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DEMAND FOR RESERVES UNDER INTERNATIONAL CAPITAL MOBILITY

Pablo García

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DEMAND FOR RESERVES UNDER INTERNATIONAL CAPITAL MOBILITY

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Resumen

En este trabajo considero la determinación de las reservas internacionales en un contexto de movilidad internacional de capital. Estudio un modelo donde las reservas representan un colateral internacional para el endeudamiento externo, el cual se determina endógenamente por inversionistas aversos al riesgo. Esta aproximación se aleja de los modelos tradicionales de demanda por reservas, que enfatizan un marco basado en demanda por dinero o acumulación óptima de inventarios. Al contrario que en la aproximación tradicional, encuentro que el efecto de variables como la tasa de interés internacional y la volatilidad de la balanza de pagos tienen un efecto ambiguo sobre el nivel de reservas. Acciones secuenciales por parte del Banco Central y del inversionista extranjero rompen esta ambigüedad. La evidencia empírica es sugerente: mientras la tasa LIBOR y la volatilidad de los términos del intercambio afectan positivamente el nivel de reservas en los países de la OECD, este efecto se invierte en el resto de los países. Interpreto estos y otros resultados como indicativos que la credibilidad en las acciones es un determinante importante del nivel de reservas y de endeudamiento externo a través de distintos grupos de países.

Abstract

In this research, I assess the determinants of foreign exchange reserves under endogenous capital flows. I consider a model where reserves represent collateral to international borrowing, which is endogenously determined by risk averse foreign investors. This is a departure from usual models of reserve accumulation, that focus solely on the portfolio decision of a central bank along the lines of optimal inventory control models or precautionary saving. In contrast to this view, I find that the expected effect on reserves of changes in the international interest rate or the volatility of the terms of trade is ambiguous if actions are simultaneous. However, if foreign investors and the central bank act sequentially, this ambiguity breaks down. Empirical evidence from OECD and non-OECD economies is suggestive: while LIBOR and terms of trade volatility positively affects the demand for reserves in OECD economies, the effects are reversed in non-OECD countries. This indicates that commitment issues are an important factor in the determination of reserves in non-OECD countries.

Comments are welcome. The views presented in this paper do not necessarily represent the opinion of the Central Bank of Chile. This research is a modified version of Chapter 3 of the author's PhD dissertation at MIT. I thank participants at seminars at the Central Bank of Chile, LACEA 1999, and at the MIT International Economics and Money workshops for useful suggestions. I am particularly grateful to Jaume Ventura, Rudi Dornbusch, Ricardo Caballero and José De Gregorio. All remaining errors are mine. E-mail: pgarcia@condor.bcentral.cl

1 Introduction and Motivation

The volatility of the balance of payments has been at the center of policy discussion in recent times, due the large real effects that seem to be associated with it. The literature on optimal reserve demand has traditionally dealt with this issue by arguing that reserves provide a buffer stock that helps smooth the shocks to the balance of payments. This traditional framework stems from the portfolio decision of a representative agent, along the lines of a money demand equation or optimal inventory models. This is an adequate framework in a situation with fixed exchange rates and pervasive capital controls, like the pre-floating era.

In a narrow sense the role of reserves as a buffer stock has not changed. However, the economic environment where small economies operate has undergone a large transformation in the last few decades. Now it is aknowledged that the capital account of small open economies displays large amounts of variation that are reflected both in the size and composition of capital flows. Furthermore, small economies differ markedly in the conduct of monetary and exchange rate policy. This is reflected both in the choice of the exchange rate regime and on the actual sterilization of sudden capital inflows or outflows, the latter sometimes leading to balance of payments crisis.

These considerations loom large in the usefulness of traditional models of optimal reserve determination. Indeed, in the presence of endogenous capital flows, sterilization and default, the effect of various disturbances on reserves must be assessed in an expanded setting that considers the interaction with international borrowing.

I will focus on a model of international borrowing and reserve accumulation, that brings to the fore borrowing constraints, the endogenous determination of the probability of default, and reserves as collateral. Demand for reserves and international borrowing are determined jointly by the actions of an international lender and a central bank. From a methodological point of view, this strategy implies leaving the current account in the background. I think this is a realistic approach, as intertemporal models of the current account (like in Obstfeld and Rogoff 1996, Frenkel and Razin 1996) are not able to account for the large swings in relative prices and capital flows that are observed over time and across countries. Moreover, the theoretical implications on the equilibrium net foreign asset position in less developed countries appear out of line with what is observed in the data.[1]

This model will be used to assess the effect on reserves of the international interest rate, the volatility of the terms of trade, and the choice of the exchange rate regime. These issues are at the core of the literature on demand for reserves.

The traditional view in the literature is as follows.[2] First, the international risk free rate is typically related to the return earned on reserves. Hence, everything else constant an increase in the risk free rate decreases the opportunity cost of holding reserves. As demand is downward sloping, in equilibrium reserves increase. Second, an increase in the

[1]Obstfeld and Rogoff (1996), pp.116 make this point: a back of the envelope calculation predicts unrealistically large current account deficits on growing economies. Note that recent work by Kray and Ventura (1999) qualifies these effects for OECD economies.

[2]In next section I give a more detailed review of the literature

volatility of the terms of trade increases the demand for reserves, through precautionary saving motives. Third, countries with flexible exchange rates should be expected to hold less reserves, as they instead use the flexibility of the exchange rate as an alternative adjustment mechanism.

I will complement this traditional view with the endogenous determination of international borrowing, considering that foreign exchange reserves are an important component of the international collateral of the country. In this environment, the expected effect of the international interest rate and the volatility of the terms of trade become ambiguous. This ambiguity stems from two conflicting effects. On the one hand, changes in the international interest rate directly affect the demand for reserves through the opportunity cost argument described above. However, interest rate changes also induce a shift in the portfolio of international investors, changing the need to hold reserves as collateral. These two effects work in different directions. Terms of trade volatility similarly has conflicting effects.

The intuition for these results is as follows. If external borrowing is constrained (because of moral hazard considerations for example) and reserves represent collateral provided by the country and default is costly, the central bank will optimally demand reserves. At the margin, the central bank chooses reserves in such a way that the opportunity cost equals the marginal benefit, given by the decrease in the likelihood of default times the cost of default. An increase in the international interest rate decreases the opportunity cost, but also *ceteris paribus* decreases the amount of international borrowing and thus the likelihood of default. An increase in the volatility of the terms of trade increases the likelihood of default, hence increasing the demand for reserves. However, foreign borrowing, and thus the likelihood of default decreases.

Commitment by either international lenders or the domestic central bank breaks this ambiguity, as international borrowing and reserves are strategic complements in the model. If the central bank can commit itself to hold a certain amount of reserves before international borrowing is determined, then at the margin the traditional effect of international interest rates and balance of payments volatility on reserve demand dominates. Similarly, if international borrowing is determined before reserves, then at the margin the effect of international interest rates and volatility work through the decisions of the foreign investor. Hence it should be expected for example that increases in international interest rates lower the demand for reserves.

I present empirical evidence that is broadly supportive of these claims. I estimate reserve demands in a panel of small OECD and non-OECD countries over the period 1970 to 1998. I find that increases in the LIBOR as well as in the volatility of the terms of trade are positively related to reserves in OECD countries. In non-OECD countries however the results are reversed. Higher international interest rates and the terms of trade volatility are negatively associated with reserves. This is in line with the commitment argument outlined above.

Furthermore, I check the effect of the exchange rate regime and the maturity composition of external debt in non-OECD countries. The findings imply that a low stock of reserves is associated to fixed exchange rates and short-term external debt. This points out that fixed exchange rates *per-se* are not a sufficient commitment strategy.

The rest of the paper is structured as follows. In Section 2 I provide a brief assesment of the related literature. In Section 3 I construct a partial equilibrium model based on porfolio choice, borrowing constraints, and costly default, that highlights the interaction between the stock of reserves and foreign borrowing. I then analyze what is the role of the international interest rate, the volatility of the terms of trade and the choice of exchange rate arrangements in determining equilibrium reserves. In section 4 I estimate a reduced form of the model in a panel of countries. Section 5 concludes.

2 Related literature

The literature on the optimal level of international reserves dates back to interwar attempts to reconstruct the international financial system. In the post-war era, the Bretton-Woods arrangement and the creation of the IMF renewed the interest on the topic [3]; in a world economy where capital controls were prevalent and fixed exchange rates were the norm, the adequate provision of liquidity in times of need was of ultimate importance. This is the case even though the IMF, then and now, has the ability to provide limited balance of payments support in times of crisis.

In the sixties, the development of money demand theory along the lines of optimal inventory control provided a natural theoretical benchmark for the study of optimal reserve accumulation. Indeed, a world of fixed exchange rates and capital controls closely mimics the environment that a credit constrained individual agent faces in the economy. This led to a large body of empirical research in the late sixties and early seventies.[4]

This framework was subsequently refined theoretically and empirically. Frenkel and Jovanovic (1981) focused on a stochastic inventory control model, explicitly considering the process driving the balance of payments. In particular, they assumed that the balance of payments is the following

$$dR(t) = -\mu t + \sigma dW(t); \quad R(0) = R_0, \quad \mu \geq 0 \tag{1}$$

where $W(t)$ is a Wiener process. Hence the change in reserves over a small time interval dt has mean $-\mu dt$ and variance $\sigma^2 dt$.

Furthemore, a cost of depletion D is incurred whenever reserves reach a lower bound. Frenkel and Jovanovic relate this cost to the process of replenishment of the optimal stock of reserves once it reaches the lower bound.[5] More generaly, this cost can be associated with the use of alternative balance of payments adjustment mechanisms once reserves are depleted; the argument states that exchange rate, fiscal and monetary policies are more costly to implement without a buffer of foreign exchange.[6]

[3]Grubel (1971) cites League of Nations (1930) and IMF (1958) as earlier empirical studies

[4]For a review of that literature, see Grubel (1971), Kelly(1970)

[5]The basic features of the model are not altered if an upper bound for reserve accumulation is imposed, as in Jung (1995).

[6]Another way to understand the cost of depletion is to associate it with costly renegotiation.

Apart from the cost of depletion, Frenkel and Jovanovic include a *flow* cost r related to the opportunity cost of holding reserves. Total cost minimization then leads to a log-linear expression for the optimal level of reserves.

$$\ln \bar{R} = a_0 + a_1 \ln \sigma + a_2 \ln r + \ln D \tag{2}$$

where D is the depletion cost, r is the opportunity cost and σ is the measure of balance of payments volatility.

An interesting aside of this literature is that it can be related to first generation stochastic models of balance of payment crisis. Indeed, in these models the exchange rate is fixed and reserves gradually fall, until they reach a lower bound where they are suddendly depleted. Moreover, at the transition this is accompanied by a fall in money demand, in such a way that there are no capital losses on the path to the floating exchange rate regime.[7]

Typically in these models domestic credit follows a stochastic process with drift, which implies a steadily decreasing level of reserves, given money demand, that is represented by an equation like 1. Hence, Equation 2 can be interpreted as the desired level of reserves by a central bank given that it knows it will be subject to a speculative attack, and weighs the costs and benefits of delaying reserve depletion.

Following this interpretation, the optimal reserve literature can be understood as a first-stage portfolio problem where the central bank chooses the *composition* of its balance sheet (given money demand).

This interpretation is useful because it highlights the partial equilibrium side of traditional models of reserve demand. Indeed, terms of trade volatility and interest rates are given exogenously and have unambiguos effects on the timing of the crisis.

Moreover, the estimation of Equation 2 has typically considered a scaling factor A. Hence, the equation estimated becomes

$$\ln \bar{R} - \ln A = a_0 + a_1 \ln \sigma + a_2 \ln r + \ln D \tag{3}$$

Equation 3 has been estimated over time and across countries. The literature has paid particular attention to the empirical counterpart to measures of r, σ, D and A. I will briefly describe the main approaches.[8]

Flow cost r. Edwards (1985) pointed out that this should be associated with an interest rate spread, considering the interest paid on reserves, and the marginal opportunity cost of using the stock of reserves. If at the margin investment is financed through capital flows, then the appropriate alternative cost should be the marginal utility of consumption, or the interest on government debt.

[7] Flood and Garber (1984) and Dornbusch (1986) provide the prototypical models. Broner (1998) considers a version in which capital losses can occur on the transition.

[8] A complete survey on the historical empirics of reserve demand is out of the scope of this research. The more recent literature is summarized in Miller (1995), Lizondo and Mathieson (1987) and Bahmani-Oskooee (1985)

Volatility σ. Here there are two approaches in the literature. One considers a direct measure of balance of payments volatility. However, this variable is endogenous. Hence, the volatility of export returns or the terms of trade seems is an appropriate choice for small economies.

Cost of depletion D. Gottlieb and Ben-Bassat (1995) construct a discounted measure of output losses after default, as a proxy for the cost of depletion. Mostly though this term has been embedded in the estimation constant.

Scaling factor A. The tradition here has been to consider imports as the appropriate scale for reserves. This has several shortcomings though. First, it does not consider the effect of maturity mismatch on the severity of a balance of payments crisis. It can also be argued that commercial credit is the last component of capital flows that is subject to borrowing constraints. The size and violence of capital outflows in recent balance of payments crisis, along with the large balance sheet effects that follow from the adjusment in relative prices have been of the same order of magnitude as import compression. These issues have been highlighted in recent research on the effect of capital market imperfections in open economies (Caballero and Krashnamurthy 1998). Typically the stock of international reserves will be the most readily available collateral in case of a liquidity shock. Therefore, international reserve accumulation, by reducing the liquidity premium on foreign investment in the country, creates a positive externality. However, the degree to which reserves correspond to the total stock of international collateral depends on the degree of financial development of the economy.[9]

All variables in Equation 3 are endogenous, in particular under international capital mobility. The empirical section will detail in which way I will tackle this endogeneity problem.

In the next section I construct a partial equilibrium model in which the stock of reserves is determined jointly with international borrowing. This moves away from the usual assumption that the reserves to imports ratio is the important consideration, and focuses on the role of reserves as international collateral.

3 A model of international borrowing and reserve accumulation

I will consider a two period model of the balance of payments in which portfolio decisions, given by external borrowing and reserve accumulation, are made in period 1. At the beginning of period 2 uncertainty about the flow of funds in the economy is revealed, leading to the possibility of default. At the end of period 2 consumption occurs. Equilibrium in this stylized economy is determined by the interaction between two agents: (1) a risk-averse lender which in period one determines the capital account of the economy,

[9]This point is stressed in Aghion, Bachetta and Banerjee (1999). They focus on the role of capital market imperfections in driving aggregate fluctuations. In their model, only countries at an intermediate level of financial development experience cycles as the economy moves between constrained and unconstrained states. Highly developed countries and countries at low levels of development are never constrained and always constrained, respectively. Therefore their economies do not experience cycles.

and that in case of default only obtains the international collateral that is available, which consist of the stock of international reserves accumulated by the central bank in period 1. (2) a risk-neutral central bank that manages the capital account surplus between a current account deficit and reserve accumulation, considering the alternative cost of reserve accumulation, as well as the likelihood of costly default.

This model, by focusing on the capital account side of the balance of payments will highlight the tradeoffs inherent in a world of international capital mobility.

It will be a partial equilibrium model: it assumes two specific imperfections in the economy. On the one hand (and as was mentioned above) there is a capital market imperfections that leads to the existence of collateral. This can be motivated by a variety of forms, but can be assumed to be the endogenous response of the central bank to the existence of credit constraints.[10] On the other hand, the reserve accumulation decision is not privatized, and is undertaken by the central bank independently of the private sector.

Borrowing constraints. The recent crisis in emerging markets has spurred a large literature, in which borrowing constraints are a prime ingredient to understand volatility (as in Aghion, Bachetta and Banerjee (1999)) and large swings of relative prices not related to fundamentals (as the fire-sales in Caballero and Krishnamurthy 1998). In these settings, the imperfections in capital markets imply that the constraints agents face change endogenously according to the environment and the size of the shocks that hit the economy. This is an important feature in countries with under-developed domestic financial markets, due either to a history of government default or of moral hazard considerations that lead to distortions on the private allocation of credit by domestic agents. [11]

Centralization of Reserve management. Governments typically are in charge of reserve accumulation at the central bank. Or in other words, even though the stock of reserves is rarely a policy objective *per-se*, the mix of monetary, fiscal and exchange rate policy, along with structural features of the economy, like the openness of the current and capital account, imply a certain stock of reserves in equilibrium. However, some recent experiences have shown how this role can be somewhat decentralized by the development of the domestic financial sector. For example, the move towards narrow-banking under a currency board allows a certain degree of privatization of reserve management. Also, and related to the point above, in countries with a high degree of financial development the private sector can hedge exchange rate risk. Some recent experiences though show how in underdeveloped financial markets, the stock of international reserves at the central bank ends up being the only usable international collateral under extreme financial distress, either because of default on forward contracts or because of the fragility of the banking sector.

Next I will focus on the behaviour of the agents in the economy and how reserves

[10] Therefore, by publicly providing collateral, the central bank relaxes the credit constraints on the economy.

[11] Corsetti, Pesenti and Roubini (1998) present a model along these lines, in which a balance of payments crisis happens not because of the explicit growth of government liabilities, but through the implicit backing of private borrowing.

and international borrowing are determined. [12].

3.1 The economic environment

The economy can be characterized as an asset that yields a stochastic flow of *tradable* production during period 2, given by Y_T. There is a debt contract between the domestic owners of the productive asset and foreign lenders, that specifies a borrowing amount B_i (denominated in foreign currency) and an interest rate r_i on the loan. However, there will be *ex-post* default if the tradeable resources available in the economy are not enough to cover the repayment on the debt. These are Y_T plus the amount of international collateral available, which I will relate to the stock of international reserves, adjusted for the interest they receive abroad, assumed to be the riskless rate ρ^*. Hence, default occurs if

$$R(1+\rho^*) + Y_T < B_i(1+r_i) \tag{4}$$

Equation 4 gives the probability of default, that can be related to the stochastic behaviour of tradable output. Default occurs if $Y_T < \bar{Y_T} = B_i(1+r_i) - R(1+\rho^*)$. If Y_T has a cdf given by $\Phi(Y_T)$, then the probability of default is given by

$$\Pr(\text{default}) = \Phi[B_i(1+r_i) - R(1+\rho^*)] = \Phi[\bar{Y_T}] \tag{5}$$

3.2 Agents

The key ingredient of the model is the endogenous determination of the probability of default, through the interaction between foreign investors that determine external borrowing B_h and the Central Bank that sets reserve accumulation R.

The foreign investor. The foreign investor has wealth W, that it can allocate either to a loan to the domestic firm or to an emerging market mutual fund, with returns with mean ρ and variance σ^2. Given that default is possible, the return on the loan is stochastic. In particular, the expected return ρ_i and variance σ_i^2 on the loan are given by

$$\rho_i = (1-\Phi)r_i + \Phi\frac{R}{B_i} \tag{6}$$

$$\sigma_i^2 = \frac{\Phi}{1-\Phi}\left(r_i - \frac{R}{B_i}\right)^2 \tag{7}$$

Now, from Equations 6 and 7 we see that the extent of borrowing affects both the mean and variance of the returns. I will assume however that the bank behaves

[12] Part of the model is based on Frenkel and Razin (1996)

competitively, hence it does not internalize these effects. This can be justified by thinking of the representative bank as the collection of a large number of identical nean-variance banks. Thus, if a share θ of its wealth is allocated to the domestic economy, utility is given by

$$U(W) = \theta\rho_i + (1-\theta)\rho - \frac{\gamma}{2}(\theta^2\sigma_i + (1-\theta)^2\sigma)$$

Therefore, $B_i = \theta W$ is given by

$$B_i = \frac{\rho_i - \rho}{\gamma(\sigma_i^2 + \sigma^2)} + W\frac{\sigma^2}{\sigma_i^2 + \sigma^2} \tag{8}$$

Clearly, the country faces an upward sloping supply of foreign capital.

The Central Bank. The Central Bank demands reserves considering an exogenous cost of depletion and default given by D. This can be rationalized as costly macroeconomic adjustment following a balance of payments crisis, the fiscal costs of the bailout of financially insolvent institutions, or as the reputational cost of renegotiation after default occurs.

Furthermore, there is a flow cost of holding reserves. This is typicaly associated with the need to sterilize reserve accumulation by raising domestic interest rates. Also, it can be related to the opportunity cost of reserves given by the alternatives to reserve accumulation, like the payment of existing government debt, the marginal utility of consumption or the productivity of capital. As stressed by Edwards(1985), this opportunity cost must consider the return earned by reserves. In this case, I will simply assume that this cost is represented by the spread between a domestic interest rate ρ_d over the risk-free rate in foreign currency ρ^*.

Hence, total expected cost faced by the central bank is

$$TC = \Phi D + (1-\Phi)(\rho_d - \rho^*)R \tag{9}$$

Cost minimization leads to the following demand for reserves.

$$R = \frac{D}{\rho_d - \rho^*} - \frac{1-\Phi[\bar{Y_T}]}{\phi[\bar{Y_T}]} \tag{10}$$

where as before Y_T denotes the threshold amount of tradable output that allows no default.

Equations 6, 7, 8 and 10 characterize equilibrium. Next, I will turn to the determination of equilibrium, and to the comparative statics of changes in the international interest rate and the volatility of the balance of payments.

Equations 8 and 10 describe the optimal response schedules of the investment bank and the central bank. Here I will characterize these best responses, and explore the role of sequencing.

3.3 Equilibrium

First, note that reserve accumulation affects both the mean and the variance of the returns of the loan

$$\frac{\partial \rho_i}{\partial R} = \phi \left(r_i - \frac{R}{B_i} \right) + \Phi B_i^{-1}$$

$$\frac{\partial \sigma_i^2}{\partial R} = -2 \frac{\Phi}{1-\Phi} \left(r_i - \frac{R}{B_i} \right) B_i^{-1} - \frac{\phi}{(1-\Phi)^2} \left(r_i - \frac{R}{B_i} \right)^2$$

Thus, *ceteris paribus* changes in reserves have an unambiguous effect on the extent of international borrowing. Indeed, it is the case that

$$\frac{\partial B_i}{\partial R} = \frac{\partial \rho_i / \partial R - \gamma B_i \partial \sigma_i^2 / \partial R}{\gamma(\sigma_i^2 + \sigma^2)} \tag{11}$$

Regarding the determination of reserves, note that Equation 10 can be written as

$$R = \frac{D}{\rho_d - \rho^*} - \Lambda^{-1} \tag{12}$$

where Λ is the default hazard.

A particular case is the exponential distribution. In this setting, the hazard is constant, hence reserves are uniquely determined by D, $\rho_h - \rho^*$ and a constant Λ. Moreover, log-linearization of 12 implies

$$\ln R = \beta[\ln D + \ln(\rho^* - \rho_d)] + (1-\beta) \ln \Lambda$$

This is the traditional reserve demand that has been estimated in the literature (like Equation 3). In this setting, balance of payments volatility(through the effect on the hazard Λ) and the international interest rate have unambiguous effects on the demand for reserves

The general case, with a non-constant hazard, implies that

$$\frac{\partial R}{\partial B_i} = 1 - \frac{\phi'}{\phi} \frac{1}{\Lambda} \tag{13}$$

Hence, whether reserves increase in the face of changes in international borrowing hinges on two effects. On the one hand, to keep the spread constant reserves increase one on one with international borrowing. This effect is dampened by an additional factor, related to the effect through the shape of the default hazard. This is the second term in

Equation 13. Note that $\bar{\phi}' < 0$ is sufficient to ensure that the second effect is actually positive.[13]

Given that for the foreign investor $\partial B_i/\partial R > 0$ and that for the Central Bank $\partial R/\partial B_i > 0$, reserves and international borrowing are strategic complements. This implies that sequencing of the actions can potentially affect the equilibrium and the comparative statics response to exogenous shocks. Below I discuss these issues, first focusing on a simultaneous solution, and then examining the effect of sequencing.

3.4 Comparative statics - Nash equilibrium

Nash equilibrium is obtained if actions are simultaneous, using Equations 10 and 8 to solve for B_i and R.

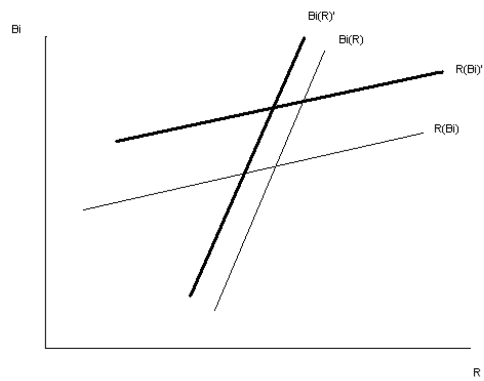
In equilibrium, ρ^* will have two effects on reserves. First, the direct effect that works through the opportunity cost. This is the traditional effect that has been stressed in the literature on reserve demand. However, there is an additional effect operating through the crisis hazard. Indeed, changes in ρ or σ^2 also change Λ through the effect on the portfolio composition of the investment bank. Everything else constant, an increase in foreign borrowing increases the likelihood of default. This leads the central bank to increase its demand for reserves. This effect works in the opposite direction of the opportunity cost.

The other interesting comparative statics exercise is to see the effect of an increase in country-specific volatility. This was associated above with the volatility of output Y_T, or equivalently in this formulation, with the volatility of the real exchange rate. For both reasons I want to associate it with the volatility of the terms of trade, arguably exogenous in small economies.

What is the effect of a mean-preserving spread on the pdf Φ? Again, everything else constant this will increase the probability of default. As with the case of the risk free interest rate, this has opposite effects on international borrowing and the demand for reserves. On the one hand, international borrowing decreases, thus diminishing the need to keep reserves as collateral for the loan. On the other hand, the increase in the likelihood of default leads the central bank to want to hold more reserves. The final effect is ambiguous. Figure 1 shows the comparative statics.

[13]The adequate hazard to assume at this stage depends on the nature of the shock that drives the process for Y. For example, a log normal distribution for output Y implies a hazard that is not monotonic. However, this does not necessarily imply a negative sign for the derivative $\partial R/\partial B_i$. A Weibull hazard does imply monotonicity.

Figure 1 - Increase in volatility or ρ^*.



3.5 Comparative statics - Sequential equilibrium

In this model, reserves and international borrowing are strategic complements, and there is an externality given by the existence of costly default and the role of collateral. The externality however is different for both agents; reserves have a *positive* externality on international borrowing, given by the fact that a small increase in reserves lowers the probability of default and hence increases the expected return for the foreign investor. On the other hand, international borrowing has a *negative* externality on the central bank: increases in international borrowing, everything else constant, imply a higher likelihood of default.

Thus, the sequencing of the actions will crucially affect the comparative statics results, like the effect of changes in international interest rates and the volatility of the terms of trade.

For example, consider the situation where the central bank moves first, and sets the amount of reserves before international borrowing is determined. Envelope theorem arguments imply that there is a small loss of deviating from the best response, but a first order gain because of the externality. In other words, a small increase in reserves implies a first order reduction in the probability of default, while only having a negligible effect on the opportunity cost. Hence, the central bank will choose a higher level of reserves than in the Nash equilibrium. This will then imply a higher degree of foreign lending by the investment bank.

The situation is opposite if the investment bank moves first. Indeed, in this case the incentive is to reduce external borrowing. Given reserves, reducing B_i reduces the probability of default.

What are the implications of sequential actions on the comparative statics? If complementarities are not too large, relative to the direct effect if changes in fundamentals (international interest rates and the volatility of the terms of trade), then the sequencing of the actions makes the ambiguity described above less probable.[14] Indeed, in this setting changes in the fundamentals can be fully internalized by the leader. This implies that if the investment bank moves first, then increases in the international interest rate (or the volatility of the terms of trade) are reflected in a reduction in reserves. The opposite happens if the central bank moves first.

To summarize, the incorporation of endogenous capital mobility in a standard model of reserve demand makes the effect of international interest rates and terms of trade volatility ambiguous. However, this ambiguity breaks down under sequential actions by the the agents. This conclusion is similar to the effect of commitment on the soverign debt literature. As noted by Eaton and Fernandez (1995), a debtor has reasons to modify its actions to increase repayment if it can commit to taking those actions before credit terms are established. However, once those terms are set, incentives are reversed.

3.6 Increasing marginal cost of reserve accumulation

Although the portfolio decisions by domestic agents (investment or money demand for example) have not been modelled, their inclusion would be straightforward by assuming for example that

$$\frac{\partial \rho_d}{\partial R} > 0$$

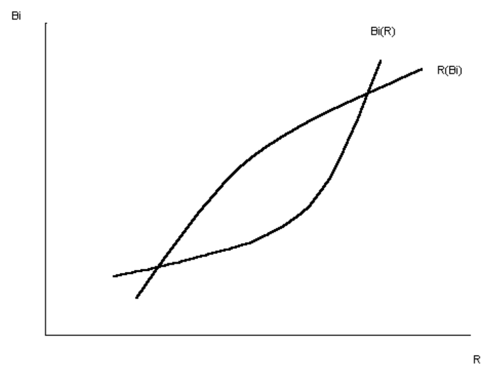
That is, there is an increasing marginal cost to sterilization of capital flows. This effect can be motivated in several ways. As a flow, it is the case that reserve accumulation dampen investment that would be channeled through a current account deficit. As a stock, higher reserves imply a lower supply of net domestic credit, given money demand. Both effects would imply an increasing relationship between domestic interest rates and the stock of international reserves.

3.7 Multiple Equilibria?

The non linearity Equations 8 and 10 might give rise to multiple equilbria, as shown in Figure 2. In this case the sequencing of the actions is even more relevant, as it can help coordinate one equilibria instead of another one.

[14] Actually, it implies that the size of the set of parameters under which the results are ambiguous is reduced.

Figure 2 - Possibility of multiple equilibria.



4 Empirics

What has been the behaviour of reserves in the post-war era? Is there evidence pointing towards the expanded role stressed above? Is it possible to resolve the theoretical ambiguity on the effect of crucial variables like the international interest rate and terms of trade volatility? Below I present empirical estimates of reserve demand that will try to clarify these issues, by using postwar data to estimate reserve demand equations for OECD and non-OECD countries.

4.1 Reserves in the post-war period

To get a first look at the evidence, Figures 3 and 4 display the evolution of the average reserves to imports ratio and the average reserves to external liabilities ratio, along with nominal LIBOR, in OECD and non-OECD countries. Table 1 shows the countries included and how they are classified according to OECD membership and oil production. Several features are apparent.

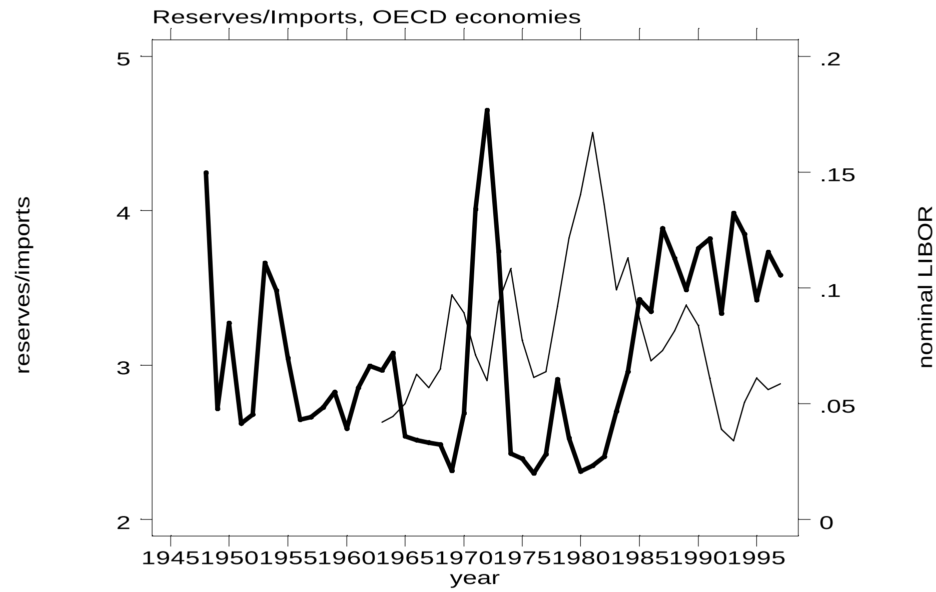
First, the volatility and trend of reserves over imports display large changes over the period, with the seventies and early eithties being a particularly turbulent decade. Three features of this period stand out on the data. First, the breakdown of the Bretton-Woods arrangement and the devaluation of the dollar, leading to a sharp increase in reserves; second, the oil shocks in the early and late seventies, and third the large increase in nominal interest rates in the early eigties. It is readily apparent how these shocks affected reserves in different countries.

Secondly, the reduction on the LIBOR after 1980 led to a parallel increase in reserves over imports, that lasts well into the nineties. This is particularly noteworthy for the non-oecd, non-oil economies: both the trend and cycle of reserves over imports seems to be associated with the movements in the nominal LIBOR. Moreover, the sharp increase in reserves over imports seemed to slow down in the mid nineties. This coincides with the recovery of the US economy from the 1990-1991 recession and the gradual increase in interest rates.

Over the long run, the ratio of reserves to imports has increased in all country groupings, almost doubling from a few months of imports to half a year. Part of this increase can be attributed to movements in nominal interest rates. As mentioned above, these movements stand in stark contrast with the expected effect of international interest rates on reserve demand, and closely mirrors the well-known relationship between capital flows to developing countries and international interest rates, noted in IDB(1996) and World Bank (1997).

Moreover, the evolution of ratio of reserves to international liabilities also displays a different picture across country groupings. First, reserves over international liabilities in OECD countries seem to move in tandem with LIBOR. However, for non-OECD countries the relationship is the opposite: increases in LIBOR are accompanied by substantial falls in reserves over external debt. This has an immediate interpretation in terms of the ease of access to international financial markets as a substitute to reserve accumulation. When LIBOR is high, OECD countries tend to substitute external debt for reserves. On the other hand, non-OECD countries suffer the opposite effect: not only when LIBOR is high the cost of indebtedness increases, but also capital flows make the self-provision of international liquidity more difficult.

Figure 3 - Reserves over imports



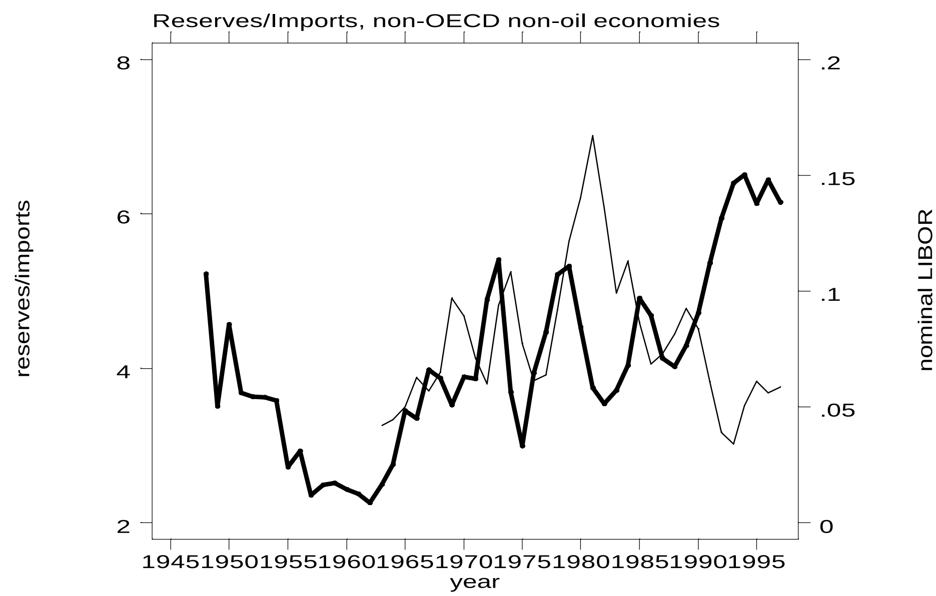
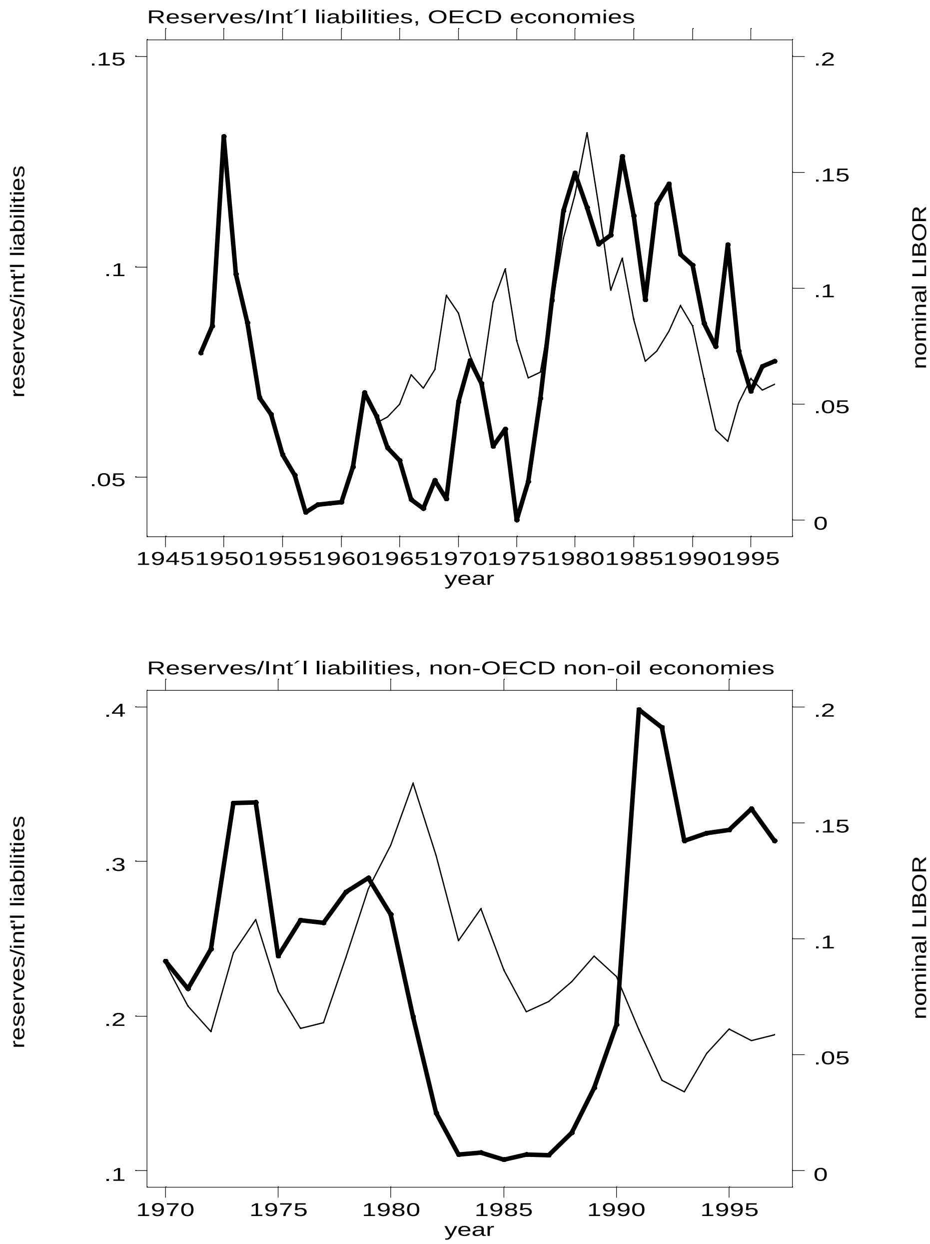


Figure 4 - Reserves over international liabilities



4.2 Data and estimation

I will focus on the following panel data specification for the demand for reserves, by country i as of period t. Variables are defined as in the model above, and below is a description of their empirical counterparts.

$$\ln R_{it} = a_0 + a_1 \ln \left[\frac{1+\rho_t^*}{1+i_{it}} \right] + a_2 \ln \sigma_{it} + a_3 \ln B_{it} + \ln D_i + \eta_{it} \tag{14}$$

In this equation, there are time-specific and country-specific components. The time-specific element comes from the international interest rate ρ_t^*. On the other hand, the country-specific effect reflects the cost of default in the equation for reserves D_i, and other unspecified country components in foreign borrowing that can be related to changes in investor's wealth, risk aversion, or the opportunities for international porfolio diversification. As this equation is a reduced form, the expected sign of the coeffients is ambiguous. That is the reason why I scale by foreign borrowing B_{it}.

Below I give a more detailed description of the data used in the empirical estimation. Table 1 shows the countries and some data related issues that will be discussed below. [15]

International borrowing. Even though there is good data availability on reserves both on the time-series and cross-country dimension, this is not at all the case for other components of countries' balance sheets. I will use proxies for international borrowing. There are two basic cross-country candidates for the stock of foreign liabilities, that happen to be closely related to other country specific variables, like financial development and income per capita. One is gross liabilites, from the international investment position of countries. This data is available for some developed countries on an annual basis. This data though does not in general span a long period of time. Also, it is not available for most of the less developed countries. However, there is World Bank data on stocks of external debt for many LDC since 1970. Table 1 shows which data is available for which country in the sample.

Balance of payments volatility. I construct a measure of balance of payments volatility based on the stochastic behaviour of the detrended terms of trade. This is an appropriate measure for many reasons. Firsr, it allows the specification to be compatible with previous literature, and is available for a large number of countries over a long period of time. Moreover, for a subset of countries it is possible to construct separate export and import price volatilites. Second, the terms of trade display large amounts of volatility, both over time and across countries. Furthermore, terms of trade shocks have both income and subtitution effects, thus affecting not only the intratermporal allocation of resources but also leading to intertemporal smoothing of consumption. This proxying for precautonary saving motives that determine the current account. Third, and related

[15] In this table "iip xx" refers to international investment position from IFS, available since 19xx. "x,m uv" implies availability of export and import unit value indexes, also from IFS. "tot" and "xtd" are terms of trade index and external debt from World Development Indicators. Oil countries are Norway, Ecuador, Venezuela, Kuwait, Saudi Arabia and Indonesia. In bold are the countries that are used in the final estimation in Table 6.

Table 1: Country classifications

OECD			Non-OECD		
country	balance sheet data	terms of trade	country	balance sheet data	terms of trade
UK	iip 80	x,m uv	Turkey	iip 83	x,m uv
Austria	iip 80	n/a	South Africa	iip 86	x,m uv
Belgium	n/a	n/a	Argentina	xtd	tot
Denmark	iip 91	x,m uv	Bolivia	xtd	tot
France	iip 89	x,m uv	**Brazil**	xtd	tot
Italy	iip 72	x,m uv	Chile	xtd	tot
Netherlands	iip 82	x,m uv	Colombia	xtd	x,m uv
Norway	iip 88	x,m uv	**Costa Rica**	xtd	tot
Sweden	iip 82	x,m uv	Ecuador	xtd	x uv, tot
Switzerland	iip 84	x,m uv	Paraguay	xtd	x uv, tot
Canada	iip 48	x,m uv	Peru	xtd	x uv, tot
Finland	iip 75	x,m uv	Uruguay	xtd	tot
Greece	n/a	x,m uv	**Venezuela**	iip 83, xtd	x,m uv
Iceland	iip 88	x,m uv	Israel	n/a	x,m uv
Ireland	n/a	x,m uv	Jordan	n/a	x,m uv
Portugal	iip 93	x,m uv	Kuwait	n/a	n/a
Spain	iip 81	x,m uv	Saudi Arabia	n/a/	x,m uv
Australia	iip 86	x,m uv	Egypt	xtd	tot
New Zealand	iip 89	x,m uv	Taiwan	n/a	n/a
			Hong Kong	n/a	x,m uv
			Indonesia	xtd	x uv, tot
			Korea	iip 80	x,m uv
			Malaysia	iip 80 xtd	tot
			Philippines	xtd	x,m uv
			Singapore	n/a	x,m uv
			Thailand	xtd	x,m uv
			Algeria	xtd	tot
			Morocco	xtd	x,m uv

to the other points, the terms of trade are strongly correlated with the real exchange rate, thus reinforcing the aforementioned effects.

The volatility measure will stem from the construction of rolling variances for the detrended terms of trade. Table 1 shows the sources available for terms of trade data. The data comes from either export and import unit values from IFS, or directly from World Bank data. It spans various time periods, depending on the country. I will apply the same methodology for each of them. Let $p_t = \frac{P_t^x}{P_t^m}$ be the terms of trade for a given country. I run an AR(1) process with a quadratic trend, hence

$$p_t = \delta_0 + \delta_1 p_{t-1} + \delta_2 t + \delta_3 t^2 + \eta_t$$

Volatility will be measured as the 5-year moving standard deviations.

$$\sigma_t = \sqrt{\frac{1}{10}\sum_{s=1}^{10} [\eta_{t-s}]^2}$$

A similar procedure was done to export and import unit value indexes, deflated by the US wholesale price index. Furthermore, this allows to construct dollar measures of volatility. For example, using dollar exports X_t from trade data, quantum indexes Q_t^x are constructed as

$$Q_t^x = \frac{X_t}{P_t^x}$$

The detrended component of deflated exports, X_t^T, is given by

$$X_t^T = Q_t^x \exp[\eta_t^x]$$

And the 5-year window volatility measure is

$$\sigma_t^x = \sqrt{\frac{1}{10}\sum_{s=1}^{10} \left[X_{t-s}^T\right]^2} \tag{15}$$

The same procedure was done for imports.

How good are these measures of volatility in accounting for the actual volatility of reserves? By directly detrending reserves [16] it is possible to compare these measures. Tabletbl:volat gives the result of several panel estimations. It is clear that in the within and random effects specification the terms of trade volatility is a good proxy. This is expected from a measurement point of view. Indeed, the terms of trade is an index, hence the scaling of this variable is the same for all countries. This is not so using the

Table 2: Volatility measures in the sample

terms of trade volatility				
	pooled	within	GLS	between
σ_t	0.0752	0.514	0.496	-0.330
	(0.059)	(0.048)	(0.048)	(0.322)
R^2	0.002	0.119	0.033	0.033
p-hausman		0.002		
export and import volatility				
	pooled	within	GLS	between
σ_t^x	0.346	0.375	0.371	0.273
	(0.028)	(0.032)	(0.031)	(0.161)
σ_t^m	0.453	0.307	0.316	0.532
	(0.453)	(0.033)	(0.033)	(0.167)
R^2	0.723	0.693	0.7240	0.704
p-hausman		0.193		

measures of export and import volatility as by construction they are denominated in 1990 dollars.

*Interest rates.*There are no comparable measures of domestic interest rates for the broad cross-section of countries I am considering. I will follow three strategies to deal with this issue. First, I will use the data that is available at the country level on government bond yields, and laking that, on lending rates by the financial sector. Second, I will exclude the domestic interest rate from the estimation.[17]. Third, I will rely on macroeconomic data on consumption growth rates to construct discount factors based on traditional asset pricing equations. Even though this is a bad proxy for domestic interest rates if agents are credit constrained, it captures the countercyclicality of the opportunity cost of holding reserves; i.e. during slowdowns this opportunity cost is larger than in expansions.

A Ramsey type model of growth and consumption implies a relationship between the real interest rate and consumption growth

$$\frac{C_{t+1}^i}{C_t^i} = \left[\frac{1+i_{it}}{1+\nu}\right]^{1/\zeta} \tag{16}$$

where ν and ζ reflect the intertemporal discount factor and elasticity of substitution. Hence, the opportunity cost in Equation 14 can be proxied by

[16]The detrending of reserves was done linearly, instead of log-linearly

[17]This is adequate as long as the domestic interest rate is endogenously determined by th rest of the variables

$$\ln \frac{1+\rho_t^*}{1+i_{it}} = \ln \frac{1+\rho_t^*}{(1+\nu)\left(\frac{C_{t+1}^i}{C_t^i}\right)^{\zeta}} \tag{17}$$

In this specification, I take as a benchmark $\zeta = 1$, while ν is subsumed in the constant.

As a measure of the international interest rate, I use the six-month LIBOR. I also include imports as an additional scaling variable on the right hand side.

In equation 14 most of the variables are endogenous. This is inevitable given the empirical strategy that has been chosen. However, several factors help control in part for this endogeneity. First, the small country assumption implies that both the international interest rate and the volatility of the terms of trade are exogenous. Second, by focusing on two measures of the domestic interest rate, and also excluding it from the estimation, it is possible to assess the degree of bias on the rest of the estimates. Third, the model in Section 2 suggests that the sequencing of actions should lead to different signs on the effects of the right hand side variables on reserves. If one assumes that the ability to commit differs between OECD and non-OECD countries, then estimating Equation 14 separately for each country grouping provides a way to control for the endogeneity problem.

Tables 3, 4 and 5 show the estimation results for the different ways to deal with domestic interest rates.

The results are suggestive, both within as well as between country groupings. First, in all estimations involving non-OECD countries, the effect of LIBOR is highly significant and large but *negative*. This is as expected from inspection of Figure 3. A 1 percentage point increase in LIBOR is associated with a 4% to 8% drop in reserves. It is noteworthy that this result is not preserved in OECD economies. In most of the estimates LIBOR is not significant, and is positive in some of the specifications (Table 4 and 5).

Volatility presents a similar pattern. Using the measure of terms of trade volatility, it is found that it is negatively associated with reserves in non-OECD countries. This is reversed for the case of OECD countries. Note though that using the measures of export and import volatility lead to negative coefficients in all country groupings. It is possible that this is capturing within group heterogeneity. Indeed, as terms of trade volatility is constructed from an index it is scale invariant. The measures of export and import volatility on the other hand are denominated in dollars.

How do these results compare to previous literature? Frenkel and Jovanovic (1981), in a pre-floating sample of OECD countries find significant effects of the opportunity cost and volatility on reserves, in line with the theory based on inventory control. The results here for OECD countries are compatible with this previous literature. However, for non-OECD countries the international interest rate affects reserves negatively.

4.3 Exchange rate regimes and the maturity of external debt

As commitment and the sequencing of actions are expected to be important issues on the determination of reserve demand, I explore the effect on the estimated equations of

Table 3: Fixed effects estimation - 1970-1998

	non-OECD			OECD		
$\ln \frac{1+\rho^*}{1+\rho_h}$	0.080	-0.082		1.262	0.932	
	(0.112)	(0.103)		(0.366)	(0.377)	
$\ln(1+\rho^*)$			-7.287			-0.683
			(1.650)			(1.323)
$\ln(1+\rho_d)$			-0.147			0.446
			(0.346)			(0.262)
σ	-0.283	-0.205		0.445	0.437	
	(0.059)	(0.054)		(0.151)	(0.144)	
σ^x			-0.024			-0.108
			(0.089)			(0.056)
σ^m			-0.256			-0.195
			(0.087)			(0.080)
$\ln B$	0.294	0.098	-0.091	0.855	0.585	0.468
	(0.063)	(0.074)	(0.123)	(0.085)	(0.139)	(0.122)
$\ln M$		0.859	1.246		0.659	0.677
		(0.119)	(0.153)		(0.412)	(0.180)
R^2	0.236	0.392	0.412	0.712	0.746	0.596
sample	17	17	9	8	8	12
# obs.	222	222	128	65	65	182

Table 4: Fixed effects estimation - No domestic interest rate

	non-OECD			OECD		
$\ln(1+\rho^*)$	-1.281	-1.281	-6.552	1.565	-0.843	0.913
	(1.128)	(1.128)	(1.297)	(2.045)	(2.048)	(1.513)
σ	-0.164	-0.164		0.321	0.461	
	(0.040)	(0.040)		(0.141)	(0.138)	
σ^x			-0.079			0.049
			(0.044)			(0.063)
σ^m			-0.129			-0.233
			(0.049)			(0.086)
$\ln B$	0.588	0.224	0.102	1.001	0.536	0.577
	(0.058)	(0.061)	(0.089)	(0.105)	(0.179)	(0.141)
$\ln M$		0.962	1.109		0.937	0.501
		(0.088)	(0.117)		(0.298)	(0.208)
R^2	0.228	0.410	0.575	0.699	0.745	0.521
sample	19	19	11	8	8	12
# obs.	408	408	200	67	67	189

Table 5: Fixed effects estimation, Consumption Growth

	non-OECD			OECD		
$\ln \frac{1+\rho^*}{C_{+1}/C}$	-1.927			-1.884	-1.093	
	(0.391)			(1.438)	(1.438)	
$\ln(1+\rho^*)$		-1.368	-4.871		3.234	-0.228
		(0.907)	(1.269)		(1.834)	(1.439)
$\ln(C_{+1}/C)$		2.076	3.076		4.429	1.976
		(0.448)	(0.896)		(1.637)	(1.583)
σ	-0.063	-0.058		0.051	0.182	
	(0.032)	(0.032)		(0.092)	(0.09)	
σ^x			-0.019			0.067
			(0.044)			(0.066)
σ^m			-0.109			-0.246
			(0.041)			(0.075)
$\ln B$	0.294	0.267	0.397	0.757	0.533	0.649
	(0.063)	(0.074)	(0.107)	(0.234)	(0.223)	(0.193)
$\ln M$	0.901	0.918	0.574	0.631	1.192	0.496
	(0.096)	(0.099)	(0.161)	(0.419)	(0.412)	(0.324)
R^2	0.397	0.398	0.361	0.732	0.789	0.496
sample	19	19	12	7	7	7
# obs.	383	383	179	52	52	52

including two other measures of countries ability or willingness to commit. There are the exchange rate regime and the maturity structure of foreign debt. I will focus on non-OECD countries, given the availability of data on short and long term debt data for LDC's. I construct a dummy variable that takes the value 1 for flexible exchange rate regimes and 0 otherwise. I use the exchange rate regime classification of Cottareli and Giannini (1997), based on IMF criteria. Table 6 shows the result of the estimation.

Including these variables doesn't affect the rest of the coefficients.[18] Also an interesting asymmetry is apparent. Although long term debt is related to reserves in the expected way, short term debt negatively affects reserves. If the variable included is the log of the ratio of long to short term debt, it can be seen that a 10% increase in this ratio leads to a 1.5% increase in reserves. Moreover, flexible exchange rates are associated with a *larger* stock of reserves. This also is in contrast with the usual view that fixed exchange rates imply a larger stock of reserves. However, fixed exchange rate regimes have been a poor commitment device in non-OECD countries, being instead on of the ingredients that characterize the run-up to balance of payments crisis. On the other hand, the lack of ability to commit should be reflected by a shorter maturity structure of the debt that the country issues.

5 Concluding Remarks

Under capital mobility the traditional effects of interest rate movements and the volatility of the balance of payment on reserve become theoretically ambiguous. This ambiguity is resolved by the sequencing of actions by the central bank and the foreign investor. This is in line with the empirical results. In countries less able to commit (as most non-OECD countries), reserves are negatively associated with the international interest rate. The relationship is very strong. A 1 percentage point increase in LIBOR leads to a drop in reserves of between 4% and 7% in non-OECD countries. For OECD countries the results are different; the international interest rate does affect reserves in the way implied by traditional models of reserve demand.

Terms of trade volatility also displays opposite effects on reserve demand depeding on the country grouping. For non-OECD countries, higher volatility is associated with lower reserves, while the opposite happens in OECD countries.

These results are not sensitive to the choice of the domestic interest rate. In the three cases considered both LIBOR and terms of trade volatility present this opposite effects on reserves between OECD and non-OECD countries.

These results are supportive of the argument developed in the model above. The ability to commit determines the expected sign of exogenous shocks to demand for reserves. The empirical evidence suggests that countries with a lower degree of financial development are less able to commit in this sense, and therefore the stock of reserves is sensitive to international capital flows and its determinants. On the other hand, more developed countries, like the OECD countries in the sample, are able to commit and therefore determine their stock of reserves independently. Empirical measures of com-

[18] See Table 5 and Table 6.

Table 6: Exchange rate regime and debt composition

	non-OECD				
$\ln(1+\rho^*)$	-4.855	-3.069	-4.423	-3.069	-3.891
	(1.326)	(1.042)	(1.282)	(1.042)	(1.139)
$\ln(C_{+1}/C)$	3.019	2.232	2.441	2.233	2.319
	(0.934)	(0.911)	(0.913)	(0.911)	(0.907)
σ^x	-0.023	0.004	0.0155	0.0049	0.009
	(0.046)	(0.045)	(0.045)	(0.045)	(0.045)
σ^m	-0.109	-0.127	-0.159	-0.127	-0.143
	(0.042)	(0.041)	(0.043)	(0.041)	(0.041)
$\ln B_{short}$		-0.236		-0.236	
		(0.074)		(0.073)	
$\ln B_{long}$	0.428		0.339		
	(0.111)		(0.109)		
$\ln(B_{long}/B_{short})$					0.159
					(0.047)
$\ln M$	0.486	0.879	0.674	0.879	0.763
	(0.169)	(0.138)	(0.171)	(0.137)	(0.150)
ER			0.468	0.414	0.417
			(0.132)	(0.137)	(0.135)
R^2	0.344	0.399	0.361	0.399	0.404
sample	10	10	10	10	10
# obs	160	160	160	160	160

mitment, like the maturity of the external debt and the exchange rate regime also give some insight about this issue. Indeed, estimates show that a short maturity of external debt is associated with lower reserves. If maturity is an indication of commitment, then this is in line with the model. More short term debt signals a lower ability to commit, and hence is associated with lower reserves. The exchange rate regime dummy used in the estimation implies that fixed exchange rates are associated with lower reserves. Again, this feature can be a reflection of lack of commitment. Indeed, fixed exchange rates in non-OECD countries have been a feature of balance of payments crises in the sample period. In that sense, it is hard to argue that fixed exchange rate regimes necesarily represent a useful commitment strategy, if they are not complemented with other institutional features that allow the peg to survive.

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