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By Roland Beck[1] and Sebastian Weber[2]

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Abstract

The notable increase in international reserve holdings over the past decade and their use during the global financial crisis of 2008/2009 has sparked renewed interest in the analysis of the optimal level of reserve holdings, in particular in countries which are subject to sudden stops. Less attention has been given to the optimal composition of reserves and even less to the joint determination of level and composition. In light of current developments, we show that despite the common belief that higher reserve levels should go along with higher diversification to minimize the opportunity costs from holding reserves, the opposite may even be true. It depends on the factors that stand behind the increase in reserves whether increased diversification is optimal or not. We estimate for a panel of 20 countries the determinants of the currency composition of reserves and show how it is affected by the different motives of reserve accumulation. In line with the recent literature on reserve levels we find that reserve accumulation is primarily driven by precautionary motives, which in turn underpins the allocation of reserves to safe assets. While we find primarily evidence of the allocation being a function of precautionary motives, we also find some weak evidence for reserve accumulation to lead to more diversified portfolios if reserve accumulation is driven by other factors than precautionary motives.

Keywords: Reserve Accumulation, Currency Composition, Precautionary Motives
JEL Classification: F31, F33, E42, G11

Non-Technical Summary

The notable increase of foreign exchange reserve holdings by emerging market central banks –which was only temporarily interrupted during the 2008/09 crisis – has triggered a debate on whether central bank reserve portfolios should be more diversified across currencies and asset classes. Traditionally, central banks have invested the bulk of their foreign exchange reserves into low-yielding government securities mostly denominated in US dollars. Since the level of reserves accumulated by many emerging market central banks has started to exceed conventional measures of appropriate reserve holdings for precautionary balance-of-payment purposes, some observers have started to wonder whether reserve accumulation will eventually also lead to more widespread reserve diversification.

Yet the empirical evidence supporting such reasoning has been scarce. According to IMF data, aggregate currency shares in global reserves have remained relatively stable over the past years, despite large increases in reserve levels. In addition, the available evidence from countries which publicly disclose such information suggests that higher reserve levels might be even associated with less diversified reserve portfolios.

In this paper, we propose a possible explanation for such a negative relationship between reserve accumulation and reserve diversification: In a model in which optimal reserve levels and their optimal composition are determined jointly, a rise in reserves which is driven by precautionary motives leads to reserve portfolios with a larger optimal share of the "safe asset". An exogenous rise in reserves not explained by precautionary motives leads to more reserve diversification, however.

In an empirical application, we show that the rise in reserves in our sample of countries is mainly driven by "precautionary motives", measured by capital account openness, the imports-to-GDP ratio and exchange rate anchoring. Taken together, these factors explain more than 50% of the variation in reserve holdings. Therefore, it is reasonable that the rise in reserves in these countries was associated with larger allocations to the "safe asset". A regression of the portfolio share of the safe asset on the residual part of the reserve increase provides some evidence for the notion that an exogenous rise in reserves - i.e. one that is not driven by precautionary motives - leads to more reserve diversification. The emergence of sovereign wealth funds which have been created to manage "excess reserves" to achieve higher returns appears to be consistent with this reasoning.

1 Introduction

The notable increase in international reserve holdings over the past decade and their use during the global financial crisis of 2008/2009 has sparked renewed interest in the analysis of the optimal level of reserve holdings, in particular in countries which are subject to sudden stops of capital inflows. At the same time, a separate strand of the literature attempts to determine the optimal currency composition of emerging market central banks' reserve portfolios which are mostly invested in low-yielding dollar-denominated assets. While the general presumption has been that a rise in reserve levels leads to more reserve diversification, no rigorous attempt has been made to study possible mechanisms behind such a relationship. One exception is a recent paper by Beck and Rahbari (2008) where an exogenous rise in reserves can lead to reserve diversification. However, in this model, the level of reserves may not be optimal and nothing can be said about the various drivers of the rise in reserves which may have a different impact on optimal reserve portfolios. For example, a rise in reserve levels which is driven by a rise in risk aversion of the central bank could impact optimal reserve portfolios in a different way than an exogenous increase in reserves levels.

In this paper, we show that when determining optimal reserve levels and optimal reserve portfolio shares jointly, our understanding for the circumstances under which increased reserve holdings go along with more reserve diversification improves considerably. The basic mechanism behind our results is rather simple: higher reserve holdings lower the probability of a crisis. Therefore, as the central bank increases its reserve holdings, the expected additional cost of having to intervene potentially in a currency which is not the anchor currency is relatively small compared to the gains of diversification, since this cost is only paid in the advent of a crisis whereas diversification gains are made in all other circumstances. Hence, an exogenous increase in reserves triggers in our model indeed increased reserve diversification. However, if reserve increases are driven by higher risk aversion our results suggests that more diversification may not materialize. We also show that the cost associated with the holding of reserves is mainly driven by the level of reserves and only marginally affected by their composition favoring precautionary motives over diversification incentives. However, in some particular cases gains from diversification are becoming potentially important.

In an empirical part we draw on a sample of 20 countries which disclose the currency composition of reserves to analyze to which extent the reserve composition is altered by different motives for the accumulation of reserves, in particular the precautionary aspects. We find consistently that to the extent that reserve accumulation is driven by precautionary motives, the share of the safe asset in total reserves tends to increase.[1] This is true for both the dollar and the euro share and countries that anchor to the euro and those that anchor to the US dollar. However, results regarding the reserve accumulation which is unrelated to precautionary motives are less strong. For countries that anchor to the US there is evidence that higher reserves

[1]For the purpose of this paper a 'safe asset' is an asset which can be used for intervention at a lower 'hair-cut' cost in times of a crisis in comparison with 'alternative' assets.

do in fact lead to a higher weight of the alternative asset in the reserve composition. Countries which anchor to the euro zone do show no significant link between the reserve fraction unrelated to precautionary motives and the currency allocation of the reserves.

The paper starts out with a brief overview of the literature on international reserves. Section three outlines our theoretical framework. Simulation results for the reserve level and composition and the associated costs of the holdings are presented in section four. Section five consists of the empirical analysis and section six concludes.

2 The Literature

The literature on international reserves has a relatively long tradition and has traditionally been subdivided into two main fields.[2] The first, more prominent part, focuses on the optimal level of international reserves. The second, less studied, part centers around the optimal currency composition of international reserves.

Turning first to the literature on optimal reserve levels, we may again broadly subdivide this literature into four strands according to the underlying motives for reserve accumulation: 1) Inventory-Based 2) Crisis Mitigation and 3) Crisis Prevention. Inventory-based models have the longest tradition with various contributions in the 1960s and early 1970s, including the work by Heller (1966) and Olivera (1969). According to the findings of these studies the optimal reserve level is generally increasing in the size and variance of the reserve need (arising from balance of payment disequilibria) and decreasing in the propensity to import [3] and the opportunity cost.[4] Frenkel and Jovanovic (1981) synthesize these early contributions later on, combining the opportunity cost considerations and the stochastic nature of reserve needs using a transaction motive in the spirit of the Baumol-Tobin model (Baumol, 1952; Tobin, 1956). They find empirical evidence to be remarkably in line with the predictions of their model not only in terms of sign but also magnitude of the coefficients.[5] The literature on currency and balance of payment crises

[2] A third field, which is of less relevance from a country's point of view (unless it aspires to become a reserve currency country) takes a global stance and is concerned with the characteristics which allow a currency to emerge as an international reserve currency. This literature builds primarily on the potential reserve currencies characteristics (like share in world GDP, financial depth etc.) and on network externalities coined by the early contributions of Swoboda (1968) and Krugman (1984). Recent contributions include Matsuyama et al. (1993) and Eichengreen (1998) who uses these insight for an empirical analysis of the (world) aggregate composition of reserve currencies. Its primary relevance is within the fields of trade invoicing (Goldberg and Tille, 2008) and the choice of anchor currencies (Meissner and Oomes, 2006) but is also present in the literature on the reserve currency choice as in Chinn and Frankel (2008).

[3] Frenkel (1974) showed later on that the sign with respect to the propensity to import may also be positive. This is the case if it stands for the country's openness and thus measures its vulnerability to external shocks

[4] Oliviera (1969) already introduced a notion of a "coefficient of security" which raised the level of reserves and Heller (1966) noted that his analysis neglected the aspect of confidence in the countries currency and the role reserve holdings may play in affecting the confidence. Hamada and Ueda (1977) qualified the original formula by Heller later on in an extension.

[5] Flood and Marion (2002) confirm the authors' findings based on more recent data, however,

advanced by Krugman (1979) has also attached a central role to the reserve level. If the government runs a policy which is inconsistent with the country's exchange rate regime, reserves are depleted and an exchange rate peg needs to be abandoned. While a higher reserve level postpones the crisis it can not prevent them in these models. Against the backdrop of an increase in financial cross-border flows, more emphasis has recently been put on the role of capital flows in triggering crises and hence the role of reserves in mitigating and preventing so-called sudden stops. For example, Ben-Bassat and Gottlieb (1992) formalize the link between the risk of reserve depletion and the default on the external debt. However, the authors derive no closed form solution but rather a framework for estimating jointly default risk and the implied optimal level of reserves. This strand was followed by the second generation models which focused on the self-fulfilling crises aspect (Obstfeld, 1986, 1996; Morris and Shin, 1998). Here reserves can be understood as reflecting fundamentals or as in Obstfeld (1996) the commitment level to defend the peg. If reserves are high enough the joint sale of domestic currency of all foreign exchange traders is not sufficient to lead to a break of the peg. Speculating that the peg will be abandoned is thus an unprofitable strategy. If instead reserves (commitment) are low (is weak) sales can cause the authorities to abandon the peg. The motivation for precautionary reserve holdings is therefore, firmly anchored in second generation models. The relevance of reserves for preventing crisis has been confirmed by empirical studies (e.g. Bussiere and Mulder (1999)). Variants and extension of the role of reserves in crisis mitigation have been developed in the following years with the most recent proponents including Aizenman and Lee (2007) and Jeanne and Rancière (2008).

Based on a consumption smoothening approach, Jeanne and Rancière (2008) derive a simple formula for the optimal reserve level.[6] Using calibrations they conclude that apart from the post 2004 period their approach can account for most of the change in reserve levels. This stream has been supplemented by a very recent contribution of Obstfeld et al. (2008) which focus on sudden flights, characterized by periods where not only foreign money leaves the country but emphasizing the potential for the entire M2 to flee the country in a period of severe crisis. Caballero and Panageas (2004) added an interesting extension to the mitigation literature by emphasizing the role hedging can play. They argue that consumption smoothening can be obtained via the choice of instruments that behave "counter-cyclical" to sudden stops and pay higher returns in those times, essentially limiting the required reserve level and thereby reducing the cost of reserve holdings significantly.

A rather small part of the literature focuses on the prevention effect of reserves. However, it has been recognized already in the early literature that the probability of balance of payment financing needs is not independent of the reserve level as in Clark (1970) who derives jointly the optimal level of reserves and the speed of

argue that the measures lead to biased estimates. Re-estimating the regression with a different volatility measure (and fixed effects) leads them to conclude that despite the significance of the variation measure the model explains rather little of the cross-country variation and the coefficient on the opportunity cost is relatively instable.

[6]More recently Carroll and Jeanne (2009) apply the precautionary motive to individual agents' choice over foreign asset holdings, explaining the "upstream" flows of capital from developing countries to advanced countries, and the long-run impact of global financial imbalances.

adjustment to external disequilibria. In the wake of the Mexican and the Asian crisis the interest in liquidity for crisis prevention re-emerged in various articles, although not necessarily being the center of analysis and linked to optimal level considerations (see for instance Chang and Velasco (1999), Bussiere and Mulder (1999) and Jeanne and Wyplosz (2001)). In a recent contribution, Garcia and Soto (2004) empirically determine the optimal level of reserves based on an insurance policy approach and find that reserves strongly impact the risk of a crisis.

Finally, Dooley et al. (2004) have advanced the notion that the recent rise in reserve levels is unrelated to any direct decisions on the appropriateness of the reserve level, but is a side product of maintaining competitive exports. According to this interpretation which has been put forward mainly with reference to the case of China, the recent rise in reserve levels is a result of an inflexible exchange rate regime aimed at promoting export-led growth through an undervalued exchange rate. Aizenman and Lee (2007) test the importance of this "Mercantilist" motive versus the importance of the precautionary motive for accumulating reserves. The authors show that though being statistically relevant, the Mercantilist argument is dominated economically by the precautionary accumulation motive, rationalizing the latter in a Diamond-Dybvig style liquidity shock model.

The literature on the composition of international reserves has been less visible since data on the currency composition of reserves at the country-level is in most cases confidential, making an empirical analysis difficult. Nevertheless, there are two main approaches that have been considered: First, under the assumption that central banks pursue similar objectives as private investors, portfolio optimization models have been used to explain the currency composition of foreign exchange reserves. Second, "transaction" needs of central banks, i.e. temporary import financing, foreign exchange interventions or the smoothing of capital outflows have been considered as a possible explanations of the composition of reserve portfolios. With respect to portfolio optimization Ben-Bassat (1980) suggests applying mean-variance optimization in terms of a basket of import currencies. When comparing optimal to actual reserve portfolios using data for 1976 and 1980, he finds some evidence for portfolio objectives as a determinant of the currency composition of reserves of the emerging markets but not for industrialized countries. Dellas and Bang Yoo (1991) use currency composition and import currency data for South Korea and find that the mean-variance approach fares relatively well in explaining at least the share of the main currency, the US Dollar. Heller and Knight (1978), on the other hand, find support for the transaction motives relating to the exchange rate regime and the trading partners which play the major role for the currency composition. Dooley et al. (1989), hereafter DLM, use the entire country-level COFER data for an empirical exercise to analyze the determinants of the currency composition, which has been updated and supplemented more recently by Mathieson and Eichengreen (2000). The recent study confirms former findings that the main determinants are the dominant trading partners the choice of the currency peg and the currency composition of foreign debt. DLM (1989) argue that it is worthwhile to distinguish net (of foreign liabilities) and gross reserves. While the former seem to be governed by risk-return considerations as in the mean-variance framework the latter tend to be affected by a country's exchange rate regime and the currency composition of foreign debt and trade, making transaction motives more relevant. Despite its intuitive appeal it has been argued that this classification is not without problems, since the line between gross and net becomes blurred when M2 is considered as being potentially a liability that need to be entirely converted into foreign reserves. In addition, institutions which set the liability level (the government via the finance ministry) are not directly linked to those which set the asset composition and the level of foreign exchange reserves (central bank). And lastly transaction costs, measured in the traditional ask-bid spread, despite their empirical relevance pose no clear theoretical constraint since they tend to be small in most currency markets. More recently, Chinn and Frankel (2008) use the findings of the literature on transaction motives, portfolio choice and the international currency determinants[7] to show that using aggregate data, currency shares are dominated by the size of the home country, the "confidence" in a currency and return considerations. They also find some support for network externalities leading to slow adjustment and higher liquidity favoring one over another currency. Papaioannou et al. (2006) develop a dynamic mean-variance framework and compute the optimal reserves (under some constraints) for several countries. Different to Chinn and Frankel they conclude that the Euro is likely to be already over represented from a mean-variance optimal point of view. Finally, Beck and Rahbari (2008) compute the optimal euro and dollar shares for 24 emerging market countries in the context of a minimum variance framework that incorporates transaction needs arising due to sudden stops. When the reference currency of the central bank is the local currency, central bank portfolios tend to be dominated by a country's anchor currency (and the implied low volatility against assets denominated in these currencies) while the currency denomination of foreign debt has little bearing for the portfolio decision. Furthermore, do the authors conclude that dollar reserves tend to hedge better against regional sudden stops in Asia and Latin America while the Euro is preferable in emerging markets in Europe.[8] While their framework includes no decision rule for the level of reserves, an exogenous increase in reserves leads to a decline of transaction motives and more diversification towards the minimum variance portfolio.

Most of the literature on reserves has treated the optimal level of reserves and their allocation as two independent decisions.[9] While this may be true for the optimal reserve level (and in fact is so in our model for a limiting case) this is clearly not true for the allocation of reserves.[10] While the literature has generally

[7] See footnote (2) for references to this literature.

[8] Recently, Wong (2007) and Lim (2006) have looked at the role of exchange rate movements for the composition of reserves, finding that central banks behave in a balancing manner (buying reserves when prices are low).

[9] Caballero and Panageas (2004), though focusing primarily on the hedging properties against a sudden stop, are a notable exception. Dedola and Straub (2008) analyze the holdings of reserves and their composition jointly in a three country model context, distinguishing between equity and debt holdings. They find important consequences of different foreign reserve allocation strategies of the financially constrained country on the international asset allocations.

[10] Caballero and Panageas (2004) have demonstrated that the hedging property of certain assets allows a lower reserve level. Hence, even the independence of the level from the allocation choice is not necessarily a reasonable assumption.

accepted that there is a positive impact of the reserve level on the probability of a crisis (García and Soto, 2004; Jeanne and Rancière, 2008; Levy Yeyati, 2008) the implications for the portfolio choice has been mostly ignored.

With the following we make an attempt to fill this gap, which given the recent hike in reserve levels and the accompanying controversy on reducing levels versus allocating optimally seems an important analytical element that has not received enough attention. We do so by emphasizing the role reserves play in crisis prevention. We do not regard the alternative reasons for reserve holdings to be less relevant, but rather prefer to focus on the element which we believe to build the strongest link between the choice of the optimal level and composition of international reserves.

3 The Model Framework

Reserves are considered to serve three main functions: (1) they are a buffer to finance any gap between private supply and demand for foreign exchange *at a given* exchange rate (transaction motive), (2) a store of national wealth (mitigation motive) and (3) a potential collateral or "sweetener" to attract and keep externally borrowed funds at reasonable conditions (prevention motive). The decisions concerning the level and the composition are independent only if these functions can be fulfilled independently (Horii, 1986). For this to be the case, markets need to be highly liquid such that currencies can be converted at any time at zero cost and taking on additional debt must be cost neutral to the advent of a crisis. The latter is essentially ruled out by the nature of the definition of a crisis. Furthermore, the portfolio decision reflects the optimal risk minimizing portfolio in the traditional sense only if markets are sufficiently liquid, there are no ask-bid spreads which may make cross-conversion more costly or the probability of the need to intervene is essentially nil.

The model which we sketch in the next paragraph breaks with two traditions in the literature. First and foremost we allow interaction between the level and the composition. Second, we allow the composition to be deviating from the optimal composition based on a standard variance minimizing approach. The deviation is based on a "worst case" scenario consideration in which reserves need to be liquidated and hence the property of the asset class in the worst case affects the allocation. To keep things tractable we pay however the price of presenting a very stylized approach, which neglects many of the aspects that have been shown to affect the decisions in order to focus on the channels we like to highlight here. The essential problem can be described with two reduced form equalities. The first guarantees the optimal level of reserves, the second the optimal allocation across a given number of assets. Under most circumstances these decisions will not be independent from each other. The authority chooses optimally level and composition based on a mix of standard variance minimizing approach and "worst case scenario" dimension by maximizing the net benefits from holding reserves. For the remainder of the paper we will make use of the terms market portfolio and minimum variance portfolio interchangeable.

3.1 The Economic Environment

To highlight the origin of the costs and benefits of reserves we first sketch the stylized economy before turning to the authorities optimization problem. Consider an economy with an exogenous level of output Y. There is no private saving such that the representative consumer's consumption level is given in times of tranquility by

$$C_t^T = Y - Z_t$$

where Z_t is a transfer to the authorities. The transfer is given by the amount the government needs to maintain its wished level of reserves R_t. To maintain the reserve level the government needs to pay a fee for the management of its reserves (ρ^*) which insures the authority against fluctuation in returns in tranquil times. Additionally, the government pays a premium g to raise the new reserves which corresponds to the return it could have made by investing in the local economy rather than holding foreign assets.[11] The government inherits the reserves from last period (R_{t-1}) plus the return on the holdings ($\sum \alpha_i r_i R_{t-1}$) where α_i is the share in the respective asset and r_i is the return on asset i given by $r_i = \frac{1+i}{1+\pi}(1+\Delta e_i) - 1$. The transfer in times of tranquility is then given by:[12]

$$Z_t = [(1+g)R_t + \rho^*] - \left[R_{t-1} + \sum \alpha_i r_i R_{t-1}\right]$$

Using the transfer rule in the definition of consumption gives:

$$C_t^T = Y - \sum \alpha_i \left(g - r^i\right) R_{t-1} - (1+g)\Delta R_t - \rho^*$$

We assume that there is a unique optimal pre-crisis level of reserves which is stable, such that $\Delta R_t = 0$.[13] The cost of holding reserves in such a context is given by the the fee ρ^* and the opportunity cost $\sum \alpha_i \left(g - r^i\right)$ which is assumed to be positive in line with empirical evidence (see Rodrik (2006)). Hence, pre-crisis consumption will always be given by:

$$C_t^T = Y - \sum \alpha_i \left(g - r^i\right) R_{t-1} - \rho^* \tag{1}$$

In times of a crisis no reserves are levied and no returns from the investment are received but instead transaction costs may have to be paid due to the premature liquidation. A crisis is defined as a period in which output drops by a fraction γ below its tranquil time's value as in Jeanne and Ranciere (2008). Consumption in crisis times is hence given by:

$$C_t^C = (1-\gamma)Y + R_t^* \tag{2}$$

[11] Alternatively, this could be interpreted as the implicit cost of issuing long term bonds to finance the reserve stock (Jeanne and Ranciere, 2008).

[12] A foundation based on a trade -off between long term and short term debt for such a set up is given by Jeanne and Ranciere (2008).

[13] Note that in our context Y is given and does not grow over time such that the $R/Y-$ratio is assumed to be stable.

where R_t^* is the level of reserves available for intervention which is given by

$$R_t^* = \left[1 - \left(t_* - \sum t_i \alpha_i\right)\right] R$$

where t_i is the "haircut" cum transaction cost of asset i above a reference level t_*. We assume $\sum t_i = 0$ such that the term t_i can be positive for some assets and negative for others. If t_i is positive then it is a better hedge against the sudden stop then the alternative assets.

3.2 The Management Fee

One way to determine the extent of the fee is given by the notion that the reserve manager is to some extent risk averse. The fee is hence equivalent to the compensation needed to induce the manager to take on the risk of holding the portfolio and insure the authority against fluctuations in its value in tranquil times. We assume that the reserve management fund is not able to insure against the sudden stop but only against "standard" fluctuations in tranquil times and therefore simply cares about the utility derived from the standard portfolio.[14] In sudden stop periods the insurer simply transfers to the authorities the current value of the reserve holdings (R_t^*). The risk premium for the authority's portfolio is then given by:

$$E\left[u\left(X\right)\right] = u\left(E\left(X\right) - \rho^*\right)$$

where $u\left(X\right)$ is the utility of the manager associated with the wealth X, which is the gross return on the portfolio

$$X = \sum \alpha_i \left(1 + r_i\right) R$$

We assume for simplicity equal expected returns and a utility function of the CRRA type with risk aversion parameter σ_P. In such a context, it can be shown that an approximation to ρ^* is given by:[15]

$$\rho^* \approx \rho \sigma_P R$$

where $\rho = \frac{Var\left(\sum \alpha_i r_i^*\right)}{2[1+E(r)]}$ and $r_i^* = r_i - E\left(r_i\right)$. Hence, the management fee is linearly increasing in the level of reserves, the variance of the portfolio and the risk aversion of the reserve manager.

3.3 The Optimization Problem

We let the authorities maximize the net benefits from holding reserves, by maximizing a weighted sum of the cost and benefits from reserve holdings:

$$\mathcal{L} = -\phi\left(R\right)\left(\frac{\sigma_P}{\sigma_G}\rho + g - \sum \alpha_i r_i\right) R + h\left(\sigma_G\right)\left[1 - \phi\left(R\right)\right]\left[1 - \left(t_* - \sum t_i \alpha_i\right)\right] R \tag{3}$$

[14]The assumption seems in line with recent experience of several reserve funds which experienced big losses from their management strategies while there has been a strong drain on the reserve levels.

[15]For details see the Appendix.

$1-\phi(R)$ is the probability that a crisis occurs and is assumed to be decreasing in the reserves. For $h(\sigma_G)=1$ the policy maker would weight each period the same, i.e. a loss in crisis times is equivalent to a loss in times of tranquility. However, it may be reasonable to presume that $h(\sigma_G)>1$ which is akin of overweighting the worst case scenario. A motivation may be seen in the idea that bad performance in the crisis period is much more costly for the authority than bad management of reserves during tranquil times. Additionally, we allow the risk aversion (σ_G) to affect the trade-off between return and cost of insurance, by decreasing the weight on the cost of insurance with a higher degree of the authority's risk aversion.[16] The level of reserves is determined by setting the marginal cost of holding reserves equal to the marginal benefit from holding them, which is given by the first order condition with respect to the reserve level:

$$\left[\phi'(R)R+\phi(R)\right]\left(\frac{\sigma_P}{\sigma_G}\rho+g-\sum\alpha_i r_i\right)=\left[\left[1-\phi(R)\right]-\phi'(R)R\right]h(\sigma_G)\left(1-t_*+\sum t_i\alpha_i\right)$$

Defining the elasticity of the probability of no crisis with respect to reserves by $\varepsilon_{\phi,R}=\frac{\phi'(R)}{\phi(R)}R$ then we have

$$\frac{\left[1-\phi(R)\right]}{\phi(R)}=\frac{(1+\varepsilon_{\phi,R})}{h(\sigma_G)}\frac{\left(\frac{\sigma_P}{\sigma_G}\rho+g-\sum\alpha_i r_i\right)}{\left(1-t_*+\sum t_i\alpha_i\right)}+\varepsilon_{\phi,R} \tag{4}$$

From a partial equilibrium perspective (i.e. assuming $\frac{\partial\rho}{\partial\phi(R)}=\frac{\partial\alpha_i}{\partial\phi(R)}=0$) this equality implies for our assumption of $\phi'_R(R)>0$ that a higher degree of the authorities level of risk aversion (σ_G) leads to a higher reserve level given the natural assumption that $h'_{\sigma_G}(\cdot)>0$. An increase in the opportunity cost $(g-\sum\alpha_i r_i)$ leads to a reduction in the reserves as does an increase in the general transaction cost (t_*). An increase in the risk aversion of the international investor relative to the authority $(\frac{\sigma_P}{\sigma_G})$ leads to a lower reserve level. It is worth noting that in this simplified functional form $\varepsilon_{\phi,R}$ governs the entire shape of the probability, the implications of which are described in more detail in the Appendix.[17]

[16] This is not essential, seems however realistic since a very risk averse government is likely to accept a higher fee to insure against fluctuations.

[17] Levy-Yeyati (2006) found no significant impact of reserves on the elasticity itself using spreads as dependent variable, which should reflect the crisis probability. To arrive at a simple solution we use this finding and make the assumption that the elasticity of the crisis probability is independent of the level of reserves. Under $\frac{\partial\varepsilon_{\phi,R}}{\partial R}=0$ we may postulate $\phi(R)=\left(\frac{R}{Y}\right)^{\varepsilon}$ and hence have the solution

$$\frac{R}{Y}=\left(1+\frac{(1+\varepsilon_{\phi,R})}{h(\sigma_G)}\frac{\left(\frac{\sigma_P}{\sigma_G}\rho+g-\sum\alpha_i r_i\right)}{(1-T_i\alpha_i)}+\varepsilon_{\phi,R}\right)^{-\frac{1}{\varepsilon}}$$

If we were to abstract from the portfolio considerations, the optimal reserve level in such a scenario is entirely linked to the elasticity, the opportunity cost and the risk aversion and may be determined by the single equation

$$\frac{R}{Y}=\left((1+\varepsilon_{\phi,R})\left(1+g^*/h(\sigma_G)\right)\right)^{-\frac{1}{\varepsilon}}$$

The first order condition pinning down the optimal shares is determined by setting the gain from diversification equal to the cost and is given for all i by:[18]

$$\begin{aligned}
\phi(R)\left(\frac{\sigma_P}{\sigma_G}\frac{\partial\rho}{\partial\alpha_i}-E(r_i)\right) &= h(\sigma_G)\left[1-\phi(R)\right]t_i \qquad (5)\\
\alpha_i Var\left(r_i^*\right)+\sum_{j\neq i}\alpha_j Cov(r_i^*,r_j^*) &= \frac{\sigma_G}{\sigma_P}\left(r_i+h(\sigma_G)\frac{1-\phi(R)}{\phi(R)}t_i\right)\left[1+E(r)\right]
\end{aligned}$$

Using matrix notation the optimal share condition is given by

$$A=\left[1+E(r)\right]\frac{\sigma_G}{\sigma_P}\Gamma\left(E(r)+h(\sigma_G)\frac{1-\phi(R)}{\phi(R)}T\right)$$

and $\sum\alpha_i=1$. Γ is the inverse of the variance-covariance matrix and T is the vector of transaction costs and A the vector of asset shares.

3.4 Composition and Level of Reserves in the Two Asset Case

In general (4), (5) and $\sum\alpha_i=1$ can be used to pin down the implied shares and reserve level in the multiple asset case. To gain a better understanding for the mechanisms, we will work however with the two asset case. Fixing the amount of assets under consideration to two implies the identity $\alpha_1+\alpha_2=1$ and $t_1=-t_2$. For a given level of reserves it can be shown that the shares are then given by:

$$\alpha_i=\alpha_i^*-\frac{\left[1-\phi(R)\right]h(\sigma_G)}{\phi(R)}\frac{\sigma_G}{\sigma_P}\theta t_i \qquad (6)$$

where α_i^* stands for the (standard variance-minimizing) optimal market portfolio of a risk averse agent and θ is a positive coefficient.[19] In the presence of transaction costs, the extent of the deviation of the authority's portfolio from the market portfolio is influenced by the relative risk aversion ($\frac{\sigma_G}{\sigma_P}$) and the "subjective probability" of a crisis ($\frac{[1-\phi(R)]h(\sigma_G)}{\phi(R)}$). A reduced crisis probability drives the portfolio closer to the optimal market portfolio as does a lower importance attached to the consumption level in the crisis period. In fact for the extreme case of zero probability of a crisis the portfolio is equal to a private agent's portfolio. Higher transaction cost tend to drive the authority away from the optimal market portfolio. An increase in the relative risk aversion of the authority does alike. Combining these with the first

We may allow a more general form of the probability which may be described by

$$\phi(R)=\beta+\gamma\left(\frac{R}{Y}\right)^{\varepsilon}$$

This implies however that the solution is not easily obtained, since the function is not any more quadratic but cubic.

[18] $Var(\sum\alpha_i r_i^*)=\sum\alpha_i^2 Var\left(r_i^*\right)+\sum\sum\alpha_j\alpha_i Cov\left(r_i,r_j\right)$

[19] For asset 1 we would hence have that $\alpha_1^*=\frac{Var\left(r_2^*\right)-Cov\left(r_1^*,r_2^*\right)}{Var\left(r_1^*\right)+Var\left(r_2^*\right)-2Cov\left(r_1^*,r_2^*\right)}$. And the coefficient is given by $\theta=\frac{(1+E(r))}{\left[Var\left(r_1^*\right)+Var\left(r_2^*\right)\right]-2Cov\left(r_1^*,r_2^*\right)}$.

order condition with respect to reserves, yields a quadratic equation for the ratio $X = \frac{[1-\phi(R)]}{\phi(R)}$. The solution to this quadratic formula is given in the Appendix and used for depicting the following calibrations.

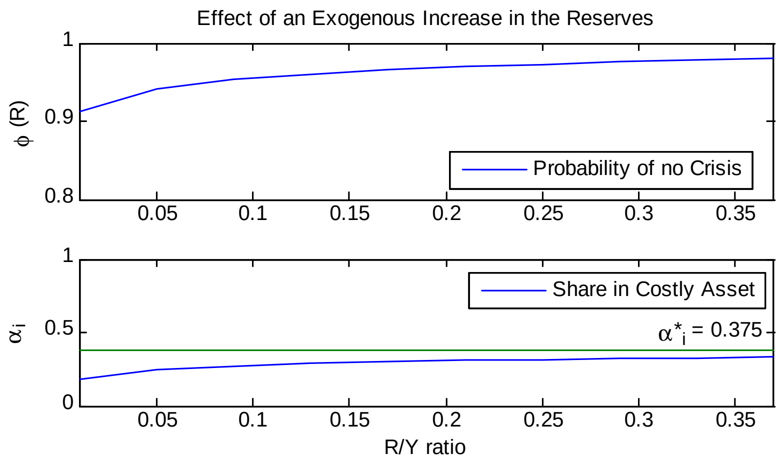
4 The Baseline Calibration

Even though the model yields a closed form solution (see Appendix), many analytical results depend on parameter values. However, for reasonable parameter values, results are unambiguous. For the opportunity cost we have independently of the parameters that $\frac{\partial R}{\partial g} < 0$ which leads directly to $\frac{\partial \alpha}{\partial g} < 0$, where α is taken to be a costly asset in the sense that its return exhibits a higher volatility than the safe asset and it has a higher transaction cost in periods of a crisis. One way to think about this asset is in the context of an exchange rate peg to the dollar, where α could stand for the share of euro denominated reserves.

In the following we present how the optimal reserve ratio, the probability of no crisis and the share invested in the costly asset varies with the various parameters of the model. For the baseline case we assume the authorities to be twice as risk averse as the international investor taking on the values: $\sigma_G = 4$, $\sigma_P = 2$. In line with real returns on low risk government bonds we take the expected yearly return on the two assets to be $E(r_1) = E(r_2) = 0.02$. The premium g is taken to be 6% such that the resulting opportunity cost from holding reserves is given by 4% in line with average estimates (See Rodrik 2006). The functional form for the probability is given by the most simple case ($\phi(R/Y) = (R/Y)^{\varepsilon_{\phi,R}}$) and the elasticity is taken to be $\varepsilon_{\phi,R} = 0.02$ such that a reserve ratio of 5% implies a crisis roughly every 20 years and a ratio of 30% a crisis every 50 years. We set $h = \sqrt{\sigma_G}$ such that in the baseline case the crisis period is weighted double relative to a period of tranquility and an increase leads to a higher weight of crisis periods though at a diminishing rate. We assume a haircut cum transaction cost of 2% for the costly asset. While this is well above the standard bid-ask spread which is unlikely to be anywhere close to a percentage point even for developing countries' currencies, it is not very high if we take into account that the cost is incurred under financial stress and represents to some extent the hedging property of the respective asset. It implies that on average the "safe" asset pays 2% higher return than the average return on the portfolio under financial stress. Hence we assume the "safe" asset to hedge better against a sudden stop then the costly asset. Finally, the properties of the assets are described by the annual standard deviation of the save asset with 10%, the costly asset with 14% such that the variance of asset one is half the variance of asset two. The correlation between the two assets is taken to be negative to have a clear gain from diversifying, where the correlation is taken to be -0.35 (implying a covariance of -0.005). The latter three specifications imply that the market portfolio is given by a 62.5% to 37.5% split between the save and alternative asset.

4.1 An Exogenous Increase in Reserves

Let us first consider how the optimal composition changes if we exogenously change the level of reserves from close to zero to 40% of GDP.



Not surprisingly, the chosen optimal portfolio for the authority's preferences gets closer to the market portfolio the higher the reserve ratio. The reason for this is in the declined crisis probability, which is implied by the higher reserve ratio. This mechanism is essentially what several observers regard as the argument for the need to increased diversification given the current (perceived) high levels of reserves. However, as the next experiment will show, observing a higher level of reserves *per se* does not imply that a move towards the market portfolio is necessarily optimal.

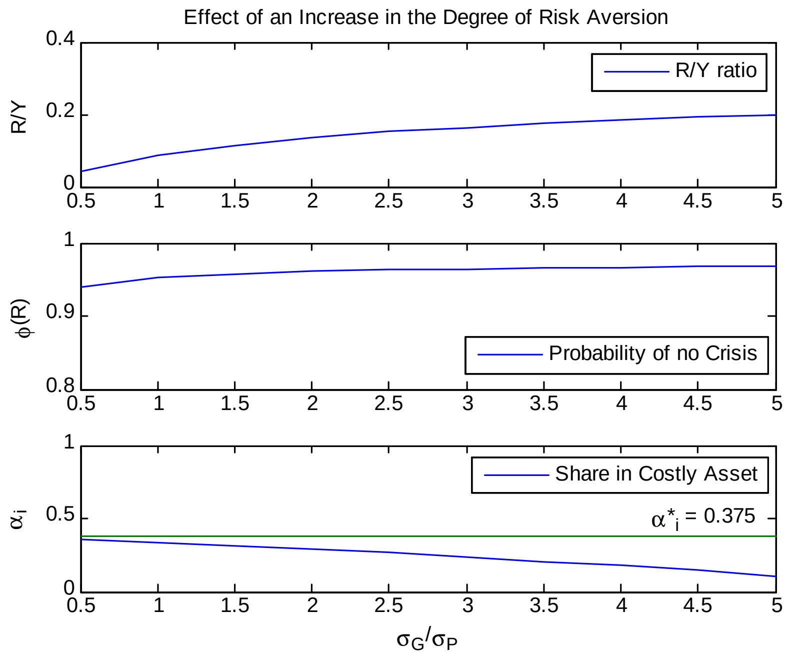
4.2 A Rise in the Government's Risk Aversion

Consider an increase in the risk aversion of the authority. The increased risk aversion has the effect that (1) authorities are more concerned about crisis periods relative to tranquil times and (2) value less the cost from increased insurance against fluctuations relative to the opportunity cost (Or put differently: tolerate a higher cost associated with varying returns for a given loss due to the opportunity costs). Both the channels lead to an increase in the reserve level and a move away from the market portfolio. However, their contribution is different. The increased weight on the crisis period leads to an increase in reserves to avoid crisis periods. This has via the falling probability of a crisis the effect that the authorities tend to move *closer* to the market portfolio as with an exogenous increase in reserves. However, the higher weight that is put on the loss in crisis periods outweighs this effect and makes the safe asset relatively more attractive.[20] The second effect of an increase in the risk aversion, leads primarily to a shift away from the market portfolio and increases marginally the reserve ratio.[21] The move away from the market portfolio is a result of the fact that the authority cares less about the cost of insurance, allowing her

[20] Recall that we set $h = \sqrt{\sigma_G}$. Using higher powers reinforces the latter effect.

[21] Generally the latter effect is below 1 percentage point.

to put more emphasis on the transaction motives, as can be seen in the reduced form solution (6). Similarly the lower perceived cost from reserve holdings (as of the lower insurance cost) allows an increase in the reserve level to equalize marginal costs to marginal benefits.[22] The combined effect is presented in the graph below by moving the degree of risk aversion form half the international investor's level to 5 times the international investors risk aversion.



4.3 A Change in the Elasticity of the Crisis Probability to Reserves

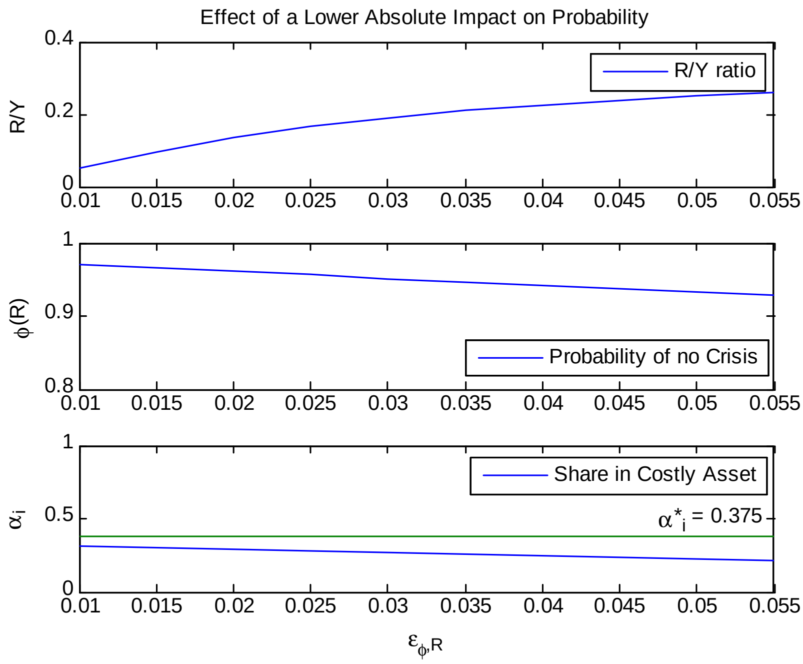
Next we consider a change in the shape parameter of the crisis probability. In this reduced form the parameter $\varepsilon_{\phi,R}$ governs the entire probability. An increase makes the probability of no crisis more sensitive to an increase in reserves, implies however

[22] Mathematically, it is worth noting that using (6) in ρ, $\sum \alpha_i r_i$ and $(1 - T_i \alpha_i)$ of (4) and taking into account equal expected returns as well as the symmetry of the transactions cost in the two asset case yields:

$$X = \frac{[1 - \phi(R)]}{\phi(R)} = \frac{(1 + \varepsilon_{\phi,R})}{h(\sigma_G)} \frac{\left[\frac{\sigma_P}{\sigma_G}\rho(\sigma_G) + g - E(r)\right]}{\left(1 - t_* - t_2(\alpha_2^* - \alpha_1^*) + 2t_2^2\theta\frac{\sigma_P}{\sigma_G}X\right)} + \varepsilon_{\phi,R}$$

Since $\frac{\partial \phi(R)}{\partial R} > 0$ and $\frac{\partial \rho(\sigma_G)}{\partial \sigma_G} > 0$ it follows that $\frac{\partial R}{\partial \sigma_G} > 0$ iff $\frac{\partial \rho(\sigma_G)}{\partial \sigma_G}$ is outweighed by the two other effects trough which σ_G enters independently and in a increasing manner the reserve ratio. In plain terms: The reserve level will increase as long as the increased variance of the portfolio due to a move to a less diversified portfolio $(\rho(\sigma_G))$ is outweighed by the decreased importance of the insurance cost $\left(\frac{\sigma_P}{\sigma_G}\right)$ and the increase expected benefit of reserves due to the lower expected transaction costs in terms of crisis (as of the move to the safer asset).

also that for a given level of reserves the probability of no crisis is lower.[23] This may be synonymous for countries which are well developed and have a very low crisis probability independent of the level of reserves, at one extreme. And at the other extreme, countries which have a high "exogenous" crisis probability, but can steer confidence in their economy via increasing reserves.[24] Again we find that despite an observed increase in the reserves the optimality conditions imply a move away from the market portfolio.



As the shape parameter increases the probability of a crisis for a given level of reserves becomes more likely. However, at the same time do we have that an increase in the parameter increases the marginal effect of the reserves on the crisis probability, creating a gap between expected costs and now higher expected benefits of reserves. This gap is closed by increasing the reserve level, which dampens the fall in the probability of no crisis. Overall the probability of a crisis will still increase making transaction motives more relevant and thereby shifting the allocation away form the market portfolio.[25]

[23] This dichotomy can be broken by assuming the more general form. See the Appendix for details. However, some of the findings in the literature indicate the possibility of such an effect (Garcia and Soto 2004).

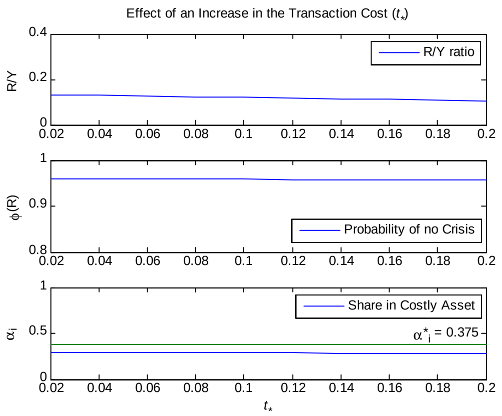
[24] In terms of the literature on self-fulfilling crisis the former countries are essentially in the zone were fundamentals are so strong that a crisis is not to be expected, making the reserves' effect on the crisis close to nil and those countries with intermediate fundamentals which may avoid the crisis only by increasing reserves.

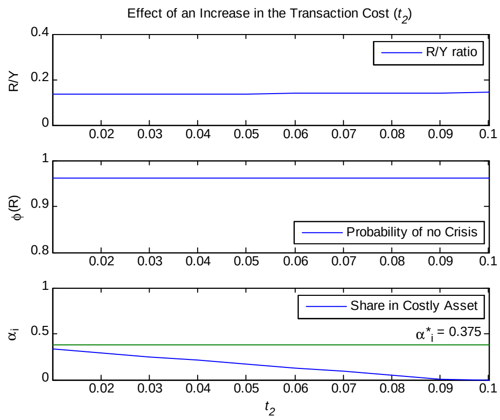
[25] If only the first effect would be present (i.e. an increase in the crisis probability without affecting the marginal effect of reserves) we would observe an increase in the reserve ratio and a move away from the market portfolio. If only the latter effect is present, we would see a fall in the reserve ratio (a fall in the crisis probability) and a move toward the market portfolio.

4.4 A Change in the Transaction Cost

Finally, we look at the impact of the transaction cost. This may be seen in two ways. First there is t_* which applies generally. Second, we may vary t_2 which is essentially reflecting the relative hedging properties in sudden stops of asset 2 relative to asset 1 and the difference in the transaction cost of the two. From (6) we immediately see that there is no direct impact of t_* on the portfolio split. (4) implies together with $\frac{\partial \phi}{\partial R} > 0$, that $\frac{\partial R}{\partial t_*} < 0$, i.e. the reserve level falls with a general increase in the transaction cost (from 13% to 10% for a move from 2% to 20%!).

This is intuitive since a higher t_* implies a lower level of reserves available for intervention in crisis times, reducing the marginal benefit of reserve holdings.[26] This in turn leads via the increased crisis probability to a move to the asset which pays more in crisis times reinforcing the transaction motives. The latter effect is very low since the reserve level is only moderately affected by t_*. Not surprisingly, the effect of an increase in t_2 has more pronounced effects on the portfolio. Increasing t_2 (worse hedging properties of asset 2) directly moves the portfolio away from the market portfolio as is easily seen in (6). The impact on the reserve level is ambiguous, however tends to be positive, for reasonable parameters. In our baseline scenario it leads to an increase of the reserve level by less then one percentage point.





The graph depicts an increase of t_2 from 1 to 10 %. As mentioned, reserves are essentially unaffected, while the portfolio moves from the market portfolio to a portfolio which consists entirely of the safe asset, with the improved hedging properties.

[26]This effect is different to the idea in Caballero and Pangeas (2006), who show that reserves may even be reduced by several percentage points if the hedging properties of the portfolio is improved. The two findings can be reconciled. A lower level of t_* implies better hedging properties of the portfolio against sudden stops. According to Caballero and Pangeas this should lead to a reduction in the reserves. In our framework it leads to an increase since the marginal benefits from reserve holdings have increased while the costs have remained unchanged. However, the reserves available for intervention R^* increase by more than the level of reserves R. Hence, if the authority aims at a given level of reserves for intervention R^* (as is the case in the mitigation literature) this could be done with a lower level of actual reserve holdings R when t_* falls, reducing the pre-crisis level of reserves.

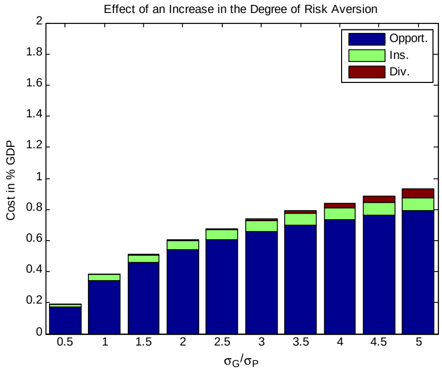
Our results have shown that ceteris paribus an increase in the reserve level should lead via a reduction in the probability of a crisis to a move towards the (diversified) market portfolio. However, this is conditional on the underlying parameters. A reserve increase which is rooted in an increased risk aversion or the believe that the crisis probability has increased is more likely to be associated with a move *away* from the market portfolio since transaction motives become more important in guiding the authorities investment decisions. To the extent that the recent build up in reserves is rooted in precautionary motives, diversification should not be expected. If, however, the accumulation is rooted in a more exogenous driver of reserves, like mercantilist exchange rate policies, the associated reserve increase should go along with a move towards the market portfolio.

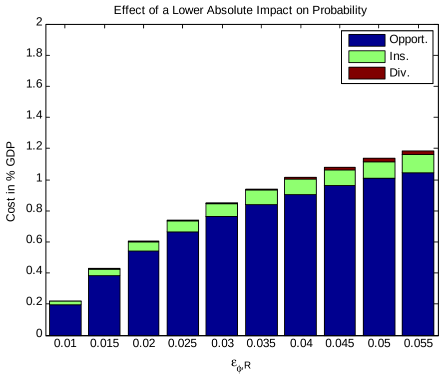
4.5 The Cost of Reserves

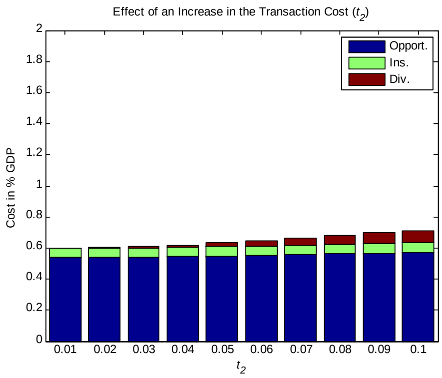
The optimal level of reserves is inseparably linked to the cost of reserves.[27] What are the costs associated with the reserve levels and the optimal composition implied by our calibration? The monetary cost of reserve holdings can be split into three components: (1) the opportunity cost $(g - \sum \alpha_i r_i)\, R$, (2) the insurance cost $\rho\,(\alpha^*)\,\sigma_P R$ and (3) the cost of not diversifying $[\rho\,(\alpha) - \rho\,(\alpha^*)]\,\sigma_P R$. While the first component is standard in the literature which generally abstracts from portfolio decisions (i.e. it takes usually the form $(g - r)\, R$ as it does here in expected terms), the second and third components derive from the portfolio decision and deserve some attention. (2) may be understood as a shadow cost that is implied by the fact that returns on the assets are not constant but vary. An authority which dislikes varying returns may buy the certainty equivalence which is either feasible via forward operations or outsourcing the portfolio management and paying a fee in return for a certain return. Both of which is common today. Finally (3), represents the notion that the authority asks a different portfolio allocation (i.e. gives a benchmark to the external investor) than the one an international investor would choose, since it is also concerned with liquidity needs. To hold this portfolio an extra cost is charged, since it is not the optimal portfolio from a mean variance point of view in tranquil times. Depending on the particular parameters the implied cost of reserve holdings varies between 0.2 and 1.2% of GDP in our baseline calibration.[28]

[27] Recent estimates may be found in Rodrik (2006)

[28] Our calibrations yield costs which are consistent with recent estimates by Rodrik (2006). According to his estimates the cost of reserves for developing countries in 2004 are for a spread of 4% around 0.7% of GDP. Since Rodrik uses the concept of "excess" reserves, i.e. above the 3-month import coverage, and reserves are on average at 8-month coverage for this group in 2004 the value which is comparable to our model is 1.12% $(= 0.7 \cdot \frac{8}{5})$. This value is obtained in our calibrations if for instance $\sigma_G = 6$ and $\varepsilon = 0.04$.







Compared to the opportunity cost, the cost from (optimally) deviating from the market portfolio seems relatively small; it contributes never more than 10% to the total cost and never exceeds 0.1 % of GDP per annum. Hence, at first sight there is little incentive for a central bank to trade-off its transaction motive objectives against a more return oriented approach.[29] However, compared to the costs associated with business cycle fluctuations, it is not low in magnitude in particular for

[29] Note that with increasing risk aversion and a higher level of the shape parameter ε the cost associated with the deviation from the market portfolio increases. However, this cost has a natural limit, i.e. when all assets are invested in the "safe" asset. Allowing expected returns *across* assets to deviate may also add to the cost. This point has been made strongly be Caballero and Pangeas (2006). Furthermore, it has been noted that the standard spread tends to overstate the cost of the reserves since higher reserve holdings tend to reduce the cost of (private) foreign debt (Levy-Yeyati, 2006) a factor which has not been considered here.

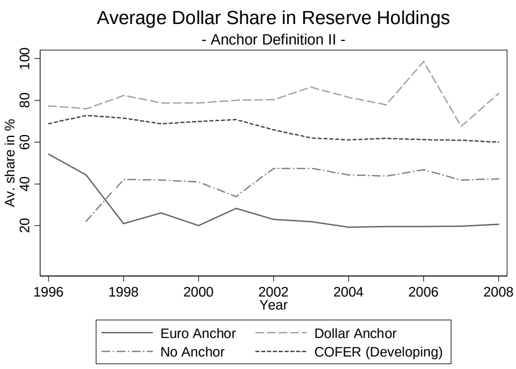
higher levels of risk aversion.

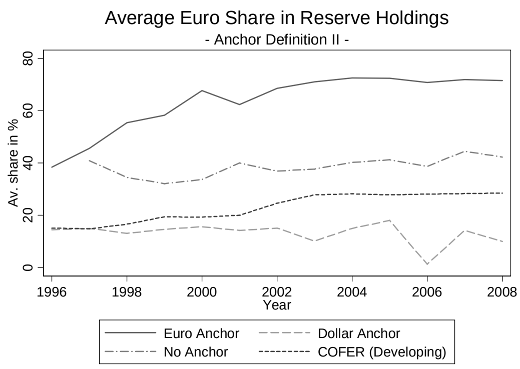
5 Empirical Implementation

Our simple model shows that the decision about the optimal portfolio allocation is dependent on the level of reserves. While an exogenous increase in the reserve ratio pushes the portfolio towards more diversification since it reduces the probability of a crisis and hence increases the expected gain from diversification, this is not generally true if the reserves change endogenously. There is no simple one-for one relationship between the level of reserves and the degree of diversification. In particular, an increase in the degree of risk aversion of the authority generally leads to an increase in the reserve ratio but is associated with a move into safe assets, away from the optimally diversified market portfolio. Hence, to the extent that the recent reserve accumulation is motivated by such considerations it is not at all clear why we should see a move towards more diversified portfolios.

5.1 Data

Using a sample of 20 countries over different periods in time we investigate to which extent these predictions of the model are consistent with the data.[30] With the exception of the US, which has to be excluded from our analysis, the choice of countries reflects the fact that these are the only countries which make information on their reserve composition publicly available. In comparison with the aggregate allocation of reserves of all developing countries which communicate their individual allocation on a confidential basis to the IMF (COFER data) our data set has a bias to countries which hold on average higher shares in the Euro.

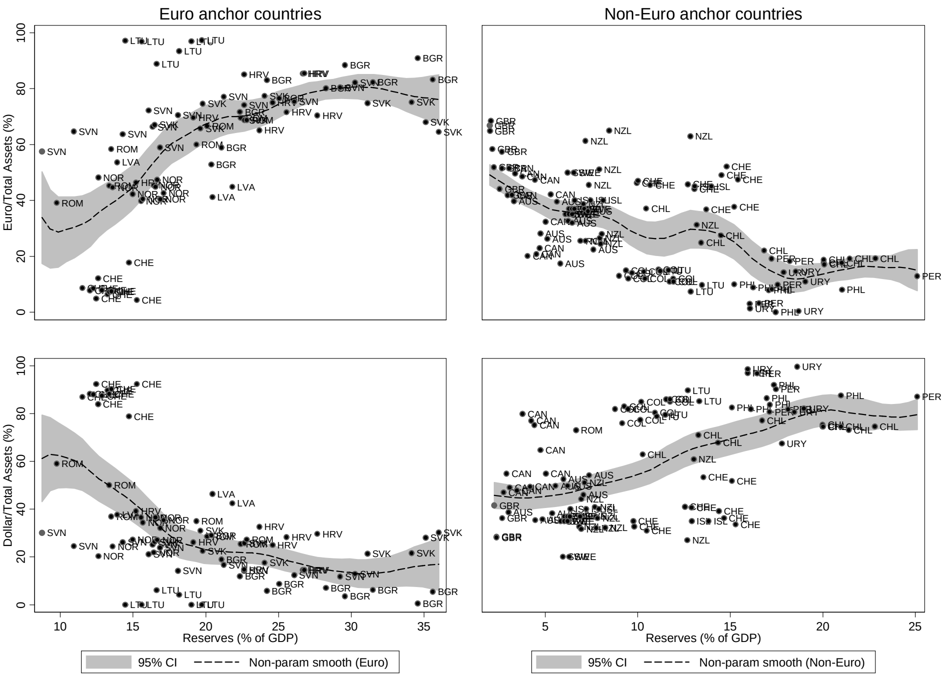




In a preliminary step we check whether their is any link between the reserve ratio and the currency shares of the 20 countries in our sample. Using local polynomial regression of the currency shares on the reserve ratio (as depicted in the four graphs) suggests that there is a clear positive link between the level of reserves and the

[30] For a detailed description of the data see the Appendix.

allocation of reserves into the safe asset. Countries which anchor to the euro tend to increase the euro share as the level of reserves increases while other countries tend to do the contrary. The results for the dollar share mirror this pattern, with countries anchoring to the euro reducing their dollar holdings as the reserve ratio increases. These findings are consistent with the predictions of the model to the extent that a significant part of the reserve increase is explained by a higher level of risk aversion.



5.2 Estimation

To analyze the link between reserve level and composition in more depth we estimate a linear approximation of the relationship as set out by the theoretical framework. Consider again the reduced form of the rule for the composition of reserves:

$$\alpha_i = \alpha_i^* - \frac{[1-\phi(R)]\, h(\sigma_G)}{\phi(R)} \frac{\sigma_G}{\sigma_P} \theta t_i$$

An approximation of this rule is given by

$$\alpha_{i,t} = c + \alpha_i^* + \sum_{k=1}^{2} \gamma_1^k D_{i,t}^k \cdot \sigma_{G,it} + \sum_{k=1}^{2} \gamma_2^k D_{i,t}^k \cdot R_{i,t} + \gamma_3 t_{i,t} + e_{i,t} \tag{7}$$

where $c = \frac{\theta}{\sigma_P}$, which is constant across i and assumed to be constant across time.[31] $D_{i,t}^k$ is an indicator dummy which reflects whether the country anchors to

[31] While the assumption of c being constant across i derives form the model for the 2-asset case with an international investor, the constancy across time is reasonable for the short horizon we consider. The use of a year fixed effects or a trend may capture possible changes.

the US ($k = 1$) or the Euro ($k = 2$) or is an independent float. We choose the float as the natural base category. Regarding the last term $t_{i,t}$, we follow Dooley et al (1989) and Eichengreen and Mathieson (2000) and use the import share in the reserve currency as an independent proxy for transaction motives (debt in the respective currency is only relevant for developing countries which would exclude several of the countries in our sample). Since the impact of the share on the reserve ratio ($R_{i,t}$) is of second order we consider reserves in this regression as exogenous. However, the reserve level may be driven by various factors, which we divide for our purpose into precautionary and other motives. Hence, a second equation is given by

$$R_{i,t} = \mu_i + \delta_1 \sigma_{G,it} + \delta_2 X_{i,t} + u_{i,t} \tag{8}$$

It is difficult to exactly pin down which fraction of the reserve increase is due to precautionary aspects and which part may be regarded as a more exogenous increase. Our approach to the division is a pragmatic one in the sense that we rely on the literature's postulations. According to Aizenman and Lee (2007) reserve accumulation is driven by precautionary motives if they are due to an increase in a country's capital account openness or the experience of severe (regional) economic crises. Additionally, the authors divide between external motives (exchange rate volatility and import to GDP ratio), domestic factors (population) and mercantilist factors (undervaluation and export growth). Due to the restricted time frame of our data set the use of crisis dummies is ill suited which leads us to drop this dimension from the analysis. Instead we consider the capital account openness and what Aizenman and Lee (2007) call external factors as causing an increase in the risk aversion and a related increase in the reserve ratio. Hence, our measures for $\sigma_{G,it}$ include the capital account openness as measured by the index of Chinn (2008), the imports to GDP ratio as well as a dummy which takes the value unity if the country is considered to anchor its currency's value to the dollar or the euro. To measure the exogenous part of the reserve increase we simply estimate

$$R_{i,t} = \mu_i + \delta_1 \sigma_{G,it} + e_{i,t} \tag{9}$$

and consider the part of reserves which can not be attributed to precautionary motives as "exogenous".

$$R_{i,t}^{EX} = R_{i,t} - \hat{\delta}_1 \sigma_{G,it} = e_{i,t}$$

The model predicts that an increase in reserves driven by $\sigma_{G,it}$ should lead to a move into the safe asset while the other changes should lead to the contrary. Inserting, (8) in (7) results in our estimation equation:

$$\alpha_{i,t} = c + \alpha_i^* + \sum_{k=1}^{2} \beta_1^k \cdot \sigma_{G,it} + \sum_{k=1}^{2} \beta_2^k \cdot R_{i,t}^{EX} + \beta_3 \cdot t_{i,t} + \varepsilon_{i,t} \tag{10}$$

where $\beta_1 = \left(\gamma_1^k + \gamma_2^k \delta_1\right) D_{i,t}^k$ and $\beta_2 = \gamma_2^k D_{i,t}^k$. While an OLS estimation of this relationship may provide a good approximation, the censored nature of the data, being limited to values within the interval from 0 to 100%, makes a Tobit technique preferable. Additionally, due to the presence of α_i^* it may be important to explicitly take account of time invariant fixed effects.[32] While there is no direct counterpart as the fixed effect regressor in the OLS case, a procedure proposed by Chamberlain (1984) and Mundlak (1978) provides an unbiased estimator under certain assumptions. The procedure requires to augment (10) by including the average value of the regressors as additional controls.[33] It turns out that in many of the regressions the adjustment is not necessary and the traditional random effect Tobit model is accurate, since the correction terms which are included under the Chamberlain procedure turn out to be insignificant.

5.3 Results

The first stage fixed effects regression (9) for the determinants of the reserve level confirms the findings by Aizenman and Lee (2007) and Obstfeld et al (2008).[34] Reserves are increasing in all the aspects which are meant to capture the precautionary motives.[35] An increase in the capital account openness index by one standard deviation increases the reserve ratio by 1.5 percentage points, while a one standard deviation increase in the imports to GDP ratio increases reserve holdings by 4 percentage points. Being classified as anchoring to a foreign currency increases reserve holdings by 9.6 percentage points compared to floats. The latter effect works partly through increased imports. In fact when using import in % of GDP rather then the orthogonal part of imports of GDP to the anchor dummy the coefficient on the anchor drops to 6.3. Together the precautionary factors explain more than 50% of the variation in reserve holdings. The split between the fraction of reserve holdings driven by precautionary motives as opposed to other factors is depicted in the Appendix for each country.

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[32] While it is not necessarily true that α_i^* is time invariant, it is likely to be a good approximation in our rather short sample.

[33] In particular, our model resembles an unobserved effects Tobit model which is characterized by $\alpha_{i,t} = \max(0, x_{i,t}\beta + \alpha_i + \varepsilon_{i,t})$ where $\varepsilon_{i,t}|x_i, \alpha_i \sim N(0, \sigma_\varepsilon^2)$. The latter assumption can be relaxed to allow a more general model under which we only assume that $\alpha_i|x_i \sim N(\psi + x_i\xi, \sigma_u^2)$ where σ_u^2 is the variance of u_i in $\alpha_i = \psi + x_i\xi + u_i$. The random effects Tobit model with Chamberlain adjustment term is then given by $\alpha_{i,t} = \max(0, \psi + x_{i,t}\beta + x_i\xi + u_i + \varepsilon_{i,t})$ with $\varepsilon_{i,t}|x_i, u_i \sim N(0, \sigma_\varepsilon^2)$ and $u_i|x_i \sim N(0, \sigma_u^2)$. See also Wooldrige (2002). Honore proposes an alternative semi-parametric estimator which allows to drop the distributional assumption. See Honore (1992) and Honore and Kyriazidou (2000).

[34] The estimation includes country fixed effects and the imports in % of GDP are the residuals from an OLS regression of imports in % of GDP on the peg variable, since countries which peg tend to have higher imports. While this leaves all other coefficients unaffected, not controlling for this aspect leads to underestimating the effect of the peg on the reserve level.

[35] Using a longer time period for the first stage regression than the one which is available for the asset allocation data leaves significance unaffected but increases slightly the coefficient values on KAOPEN and Imports in % of GDP while reducing the impact of the anchor on reserves.

First Stage: Reserve Level

KAOPEN	1.10*** (0.39)
Imports (% of GDP)	0.26*** (0.06)
Anchor	9.65*** (1.83)
Constant	7.54*** (1.08)
Obs. (Countries)	171 (20)
$R^2(overall/within)$	0.53 / 0.28

Standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Our focus is however on the second stage regression (10). We divide between the regression for the US dollar share and the euro share. We first present the results when using the aggregate measures from the first stage estimation as regressors. Under this situation we impose all influence to be channeled via the reserve accumulation and allow but for the traditional transaction motives as controls.[36] The regression is hence given by setting $\gamma_2 = 0$ and constraining coefficients such that:[37]

$$\begin{aligned} \alpha_{i,t} &= c + \alpha_i^* + \sum_{k=1}^{2} \beta_1^k \cdot \sigma_{G,it} + \sum_{k=1}^{2} \beta_2^k R_{i,t}^{EX} + \beta_3 t_{i,t} + \varepsilon_{i,t} \\ &= \beta_1^{EA} \sigma_{G,it} + \beta_2^{EA} R_{i,t}^{EX} + \beta_1^{US} \sigma_{G,it} + \beta_2^{US} R_{i,t}^{EX} \\ &\quad + c + \alpha_i^* + \beta_3 t_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{11}$$

The following two tables provide an overview of the main specifications.[38] As a reference, we provide in the first column the regression results based on the standard transaction motive model. The statistics include the log likelihood and the adjusted R^2 value of an OLS counterpart to the respective estimation in order to compare the models explanatory power. The F-statistic indicates whether the Chamberlain adjustment terms are entering jointly significant in the regression or not.

[36] It turns out that this has no relevance, since any separately included precautionary variables enter the regression insignificant and leaves results unaffected. What however matters is that the coeffeicents are constrained as will be shown in the second set of regressions.

[37] Note that the regression is synonymous for a constrained regression of the following type:

$$\begin{aligned} \alpha_{i,t} &= \beta_1^{EA} \lambda_1 KAOPEN_{i,t} + \beta_1^{EA} \lambda_2 IMP_{i,t} + \beta_1^{EA} \lambda_3 D_{i,t}^{EA} + \beta_2^{EA} R_{i,t}^{EX} \\ &\quad + \beta_1^{US} \lambda_1^* KAOPEN_{i,t} + \beta_1^{US} \lambda_2^* IMP_{i,t} + \beta_1^{US} \lambda_3^* D_{i,t}^{US} + \beta_2^{US} R_{i,t}^{EX} + \varepsilon_{i,t}^* \end{aligned}$$

where $\varepsilon_{i,t}^* = c + \alpha_i^* + \beta_3 t_{i,t} + \varepsilon_{i,t}$ and the constraints are given by $\lambda_1 = \lambda_1^*$, $\lambda_2 = \lambda_2^*$ and $\lambda_3 = \lambda_3^*$.

[38] See the Appendix for some additional specifications.

	Second Stage: Euro Share in Reserves				Second Stage: Dollar Share in Reserves			
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)	(A7)	(A8)
Anchor EA/US	27.24***				49.76***			
	(4.52)				(5.35)			
Trade EA/US	0.36**	0.36***	0.58***	0.64***	0.60***	0.63***	0.39*	0.42*
	(0.15)	(0.14)	(0.14)	(0.15)	(0.22)	(0.21)	(0.22)	(0.23)
Prec. EA		1.90***	1.17***	1.04***		-1.27***	-0.92***	-0.79**
		(0.28)	(0.26)	(0.26)		(0.32)	(0.32)	(0.33)
Prec. US		-2.94***	-3.09***	-2.64***		3.87***	3.81***	3.40***
		(0.46)	(0.38)	(0.44)		(0.50)	(0.47)	(0.53)
Exog. EA				0.16				-0.16
				(0.22)				(0.27)
Exog. US				1.18**				-1.13*
				(0.48)				(0.58)
Trend			2.24***	2.34***			-1.42***	-1.49***
			(0.23)	(0.24)			(0.28)	(0.29)
Const.	19.92***	23.96***	17.00***	14.62**	30.28***	40.23***	44.04***	43.76***
	(5.46)	(5.24)	(5.72)	(5.99)	(4.97)	(5.31)	(5.53)	(5.70)
Obs. / Cntry.	175 / 20	171 / 20	171 / 20	171 / 20	175 / 20	171 / 20	171 / 20	171 / 20
Log Lik	-718.9	-653.5	-617.4	-614.2	-694.2	-650.4	-638.6	-636.6
R2 (OLS)	0.507	0.668	0.694	0.696	0.482	0.579	0.578	0.593
Censored			1	1	4	4	4	4
Prob > F	0.708	0.379	0.258	0.037	0.884	0.831	0.187	0.241

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The traditional models (A1 and A5) do a fairly good job in explaining the allocation of reserves. In fact only the two regressors (anchor and trade with the anchor country) explain for both the US dollar and the euro share about 50% of the overall variation. As theory predicts anchoring to the currency has a significant positive impact on the holding of the respective currency in total reserve holdings. The impact appears to be more pronounced for countries that use the dollar as an anchor. Similarly increasing trade with the anchor country increases the share of that country's currency in total reserves. If we estimate the second stage regression of the reserve augmented model (11) the fit improves markedly. For the euro share the model explains close to 70% and for the dollar share 60% of the variation. In all specifications do we find the precautionary motive of reserve accumulation to be associated with an increase in the share of the respective anchor currency, the safe asset and a decrease in the alternative asset. Generally the effect appears to be stronger for countries anchoring to the US dollar. The precautionary effect is robust across specifications and the two currencies. Additionally, we find evidence that the exogenous part of reserve accumulation of countries anchoring to the US dollar is invested in the alternative currency (euro) while diminishing the share invested in the safe asset, the US dollar. The share of trade with the respective currency area enters in all regressions significantly with the expected positive sign. Note that in all regressions except for (A4) the adjustment terms from the Chamberlain procedure enter jointly insignificantly validating the traditional random effects Tobit approach.

Motivated by the promising results we go one step further and relax the assumption that all adjustment comes via the reserve level and allow $\sigma_{G,it}$ to have an independent effect on the composition of reserves by estimating:

$$\begin{aligned}\alpha_{i,t} \;=\;& \beta_1^{EA}\lambda_1 KAOPEN_{i,t} + \beta_1^{EA}\lambda_2 IMP_{i,t} + \beta_1^{EA}\lambda_3 D_{i,t}^{EA} + \beta_2^{EA} R_{i,t}^{EX} \\ &+\beta_1^{US}\lambda_1^{*} KAOPEN_{i,t} + \beta_1^{US}\lambda_2^{*} IMP_{i,t} + \beta_1^{US}\lambda_3^{*} D_{i,t}^{US} + \beta_2^{US} R_{i,t}^{EX} + \varepsilon_{i,t}^{*}\end{aligned} \tag{12}$$

The following two table give an overview of the regression results from (11). Regression (B1) and (B7) use the capital account openness measure of Chin and Ito as the single measure of risk aversion. For the main specification, which includes a time trend, it turns out that an increase in openness significantly increases the holdings of the safe asset only for countries that anchor to the US. Excluding the time trend renders all coefficients significant except for the coefficient on KAOPEN·US in the euro share regression (see Appendix B19 and C19). If we use instead the import to GDP ratio as measure of risk aversion (B2) and (C2) we find the coefficients to be correctly signed and significant for both regressions, the euro share and the dollar share in reserve holdings. While the exogenous part of the reserve accumulation is correctly signed and significant for countries that anchor to the US when excluding precautionary motives from the regression ((B3) and (B9)) and when adding the capital account openness as precautionary motives ((B4) and (B10)) adding the imports as precautionary motive renders the coefficients insignificant ((B5) (B6) and (B11) (B12)).

	2^{nd} Stage Detailed: Euro Share						2^{nd} Stage Detailed: Dollar Share					
	(B1)	(B2)	(B3)	(B4)	(B5)	(B6)	(B7)	(B8)	(B9)	(B10)	(B11)	(B12)
Anchor EA	16.9***	6.2*	11.3***	9.4*	9.7**	11.5**	-13.5**	2.6	-5.4	-4.6	-2.7	-6.8
	(4.76)	(3.68)	(4.03)	(4.97)	(3.87)	(4.88)	(5.66)	(4.69)	(4.97)	(5.96)	(4.87)	(5.90)
Anchor US	-16.3***	-41.3***	-24.6***	-24.4***	-36.3***	-35.4***	25.0***	53.4***	33.6***	34.8***	46.5***	46.1***
	(5.26)	(4.82)	(4.43)	(5.34)	(5.75)	(6.34)	(6.11)	(5.98)	(5.21)	(6.28)	(7.01)	(7.64)
Trade EA	0.5***	0.7***	0.6***	0.6***	0.6***	0.6***	0.3	0.5*	0.4	0.4	0.5**	0.4*
	(0.16)	(0.16)	(0.16)	(0.17)	(0.16)	(0.17)	(0.22)	(0.26)	(0.24)	(0.24)	(0.24)	(0.25)
KAOPEN·EA	0.6			0.8		-0.7	-0.20			-0.22		1.7
	(1.27)			(1.19)		(1.21)	(1.45)			(1.36)		(1.37)
KAOPEN·US	-6.2***			-0.2		-0.3	6.38***			-0.78		-0.6
	(1.57)			(1.96)		(1.81)	(1.87)			(2.33)		(2.15)
IMP·EA		0.4***			0.4***	0.4***		-0.6***			-0.6***	-0.6***
		(0.14)			(0.14)	(0.15)		(0.17)			(0.17)	(0.18)
IMP·US		-2.0***			-1.5***	-1.5***		2.5***			1.7***	1.7***
		(0.34)			(0.46)	(0.46)		(0.42)			(0.58)	(0.57)
Exog EA			0.1	0.1	0.2	0.26			-0.13	-0.13	-0.2	-0.3
			(0.24)	(0.24)	(0.22)	(0.22)			(0.27)	(0.28)	(0.26)	(0.26)
Exog US			2.7***	2.7***	0.8	0.7			-3.0***	-3.2***	-0.9	-1.1
			(0.43)	(0.57)	(0.60)	(0.70)			(0.52)	(0.69)	(0.72)	(0.84)
Obs. / Ctry	171/20	175/20	171/20	171/20	171/20	171/20	171/20	175/20	171/20	171/20	171/20	171/20
Log Lik	-631.8	-625.7	-621.6	-621.3	-609.6	-609.4	-651.3	-647.9	-641.1	-641.0	-629.8	-629.0
R2 (OLS)	0.653	0.711	0.641	0.649	0.715	0.714	0.589	0.600	0.588	0.589	0.611	0.611
Prob > F	0.855	0.155	0.111	0.165	0.217	0.09	0.112	0.0004	0.0031	0.0055	0.0055	0.0020

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The results clearly support the idea that precautionary motives are dominant in the allocation of reserve holdings while other motives appear to play a subordinate role.[39] Both capital account openness and dependence on imports are causing a move to safer assets. The latter seems to be more relevant across all countries. While the traditional approach for almost all regressions that use the euro share as dependent variable seems appropriate when using the dollar share the F-test indicates in most regressions that the Chamberlain procedure appears more appropriate. We report the results in the Appendix to maintain the analysis in the main text homogeneous. The results remain unaltered with one exception: the coefficient on the trade with the US turns insignificant.

6 Conclusion

We present a simple model which links the decision of the reserve level and the allocation of reserves across currencies. While factors that primarily affect the composition of the portfolio have negligible impacts on the reserve level the reverse is not true. We show that it is unlikely that the cost of reserve accumulation can be reduced significantly by moving to more diversified portfolios unless authorities are willing to take on much higher risks (associated with higher returns). This in turn is only likely if the reserve accumulation is driven by factors other than precautionary motives. Hence, it depends on the factors that stand behind the increase in reserves whether increased diversification is optimal or not. For a sample of 20 countries we find that precautionary motives are not only the major driver behind reserve accumulation but they are also reflected in the allocation of the assets dominating over return motives. While we find primarily evidence of the allocation being a function of precautionary motives, we also find some weak evidence for reserve accumulation to lead to more diversified portfolios if reserve accumulation is driven by other factors than precautionary motives.

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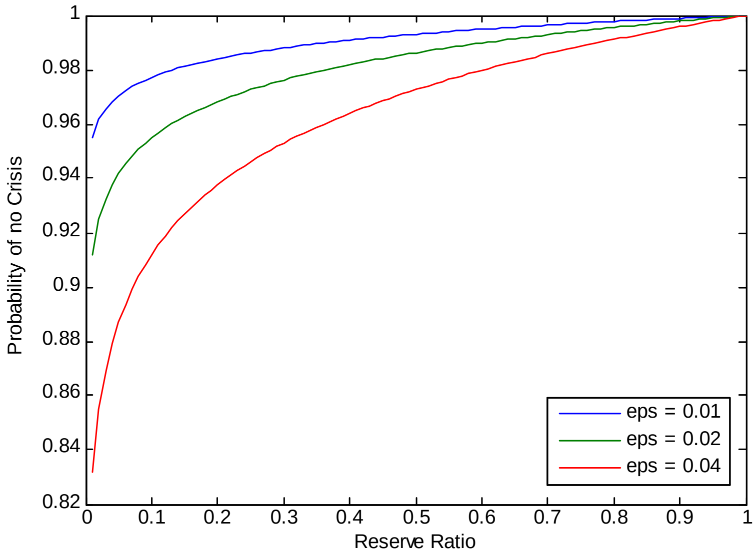
A List of Symbols

Variable	Description
Y	Output
C^T, C^C	Consumption in tranquil and crisis times
Z	Lump sum transfer
R	Total Reserves
R^*	Reserves available for intervention
$1 - \phi(R)$	Probability of a crisis
α_i	Share of reserves held in asset i
α_i^*	Share of reserves in asset i under the market portfolio
ρ^*	Total fee paid to reserve manager for managing R
ρ	Fee per unit of reserves held
r_i	Return on asset i
r_i^*	$r_i - E(r_i)$
g	Premium paid to raise reserves
γ	Fraction of output lost in crisis period
t_i	Transaction cost associated with asset i
σ_G, σ_P	Risk aversion of the government and the reserve manager
$h(\sigma_G)$	Relative weight of crisis period to tranquil period
$\varepsilon_{\phi,R}$	$\frac{\phi'(R)}{\phi(R)}R$: Elasticity of no crisis prob. w.r.t. reserves

B The Crisis Probability

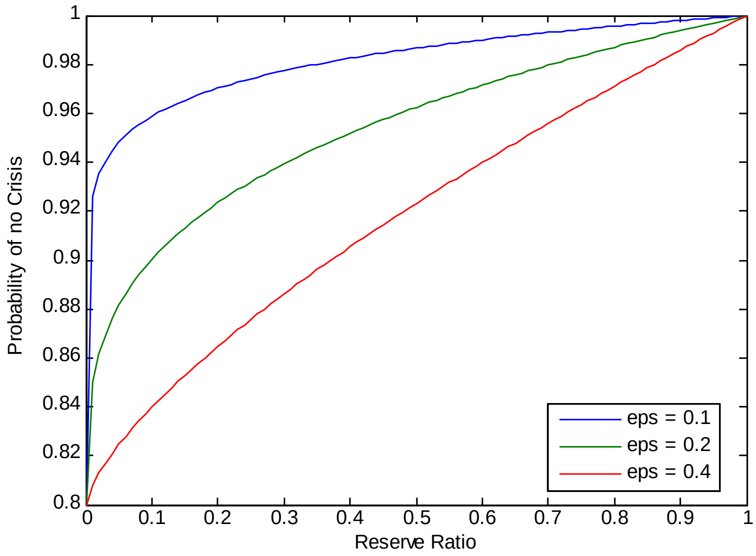
The graph below depicts three scenarios for a different value of $\varepsilon_{\phi,R}$. The lower the elasticity of the probability with respect to the reserve ratio the lower need the reserve ratio be in order to obtain a given level of no crisis probability. This somewhat counter-intuitive result derives from the fact that we are considering - as in reality - ratios *below* unity. Full coverage is here associated with a zero crisis probability.



Hence, a low level of the elasticity should be associated with countries that are presumed to require little reserves to have a high probability of no crisis. Note also that this functional form implies that the elasticity is independent of the reserve level. If we take the empirically more relevant functional form

$$\phi(R) = \beta + \gamma \left(\frac{R}{Y}\right)^{\varepsilon}$$

and restrict $\gamma = 1 - \beta$ to ensure that full coverage leads to a zero crisis probability we obtain a similar pattern as depicted in the figure below where we set $\beta = 0.8$ and varied the elasticity. Clearly, with such a functional form any increase in β will lead to a lower optimal reserve level while the effect of the elasticity remain unchanged. The coefficient β may stand for any other factors affecting the crisis probability such as the depth of the financial system, the export revenues relative to GDP, the exchange rate regime, indicators of political and institutional quality etc.



C Derivation of the Insurance Cost

Consider the case in which the authority rather than taking the risk of fluctuation in return and prices on itself, engages in forward contracts. To this end it will have to pay a fee. This fee is different to the factor g which stands for the opportunity cost which arises and the premium due to the default possibility. One way to determine the extent of the fee is given by the notion that the counterpart to this hedging is risk averse. Hence, we can ask how much we need to compensate the counterpart to take on the risk, i.e. what is the risk premium of the portfolio? However, we presume that the counterpart unlike the authority need not be liquid in the event of a sudden stop but simply maximizes the utility form the standard portfolio. The risk premium for the total portfolio is then given by

$$E\left[u\left(X\right)\right] = u\left(E\left(X\right) - \rho\right)$$

where X is given by the level of wealth, which is the gross return on the portfolio

$$X = \sum \alpha_i \left(1 + r_i\right) R$$

The premium may be retrieved via the following (second order) approximation:

$$\frac{u\left(\bar{X}\right)''}{u\left(\bar{X}\right)'} \approx \frac{2\rho}{\sigma_\varepsilon^2}$$

For the two asset case we have

$$X = R + \left[\alpha r_1 + \left(1 - \alpha\right) r_2\right] R$$

where we decomposed the level of wealth in the two terms $X = \bar{X} + \varepsilon$ where ε has mean zero. Accordingly, $\bar{X} = R + \left[\alpha E\left(r_1\right) + \left(1 - \alpha\right) E\left(r_2\right)\right] R$ and $\varepsilon =$

$[\alpha (r_1 - E(r_1)) + (1-\alpha)(r_2 - E(r_2))] R$. For a utility function of the CES class with risk aversion parameter σ_P: $\frac{u(\bar{X})''}{u(\bar{X})'} = \frac{\sigma_P}{R(1+\alpha E(r_1)+(1-\alpha)E(r_2))}$ and $\sigma_\varepsilon^2 = R^2 Var[\alpha r_1^* + (1-\alpha) r_2^*]$ where $r_i^* = (r_i - E(r_i))$. Hence we can re-write the approximation for the two asset case according to:

$$\rho \approx R\frac{\sigma_P}{2}\frac{Var(\alpha r_1^* + (1-\alpha) r_2^*)}{(1+\alpha E(r_1) + (1-\alpha) E(r_2))}$$

$$\rho \approx R\frac{\sigma_P}{2}\frac{\alpha^2 Var(r_1^*) + (1-\alpha)^2 Var(r_2^*) + 2\alpha(1-\alpha) Cov(r_1^*, r_2^*)}{(1+\alpha E(r_1) + (1-\alpha) E(r_2))}$$

For the relevant assumption of $Var(r_1^*) - Var(r_2^*) < 0$ and under $E(r_2) = E(r_1) = E(r)$ we have that

$$\rho \approx R\frac{\sigma_P}{2}\frac{\alpha^2 Var(r_1^*) + (1-\alpha)^2 Var(r_2^*) + 2\alpha(1-\alpha) Cov(r_1^*, r_2^*)}{1+E(r)} \tag{13}$$

and if

$$2\alpha[Var(r_1^*) + Var(r_2^*)] - 2Var(r_2^*) + (2-4\alpha) Cov(r_1^*, r_2^*) < 0$$

an increase in α reduces the premium. This will be true whenever

$$\alpha < \frac{Var(r_2^*) - Cov(r_1^*, r_2^*)}{[Var(r_1^*) + Var(r_2^*) - 2Cov(r_1^*, r_2^*)]}$$

Hence, increasing the share of α above this level leads to an increase in the premium. For the case of $E(r_2) = E(r_1) = E(r)$ we may approximate the fee by (13).

D Solving the 2-Asset Case

This implies for the maximization of (3) that the first order condition with respect to the share α is given by:

$$\phi(R)\frac{\sigma_P/\sigma_G}{(1+E(r))}\left[\begin{array}{c} \alpha Var(r_1^*) \\ -(1-\alpha) Var(r_2^*) \\ +(1-2\alpha) Cov(r_1^*, r_2^*) \end{array}\right] = [1-\phi(R)] h(\sigma) t_i$$

and the share is given by

$$\begin{aligned} \alpha &= \frac{Var(r_2^*) - Cov(r_1^*, r_2^*)}{Var(r_1^*) + Var(r_2^*) - 2Cov(r_1^*, r_2^*)} \\ &\quad - \frac{[1-\phi(R)]}{\phi(R)} \frac{2(1+E(r)) h(\sigma)(\sigma_G/\sigma_P) t_i}{2[Var(r_1^*) + Var(r_2^*)] - 4Cov(r_1^*, r_2^*)} \end{aligned}$$

Given that the best an investor can do with equal expected return assets is to minimize the risk associated with them, $\frac{Var(r_2^*) - Cov(r_1^*, r_2^*)}{Var(r_1^*) - Var(r_2^*) - 2Cov(r_1^*, r_2^*)}$ is the optimal portfolio in this context since it minimizes the risk premium (and hence maximizes expected utility). Therefore we have that approximately:

$$\alpha = \alpha^* - \frac{[1-\phi(R)]\,h(\sigma)}{\phi(R)}\frac{\sigma_G}{\sigma_P}\frac{(1+E(r))\,t_i}{[Var(r_1^*)+Var(r_2^*)]-2Cov(r_1^*,r_2^*)}$$

Which is the solution in the text with $\alpha^* = \frac{Var(r_2^*)-Cov(r_1^*,r_2^*)}{Var(r_1^*)+Var(r_2^*)-2Cov(r_1^*,r_2^*)}$ and $\theta = \frac{(1+E(r))}{[Var(r_1^*)+Var(r_2^*)]-2Cov(r_1^*,r_2^*)}$.

To simplify notation we re-write the first order condition for the shares according to

$$\begin{aligned}\alpha_i &= \alpha_i^* - \frac{[1-\phi(R)]\,h(\sigma)}{\phi(R)}\frac{\sigma_G}{\sigma_P}\theta t_i \\ \alpha_i &= \alpha_i^* - \delta\theta t_i X \end{aligned}\tag{14}$$

where we denote the probability ratio $X = \frac{[1-\phi(R)]}{\phi(R)}$ and $\delta = \frac{h(\sigma)\sigma_G}{\sigma_P}$. Recall that $E(r_2) = E(r_1) = E(r)$ implies $E(\sum\alpha_i r_i) = E(r)$ then first-order condition with respect to reserves is given by

$$\left(g - E(r) + \frac{\rho}{\sigma_G}\right) = \frac{h(\sigma)}{(1+\varepsilon_{\phi,R})}(X-\varepsilon_{\phi,R})\left(1 - t_* + \sum t_i\alpha_i\right)\tag{15}$$

Using (14) in (15) result in a quadratic equation in X of the form $AX^2 - BX + C = 0$ where the single coefficients are given by:

$$\begin{aligned}C &= g - E(r) + \frac{h(\sigma)\,\varepsilon_{\phi,R}}{(1+\varepsilon_{\phi,R})}[1 - t_* - t_1(\alpha_1^* - a_2^*)] \\ &\quad + \frac{\sigma_P}{\Omega\sigma_G}\left[(a_1^*)^2 Var(r_1^*) + (a_2^*)^2 Var(r_2^*) + a_1^* a_2^* Cov(r_1^*, r_2^*)\right]\end{aligned}$$

$$\begin{aligned}B &= \frac{h(\sigma)}{(1+\varepsilon_{\phi,R})}\left[1 - t_* - t_1(\alpha_1^* - a_2^*) - \varepsilon_{\phi,R}2h(\sigma)\frac{\sigma_G}{\sigma_P}\theta(t_1)^2\right] \\ &\quad - \frac{\theta h}{1+E(r)}t_1[a_2^* Var(r_2^*) + a_1^* Var(r_1^*) + (a_1^* - a_2^*)\,Cov(r_1^*, r_2^*)]\end{aligned}$$

$$A = \theta\frac{\sigma_G}{\sigma_P}h(\sigma)^2(t_1)^2\left(\Phi - \frac{2}{1+\varepsilon}\right)$$

where $\Omega = 2(1+E(r))$ and $\Phi = \frac{\theta}{\Omega}[Var(r_1^*) + Var(r_2^*) - 2Cov(r_1^*, r_2^*)]$. For reasonable parameter values the second terms of B and C are negligible since they multiply three fractions. It is worth noting that the values of A are generally such that A is irrelevant for the comparative statics, unless variance and covariance take extremely high values or transaction costs become unreasonably high, since then portfolio decision have stronger repercussions for the optimal reserve level. The relevant solution is given by

$$X = \frac{B}{2A} - \frac{\sqrt{B^2 - 4AC}}{2A}$$

It can be shown that the following relationships hold (in general) $\frac{\partial X}{\partial \sigma} >, \frac{\partial X}{\partial g} > 0$ which due to $\frac{\partial R}{\partial X} < 0$ imply that $\frac{\partial R}{\partial g} < 0$, $\frac{\partial R}{\partial E(r)} < 0$, $\frac{\partial R}{\partial t_1} < 0$ $\frac{\partial R}{\partial t_2} < 0$ and $\frac{\partial R}{\partial \sigma_P} < 0$.

E Data

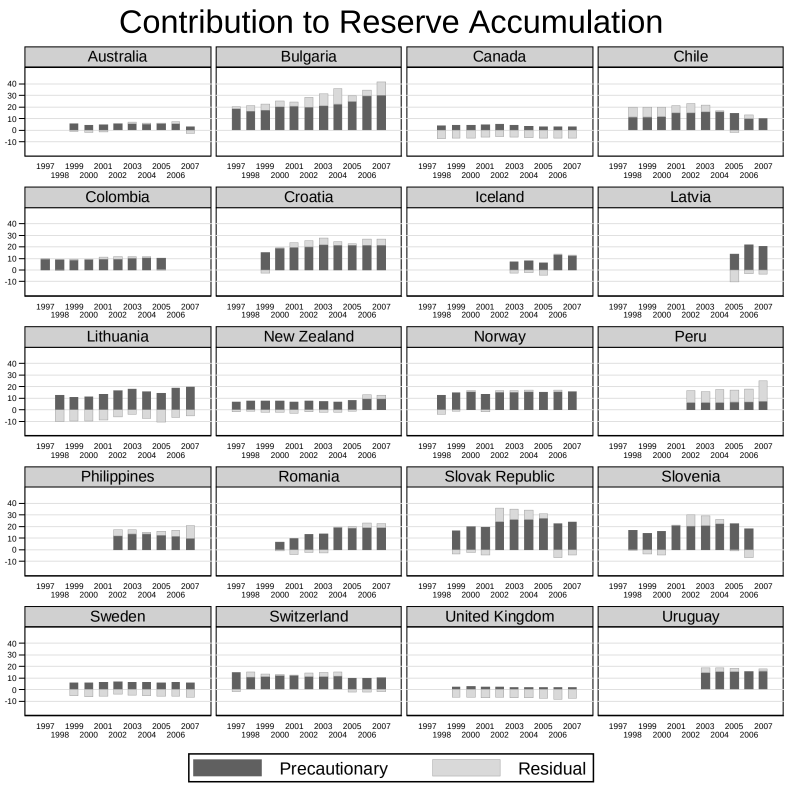
The following countries build the sample: Australia, Bulgaria, Canada, Chile, Columbia, Croatia, Iceland, Latvia, Lithuania, New Zealand, Norway, Peru, Philippines, Romania, Slovak Republic, Slovenia, Sweden, Switzerland, United Kingdom, and Uruguay. Data was taken from IMF DOT, IMF COFER, IFS, Annual Reports and SDDS of the various central banks or responsible authorities. The IMF classification and the updated classification of Reinhard and Rogoff (2002) was used to determine the pegs and the currency to which a nation pegged. The resulting anchor ordering is given in the table below:

	Anchor to			Anchor to	
Country	EA	US	Country	EA	US
Australia		80-82	Norway	80-07*	
Bulgaria	97-07		Peru		86
Canada			Philippines		85-96
Chile		88-05	Romania	01-07	
Colombia		80-07*	Slovak Republic	94-07	
Croatia	95-07		Slovenia	93-07	
Iceland	84-00		Sweden	80-92	
Latvia	02-07	96-01	Switzerland	83-97	
Lithuania	02-07	96-01	United Kingdom	91	
New Zealand			Uruguay		95-7

* From 83-86 not anchoring. Discontinued in 84.

F Contribution of precautionary motives to Reserve Accumulation

The following graph is derived from the first stage regression results. It depicts the contribution of the various aspects to the reserve accumulation by country and year. The height of the bar is the level of the reserves to GDP ratio. While the precautionary motive is positive for all countries the residual part can either be negative or adding to the precautionary motive. The residual is always the light shaded area. The precautionary motive is the distance from zero to the upper limit of the dark shaded area, if the residual is positive and the sum of the light shaded area and the dark shaded area when the residual is negative).


Contribution to Reserve Accumulation
Australia
Bulgaria
Canada
Chile
Colombia
Croatia
Iceland
Latvia
Lithuania
New Zealand
Norway
Peru
Philippines
Romania
Slovak Republic
Slovenia
Sweden
Switzerland
United Kingdom
Uruguay
40
30
20
10
0
-10
1997 1999 2001 2003 2005 2007
1998 2000 2002 2004 2006
Precautionary
Residual

G Robustness: Regression Results

	Robustness: Euro Share				Robustness: Dollar Share			
	(A11)	(A12)	(A13)	(A14)	(A15)	(A16)	(A17)	(A18)
Anchor			26.9***	19.9***			43.7***	35.9***
(EA/US)			(4.92)	(3.96)			(4.93)	(4.78)
Trade	0.76***	0.98***	0.43**	0.75***	1.05***	0.36	0.78***	0.40
(EA/US)	(0.20)	(0.19)	(0.17)	(0.17)	(0.29)	(0.32)	(0.22)	(0.25)
Exog EA	0.08	-0.34	0.40	-0.07	0.03	0.34	-0.39	-0.10
	(0.37)	(0.26)	(0.35)	(0.25)	(0.35)	(0.30)	(0.30)	(0.27)
Exog US	3.93***	4.00***	2.50***	2.97***	-4.39***	-4.22***	-3.20***	-3.29***
	(0.64)	(0.45)	(0.64)	(0.47)	(0.61)	(0.52)	(0.52)	(0.47)
Trend		3.17***		3.01***		-2.28***		-1.63***
		(0.26)		(0.24)		(0.31)		(0.29)
Constant	16.3**	4.16	17.4***	4.79	32.9***	45.9***	29.4***	38.4***
	(7.74)	(7.57)	(6.03)	(6.60)	(6.66)	(7.38)	(5.09)	(5.79)
Obs.	171	171	171	171	171	171	171	171
Countries	20	20	20	20	20	20	20	20
R2 (OLS)	0.35	0.43	0.53	0.60	0.24	0.25	0.51	0.50
Censored	1	1	1	1	4	4	4	4
Prob > F	1.38e-05	0.0001	0.002	0.00035	1.96e-05	1.11e-06	0.119	0.0068

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

	Second Stage: Euro Share in Reserves (alt I)						Second Stage: Dollar Share in Reserves (alt I)					
	(C11)	(C12)	(C13)	(C14)	(C15)	(C16)	(B13)	(B14)	(B15)	(B16)	(B17)	(B18)
Anchor EA/US	21.7***	24.2***	19.9***	17.8***	19.7***	22.0***	30.2***	51.4***	35.9***	36.8***	48.4***	50.2***
	(4.57)	(3.43)	(3.96)	(4.78)	(3.74)	(4.59)	(5.83)	(4.79)	(4.78)	(5.75)	(6.14)	(6.75)
Trade EA/US	0.57***	0.62***	0.75***	0.71***	0.60***	0.54***	0.43*	0.44*	0.40	0.39	0.51**	0.50**
	(0.16)	(0.18)	(0.17)	(0.17)	(0.16)	(0.16)	(0.23)	(0.25)	(0.25)	(0.25)	(0.24)	(0.24)
KAOPEN·EA	0.28			0.40		-1.40	-2.11*			-0.78		0.78
	(1.30)			(1.27)		(1.28)	(1.21)			(1.15)		(1.12)
KAOPEN·US	-8.68***			-5.22***		-4.67***	6.77***			-1.09		-0.87
	(1.41)			(1.73)		(1.77)	(1.88)			(2.30)		(2.13)
IMP·EA		0.83***			0.60***	0.62***		-0.63***			-0.54***	-0.57***
		(0.16)			(0.15)	(0.15)		(0.17)			(0.16)	(0.17)
IMP·US		-0.63*			0.44	0.10		2.33***			1.84***	1.87***
		(0.33)			(0.34)	(0.36)		(0.36)			(0.55)	(0.56)
Exog EA			-0.07	-0.05	0.02	0.07			-0.10	-0.10	-0.22	-0.24
			(0.25)	(0.25)	(0.24)	(0.24)			(0.27)	(0.27)	(0.26)	(0.26)
Exog US			2.97***	1.88***	2.85***	1.58**			-3.29***	-3.40***	-1.00	-1.19
			(0.47)	(0.58)	(0.56)	(0.72)			(0.47)	(0.65)	(0.72)	(0.84)
Trend	2.95***	2.40***	3.01***	2.98***	2.43***	2.56***	-1.53***	-1.22***	-1.63***	-1.55***	-1.14***	-1.16***
	(0.26)	(0.28)	(0.24)	(0.25)	(0.27)	(0.27)	(0.32)	(0.29)	(0.29)	(0.30)	(0.30)	(0.31)
Const.	11.99**	4.29	4.79	7.91	9.92	11.52*	37.81***	42.71***	38.38***	38.80***	40.55***	40.44***
	(5.95)	(7.14)	(6.60)	(6.40)	(6.31)	(6.14)	(5.33)	(6.08)	(5.79)	(5.79)	(5.80)	(5.88)
Obs. / Ctry	171/20	175/20	171/20	171/20	171/20	171/20	171/20	175/20	171/20	171/20	171/20	171/20
R2 (OLS)	0.629	0.689	0.597	0.627	0.700	0.712	0.512	0.557	0.502	0.528	0.562	0.594
Prob > F	0.482	0.003	0.001	0.027	0.019	0.121	0.135	0.0034	0.0083	0.0018	0.0096	0.00032

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

	Second Stage: Euro Share in Reserves (alt II)						Second Stage: Dollar Share in Reserves (alt II)					
	(C19)	(C20)	(C21)	(C22)	(C23)	(C24)	(B19)	(B20)	(B21)	(B22)	(B23)	(B24)
Anchor EA	7.71	6.98*	13.9***	1.04	11.7***	8.09	-4.47	4.09	-3.41	4.21	-1.68	-1.63
	(5.90)	(4.18)	(5.14)	(6.26)	(4.31)	(5.17)	(5.84)	(4.79)	(5.39)	(6.18)	(4.94)	(5.84)
Anchor US	-32.2***	-43.7***	-36.7***	-41.8***	-42.8***	-46.9***	35.2***	56.5***	42.3***	45.9***	51.8***	54.5***
	(6.32)	(5.70)	(5.64)	(6.47)	(6.71)	(7.31)	(6.23)	(6.20)	(5.41)	(6.35)	(7.13)	(7.64)
Trade US	0.40**	0.41***	0.31*	0.50***	0.35**	0.42***	0.62***	0.79***	0.73***	0.74***	0.75***	0.73***
	(0.18)	(0.15)	(0.17)	(0.19)	(0.15)	(0.16)	(0.22)	(0.24)	(0.23)	(0.24)	(0.23)	(0.24)
KAOPEN EA	5.04***			4.80***		1.41	-3.42**			-3.05**		0.16
	(1.48)			(1.41)		(1.35)	(1.43)			(1.33)		(1.37)
KAOPEN US	-2.80			3.77		2.87	4.72**			-2.99		-2.15
	(1.91)			(2.41)		(2.08)	(1.99)			(2.46)		(2.21)
IMP EA		1.08***			0.97***	0.89***		-0.92***			-0.81***	-0.81***
		(0.14)			(0.14)	(0.15)		(0.16)			(0.16)	(0.18)
IMP US		-1.44***			-1.33***	-1.36***		2.28***			1.82***	1.80***
		(0.35)			(0.50)	(0.49)		(0.42)			(0.58)	(0.58)
Exog EA			0.65**	0.48	0.62**	0.59**			-0.42	-0.32	-0.42	-0.44
			(0.31)	(0.30)	(0.27)	(0.27)			(0.30)	(0.29)	(0.26)	(0.27)
Exog US			2.35***	3.08***	0.29	0.82			-3.06***	-3.59***	-0.68	-1.11
			(0.56)	(0.72)	(0.71)	(0.79)			(0.57)	(0.74)	(0.74)	(0.87)
Const.	29.49***	25.47***	32.36***	28.63***	26.17***	24.77***	34.73***	34.54***	31.50***	29.92***	36.45***	36.64***
	(6.83)	(5.97)	(6.70)	(7.27)	(5.84)	(5.85)	(5.65)	(6.29)	(5.99)	(6.27)	(6.02)	(6.15)
Obs./ Cntry	171/20	175/20	171/20	171/20	171/20	171/20	171/20	175/20	171/20	171/20	171/20	171/20
Log Lik	-669.4	-660.9	-666.4	-659.8	-641.4	-639.9	-664.3	-656.3	-656.3	-653.0	-637.0	-636.5
R2 (OLS)	0.598	0.688	0.602	0.598	0.697	0.699	0.584	0.601	0.588	0.586	0.613	0.613
Prob > F	0.401	0.412	0.110	0.0961	0.501	0.304	0.607	0.0144	0.0761	0.0422	0.0416	0.0098

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

	Second Stage: Euro Share in Reserves (alt III)						Second Stage: Dollar Share in Reserves (alt III)					
	(C25)	(C26)	(C27)	(C28)	(C29)	(C20)	(B25)	(B26)	(B27)	(B28)	(B29)	(B20)
Anchor EA/US	15.9***	23.7***	26.9***	14.3**	21.5***	17.3***	36.6***	53.4***	43.7***	44.4***	52.9***	55.4***
	(5.77)	(4.09)	(4.92)	(6.07)	(4.41)	(5.26)	(5.98)	(5.06)	(4.93)	(5.93)	(6.32)	(6.95)
Trade EA/US	0.50***	0.28*	0.43**	0.56***	0.28*	0.34**	0.66***	0.73***	0.78***	0.70***	0.78***	0.75***
	(0.17)	(0.17)	(0.17)	(0.18)	(0.15)	(0.15)	(0.21)	(0.23)	(0.22)	(0.22)	(0.22)	(0.23)
KAOPEN EA	5.22***			5.12***		1.68	-3.97***			-2.62**		-0.04
	(1.61)			(1.60)		(1.47)	(1.23)			(1.18)		(1.16)
KAOPEN US	-7.34***			-4.80**		-2.94	4.95**			-2.77		-2.19
	(1.83)			(2.23)		(2.04)	(1.97)			(2.45)		(2.20)
IMP EA		1.43***			1.14***	1.04***		-0.95***			-0.80***	-0.79***
		(0.17)			(0.16)	(0.17)		(0.15)			(0.16)	(0.17)
IMP US		0.02			0.92**	0.75**		2.10***			1.88***	1.84***
		(0.34)			(0.36)	(0.36)		(0.37)			(0.56)	(0.56)
Exog EA			0.40	0.29	0.38	0.35			-0.39	-0.36	-0.41	-0.42
			(0.35)	(0.34)	(0.30)	(0.30)			(0.30)	(0.29)	(0.26)	(0.26)
Exog US			2.50***	1.55**	2.76***	2.04**			-3.20***	-3.42***	-0.69	-1.14
			(0.64)	(0.75)	(0.66)	(0.82)			(0.52)	(0.70)	(0.74)	(0.86)
Const.	18.6***	18.9***	17.4***	16.5**	22.9***	22.3***	32.4***	37.1***	29.4***	32.1***	35.4***	35.8***
	(6.15)	(6.61)	(6.03)	(6.40)	(5.85)	(5.52)	(4.90)	(5.35)	(5.09)	(5.21)	(5.25)	(5.31)
Obs / Cntry	171/20	175/20	171/20	171/20	171/20	171/20	171/20	175/20	171/20	171/20	171/20	171/20
Log Lik	-682.3	-686.9	-687.6	-680.0	-660.1	-658.5	-664.6	-656.7	-656.5	-653.2	-637.1	-636.6
R2 (OLS)	0.542	0.657	0.533	0.542	0.677	0.690	0.514	0.559	0.505	0.531	0.564	0.593
Prob > F	0.145	0.0004	0.0037	0.0170	0.0074	0.0923	0.978	0.0607	0.204	0.0826	0.0733	0.0052

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

H Robustness: Chamberlain Adjustment

	CM-Adjutsm.: 2^{nd} Stage: Euro Share in Reserves						CM-Adj.: 2^{nd} Stage: Dollar Share in Reserves					
	(B1*)	(B2*)	(B3*)	(B4*)	(B5*)	(B6*)	(B7*)	(B8*)	(B9*)	(B10*)	(B11*)	(B12*)
Anchor EA	16.5***	3.99	10.4**	7.05	7.78*	6.08	-11.6**	5.48	-1.76	0.06	0.85	-0.49
	(5.01)	(4.05)	(4.25)	(5.05)	(4.28)	(5.57)	(5.80)	(4.60)	(4.85)	(5.86)	(4.86)	(6.48)
Anchor US	-16.2***	-42.2***	-23.7***	-24.8***	-37.3***	-38.1***	22.4***	53.1***	30.9***	33.5***	47.5***	48.4***
	(5.83)	(5.17)	(4.82)	(5.75)	(6.23)	(6.74)	(6.66)	(5.97)	(5.45)	(6.61)	(7.00)	(7.73)
Trade EA	0.74**	0.65**	0.73**	0.85***	0.59**	0.62**	-0.74	-0.25	-0.49	-0.47	-0.11	-0.12
	(0.34)	(0.27)	(0.31)	(0.32)	(0.28)	(0.31)	(0.50)	(0.43)	(0.46)	(0.46)	(0.43)	(0.43)
KAOPEN·EA	0.99			1.26		-0.04	-0.02			-0.27		1.30
	(1.32)			(1.24)		(1.37)	(1.46)			(1.36)		(1.47)
KAOPEN·US	-6.52***			0.38		-0.28	6.76***			-1.55		-0.66
	(1.64)			(2.05)		(1.92)	(1.92)			(2.38)		(2.22)
IMP·EA		0.37**			0.35**	0.35*		-0.45**			-0.43**	-0.51**
		(0.15)			(0.15)	(0.18)		(0.18)			(0.18)	(0.21)
IMP·US		-2.52***			-2.0***	-2.07***		2.97***			2.4***	2.39***
		(0.36)			(0.54)	(0.54)		(0.42)			(0.62)	(0.62)
Exog EA			0.10	0.06	0.22	0.21			0.02	0.02	-0.13	-0.16
			(0.24)	(0.24)	(0.22)	(0.23)			(0.28)	(0.28)	(0.26)	(0.26)
Exog US			2.93***	3.00***	0.68	0.64			-3.32***	-3.65***	-0.69	-0.88
			(0.44)	(0.59)	(0.65)	(0.79)			(0.52)	(0.70)	(0.74)	(0.90)
Trend	2.66***	2.32***	2.64***	2.54***	2.29***	2.29***	-2.20***	-1.60***	-2.02***	-1.96***	-1.51***	-1.54***
	(0.28)	(0.24)	(0.24)	(0.26)	(0.25)	(0.26)	(0.38)	(0.32)	(0.32)	(0.36)	(0.34)	(0.35)
Const.	18.39**	19.65**	17.31**	16.82**	19.98***	22.69***	49.65***	48.52***	50.74***	51.06***	46.24***	46.05***
	(8.40)	(8.40)	(7.66)	(7.80)	(7.72)	(7.29)	(8.90)	(9.21)	(8.37)	(8.66)	(8.81)	(8.54)
Obs. / Ctry	171 / 20	175 / 20	171 / 20	171 / 20	171 / 20	171 / 20	171 / 20	175 / 20	171 / 20	171 / 20	171 / 20	171 / 20
Log Lik	-630.8	-622.0	-617.8	-617.0	-605.3	-603.1	-647.1	-638.7	-633.7	-632.9	-621.6	-619.2
R2 (OLS)	0.653	0.711	0.641	0.649	0.715	0.714	0.589	0.600	0.588	0.589	0.611	0.611
Prob > F	0.855	0.155	0.111	0.165	0.217	0.091	0.112	0.0004	0.0032	0.0056	0.0055	0.002

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$