents the asset allocation of the investable portfolio, which invests mostly in government bonds of the United States, Canada, and Australia. Nonetheless, it is a portfolio with a high level of diversification, considering that there are various instruments and countries in the rest of the portfolio.

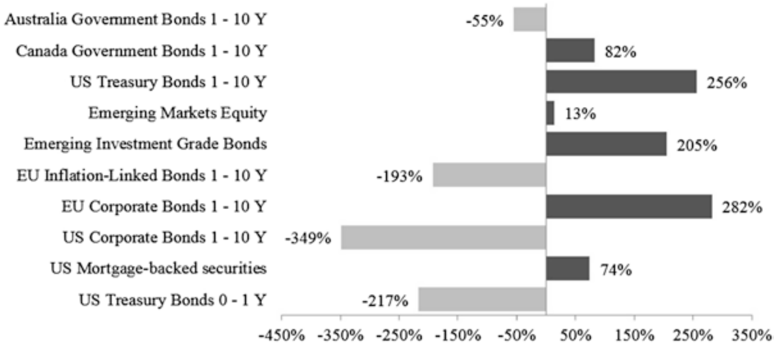

Fig. 1.4 Unrestricted portfolio

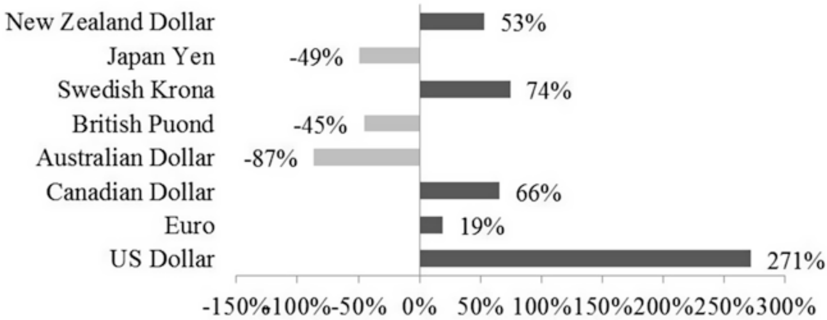

Fig. 1.5 Currency composition of unrestricted portfolio

Figure 1.7 shows the currency composition and the sector allocation of the investable portfolio. This portfolio includes 11 asset classes in three different sectors, denominated in seven different currencies. Despite this, the portfolio has high concentration in government fixed income securities, which results in low market risk (Fig. 1.7b). Finally, the portfolio achieves the objectives set out, as shown by the fact that the correlation between the investible portfolio and the liabilities is 0.73.

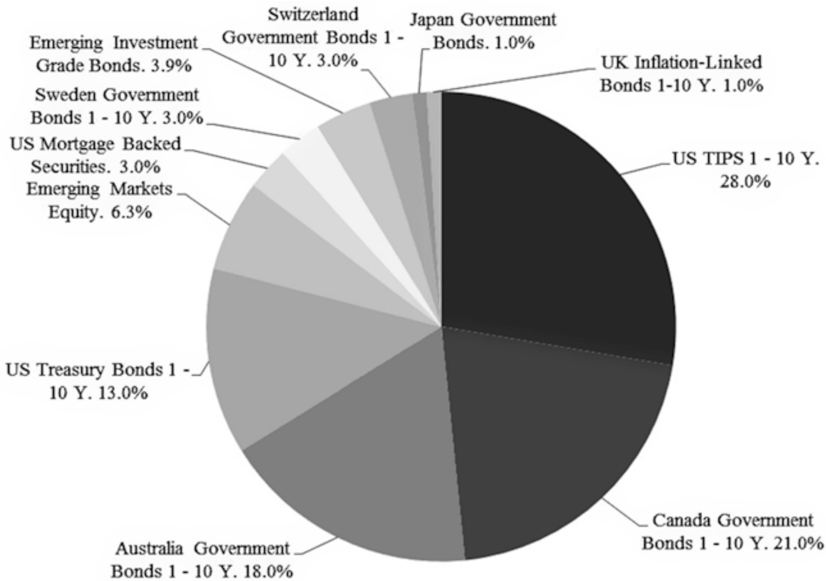

Fig. 1.6 Investable portfolio asset allocation

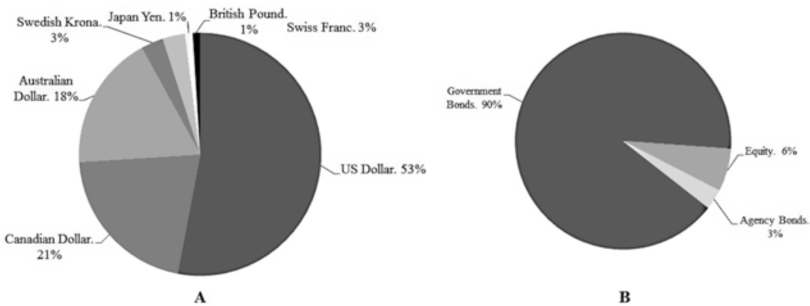

Fig. 1.7 Investable portfolio currency composition (a) and sector allocation (b)

Figure 1.8 shows the portfolio's risk and return in the mean-variance space in comparison with the efficient frontier obtained from an asset-only optimization using the same asset classes. As shown in Fig. 1.8, the ALM asset allocation is not risk-efficient from an AO perspective since the portfolio

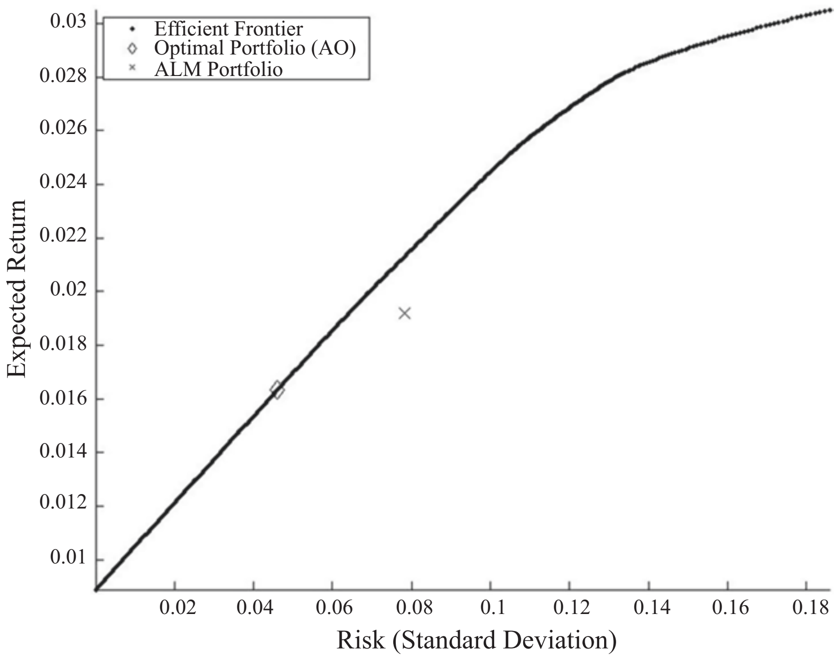

Fig. 1.8 ALM portfolio versus asset-only efficient frontier

Table 1.1 Descriptive statistics of the deviations of each portfolio returns from the adequacy level of reserves

	ALM portfolio	*Optimal portfolio (AO)*
Mean	0.43%	0.58%
Standard deviation	1.80%	2.50%
Maximum	5.21%	9.36%

Source: Authors' estimates

is located under the efficient frontier. This sub-optimality may be interpreted as the cost of meeting the objective of holding foreign reserves. As the statistics in Table 1.1 show, the ALM portfolio's annual returns deviate less from the annual variation of the liability (adequacy level of international reserves) than those obtained from the asset-only optimal portfolio.

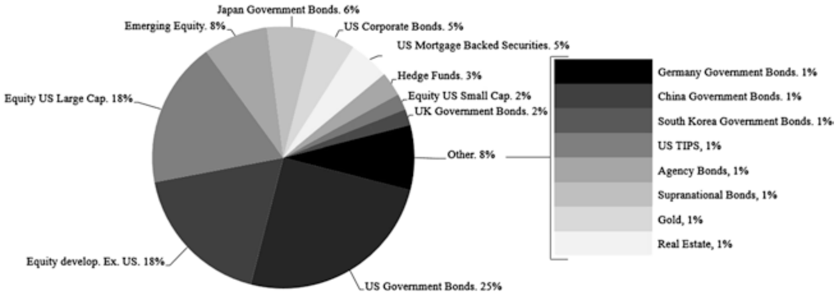

Fig. 1.9 Long-term investment tranche asset allocation

Figure 1.9 presents the asset allocation of the long-term investment tranche constructed with the García-Pulgarín et al. (2015) methodology. The portfolio is allocated mostly to US Treasuries and global equity. The portfolio has high diversification, considering its allocation in different instruments and countries, and it is more diversified in terms of sector allocation than the asset-liability tranche.

The portfolio in Fig. 1.9 does not have significant restrictions in terms of asset classes. For an implementation phase, a central bank should consider its operational, legal, risk aversion, and knowledge constraints before deciding what kind of assets and particular constraints are included in the portfolio construction.

1.7 Concluding Remarks

This document presents a methodology for the SAA of foreign reserves that takes into account the liabilities of each country. Since foreign reserves are a buffer for the entire economy and not only for the government or the central bank, the definition of liabilities is broad in order to encompass the possible sources of reserve requirements facing a balance of payments crisis.

A reserve adequacy measure proposed in García-Pulgarín et al. (2015) was used to estimate the liabilities. Unlike most standard reserve adequacy measures that are based on rules of thumb, the metric used takes into account all of the possible vulnerabilities of the balance of payments and the specific characteristics of each country.

After estimating the liabilities, a multi-factor analysis allows a better understanding of how to build an ALM portfolio. That analysis identifies which asset classes are the most appropriate to replicate the liabilities. Further restrictions were included, in order to obtain an investible and liquid portfolio.

This chapter presents a preliminary approach to enhance the role of foreign reserves to prevent and to confront external crisis, and therefore does not address certain issues that require further analysis. First, it would be desirable to have a better understanding of the relationship between liabilities, risk factors, and asset classes. Although the methodology achieves the goal of building a portfolio whose return hews closely to that of the liabilities, adjusting this portfolio over time requires an understanding of the relationships between all of the vulnerabilities of the balance of payments and each of the asset classes that are either excluded from (or included in) the final portfolio. Second, considering that certain relationships might change over time, it would be interesting to include a dynamic approach that allows for varying correlations and take into account the time-varying probability of interventions. Third, it is desirable to build larger samples of the macroeconomic variables used in the reserve adequacy measure so that it is possible to estimate a more robust indicator and include forward-looking estimations of assets and liabilities. Finally, it would be interesting to find out whether there are non-linear relationships between the liabilities and the asset classes or whether it is possible to use non-parametric estimators that are insensitive to outliers, in order to find portfolios with a better fit.

Additionally, there also remain challenges from an institutional perspective. Asset-only portfolio construction and ALM with a clearly defined set of liabilities, such as government debt, are more straightforward for policy makers from an accountability perspective. When a central bank considers a broader definition of liabilities, it may be more difficult to explain whether it has met the investment objectives. Moreover, ALM is easier to implement when assets and liabilities are in the same balance sheet. With the approach proposed here, the assets remain in the central bank balance sheet but the liabilities do not. Therefore, a central bank reports accounting losses where there is an absolute decrease in both assets and liabilities. As a result, this approach requires that policy makers take full ownership of the objectives and disclose them sufficiently.

Appendix: Selected Factors from Wilshire's Axiom Used to Explain Reserves Liabilities

Factor	*Country*
Duration	United States
	Europe
	United Kingdom
	Switzerland
	Sweden
	Canada
	Japan
	Australia
	New Zealand
	Norway
	Emerging Markets Investment Grade
Currency	Europe
	United Kingdom
	Switzerland
	Sweden
	Canada
	Japan
	Australia
	New Zealand
	Norway
Inflation	United States
	Europe
	United Kingdom
Corporate	United States
	Europe
Mortgages	United States
Supranational	All the World
Equity	United States
	Developed excluding United States
	Emerging Markets
Commodities	All the World

Note

1. A Liquidity at Risk rule takes into account the foreseeable risks that a country can face. This approach requires that a country's foreign exchange liquidity requirement can be calculated under a range of possible outcomes for relevant financial variables such as exchange rates, commodity prices, credit spreads.

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