The Accumulation of International Reserves by Central Banks: Exploring Causes and Consequences

Inauguraldissertation
zur Erlangung des akademischen Grades
eines Doktors der Wirtschaftswissenschaften
der Universität Mannheim

vorgelegt von

Andreas Steiner

im Frühjahrssemester 2009

Referent:	Professor Dr. Roland Vaubel
Korreferent:	Professor Dr. Jürgen Schröder
Abteilungssprecher:	Professor Dr. Enno Mammen
Tag der mündlichen Prüfung:	30. März 2009

Acknowledgements

This thesis evolved while I was a research assistant and Ph. D. student at the Department of Economics at the University of Mannheim. It was accepted as a dissertation by the Faculty of Economics in spring 2009.

First and foremost, I would like to thank my doctoral advisor Professor Roland Vaubel for his encouraging support and helpful advice during the process of writing this thesis. I am indebted to him for his ideas and suggestions that have improved this thesis. His way of guidance combined the freedom of developing my own research ideas with his thoughtful care of being on the right track. I appreciated his way of discussing a thesis that reflects each sentence.

I would also like to thank Professor Jürgen Schröder for being my second supervisor and for his continuous support. During my years at the University of Mannheim I was affiliated to him as a teaching assistant for his lecture in macroeconomics. This joint work was really enjoyable.

During my employment at the Chair of Economics of Professor Vaubel I enjoyed very much the friendly atmosphere. It has been a pleasure to work there. I received all the support I could ever have asked for. I am very grateful for this.

Parts of this thesis have been presented at conferences and seminars. I am grateful for the comments and suggestions of the respective audiences that have improved the work.

Finally, I would like to thank my family for their continuous support. My parents encouraged me to cut my own path and study Economics, a subject until then new in the history of my family. The love and patience of my wife and son accompanied me during each day of writing this thesis. They gave me the happiness that made this thesis possible.

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General Introduction and Summary

This dissertation analyses the accumulation of central banks' international reserves on both theoretical and empirical grounds. It aims at explaining the causes and consequences of this continuous intervention of central banks in the foreign exchange market.

The significant increase of international reserve holdings in the recent past is a puzzle for standard economic theory. It challenges existing approaches to the demand for reserves. Theoretical models as well as empirical estimations fail to explain the enormous increase of reserves. While capital mobility has increased and countries have adopted more flexible exchange rate regimes, traditional models predict that central banks would reduce their reserve holdings. However, the evidence suggests the contrary.

Chapter 1 reviews, expands and criticises the theory of the demand for international reserves. It combines the traditional buffer stock model, which derives the demand for reserves from the commitment to maintain a fixed exchange rate, with more recent approaches that emphasize the role of reserves for crisis prevention and crisis management. It argues that disequilibria in the domestic money market translate into reserve changes and have to be accounted for. On the basis of the asset market approach, the economic effects of the accumulation of reserves on the interest rate, the exchange rate and the price level are revealed. In sum, a set of variables is identified that theoretically determines the level of reserves.

Chapter 2 examines whether this set of variables succeeds in explaining actual reserve behaviour. It extends existing empirical studies on reserve holdings in several ways. First, it uses a panel data set that covers virtually all countries for which data on reserves are available. Second, the determinants of reserves are reconsidered and some new empirical measures for these determinants are proposed. The inclusion of a measure of domestic money market disequilibrium allows testing the validity of the monetary approach to the balance of payments. The appropriate specification and econometric methodology are considered in detail. A theoretical section highlights that the neglect of country heterogeneity affects the asymptotic behaviour of standard estimators. The empirical analysis examines whether conclusions of panel data studies on the determinants of international reserve holdings are

robust to the inclusion of dynamics as well as to the consideration of heterogeneity across countries.
The results show that the neglect of dynamics and heterogeneity in country behaviour may lead to fallacious inferences. Dynamic and heterogeneous regression results differ significantly from their static and homogeneous counterparts.
Independently of the chosen estimation method, the findings suggest that both traditional variables of the buffer stock model and variables related to financial crises determine the level of reserves. Country-specific time-series of reserves are characterized by a high degree of persistence.

Chapter 3 and chapter 4 offer additional explanations of the accumulation of reserves, which have not been considered so far.

Chapter 3 tests the hypothesis that central banks revise their reserve policies in the aftermath of currency crises. While the literature argues that reserves are used as a lifejacket against currency crises, research so far has neglected the question whether and how central banks change their precautionary reserve holdings after a country has been affected by a currency crisis.
This relationship is examined in a dynamic panel data model of developing and industrial countries covering the period from 1975 to 2003. The evidence suggests that currency crises induce a permanent increase of reserves. This effect is particularly strong for recent currency crises beginning with the Asian financial crisis of 1997.
This behaviour is theoretically explained by an extension of a currency crisis model of the second generation. It shows that the crisis probability increases if agents are heterogeneous. In this case, central banks might wish to signal improving fundamentals by an accumulation of reserves.

An alternative explanation of the accumulation of reserves is put forward in chapter 4: the liberalization of international capital movements. The hypothesis states that central banks fear the increasing capital mobility and use reserves to cushion the economy from the effects of financial openness. First, central banks accumulate reserves in order to protect the economy from potentially detrimental effects of sudden stops of capital flows and flow reversals. Second, central banks use the accumulation of reserves as a substitute for capital controls. Changes in the level of reserves are a way to manage net capital inflows. They permit the

central bank to preserve some leeway for an independent monetary and financial policy despite the classic policy trilemma. The empirical analysis of a large panel data set supports the hypothesis that the accumulation of reserves is the consequence of a "fear of capital mobility" suffered by central banks.

Chapter 5 addresses the potential consequences of increasing international reserves for monetary policy. According to the quantity theory of money, the accumulation of reserves might result in inflationary pressures if the resulting monetary expansion is not fully sterilized and exceeds the growth of money demand. This is especially likely for countries that operate under fixed exchange rates but may also hold true for countries with floating rates.
These hypotheses are tested in a panel data set. The evidence suggests that global reserve growth significantly raises the world inflation rate with a lag of two years. This effect is especially strong for countries with fixed exchange rate regimes. On the level of individual countries, the accumulation of reserves contributes to moderate inflation rates, but cannot explain periods of high inflation. The degree of sterilization has varied considerably over time, with the 1970s and recent years since 2000 characterised by relatively low degrees of sterilization.

In sum, this dissertation attempts to explain the causes and effects of the accumulation of international reserves by central banks. It develops a theory of central bank behaviour, which is confirmed by the empirical evidence, and it analyses the consequences of the reserve accumulation on the domestic economy. The liberalization of international capital movements and the experience of currency crises both have contributed to the unprecedented accumulation of reserves, which, in turn, has caused inflation rates to rise.

Chapter 1

Why Do Central Banks Hold International Reserves? Theoretical Considerations

1 Introduction

One puzzle of the international financial system is the enormous increase in international reserve holdings by central banks since the demise of the Bretton Woods system. In contrast to general wisdom, the transition to de-jure more flexible exchange rate regimes was not accompanied by a permanent reduction in the level of reserves. Between 1975, just after the break-up of the Bretton Woods system, and 2006, the absolute value of worldwide official reserves increased by a factor of 17.[1] This development has not come to an end, but, on the contrary, has accelerated sharply since the East Asian financial crisis. Since 1996 the level of reserves has almost tripled. More importantly, the increase is also observable in commonly used indicators of reserve adequacy, which consider the level of reserves in relation to a scaling variable like imports, GDP or external debt. (See Figure 1 for a graphical representation of reserve growth in different groups of countries and Figures 2a and 2b for the behaviour of indicators of reserve adequacy).

These developments challenge existing approaches to the demand for reserves. Theoretical models as well as empirical estimations of the reserve demand fail to explain this enormous increase in reserves. Hence, this puzzle gave rise to a series of papers that – after economists had almost ignored the topic for two decades – analyse international reserve holdings, both theoretically and empirically.[2] The more recently proposed rationales for reserve hoarding behaviour include precautionary motives, self-insurance against financial crisis, uncertain access to international capital markets as well as mercantilist export support. Empirical studies basically test the explanatory power of these new determinants of reserves.

This chapter reviews, expands and criticises the literature on the demand for international reserves. Section 2 traces the major approaches to the demand for international reserves. It describes the traditional cost-benefit analysis, which still forms the theoretical basis of many recent studies although its assumptions – fixed exchange rates and no capital flows – do not hold any longer. An alternative approach emphasises the precautionary motive for reserve holdings. Following these ideas, I develop a model that accounts for the potential role of reserves for crisis prevention and crisis management. Section 3 criticises the presented

[1] All numbers in the introduction were calculated based on the data given in the International Financial Statistics (IMF 2008).
[2] For a comprehensive survey of the literature of the 1960s and earlier see Grubel (1971); Bahmani-Oskooee and Brown (2002) provide a more recent review. A short, but well-balanced summary of the more recent lines of argumentation is given in an Occasional Paper of the European Central Bank (ECB 2006).

models, first in general terms and then on the basis of the asset market approach. It reveals economic effects of the accumulation of reserves – on the domestic interest rate, the exchange rate and the price level −, which are disregarded by the standard theory of the demand for reserves. More precisely, it shows that the accumulation of reserves causes costs that are ignored by prevailing models. The final section concludes.

2 International reserves and their determinants in theory

Based on a review of theoretical models, this section identifies possible determinants of the level of international reserves. It then proposes an enhanced model that incorporates arguments that are discussed in the more recent literature in the field of international reserves.

This is not to say that it is expected that central banks behave as predicted by these models. The purpose of this review is to identify *possible* determinants of the demand for international reserves. If the theoretical models do not represent actual central bank behaviour well, possible determinants will simply turn out to be insignificant in the empirical analysis.

2.1 Traditional models

Traditionally, exchange rate policies and the choice of adjustment measures are crucial determinants of international reserve holdings. If central banks do not intervene in the market for foreign exchange, the balance of payments is by definition in equilibrium, and the exchange rate adjusts to shocks. A fixed exchange rate arrangement or a managed exchange rate, however, may lead to foreign exchange interventions, which imply a deficit or a surplus in the balance of payments. In the case of a deficit, countries are selling reserves. This amounts to a net capital import by the central bank and requires offsetting changes elsewhere in the balance of payments, for example an increase in the trade balance. Imports can be reduced by expenditure-reducing policies. These are internal measures that basically reduce national income. For a given propensity to import, lower income reduces imports. Alternatively, expenditure-switching policies can be implemented. These are external measures like the imposition of tariffs and quotas intended to reduce imports or devaluation, which also affects exports. If the currency is permitted to depreciate, balance of payments equilibrium is automatically maintained.

According to the monetary approach to the balance of payments, i.e., with a fixed exchange rate, the loss of reserves and the balance of payments deficit implied by it, are caused by a disequilibrium in the money market, for example, an unexpected increase in the money supply. The foreign exchange intervention implies a reduction of the monetary base and thereby restores the equilibrium in the money market. The reserve losses will end, i.e., the deficit of the balance of payments will equally vanish, as soon as the money market has reached its equilibrium. Hence, there is no need for an active balance of payments policy. The central bank loses reserves – willingly or not .

The alternatives to foreign exchange intervention, expenditure-reducing and expenditure-switching policies, are variants of the absorption approach to the balance of payments. One shortcoming of this Keynesian analysis is that it focuses on the current account and disregards the capital account. It erroneously assumes that the necessary adjustment has to be borne by the current account and that the capital account balance is exogenous.
The traditional theory of optimal international reserves compares the cost of holding reserves for foreign exchange interventions with the cost of these alternative adjustment policies, if the exchange rate is not permitted to adjust. The cost of adjustment is defined as the output or wealth foregone by taking costly policy measures like expenditure-switching or expenditure-reducing.
The theory of optimal international reserves was developed along two lines: a cost-benefit approach and a utility-maximising approach.

According to the cost-benefit approach to determining the optimal level of reserves, central banks face a trade-off between the cost of holding reserves and the cost of adjustment policies that prevent the balance of payments to turn into deficit under a fixed exchange rate. Reserves can be used to temporarily mitigate these adjustment costs and allow for a smooth adjustment in the face of an external shock[3]. Central banks demand reserves until their opportunity cost equals the marginal benefit.
The pioneering work of the cost-benefit approach is due to Heller (1966). His results are based on a Keynesian model with fixed prices and a fixed exchange rate regime. He assumes that there are no capital flows and that expenditure-reducing is the only adjustment policy to maintain the equilibrium of the balance of payments. Implicitly, he also assumes that the

[3] However, in the case that the balance of payments deficit is not temporary and the use of reserves only delays a necessary adjustment, the use of reserves might even exacerbate a crisis since the adjustment takes place under less attractive terms.

monetary base can only be adjusted through foreign exchange interventions (and that the demand for money and the monetary base cannot be manipulated by economic policy, i.e. fiscal policy). Whenever reserves reach their lower bound, the adjustment cost is incurred. According to Heller the marginal cost of adjustment is equal to the inverse of the marginal propensity to import.[4] Under the assumption of a structural equilibrium in the balance of payments[5] he obtains the following formula for the optimal level of reserves (R*):

$$R_H^* = \left[\frac{\log(r^{opp} \cdot m)}{\log(1/2)} \right] \cdot \sigma$$

Hence, the optimal level of reserves increases with the variability of reserves under a fixed exchange rate (σ) and deceases with the opportunity cost of holding reserves (r^{opp}) and the marginal propensity to import (m).

Frenkel and Jovanovic (1981) refine the stochastic process of this model and focus on a stochastic inventory control model. By the minimization of total costs, they derive the following formula of the optimal level of international reserves:

$$R_{FJ}^* = A \cdot \sigma^{1/2} \cdot (r^{opp})^{-1/4}$$

where A is a fixed cost of adjustment that is incurred by expenditure-reducing or expenditure-switching policies. The exchange rate is assumed to be fix. This model is known as the buffer stock model.

Although the formula and the optimal level of reserves differ from Heller's results, the determinants of the optimal level of reserves and their expected effect coincide with those of Heller's model: The optimal level of reserves increases with the reserve variability under a fixed exchange rate (σ) and decreases with the opportunity cost (r^{opp}) and the marginal propensity to import (m). An adjustment of the exchange rate is ruled out.

[4] According to the Keynesian policy of expenditure-reduction, an external disequilibrium can be corrected by a decline of import expenditures which can be induced by a decline of output proportional to the foreign trade multiplier. Since the multiplier is inversely related to the marginal propensity to import, the smaller the marginal propensity to import is the higher the costs of an expenditure-reduction in terms of forgone output are.

[5] This implies that the probability of an increase and decrease of reserves are both one half.

Despite the fact that the buffer stock model was developed under assumptions that do not hold any longer – fixed exchange rate arrangements and no capital flows – it is still the workhorse in empirical studies (IMF 2003; see Bahmani-Oskooee and Brown 2002 for a comprehensive survey). Moreover, the theoretical contributions of the asset market approach have hardly been applied to the demand for reserves. Flood and Marion (2002) find that the buffer stock model works about as well in the post-Bretton Woods period (1976-1997) as before. Nevertheless, it explains only a small portion of reserve changes and fails to explain cross-country variations.

A basic contribution to the utility-maximizing approach is Clark (1970) who assumes a social welfare function which increases with income and decreases with income variability. Both arguments are linked to the level of reserves: A higher level of reserves implies a higher opportunity cost and therefore a lower income. The larger the level of reserves, the smaller is the probability of reserve depletion. Accordingly, enforced adjustment policies which lead to income fluctuations are less frequent.
Optimal reserves turn out to be an increasing function of shocks to the balance of payments and GDP per capita and a decreasing function of the opportunity cost and the marginal propensity to import.
Since the cost-benefit approach and the utility-maximizing approach only differ in the modelling strategy but are essentially based on the same idea, the determinants of optimal reserves do not differ much.

A more recent work in the tradition of the cost-benefit approach is Ben-Bassat and Gottlieb (1992). They adapt the original model to the conditions of the post-Bretton Woods era and allow for capital flows and flexible exchange rates. They derive the demand for precautionary reserves for a borrowing country characterised by capital imports (surplus in the private capital account). These capital imports might be the result of the efficient distribution of world capital. Whereas the traditional approach stresses the adjustment cost in case of reserve depletion, Ben-Bassat and Gottlieb shift their focus on the cost of a sovereign default. After a period of external borrowing, the sovereign entity might default on its debt obligations, a situation caused by the change of investors' sentiment and willingness to provide further capital. The probability of sovereign default is assumed to be a negative function of the ratio of reserves to imports (R/Im) and a positive function of the ratio of external debt to exports (D/Ex). The cost of reserve depletion then includes the negative output effect and the cost of

the reduced or even lost access to the international capital market for the defaulting country (due to high risk premia). This also implies that future consumption smoothing by means of foreign borrowing is more difficult. Unlike preceding models, the authors hypothesise that the cost of sovereign default is positively related to the openness of an economy since more open economies suffer more from a disruption of the flows of tradables and capital. Total expected cost (TC) is the sum of the expected cost of sovereign default and the expected opportunity cost of reserve holdings:

$$TC = p(R/\mathrm{Im}, D/Ex, ...) \cdot C + \left[1 - p(R, ...)\right] \cdot r^{opp} \cdot R$$

where p is the probability of reserve depletion which equals the probability of sovereign default. C measures the cost of reserve depletion. Since the authors do not assume any functional form, an explicit solution for the optimal level of reserves cannot be derived. However, the model identifies the following variables as determinants of the optimal level of reserves:

$$R^*_{BG} = R^*(m, \mathrm{Im}, D/Ex, r^{opp})$$

In comparison with the buffer stock model, external debt enters as a new determinant, the variability measure is no longer relevant and the expected sign of the openness variable changes - from negative to positive.

One might however question the plausibility of the assumption that reserves can prevent a sovereign default. There are two possible situations: Either the level of reserves exceeds the amount of public external debt or reserves do not cover external debt. In the first case, reserves can impede sovereign default. However, this raises the question why the country does not repay its external debt by the use of reserves. Thereby it could economize the opportunity cost since the interest rate paid on external debt is generally higher than that paid on reserves. In the second case, the level of reserves is too small to prevent a sovereign default. Hence, in this model reserves are costly and have limited benefits.

2.2 Formulation of a crisis-related model

The models presented so far ignore the implications of increasing financial integration for developing and emerging economies. With respect to reserve holdings one can distinguish two opposing effects of financial integration.

First, private sector access to international capital markets facilitates private financing of current account deficits. Loans from the international capital market can serve as a substitute for reserves in order to smooth absorption in the presence of trade shocks. Hence, the adjustment to trade shocks ceased to be a topic of great concern.

Second, open capital markets increase the exposure to external financial disturbances and speculative flows. The sources of risk move from the current account to the capital account. Crises may stem from the capital account with no change in the current account. Financial markets often bring about adjustment with no reaction of the current account being required. Therefore, the more recent literature views reserves as a precautionary cushion against the risks of capital account liberalization, namely sudden stops, reversals of capital flows and financial volatility (see as examples Aizenman and Lee (2007), Jeanne and Rancière (2006) or Li and Rajan (2005)).

This implies that open capital markets reduce the need for official reserve holdings in good times but increase the need for reserves in times of economic crisis.

The function of precautionary reserves includes both crisis prevention and crisis management. The former refers to the role of reserves in reducing the probability of a crisis. A high level of reserves may signal the central bank's ability to stabilize the exchange rate. This might prevent the outset of a speculative run which leads to a self-fulfilling crisis. Crisis management refers to the role reserves may play in a crisis. Reserves can reduce and smoothen the adjustment of the exchange rate and of output. In the presence of current account crises, banking crises or exchange rate crises, the central bank can stabilize the exchange rate. However, there are also other ways of stabilizing the exchange rate, and stabilizing the exchange rate need not be optimal.

External factors might have contributed to the rising importance of autonomous crisis management on the national policy agenda. A financial crisis often leads to a forced partnership between the affected country and an international financial institution: the country

resorts to assistance programmes provided by the IMF or the World Bank. After the experience of the loss of autonomous decision-making implied by the conditionality of the programmes a country might have an increased interest in preventing a similar situation in the future. However, empirical studies find that the participation in an IMF programme is more likely, the more frequently it received IMF credit in the past. This, however, does not contradict the hypothesis that countries are less willing to depend on international financial assistance after they once received an assistance loan. The tendency for recidivism might be caused by factors like weak governance, a volatile external sector or dependence on foreign investment. An empirical study (Evrensel 2005), however, shows that macroeconomic performance worsens with the number of IMF-supported programmes. If a country participates in an IMF programme for the second time, its current account deficit, budget deficit and inflation rate are statistically higher than during the first stabilisation programme. International reserves are found to be higher. This effect might be independent of whether a country receives IMF support or not[6], but – as shown in Chapter 3 – a general pattern observable after a country suffered from a crisis. In sum, the evidence does not support the hypothesis that governments implement more prudent policies after they engaged in an assistance programme.

Although actual compliance with conditionality has been shown to be low, governments and their voters might regard the mere presence of foreign consultants as an undesired intervention in national autonomy. Countries might also perceive this form of international crisis lending as less attractive since the number of conditions and performance criteria has steadily increased (see Dreher 2004). However, as shown in Dreher and Vaubel (2004), the number of conditions has no significant impact on policy target variables.

Countries might not only fear the conditions linked to international financial assistance. After the publication of the Meltzer Report[7] in 2000 they might also be concerned that the IMF reduces its financial support to crisis-ridden countries.[8] Nevertheless, governments may even like the conditions (IMF as a scapegoat).

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[6] In her analysis of moral hazard associated with IMF-supported programmes, Evrensel (2005) only considers countries that participated in programmes and does not control for nonprogramme countries.

[7] The Meltzer Commission (officially International Financial Institution Advisory Commission) was established by the US Congress in order to reconsider the roles of various international financial institutions and elaborate on how they could be improved in the future. With respect to the IMF, the commission recommended to restrict its lending to short-term funding for countries in economic crisis. The recipient country should have met certain pre-conditions and pay a penalty rate of interest.

[8] Martín Redrado, president of the Central Bank of Argentina, justifies the accumulation of reserves precisely with this argument. According to him, the accumulation of reserves is a necessity since the Central Bank believes that the IMF ceased to act as a lender of last resort. "The accumulation of reserves is our way to buy an insurance in a world that not anymore has a lender of last resort and that, in my opinion, will not have it in the future." (La Nación, 20 April 2006, own translation)

In sum, the evidence suggests that IMF programmes do not foster precautionary policies. The accumulation of international reserves might rather be a side-effect of the increasing international financial integration. Given increasing stocks of cross-border assets and liabilities and volatile capital flows, central banks might demand additional reserves in order to manage potential crises themselves.

A series of empirical studies supports the idea that higher reserves reduce both the probability of a currency crisis (Berg and Pattillo 1999; Bussière and Mulder 1999; Chui 2002; García and Soto 2006) and its depth (De Gregorio and Lee 2004) once it materializes. Li and Rajan (2005) show in a theoretical model that high reserves may countervail the negative impact of moderately weak fundamentals.[9]

To adapt the theory of the demand for international reserves to the current state of the empirical literature, a model is developed that accounts for the potential role of reserves in preventing and managing financial crises. It is a refinement of the model of Ben-Bassat and Gottlieb where p and C are reinterpreted as the probability and the cost of a financial crisis, respectively. The marginal benefit of reserves is given by the decrease in the probability of a crisis multiplied by the cost of a crisis. It is assumed that not only the probability of a crisis, but also its cost is a function of the level of reserves. This assumption makes use of the argument that reserves can be used to manage a crisis. Moreover, the opportunity cost r^{opp} also depends on the level of reserves since a higher level of reserves lowers the sovereign spread, which basically corresponds to the opportunity cost.
Total expected cost can be written as the sum of the expected cost of a financial crisis and the expected opportunity cost of reserves:

$$TC = p(R,...) \cdot C(R,...) + \left[1 - p(R,...)\right] \cdot r^{opp}(R) \cdot R$$

The first component of cost, the loss associated with a financial crisis, hurts society as a whole. The second component, the opportunity cost, however, is borne by the central bank. It is noteworthy that the opportunity cost does not enter the central bank's balance sheet as a loss since it is only an imputed cost, namely unrealised profits. Ultimately, this also hurts society because the Treasury receives a smaller central bank profit.

[9] More precisely they conclude that higher reserves may offset weak fundamentals within a certain range. However, in the case of very weak fundamentals, a crisis or adjustment is inevitable independently of the level of reserves.

Since it will be assumed that the central bank chooses the level of reserves that minimizes these total costs, the inclusion of social cost in the central bank's cost function has to be motivated. In particular, the inclusion of the cost of a financial crisis can only be justified if the central bank's behaviour is based on a social objective function or if the central bank is controlled by a government that wants to be re-elected. Objective functions of central banks usually contain the rate of inflation and the deviation of output from a target level as arguments. Since a financial crisis implies a loss of output, a central bank that aims to provide the conditions to realise maximal output, implicitly has to pursue the sub-goal to prevent a financial crisis. Moreover, the official statutes of central banks usually mention the stability of the currency and the normal functioning of internal and external payments as their duties. From this perspective, crisis prevention and crisis management are instruments that contribute to the achievement of the primary objective of a central bank.

The first order condition for the minimization of costs is given by

$$\frac{\partial TC}{\partial R} = \frac{\partial p}{\partial R} \cdot C + p(R,...) \cdot \frac{\partial C}{\partial R} + \left[1 - p(R,...)\right] \cdot \left[\frac{\partial r^{opp}}{\partial R} \cdot (R + D) + r^{opp} \right] - \frac{\partial p}{\partial R} \cdot r^{opp} \cdot R \overset{!}{=} 0$$

Since it is assumed that the central bank considers social costs, total external debt (D) – public and private – is added in the equation. The reduction of the marginal opportunity cost induced by an increase in the level of reserves not only reduces the cost of reserves for the central bank, but lowers the interest payments for total external debt. Hence, reserves provide a positive external effect. Since a high level of reserves is evaluated positively by international rating agencies, it generally lowers the country-specific spread. Consequently, all nationals with foreign liabilities benefit from a high level of reserves. This external effect is internalised in the determination of the optimal amount of reserves.

After rearranging, the following equation results:

$$\left(\underset{(-)}{\frac{\partial p}{\partial R} \cdot C} + \underset{(-)}{p(R,...) \cdot \frac{\partial C}{\partial R}} + \underset{(-)}{\left[1 - p(R,...)\right] \cdot \frac{\partial r^{opp}}{\partial R} (R + D)} \right) \cdot \left[\underset{(-)}{\frac{\partial p}{\partial R} \cdot R} - \left[1 - p(R,...)\right] \right]^{-1} = r^{opp}$$

The signs in parentheses indicate the expected signs of the partial derivatives. The right-hand side corresponds to the marginal cost of an additional unit of reserves, namely the opportunity cost. In optimum, this cost must equal the marginal benefit which is given on the left-hand side of the equation. Benefits arise from a reduction in the probability of a crisis, from lower costs of a crisis and from lower opportunity costs or interest payments on external debt.
The set of possible determinants of the level of reserves can consequently be extended with variables that are related to the probability and cost of financial crises like total (TED) and short-term external debt (STED):

$$R^*_{Crisis} = R^*(m, \sigma, r^{opp}, TED, STED)$$

The presented models all assign reserves a precautionary role against external risk. However, the definition of external risk is time-varying and the emphasis of the models depends directly on the experience of preceding crises: whereas the literature of the demand for reserves in the 70s considers trade shocks as the main source of external risk, sovereign debt crises dominate the literature after the debt crisis of 1981 and financial crises prevail in the literature published in the aftermath of the Asian crisis.

3 A critique

This section criticizes the models of the demand for reserves: First, central banks' demand for reserves may consistently deviate from a hypothesised optimal level. Second, the presented models ignore that changes in reserves are a monetary phenomenon in the sense that they are the result of a disequilibrium on the domestic money market. Third, existing theories ignore the effects of the accumulation of reserves on the exchange rate, interest rate and the price level.

3.1 A general critique of presented models

All approaches outlined so far implicitly assume that different central banks behave identically as individual preferences do not enter the optimising calculus. In practice, however, the level of reserves increases with a country's risk aversion, which differs due to individual historical experience, culture and stage of development.

All these models determine an optimal level of reserves. However, critics argue that the level of reserves is not the outcome of a central bank's optimising strategy.

The level of reserves is only the outcome of an optimising strategy if its determination is a policy objective of its own. The level of reserves, however, may not be an exogenous variable but depend on other policies, particularly on monetary and exchange rate policies. Therefore, it might simply be a by-product of other policies. According to the Tinbergen rule, the number of instruments should equal the number of policy objectives. Due to a lack of instruments, a central bank might deliberately deviate from the optimal level of reserves if other policy objectives – e.g. an inflation or exchange rate target – are prioritised. An example for such undesired reserve movements are changes in reserves which are necessary to support a fixed exchange rate but that result in an undesired level of reserves. Therefore, one might expect that under a flexible exchange rate system the observed level of reserves reflects its demand better than under a fixed exchange rate. Another example illustrating that changes in reserves might be rather a by-product of other policies than an intentional movement is given by the monetary approach to the balance of payments. It argues that reserve changes are the result of a disequilibrium in the domestic money market. This approach presented in section 3.2 is a fundamental critique of the theories that model a demand for reserves.

These objections might be especially important in the short run. In the long run, however, a central bank has to consider the effect of its policies on the level of reserves. When reserves decrease continuously, a central bank has to adapt its policies at the latest when there are no reserves left or when it or the government fail to borrow reserves. If reserves increase all the time (Bundesbank since 1966), there is no natural limit anyway.

According to the economic theory of bureaucracy (Niskanen 1971), an individual monetary authority would always prefer more reserves than less. A higher amount of reserves raises power and importance of the central bank as an institution and of its staff in particular, there is more room for intervention whereas the cost of reserves has to be borne by society as a whole. The success of a central bank is measured in terms of a low inflation rate and the stability of the payments system. The evaluation of its performance is, however, independent of its net earnings. Machlup (1966) even suggests that the demand for reserves by central banks, like the demand of women for clothes, is a simple desire for a little more than last year ("Mrs. Machlup's wardrobe theory").

With respect to the cost of reserves, it has to be emphasised that the opportunity cost only captures a fraction of the total costs of reserve hoarding. Changes in international reserves are a form of public intervention in the market mechanism, which creates distortions in the private sector. Since the accumulation of reserves implies that the central bank acquires foreign assets, it is a form of capital export. Consequently, if capital is not perfectly mobile, net capital imports are smaller than without public intervention, and the central bank policy prevents an efficient allocation of world capital. Thus, this policy of reserve accumulation might raise domestic real interest rates above their equilibrium value and render efficient investment projects impossible.

If net capital imports are smaller than without intervention, the balance of payments restriction requires that net imports of goods and services are also depressed. Hence, the distortion in the capital account translates into a distortion in the current account.

Since the acquisition of reserves leads to an increase of the monetary base, the central bank faces at least one of two forms of costs: Either it creates inflationary pressures or it has to sterilize the expansionary effects of reserve accumulation, e.g., through the sale of bonds. The interest paid on these bonds may increase with the extent of sterilisation.

As a further cost, a misallocation of capital and a higher inflation rate may reduce the potential growth rate of the economy.

Finally, the accumulation of reserves also imposes long-run costs on the country that supplies the reserves. Whereas the capital export to this country reduces its real interest rate, in the long run it may struggle with costs due to higher inflation, overinvestment, public budget deficits and delayed adjustment of its real exchange rate.

These objections to the theoretical models indicate that there are additional cost variables and that the level of reserves may be affected by them. Unfortunately, they are difficult to measure. They will be considered in more detail in the framework of the portfolio balance approach in the following section.

What about official central bank policy? The evidence is mixed: Whereas the Deutsche Bundesbank sees the level of official reserves as the residual outcome of its exchange rate policy, other central banks (e.g. of Chile and Mexico) officially follow the cost-benefit approach in their international reserve policy.

In this respect, the Deutsche Bundesbank states in its monthly report that "the volume and composition of Germany's reserve assets are not so much the result of an optimisation strategy as, primarily, a response to the Bundesbank's intervention obligations during the time of the Bretton Woods system and foreign exchange purchases at times when the dollar was weak." (Deutsche Bundesbank 2003, p.18).

Other central banks, among them the Central Bank of Chile, refer explicitly to the cost-benefit approach. "Holding international reserves involves both benefits and costs that the Central Bank must take into consideration." (Central Bank of Chile 2005, p.73). The report justifies the steady reduction of reserve holdings since 2003 with the reduced benefits of reserves thanks to Chile's increasingly good fundamentals. With respect to Mexico, the oil price being high, the Central Bank of Mexico is confronted with a high growth rate of its reserves. "Given the level international reserves have reached and their expected rate of accumulation for this year […], one can conclude that the benefits […] will diminish in the course of the time." (Central Bank of Mexico 2003, own translation). Consequently, the Central Bank implemented a mechanism to reduce the rate of growth of its reserves.

3.2 A critique based on the asset market approach

The models presented so far derive the demand for reserves from central banks' desire for exchange market intervention. In traditional models reserves are used to defend a fixed exchange rate in such a way that an adjustment of the current account or capital account can be avoided. The crisis-related models of reserve demand, which assign reserves a role for crisis prevention and crisis management, emphasise the stock of reserves, which signals the central banks' capacity of exchange market intervention.

Both theories ignore the link between the exchange rate and asset markets. They suggest that an exchange market intervention is a necessary instrument to control the exchange rate. This is not true. The following section criticizes these theories. It provides a new perspective by a rigorous analysis of the dependencies between the exchange rate, asset markets and the balance of payments.

There are two main criticisms: First, exchange rates can be adjusted through changes of the domestic monetary base. Instead of defending a fixed exchange rate through the sale of reserves, a central bank can adjust the monetary base by open-market operations with

domestic assets. Foreign exchange intervention is not the only instrument to defend an exchange rate. Second, the accumulation of reserves implies distortions in other markets causing costs that are ignored by existing approaches.

The missing incorporation of monetary theory in the literature on the demand for reserves has already been noted by Frenkel (1976, p.129): "Finally, the analytical framework underlying the literature on the demand for international reserves needs to be tied in with the framework underlying the literature on the monetary approach to the balance of payments." Nevertheless, the mainstream of the literature still ignores these links (exceptions are Edwards (1984) and Badinger (2004)).

According to the asset market approach, the exchange rate is the relative price between two currencies. It is determined by total demand and total supply of both currencies. The equilibrium exchange rate clears the money market and the bonds market.

3.2.1 The monetary approach to the exchange rate and to the balance of payments

The monetary approach is a special case of the general asset market approach. It assumes that domestic and foreign currency bonds are perfect substitutes. If the money demand function is stable, an increase of the domestic monetary base depreciates the domestic currency ceteris paribus (for given interest rate, level of income and constant foreign money supply and demand).

This implies that the central bank can steer the exchange rate by monetary policy. There is no need for reserves. If there is a tendency towards nominal exchange rate depreciation, the central bank may decrease the monetary base by a domestic open market operation instead of selling reserves.

Another way to analyse changes of reserves is provided by the monetary approach to the balance of payments. It postulates that changes in international reserves are a monetary phenomenon resulting from changes in money supply and demand. A positive change in reserves is related to an excess demand for money; reserves decrease if there is an excess supply of money.

The main features of the monetary approach to the balance of payments can be illustrated by an analysis of the balance sheet of the central bank. Its assets consisting of domestic credit (D) and international reserves (R) equal the monetary base (M).[10] Hence, changes in these variables are determined by the following identity:

$$\Delta D + \Delta R = \Delta M$$

Changes in reserves are given by the equation:

$$\Delta R = \Delta M - \Delta D$$

This implies that reserves can be increased either by an increase of the monetary base (the central bank purchases foreign exchange and pays in domestic money) or by a decrease of domestic credit (the central bank substitutes foreign exchange for domestic bonds). Any active policy of reserve accumulation affects the domestic money and/or bonds market.

The above equation from the central bank's balance sheet assumes that the change in money supply (ΔM) is balanced by an equal change in money demand such that the equilibrium of the money market is restored. If this is not the case, the money market will be cleared via a change of reserves (if the price level is assumed to be constant in the short run). One can think of two different mechanisms: Either the excess supply of money is used to buy foreign goods or foreign currency or the central bank itself sells reserves for domestic currency in order to prevent a depreciation of the nominal exchange rate.[11,12] The same reasoning applies for situations in which the central bank maintains money supply constant while money demand has decreased. Independently of the underlying cause, any excess supply of money implies a reduction of reserves.

$$\Delta R = \Delta M^D - \Delta M^S$$

where M^D and M^S denote domestic money demand and domestic money supply, respectively.

[10] Without loss of generality, it is assumed that net wealth of the central bank is zero. Moreover, I assume away the difference between the monetary base and money supply. In more general terms, the monetary base (B) and money supply (M) are linked by the money multiplier: $M = m \cdot B$. For a constant money multiplier $\Delta M^S = m \cdot \Delta B$. Changes in money supply are proportionate to changes in the monetary base. For our purposes, the distinction between both concepts can be disregarded without loss of generality.

[11] According to the monetary approach, an excess supply of money depreciates the nominal exchange rate ceteris paribus.

[12] In the limiting case of a fixed exchange rate, this policy illustrates the well-known result that monetary policy is endogenous.

To put it differently, any disequilibrium in the money market involves a change of reserves. This was already noted by Ricardo (1809, p.59): "The temptation to export money in exchange for goods, or what is termed an unfavourable balance of trade, never arises but from a redundant currency."

Therefore, the monetary approach suggests that a loss of reserves is generally associated with domestic money supply expanding at a higher rate than the demand for money. Thus a change of foreign reserves is basically due to domestic factors. If monetary policy clears the money market, there is no change in reserves.

Thus, in addition to real shocks the disequilibrium in the money market determines the level of reserves. The explanatory power of the monetary approach will be tested in the empirical analysis by the inclusion of a measure of money market disequilibrium.

3.2.2 The implications of reserve accumulation in the portfolio balance model

The monetary approach shows that movements in the domestic money market explain changes of reserves. A central bank that wants to accumulate reserves at a fixed exchange rate may create a shortage in the supply of money. Thus the desired level of reserves might be incompatible with other goals of economic policy, i.e. a target for the balance of payments. The following section focuses on the effects of reserve accumulation from a balance of payments perspective.

Before reserves can be sold they have to be accumulated. It is clear from the balance of payments identity that the accumulation of reserves requires a surplus in the combined current and capital account. This implies that a reserve-accumulating central bank causes at least one of two distortions: If reserves are financed through a current account surplus, the exchange rate has to be depreciated relative to its equilibrium value making the consumption of foreign goods and services more expensive. These costs are borne by private agents whose imports will be depressed. Vaubel (2005) also emphasises that the economy will be too export-oriented due to its reserve accumulation. If the reserve accumulation is financed via a surplus in the capital account, the effects depend on the degree of capital mobility. If the central bank accumulates reserves and sterilizes the expansionary effects on the monetary base through the sale of bonds, the interest rate rises. If capital is perfectly mobile, capital will flow into the country until the interest rate returns to its original equilibrium value. If capital mobility is

restricted, interest rates remain above their equilibrium value making capital costlier than in equilibrium. Therefore, domestic investment will be lower. These costs of reserve accumulation are neglected by the standard models of reserve demand described in the preceding section. They will be analysed in more detail in the theoretical framework of the portfolio balance approach.

Portfolio balance model

The portfolio balance model is an asset market approach to the determination of the exchange rate in the short run. It differs from the monetary approach in assuming that domestic and foreign financial assets are imperfect substitutes. Therefore, the supply and demand of domestic and foreign currency bonds are explicitly modelled. Prices and income are constant in the short run. Asset markets are assumed to clear instantaneously, whereas prices only adjust gradually. Exchange rate expectations are neglected. The long-run effects can be analysed when price changes are allowed for. In the very short term, there can be no changes in the current account balance and in net capital movements. The portfolio balance approach is a theory of stock adjustment rather than flow adjustment. The following exposition is based on Branson (1977). A mathematical description of the comparative statics is provided by Dernburg (1989).

The short-run effects of foreign exchange accumulation on the exchange rate and interest rate can be studied in a graph (see Figure 3). The curves represent the combinations of nominal exchange rate (E) and interest rate (i) for which supply equals demand on the following markets: the money market (MM curve), the market for domestic currency bonds (BB curve) and the market for foreign currency bonds (FF curve). There are two reasons for shifts of the curves: wealth effects (accumulation of foreign assets or nominal exchange rate changes) and substitution effects between assets (for a balanced portfolio).

The MM curve slopes upward because a reduction in the demand for money due to a higher interest rate has to be balanced by an increase in the demand for money due to a depreciated domestic currency (higher E). A depreciation raises wealth due to a higher value of foreign currency bonds in domestic currency and therefore raises money demand. The BB curve has a negative slope because an increase in the interest rate raises the demand for domestic bonds whereas an appreciation of the exchange rate decreases total wealth and thereby decreases the demand for bonds. Since an appreciation of the exchange rate decreases the supply of foreign

currency bonds in terms of domestic currency, the domestic interest rate has to rise such that the demand for foreign currency bonds decreases – the FF curve slopes downward. If one assumes that a given change in the interest rate has a stronger effect on the demand for domestic currency bonds (of which it is the interest rate) than on the demand for foreign currency bonds, BB is steeper than FF.

In the following, we study the effects of the accumulation of foreign reserves[13] by the central bank (see Figure 3). Assume that the economy starts in point A characterised by i_0 and E_0. All three markets are in equilibrium (intersection of MM_0, BB_0 and FF_0). The current account balance is zero such that the value of foreign currency bonds denominated in foreign currency remains constant.

The central bank can accumulate foreign reserves through the purchase of foreign currency bonds from domestic investors for domestic money. Alternatively, the central bank buys foreign money and the foreign central bank sterilizes this transaction through an open market operation providing liquidity through the acquisition of foreign bonds. In both cases, the amount of foreign currency bonds decreases and domestic money supply increases. The amounts of money and bonds in the foreign country are not affected.

Case 1: Flexible exchange rates without sterilization

As shown in Figure 3, the increase of domestic money shifts the MM curve to the left (MM_1). The reduction of foreign currency bonds available for private investors shifts FF up (FF_1): For a given nominal exchange rate, the domestic interest rate must rise such that investors do not want to sell domestic bonds for foreign currency bonds. The new short-run equilibrium (point B) is characterised by a lower domestic interest rate and a depreciated currency (i_1 and E_1).

We now turn to the long-run implications of this policy. If the current account was balanced in point A, it now moves into surplus.[14] Hence, in the long run the economy acquires

[13] We can either assume that the central bank accumulates foreign currency bonds or that it accumulates foreign money. However, the model does not contain foreign money and does not model asset market equilibrium of the foreign country. The accumulation of foreign money is therefore based on the following steps: The domestic central bank purchases foreign currency assets from domestic investors. These foreign currency bonds are sold against foreign money. The foreign central bank sterilizes this transaction. It purchases the foreign currency bonds and offers foreign money.

[14] The current account is made up of net exports (NX) and income from foreign investment (the interest payments of foreign currency assets hold by domestic investors). Net exports are a positive function of the real

additional foreign currency bonds which make up for the reduction of these bonds in hands of private investors. The FF curve shifts smoothly back to the left as foreign currency bonds are accumulated. The nominal exchange rate appreciates gradually. In the end, the total current account surplus is equal to the increase of foreign currency bonds. The FF curve reaches its initial position FF_0.

For a given price level and any given exchange rate, total wealth increases due to the current account surplus. Therefore, a balanced portfolio requires domestic agents to sell part of their foreign currency bonds for domestic currency bonds and money. The MM and BB curves shift gradually downward (MM_2 and BB_2). In comparison with the starting point A the resulting static equilibrium (point C) is characterised by a lower interest rate i_2 and a depreciated nominal exchange rate (E_2).[15]

Figure 4 shows a possible adjustment path of the nominal exchange rate and the price level in the long run: Originally, the real exchange rate is normalized to one. The increase in money supply causes a jump of the exchange rate to E_1. At given prices, the real exchange rate has depreciated. Provided the Marshall-Lerner condition holds, the current account becomes positive. Then the gradual adjustment starts: The current account surplus implies an accumulation of foreign currency bonds. The nominal exchange rate appreciates such that the value of foreign currency bonds expressed in domestic currency units remains constant. At the same time, the price level gradually rises due to the increase in money supply. When both time paths cross (point t(i)) the real exchange rate has fallen to its original value. However, the current account is still positive due to the increase in investment income. Therefore, equilibrium requires that the real exchange rate appreciates further. This equilibrium is reached asymptotically with a real exchange rate below one ($E_2 < P_2$).

Hence, the accumulation of reserves has the following effects: It reduces the interest rate and depreciates the nominal exchange rate. In the long run, it produces an increase in the price level and an appreciated real exchange rate.

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exchange rate (e) with $e = E \cdot \left(P^* / P \right)$ where P and P* are the domestic and foreign price level, respectively. Hence, a nominal depreciation (at constant prices) increases net exports.

[15] The depreciation compared to the starting point comes from the increased domestic money supply. With respect to the long-run value of the real exchange rate, one has to take account of the rise in the domestic price level P. In the long run, the real exchange rate will be lower than in point A, such that net imports rise, balancing the interest income from foreign assets which has also risen due to the accumulation of foreign currency bonds. The total amount of foreign currency bonds in the hands of domestic investors and the domestic central bank has risen exactly by the amount of the central bank's foreign reserve accumulation.

Case 2: Flexible exchange rates with sterilization

Figure 5 illustrates the case of sterilized reserve accumulation. If the domestic central bank wants to accumulate reserves without causing inflation, it has to hold the amount of domestic money constant. This can be achieved through an open market operation that reduces money supply (shifting the MM curve back to MM_0) and increases the supply of domestic currency bonds. This shifts the BB curve outward to BB_1 and the new equilibrium is at point B. In comparison with the original situation, the economy is characterised by a depreciated nominal exchange rate and a higher interest rate (E_1 and i_1).
The long-run analysis considers the effects of the current account surplus brought about by a depreciated real exchange rate. Analogously to case 1, the accumulation of foreign currency bonds and the desire of domestic investors to sell part of those bonds for money and domestic currency bonds shifts all three curves proportionally downward. The new equilibrium settles in point C with the interest rate i_2 and an appreciated exchange rate E_2.[16]

This makes two additional costs of the accumulation of reserves visible: First, the depreciated exchange rate in the short run implies that the economy is exporting too much and that domestic consumption of foreign goods is too expensive. Second, the higher domestic interest rate reduces investment. Both effects reduce welfare.

Case 3: Fixed exchange rate system with sterilization

The accumulation of reserves under a fixed exchange rate system is illustrated in Figure 6. It is only possible if the transactions are sterilized in both countries. The domestic central bank sterilizes the increase of money by the issuance of domestic currency bonds. This moves the BB curve to the right to BB_1 (the increased supply of domestic currency bonds increases their rate of return). The foreign central bank sterilizes the loss of foreign money through the purchase of foreign currency bonds (from domestic investors). The decrease of foreign currency bond holdings has to be compensated by an increase in the nominal exchange rate, shifting the FF curve to the right (FF_1). The equilibrium moves from point A to point B,

[16] Hence, the equilibrium exchange rate (nominal) is appreciated with respect to case (1) (see also footnote 15). This appreciation is necessary to reach a balanced current account where foreign interest income has risen. However, since the money supply and money demand are constant (due to a constant interest rate), the domestic price level will not change. Hence, the appreciation of the nominal exchange rate is the reflection of a real appreciation.

which is characterised by a depreciated exchange rate and an increased interest rate. So far, the argumentation is equivalent to case 2 (point B is equivalent to point C of Figure 5).
To move the exchange rate back to its initial value, the domestic central bank has to implement a contractionary open market operation. The swap of domestic bonds for money shifts the MM curve downwards (MM_2) and the BB curve further upwards (BB_2). The new equilibrium settles in point C at the original exchange rate E_0 at the cost of a higher interest rate i_2.

The long-run analysis of this policy shows that the accumulation of reserves causes pressures on the exchange rate.[17] Due to the contractionary monetary policy, the price level falls in the long run. This implies that the real exchange rate depreciates and that foreign currency bonds are accumulated through a current account surplus. Since the FF curve is gradually shifted downwards, pressures to a nominal appreciation emerge. A counteracting central bank has to raise money supply again. Since the exchange rate adjusts before prices react, this leads to an immediate depreciation and a long-run partial appreciation when prices rise. This sequence of jumps and gradual adjustment shows that the accumulation of reserves has long-run repercussions on the domestic money market. All else equal, it requires the central bank to adjust the monetary base in the long run.

In sum, the portfolio balance approach shows that the accumulation of reserves causes costs that are ignored by prevailing models of the demand for reserves. Depending on the chosen policy, the accumulation of reserves may raise domestic interest rates, affect the nominal and real exchange rate and cause inflation in the long run. Since it is difficult to measure these costs, they will not be controlled for in the empirical analysis. However, chapter 5 of this dissertation, which examines whether the accumulation of reserves drives inflation, contributes to a more comprehensive assessment of the total costs of reserve accumulation.

[17] It is assumed that the amounts of money and bonds are not changed through the financing of a budget deficit.

4 Conclusions

This chapter identifies a set of variables that may explain the level of central banks' reserve holdings. For this purpose, the literature on the demand for international reserves is reviewed. Since these models are based on restrictive assumptions that do not hold any longer, a new approach is developed that focuses on the potential role for reserves for crisis prevention and crisis management.
According to these models, the level of reserves might depend on the following country characteristics: its stance of development, its trade and financial openness, external volatility, the exchange rate system and the opportunity costs of reserve holdings. The crisis related models of reserve demand emphasise the role of total and short-term external debt.

These theories, however, ignore the link between the exchange rate and asset markets. According to the monetary approach to the balance of payments, any disequilibrium in the domestic money market leads to an equal change in reserves. Therefore, the conditions of the domestic money market determine the level of reserves and have to be accounted for.

The portfolio balance approach is used to show that the accumulation of reserves causes costs that are ignored by prevailing models of the demand for reserves. Depending on the chosen policy, the accumulation of reserves may raise domestic interest rates, affect the nominal and real exchange rate and cause inflation in the long run.

The following chapter builds on these theoretical considerations. It aims at examining the empirical relevance of our set of potential determinants of reserves. For this purpose, a variety of estimation methods is employed in a large panel data set of industrial and developing countries.

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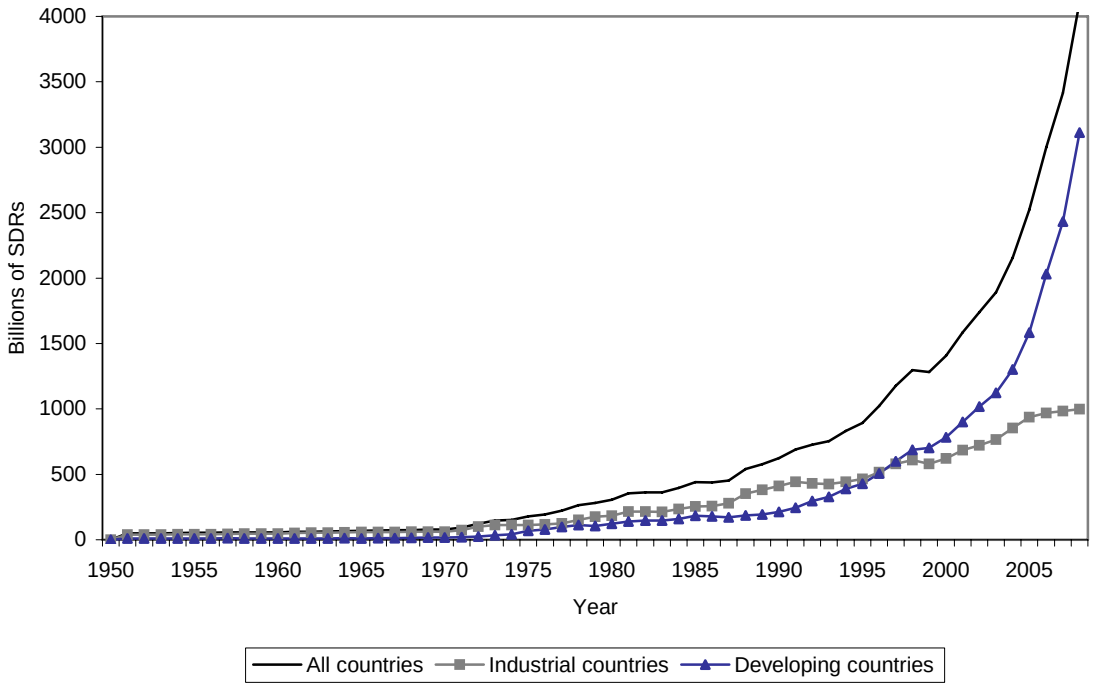
Figure 1: Total international reserves



Soucre: International Monetary Fund (2008)
Note: Country groups are in accordance with the classification given in the above cited publication.

Figure 2a: Indicators of reserve adequacy – traditional view

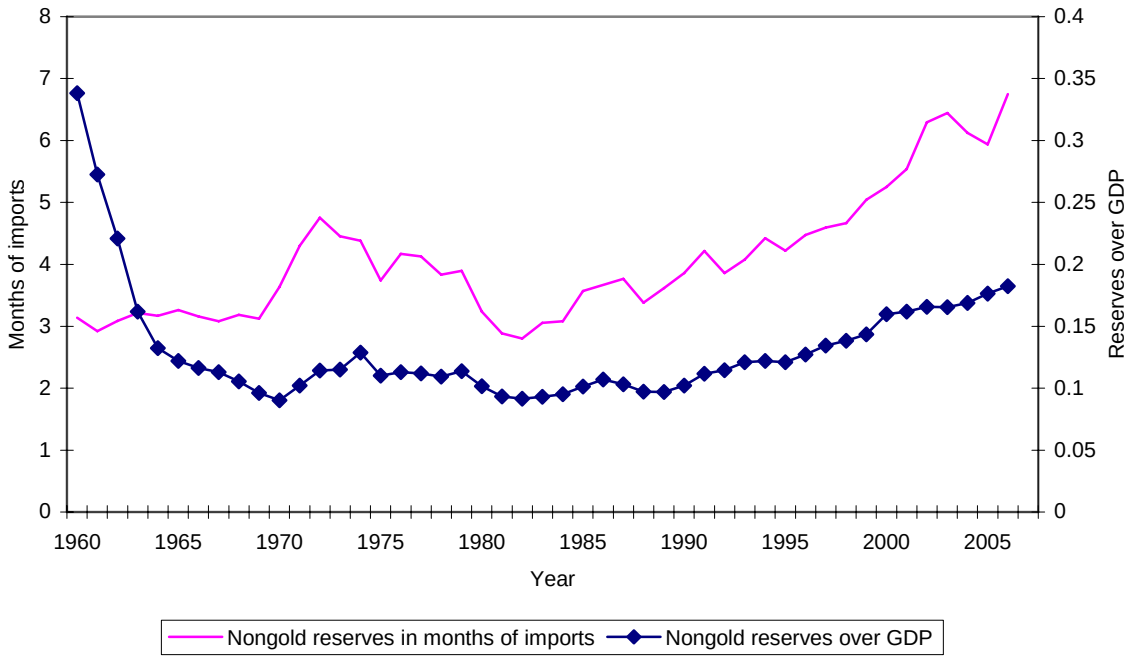
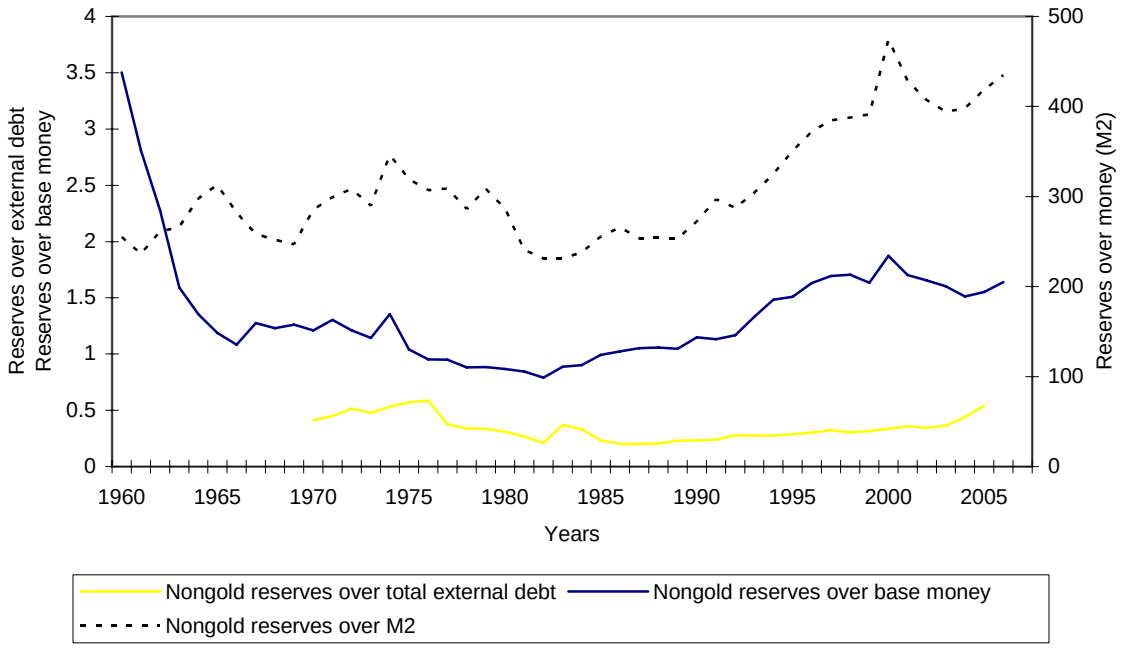
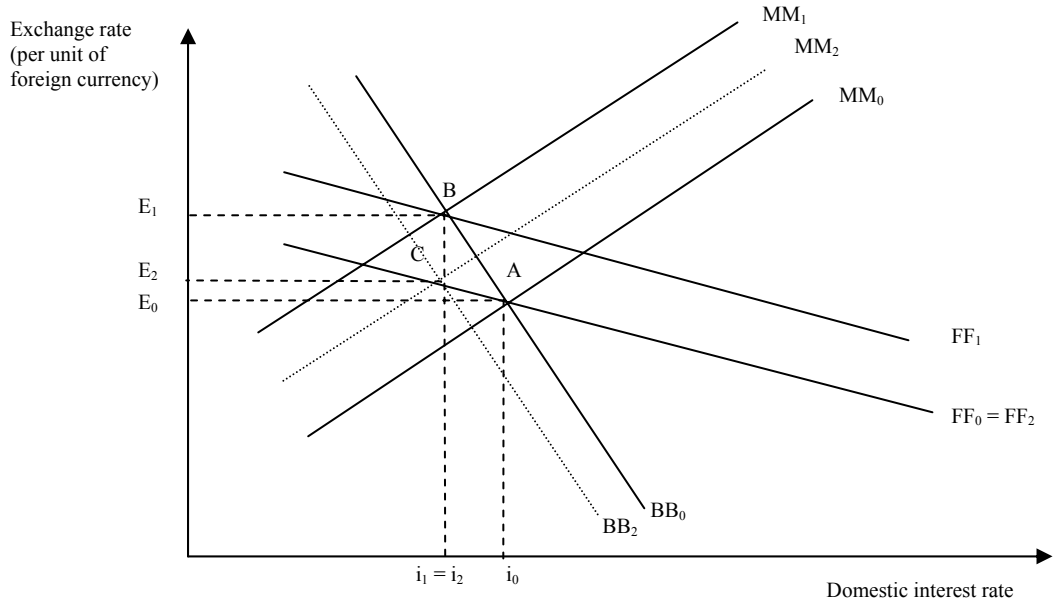


Figure 2b: Indicators of reserve adequacy – focus on capital flight



Source: Author's calculations based on International Monetary Fund (2008) and World Bank (2007).
Note: For each year, the data refer to unweighted country averages.

Figure 3: Accumulation of foreign exchange through increase of money supply



Note: Dotted lines mark the long-run effects.

Figure 4: Adjustment of the domestic price level in the long run

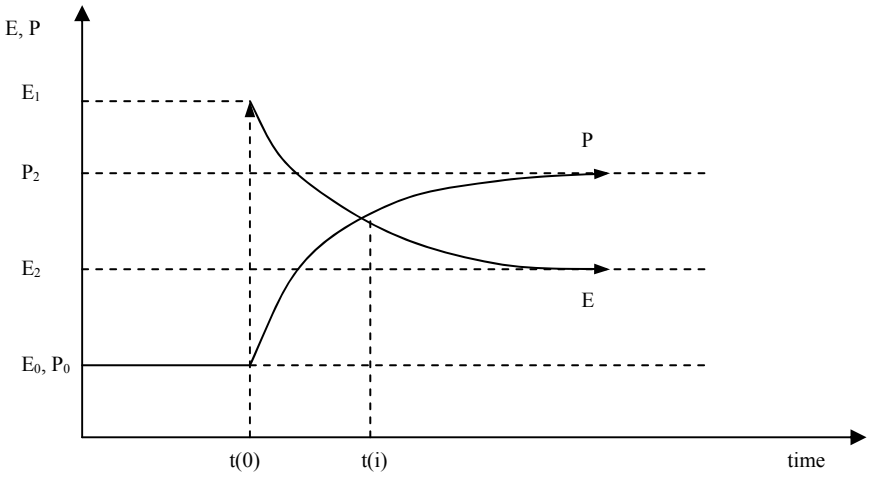


Figure 5: Accumulation of foreign exchange through sterilized open market intervention

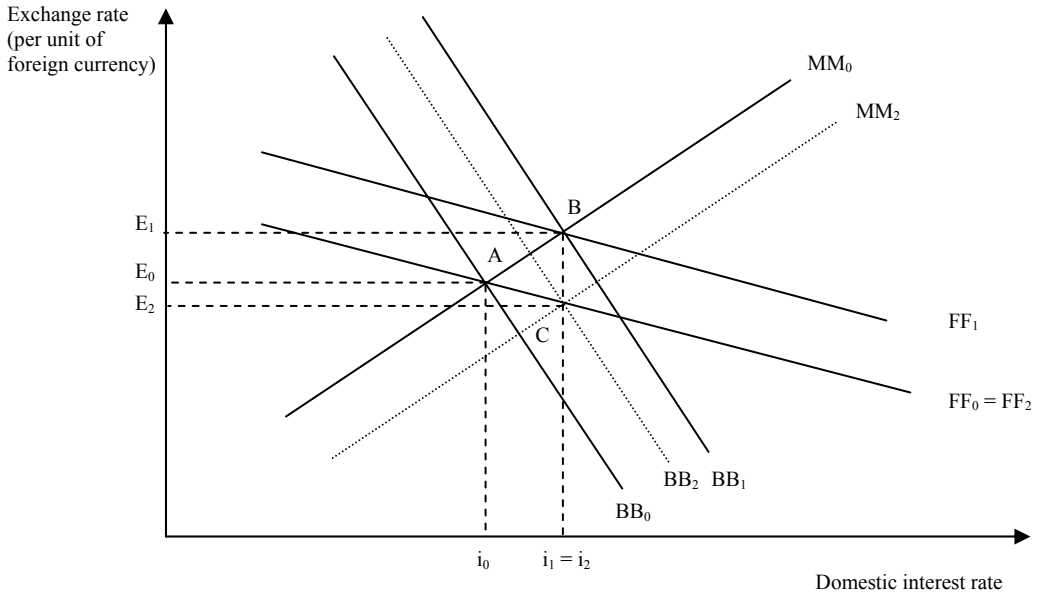
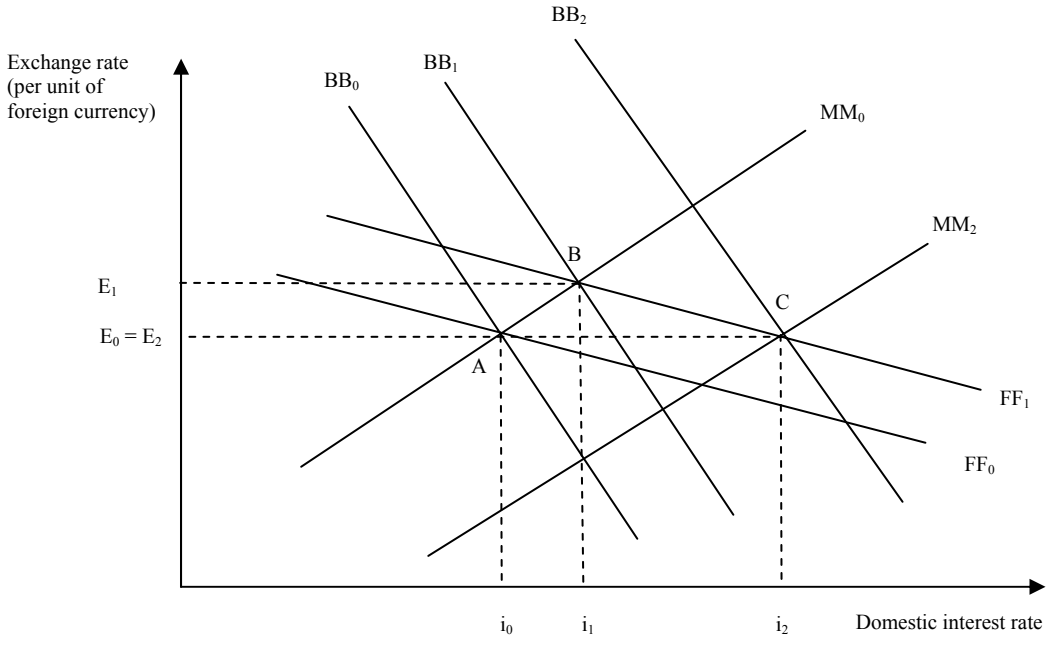


Figure 6: Accumulation of foreign exchange that is sterilized in both countries



Chapter 2

Why Do Central Banks Hold International Reserves? An Empirical Analysis

1 Introduction

This chapter investigates empirically the determinants of international reserve holdings for a large panel data set of developing and industrialized countries covering the period from 1975 to 2003. It tests the significance of the set of potential determinants, which are derived from theory in chapter 1. I argue that the estimation method matters for the results: First, the results of static and dynamic models are compared. Second, the heterogeneity of the data set is examined and estimators for heterogeneous data are applied and compared to their homogeneous counterparts. I find that pooling may not always be the best choice since results are biased if country behaviour is characterised by a substantial degree of heterogeneity.
The principal aim of this chapter consists of establishing a benchmark regression for the demand for reserves, which – in a second step – will be used to test the validity of new hypotheses in the following chapters of this dissertation.

Apart from different sets of explanatory variables, the majority of empirical studies share some common features: They focus on a small number of countries – often belonging to a certain region – or do not include the recent period of reserve accumulation. Pooling over countries and the use of static models of reserve determination are the standard methods. This implies that countries are assumed to behave identically with respect to changes in the explanatory variables. To my knowledge, the possibility of heterogeneous behaviour across countries has not been considered so far. A list of major empirical studies since the year 2000, which summarises their methodology, research question and findings, can be found in Appendix A.

The contribution of this chapter to the literature is threefold. First, a data field is used that covers virtually all countries for which data on reserves are available and that extends to the recent period of reserve accumulation until 2003. This allows us to draw more general conclusions than existing studies.
Second, the determinants of reserves are reconsidered and some new empirical measures for these are proposed. Whereas standard approaches measure trade openness in nominal terms, this chapter uses a measure for real openness. For the opportunity cost a more sophisticated proxy is used that takes inflation differentials between countries into account. Most empirical studies on the demand for reserves ignore the result of the monetary approach to the balance of payments, which states that a disequilibrium in the domestic money market implies reserve

changes. To test for this link between monetary policy and reserves, a measure of monetary disequilibrium is included.
Finally, the paper examines the extent to which conclusions from panel data studies on the determinants of international reserve holdings are robust to the inclusion of dynamics as well as the consideration of heterogeneity across countries. To this end, the results of a static model are contrasted with those of a dynamic specification and an estimation technique is proposed that takes differences in country behaviour into account. Since standard tests of poolability reject the hypothesis of equal coefficients across countries, the latter is the preferred method.

In sum, this chapter extends existing studies in terms of generality and flexibility. The resulting equation for the demand for reserves is applicable to a random country and, in particular, not restricted to countries of a certain region. At the same time, the estimation allows for differences in country behaviour without assuming equal coefficients across all countries.

The approach is positive in that it describes and explains the phenomenon of reserve accumulation without assessing its adequacy. We use a panel data set of a maximum of 162 countries over the period 1975 – 2003 to identify the determinants of international reserve holdings. Questions of the optimality and adequacy of international reserve holdings are not touched.

The main findings of this chapter can be summarized along two lines: first, with respect to the research question why central banks hold international reserves and, secondly, in a more general way concerning the effects of neglected dynamics and heterogeneity in panel data studies.
The findings suggest that countries that are more open or have a higher external debt burden hold more reserves. This supports the idea that countries hold reserves as a cushion against external shocks and financial crises. Intermediate exchange rate regimes are associated with the highest level of reserves, which might hint at the desire for heavy exchange rate management. Whereas opportunity costs seem to play no role in a central bank's strategy, persistence of the reserve stocks is an important property. The hypothesis of the monetary approach to the balance of payments is supported: An excess supply of domestic money

reduces the level of reserves. This effect is especially pronounced if a fixed exchange rate regime is in place.
The neglect of dynamics – independently of whether models for homogeneous or heterogeneous data are used – leads primarily to differences in the magnitude of the estimated coefficients. The difference between the estimates of homogeneous and heterogeneous models is more pronounced. They differ not only in the magnitude of the effects but reveal conflicting results concerning the significance of the effects. These findings suggest that pooling of cross-sectional data is not always a good idea. If the assumption of equal behaviour of all cross-sectional units is questionable, the loss of accuracy might outweigh the gain of efficiency provided by pooling. This is especially important in macroeconomic applications where countries are pooled. As long as the control variables cannot account for all country differences – which is almost always the case – the assumption that countries behave equally is heroic.

This chapter is organized as follows. Section 2 reconsiders the potential determinants of reserves, proposes some new empirical measures for these determinants and explains their expected effect on the level of reserves. Section 3 discusses the question whether the data can be pooled and shows the consequences of omitted dynamics and neglected heterogeneity across countries in a general setting. It then describes the panel data estimators that will be used in the empirical analysis. The empirical results are presented in Section 4. The final section concludes and summarizes the main findings.

2 Determinants of reserves: definitions

The following section defines the dependent variable and presents possible determinants of reserves, their expected effect and their definition in the empirical analysis in more detail.

International reserves: Reserves consist of gold, convertible foreign exchange, unconditional drawing rights with the IMF (the country's reserve position in the Fund) and special drawing rights (SDRs). In the econometric analysis, international reserves are measured net of gold

since gold holdings are relatively stable and changes in the measured level of gold reserves are primarily due to changes in its price.[18]

One problem with this measure is that observed changes in its amount do not necessarily imply that the central bank sold or bought reserve assets. An increase or decrease of reserves arises also from valuation changes of one or several of its components. Movements of the exchange rate between the dollar and other major reserve currencies – the Euro, Yen, British Pound and Swiss Franc – change the level of reserves evaluated in dollars. Since the composition of reserves is kept as private information by many central banks, a distinction between valuation changes and quantity changes is unfortunately not feasible.

The dependent variable of the empirical analysis is international reserves divided by a scale variable. Three variables are considered as possible scale variables: the price level, GDP and base money. Reserves divided by the price level, a measure of real reserves, is disregarded in the econometric analysis since the series seems to be nonstationary[19]. GDP as a scaling variable is motivated by the idea that reserves depend on the size of an economy. The ratio of international reserves to base money compares a part of a central bank's assets with some of its liabilities, namely currency in circulation and reserve holdings of commercial banks. It measures the domestic component of capital flight, that might directly affect a central bank when economic agents sell national currency for assets denominated in foreign currency.

In the following I only report the results of the regressions using reserves divided by GDP as the dependent variable. The results for reserves divided by base money can be obtained from the author upon request. They confirm the robustness of the results.

[18] Data on international reserves are taken from the International Financial Statistics and do not include foreign assets which are devoted to so-called sovereign wealth funds. Especially oil-exporting countries channel a significant part of their oil revenues into those funds. Though state-owned and state-operated, these funds are managed more aggressively than official reserves at a central bank. Assets are generally invested in less liquid and riskier instruments. There are two types of funds: stabilisation funds intended to tackle the problems of volatile resource revenues and savings funds designed to preserve part of the revenues for future generations. In 2007, sovereign wealth funds held roughly half the size of official reserves at central banks – US$ 2.5 trillion compared to US$ 5.1 trillion, respectively (estimates of the Department of the Treasury 2007 and Morgan Stanley 2007). Since IMF data on international reserves do not include assets of sovereign wealth funds, some sources blame the IMF figures to be incomplete. This critique, however, is not relevant for the study at hand since it aims at explaining why central banks hold international reserves. Therefore, it is plausible to restrict attention to official reserves that are under the direct control of a central bank.

[19] One might first-difference the series to remove the nonstationarity. This approach will not be applied in our case of a dynamic model since the fixed effects estimator usually has less bias than the first differenced estimator if the number of time periods is larger than two. More importantly, a nonstationary variable cannot be explained by stationary variables. This also holds after first-differencing. Since our right-hand side variables are stationary – as we will see later – there is no meaningful relationship between them and real reserves. Moreover, the methods to estimate dynamic relationships appropriately (GMM and bias-corrected fixed effects estimator) cannot be applied to first-differenced series.

As seen in the theoretical section (chapter 1), the traditional literature identifies a set of standard variables that is expected to determine the level of reserves. These are output per capita, trade openness, a volatility measure and the opportunity cost of holding reserves.

Development: On theoretical grounds, the expected impact of the stage of development on the level of reserves is ambiguous. On the one hand, less developed countries may wish to hold more reserves for two reasons. First, since their access to international capital markets is limited, the private financing of balance of payments imbalances is more difficult. The sale of reserves could be, at least in the short-run, a substitute for private foreign capital imports. Second, the probability that these countries are affected by a financial crisis is higher. On the other hand, less developed countries might not be able to afford to hold the ideal amount of reserves. Therefore, the stage of development can only be expected to have a positive impact on reserves if the observed amount of reserves equals its ideal level.
In the empirical analysis real output per capita is used to control for the level of development.

Trade openness: Trade openness is hypothesised to have a positive impact on the level of reserves. The more open the economy, the more vulnerable it is to external shocks.
The prevailing measure of openness used in the literature is nominal imports plus exports relative to nominal GDP. This measure, however, overestimates openness of poor countries because the relative price of nontradables to tradables is lower in less developed countries. According to the Balassa-Samuelson theory, the labour forces of poor countries are less productive than those of rich countries. This difference in productivity is especially pronounced in the tradables sector, whereas it is negligible in the nontradables sector. Since the law of one price forces prices of tradables to equal internationally, the wage level in the poor country will be lower. Hence the production costs and price of nontradables are lower in the poor country as well. This implies that a given national real GDP evaluated at national prices and then converted into dollars will be lower if it is produced in a poor country. The measure of openness is consequently biased upwards.
The Bhagwati-Kravis-Lipsey effect offers an alternative explanation for the lower price of nontradables in less developed countries. Not differences in productivity but the abundant endowment with labour relative to capital leads to lower wages in less developed countries. Lower wages, in turn, imply lower prices of nontradables, which are mostly labour intensive services.

Therefore, I use an alternative measure of openness, called real openness. This measure was first proposed in the context of trade and productivity by Alcalá and Ciccone (2004). Real openness is defined as the sum of imports and exports measured in US$ at the market exchange rate divided by GDP measured in purchasing parity US$. In other words, the national volume of production is multiplied by the corresponding prices in the United States. Using real openness instead of openness as a measure for the importance of trade for an economy eliminates distortions due to differences in the purchasing power of one dollar between countries.

External volatility: Volatility of external payments and receipts or volatility of the terms of trade may translate into large swings in the current account. It increases the probability that the (real) exchange rate can only be maintained through foreign exchange interventions and that reserves hit their lower bound. From a precautionary perspective, higher volatility is therefore expected to be associated with a higher level of reserves.
For the empirical investigation, however, a direct measure of the volatility of the trade balance cannot be used because of its endogeneity. The observed volatility is the outcome after having used reserves or other adjustment policies to mitigate disturbances so that it does not reflect the volatility without intervention.
A standard proxy for external volatility, previously used in the literature on international reserves, is the standard deviation of the previous years of the growth rate of exports. Since exports are measured in current dollars, both volume and price volatility are captured. I refer to this variable as volatility (nominal). From a current account perspective, however, exports are important because they generate foreign exchange income for the private sector which, in turn, is used to finance imports. Therefore, it might be preferable to use the growth rate of the variable exports as a capacity to import as the relevant variable. Its volatility is a measure of the volatility of the income terms of trade. Since this measure is also a proxy for the volatility of the real exchange rate, it may be a determinant of reserve demand by a central bank that aims at stabilizing the real exchange rate. Thus, the standard deviation of the previous five years of the growth rate of exports as a capacity to import is used as an alternative proxy for volatility, called volatility (real).

Opportunity cost: International reserves are part of the total assets of a country. As such, they could be used alternatively to finance productive investment projects, to repay (external) government debt or to buy other assets according to optimal portfolio considerations. The

difference between the return of these alternative investment options and the yield on liquid international reserves is the appropriate concept of opportunity cost. In the empirical analysis, the opportunity cost is measured as the real interest differential between the country under consideration and the US. Real interest rates, which are relevant for investment decisions, can be calculated as the difference between a nominal interest rate and the expected inflation rate. In our analysis, however, we will use an ex-post real interest rate differential that deduces the realised inflation rate from the nominal interest rate. More precisely, it is calculated as the difference between the national lending rate to prime customers (i) net of the national inflation rate (π) and the US treasury bill rate (i^{US}) less the US inflation rate (π^{US}):

$$r_i^{opp} = (i_{it} - \pi_{it}) - (i_t^{US} - \pi_t^{US})$$

where t stands for time period and i denotes a certain country.

The use of the ex-post real interest differential can be motivated by several reasons. First, the real opportunity cost measure is lagged by one period because of possible endogeneity. Since an increase in reserves might reduce the sovereign risk premium it may also have a negative impact on the opportunity cost. Since the measure is lagged, the ex-post real interest differential is known to central bankers. Second, it is assumed that central banks adjust their reserves to changes in the opportunity cost with some time lag. The hoarding of reserves can usually not be explained by an optimal portfolio allocation that maximises expected profits. However, a central bank might revise its reserve policy after it realised the high costs of its reserve stock in the past. Moreover, the public and politicians might force the central bank to adjust its reserves after the high opportunity costs became visible in the form of deceased central bank profits. This is an additional argument to use the lagged opportunity cost measure. Finally, data on expected inflation rates or forward exchange rates is not available for the majority of our observations.

This real opportunity cost measure is superior to the opportunity cost measure used by the mainstream of the literature.[20] It takes into account that the difference between real interest rates is the proper concept of opportunity cost. Large nominal interest payments in a high-

[20] In the existing literature, the opportunity cost is either proxied by the differential of nominal interest rates or just by the level of the domestic interest rate. More importantly, after the opportunity cost was found to be mostly insignificant in the literature of the 1970s, many authors do not include it at all (see Bahmani-Oskooee and Brown 2002 and references cited there).

inflation country are nullified as soon as the foreign currency is changed into national currency because of prior adjustments of the exchange rate.
Nevertheless, this opportunity cost measure can be criticized for not taking into account that reserves create a positive externality: Higher levels of reserves may change the interest rate spread between domestic bonds and their US counterparts of equal maturity in favour of the reserve hoarding country because higher reserves may reduce risk – exchange rate risk and risk of sovereign default – and may improve the country's credit rating with international rating agencies. Hence, any increase of the level of reserves may reduce the opportunity cost of each unit of reserves. Furthermore, it may reduce the cost of each unit of private external debt by offering a subsidy to foreign borrowing in units of foreign currency. Levy-Yeyati (2006a) shows for a sample of emerging markets that reserves have a significant positive effect on credit ratings of public debtors such that the average opportunity cost of reserves amounts to only 25% of the sovereign spread. However, this measure is incomplete since it disregards the effect that under imperfect capital mobility any reserve accumulation is a form of capital export which raises domestic real interest rates.

Exchange rate system: The need for central banks to intervene in the markets for foreign exchange depends substantially on the exchange rate system. The more flexible the exchange rate, the less reserves are needed for its management. In a fixed exchange rate system the central bank is committed to buy and sell foreign exchange at the fixed parity. This, however, is no justification for reserve holdings since it does not have to intervene if its monetary policy is geared to the exchange rate target. If the exchange rate is flexible, market forces determine the value of the exchange rate such that the balance of payments is in equilibrium. The exchange rate is used as an adjustment mechanism and balance of payments imbalances cannot materialize.

On the basis of the de-jure classification of exchange rate arrangements provided by the IMF three dummy variables of exchange rate flexibility are constructed for the empirical analysis: Fixed, intermediate and flexible exchange rates.[21] The robustness of the results is tested in section 4.4 where the de-jure measures are replaced by two types of de-facto classifications.

So far the traditional determinants of reserves have been discussed. These variables were already present in the extensive literature of the 1970s when the need for reserves was

[21] A description of how the finer IMF classification is grouped into these three broad categories of exchange rate regimes can be found in the appendix at the end of the dissertation (pp. 231-234).

primarily thought to be linked to imbalances of the current account. At that time, the adequacy of reserves was measured as the number of months during which imports could be financed by reserves.
The focus of the more recent literature that emerged after the series of financial crises during the 1990s shifted from the current account to the capital account. It assigns reserves a role for crisis prevention in the absence of flexible exchange rates. Reserves may be held as a self-protection against financial, currency and banking crises. Financial crises are about capital flows and not trade financing. As a result, new determinants of reserve demand were asserted. These are financial openness, total external debt and short-term external debt.

Financial openness: Whereas the inclusion of trade openness is motivated by the idea that reserves are held as a buffer against real shocks, reserve holdings might also depend on financial openness. Its effect is ambiguous. Financially open countries can – at least theoretically – finance a current account deficit by a capital account surplus, that is by credits of the international financial market. The sale of reserves and the accumulation of foreign debt are substitutes in a fixed exchange rate system since both can finance a deficit in the current account. Thus, financially open countries are expected to need fewer reserves to finance imbalances in the balance of payments or to smooth the adjustment process of the current account. On the other hand, integration in the international financial market also contains the risk of sudden stops and reversals of capital flows. The access to global capital markets is uncertain. Since financially open countries are more vulnerable to currency and financial crises they are expected to hold more reserves.
In the empirical analysis, financial openness is proxied by the amount of gross private cross-border capital flows as a percentage of GDP.

Total external debt: Reserves foster the credibility of central banks' commitment to stabilize the exchange rate. They may enhance foreign investors' willingness to invest in the domestic economy. Moreover, empirical studies show that both a high level of external debt and a low level of reserves increase the probability of a debt crisis defined as significant arrears on external obligations towards commercial creditors (Detragiache and Spilimbergo 2001). The level of external debt that falls due within the coming twelve months, is one of the leading indicators of financial crises (Bussière and Mulder 1999; Chamon et al. 2007; Kamin et al. 2007) Hence, reserves might offset the vulnerability induced by external debt. Therefore, it is

expected that countries with a high level of external debt hold more reserves for precautionary reasons.

However, there might be exceptions from this expected behaviour: Highly indebted countries might not be able to acquire the desired level of reserves. Therefore, there might exist a discrepancy between the desired and affordable level of reserves.

In the context of external debt it is also worth taking a closer look at the dynamic process of reserve accumulation and to raise the question how this accumulation is financed. If it is financed by the issue of public debt, reserves and debt are complements. They increase simultaneously. Thus, a higher level of reserves does not always signal a healthier economy. However, an analysis based on the ratio of reserves to external debt might cause mistaken conclusions. If total external debt exceeds the level of reserves – which is a plausible assumption – , the reserve-to-debt ratio rises if the increase in reserves is completely financed by the issue of external debt. This might be perceived by rating agencies as well as international investors as a signal of improved fundamentals. In reality, however, the economy is worse off: Fundamentals remain unchanged, but the economy faces costs – the opportunity cost of the additional external debt.

On the other hand, the sale of reserves and the issuance of public debt might be substitutes in the sense that both can be used to smooth domestic absorption across periods when revenues from exports vary. When external borrowing is impossible during periods of crises, the sale of reserves substitutes external credit to finance a temporary discrepancy between a country's payments and receipts. This is the idea of precautionary reserve holdings which are financed by a balance of payments surplus.

In the empirical analysis total external debt is defined as the sum of public and private long-term and short-term debt. It is expressed as the ratio of GDP.

Short-term external debt: Reserves that cover short-term debt enable a central bank to provide the necessary foreign exchange at a fixed exchange rate such that private agents can repay their external obligations as scheduled even if capital inflows stop suddenly. Hence, the real exchange rate effects of capital flight can be mitigated. More importantly, the negative long-term effects of credit loss by foreigners in terms of lost access to international capital markets may be averted. These arguments are the basis of the Guidotti rule, a rule of thumb for reserves adequacy proposed in 1999 by Argentina's former Deputy Minister of Finance. It says that countries should hold reserves equivalent to one year's debt repayments. Given that this rule has become quite popular – central bankers as well as investors use it to assess the

adequacy of reserves at low cost – emerging and developing countries whose reserves do not cover their short-term debt may be penalized with lower sovereign ratings.

In this context a short note concerning the prevailing use of rules of thumb for the assessment of reserve adequacy might be indicated. Central bankers, rating agencies, investors and international institutions like the IMF seem to agree that these rules are important indicators of reserve adequacy. Although these rules might be inadequate and meaningless – they are not based on sound theoretical models –, they are important for our analysis. If there exists a general consensus between central bankers, rating agencies and investors that these rules are important indicators of the reserve adequacy, they might be self-fulfilling: if the evaluators of reserve adequacy – international investors, the IMF and domestic citizens – also use these rules, compliance with these rules might be a way to impede speculative attacks. Or, to put it differently, countries that disregard these rules might be penalized. Hence, the level of reserves might be driven by such rules if central banks orientate their demand for reserves towards compliance with them.

Therefore, a positive effect of the level of short-term external debt on the stock of reserves is expected. In the empirical analysis short-term external debt is defined as external debt with a remaining maturity of one year or less. The regressions consider the effect of short-term external debt divided by GDP. Its value is lagged by one period because of its possible endogeneity: the level of reserves and of public short-term debt might be determined simultaneously.

Monetary disequilibrium: According to the monetary approach to the balance of payments, any disequilibrium in the money market leads to an equal change in the level of reserves. Therefore, a proxy for monetary disequilibrium is included in our set of determinants of the level of reserves.

Standard theories of the demand for money (for a survey see Goldfeld and Sichel 1990) assume that real money demand depends positively on the level of income (due to the transaction motive) and negatively on its opportunity cost. According to the functional form given by Cagan, the real money demand for country i in time period t can be written in logarithmic form as[22]

[22] While this model neglects some factors that might be relevant for money demand (e.g. interest rates for deposits of different maturity or the inflation rate as a determinant of currency substitution), I opt to use this simple specification.

$$\ln\left(\frac{M}{P}\right)_{it} = \alpha_i + \beta \cdot \ln(Y_{it}) + \gamma \cdot i_{it} + \varepsilon_{it}$$

where M is an aggregate of nominal money, P is the price level measured by the GDP deflator, Y stands for real GDP and i, the money market interest rate, is a measure for the opportunity cost. α is the country fixed effect, β denotes the income elasticity of the demand for money, γ measures the semi-elasticity of money demand with respect to the opportunity cost and ε is the error term.

The demand for money is estimated for the same panel data set that is used to estimate the demand for reserves. Two different estimation techniques are employed: First, a fixed effects estimator that accounts primarily for the variation within each country over time and, second, the between estimator that averages the data for each country and therefore makes use only of the cross-sectional variation.

The variables of the money demand equation are usually found to be nonstationary, but cointegrated, such that a meaningful long-run relationship between these variables exists. Therefore, the results of the fixed effects model can be interpreted as the long-run money demand. The between estimator is employed to test for robustness since the use of country averages eliminates the problems of nonstationarity.

Two different money aggregates are used as dependent variable: M1 and M2. The estimation results are presented in Table 1. As expected the income elasticity of the demand for money is around one. Moreover, the results are in line with the standard finding that the income elasticity is the larger the broader the chosen money aggregate is. The opportunity cost is insignificant in all presented regressions.

The fitted values from this demand for money equation ($\ln \hat{M}_{it}$) are used as a proxy for money demand ($\ln M_{it}^{d}$). A disequilibrium in the money market is defined as the difference between supply of and demand for money ($\ln M_{it}^{s} - \ln M_{it}^{d}$), i.e., the error term ε. Hence, a positive value of the disequilibrium measure indicates an excess supply of money whereas a negative value signals an excess demand for money.

As described in the theoretical section, an excess supply of money is expected to exert a negative effect on the level of reserves.

This effect is expected to be the stronger, the more rigid the exchange rate is. An excess supply of money depreciates the exchange rate according to the monetary approach to the exchange rate. Under a fixed exchange rate, the central bank has to reduce money supply via the issuance of domestic bonds or the sale of reserves. This is the consequence of the fundamental result that money supply is endogenous under a fixed exchange rate system with capital mobility. Under a flexible exchange rate, the adjustment of the exchange rate might bring about equilibrium in the domestic money market without inducing changes in reserves.

To account for this relation between monetary disequilibrium and exchange rate regime, an interaction term between our proxy for monetary disequilibrium and the dummy for a fixed exchange rate regime is also included.

Since the dependent variable in the regression analysis is international reserves over GDP, the disequilibrium measure is also scaled by GDP.

3 Empirical strategy

3.1 Data

The empirical analysis is carried out using annual data from 1975 to 2003. The beginning of this period is motivated by the previous breakdown of the Bretton Woods system. This institutional change probably led to a structural break in the time-series of international reserve holdings from which we would like to abstain in this study.
The database extends to a maximum of 181 countries. These are all countries – industrial, emerging as well as developing countries – for which data on official reserve holdings for the period from 1975 to 2003 are available in the International Financial Statistics. A list of the countries included in the sample can be found in Appendix C. Since data for some of the explanatory variables are not available for all countries, the econometric analysis makes use of a maximum of 162 countries. Moreover, since some of the data is not available for all years, the panel data set is unbalanced. With a few exceptions data are taken from the International Financial Statistics of the IMF and the World Development Indicators of the

World Bank. A list of data sources and definitions of the variables can be found in the appendix at the end of the dissertation. Appendix D provides summary statistics.

3.2 Econometric methodology

The standard model to analyse panel data is the unobserved effects model. Observations are pooled over time and units of observation, with or without individual-specific effects. These effects can be fixed (fixed effects model) or random (random effects model). Analytically it can be written as

$$y_{it} = x_{it}\beta + c_i + u_{it} \tag{1}$$

where *y* is the level of reserves and *x* represents a set of variables that potentially affect the level of international reserves. ß is a vector of slope parameters, *c* represents the country specific effect and *u* is the error term. *i* denotes a specific country and *t* stands for time. In total, we observe N countries over T time periods.

With respect to the functional form of the regression equation, the model is assumed to be linear. This specification implies that the effect of a unit change in an explanatory variable on y is assumed to be constant independently of the level of the variables. Alternatively, one might assume that the underlying model is exponential and apply a logarithmic transformation. In the resulting log-linear model the slope coefficients measure the elasticity of y with respect to the explanatory variables. In contrast to the linear model, the elasticity is constant in this model.

3.2.1 Fixed versus random effects

The choice between a fixed or random effects formulation can be justified by considerations on the data-generating process as well as by statistical tests.

When the sample is open, i.e. when the N cross-section units are drawn randomly from a large population, random effects are natural candidates. When, on the other hand, the sample contains all units of interest and is not a sample draw from a larger population, fixed effects are appropriate.

Statistically, consistent estimation of the random effects model requires that the observed explanatory variables not be correlated with the unobserved effect ($Cov(x_{it}, c_i) = 0$). The fixed effects model, in contrast, allows for arbitrary correlation between the observed explanatory variables and the unobserved effect. If the assumption of zero correlation is violated, the random effects estimator is inconsistent, whereas the fixed effects estimator is consistent independently of the correlation between explanatory variables and unobserved effect. These properties are utilized by the Hausman test, which is based on the difference between the random and fixed effects estimates. A statistically significant difference is interpreted as evidence against the random effects specification.

For our specific analysis of a sample of countries, all mentioned considerations point to the fixed effects formulation. The sample is closed in the sense that it contains almost the whole population, namely all countries for that data on international reserves are available. Moreover, it is likely that the individual effects are correlated with the observed explanatory variables. One might think of country characteristics like institutions, social factors or history, which are not included in our empirical model and are therefore part of the individual effects but are possibly linked to the observed variables. Finally, the hypothesis of the Hausman test that the difference between the estimates of the random and fixed effects model is not systematic, can be rejected at a conventional level of significance. For our benchmark regression (Table 5, column 2) the hypothesis has a p-value of 0.00.
The choice between fixed and random effects also determines the nature of inferences that can be made. In the random effects model, inferences can be made unconditionally about a larger population from which the data in the sample are (thought to be) just a random draw. Inferences of fixed effects models are limited to the behaviour of the set of observations included in the model and cannot be applied to "similar" units.

3.2.2 Static versus dynamic specification

Apart from the determination of an appropriate set of explanatory variables, one has to make an assumption concerning the properties of the dependent variable. Either it is static or it follows a dynamic adjustment process.

From a theoretical perspective, models often relate to a stationary or static world in which the equilibrium value of a variable is exclusively determined by its determinants and in particular

independent of its own realization in the previous period. However, most empirical economic relationships are characterized by a dynamic adjustment process where the equilibrium value is not reached immediately. In these cases, the current value of a variable depends on its past value, the current value may deviate from its optimal or desired value and the analysis of the time path to its equilibrium value is important.

Nevertheless, empirical models are often based on static estimation when a dynamic one might be warranted. However, since the availability of data sets over long time periods has improved and estimation methods for dynamic models, which are more complicated and require stronger assumptions than those of static models, have been developed, the addiction to static models is no longer justified.
Moreover, the neglect of dynamics is not without cost. An incorrect specification of the process governing the dependent variable may also affect the estimated coefficients of its explanatory variables.

In terms of empirical modelling, a static model is represented by equation (1) whereas a dynamic one includes the lagged dependent variable as a right-hand-side variable:

$$y_{it} = \delta y_{i,t-1} + x_{it}\beta + c_i + \varepsilon_{it} \tag{2}$$

where δ is the coefficient of the lagged dependent variable.
This demonstrates that the neglect of dynamics is a special case of an omitted variable problem. The standard result of the literature on omitted variables states that the coefficients of the included explanatory variables are biased if the neglected variable is correlated with the included ones. In the case of neglected dynamics, the omitted variable contains all past values of the explanatory variables. Therefore, consistent estimation is only viable if the explanatory variables are uncorrelated over time.

An alternative illustration of this problem can be obtained from an examination of the relation between explanatory variables and the error term. Estimation of fixed effects models by pooled OLS relies on the assumption that the explanatory variables are exogenous, i.e. uncorrelated with the error term. If the lagged dependent variable is neglected, it becomes part of the error term. By repeated substitution, the error term can be expressed as:

$$u_{it} = \delta^t y_{i0} + \sum_{j=1}^{t-1} \delta^j x_{i,t-j} \beta + \frac{\delta - \delta^t}{1-\delta} c_i + \sum_{j=0}^{t-1} \delta^j \varepsilon_{i,t-j} \quad (3)$$

It is noteworthy that this error term contains all past values of the explanatory variables x_i. In consequence, if the explanatory variables are correlated over time, then the error term is as well correlated with the current explanatory variables in equation (2) and there is an endogeneity problem. This leads to a bias in the estimation.

I would like to illustrate these theoretical considerations with an example. The current level of external debt is likely to depend on its past value; it moves slowly over time and shows cyclical rather than erratic movements. External debt is serially correlated. In our application, external debt belongs to the set of control variables that determine the demand for reserves. Hence, reserves and external debt are correlated in any given time period. If reserves follow a dynamic process that is, however, neglected in the estimation, lagged external debt becomes part of the current error term. By assumption, the error term – containing lagged external debt – is then correlated with one of the current explanatory variables, namely current external debt.

For a fixed time dimension T and a cross section dimension N that goes to infinity, the omission of dynamics may result in a substantial bias. The static fixed effects estimator is downward biased if the coefficients (β and δ) are positive. It is the larger, the slower the dependent variable adjusts and the lower the serial correlation of the explanatory variables.

Hence, it is important to determine whether the dependent variable of a panel data study is generated by a static or dynamic data generating process. A first technique to detect dynamics simply consists in the estimation of a dynamic relationship (equation (2)) and the verification if δ is significantly different from zero. Alternatively, one might estimate a static model like (1) and test for serial correlation of the error term. The presence of serially correlated errors might be an evidence for the presence of dynamics.

In our study of the demand for reserves, we have to determine whether the dependent variable – international reserves divided by GDP – follows a static or dynamic process. There are several arguments why a dynamic behaviour is more plausible.

As a first approach, one might consider the nature of this variable. The level of reserves is a stock variable that would be constant over time if the central bank were totally passive (under a freely floating exchange rate system). The initial stock of reserves is not zero, but there is an existing level which is inherited from the previous period. When a central bank determines the level of reserves, it always starts from this level and has to define the desired changes. Therefore, the determination of the level of reserves is a natural candidate for a dynamic specification that includes the lagged level of reserves as one of its determinants.

Analytically, the inclusion of the lagged dependent variable can be motivated by a partial adjustment or habit-persistence model (see Appendix B for a theoretical illustration). A central bank might only partially adjust the level of reserves to its desired level when the adjustment is costly and when an optimising behaviour is assumed, trading off the costs of making the adjustment and the costs of not having the desired level of reserves. In addition, the lagged dependent variable might be interpreted as a measure of inertia or historical persistence. A central bank that evaluates the past level of reserves as adequate will be inclined to stick to this level, even if the determinants of reserve holdings call for a reduction. Bordo and Eichengreen (2001) show that inertia is at least present for gold holdings of central banks.

Persistence of reserves might also be the result of a central bank considering the link between reserves and the confidence which is attributed to its paper money. Economic agents still associate the reliability of paper money, namely its price stability, with the level of reserves. If a central bank reduced abruptly but appropriately the level of reserves – for example in response to the move to a less managed exchange rate system – economic agents might question the reliability of national money, expect higher inflation, substitute national paper money for other sources of wealth, thereby destabilize the national money market and finally self-fulfil their expectations. Therefore, if fundamentals call for a reduction of reserves, central banks might sell reserves only smoothly such that the public is not unsettled.

Finally, empirical tests also point to dynamics in the level of reserves. The lagged dependent variable is highly significant in our estimations independently of the included set of control variables (see Table 7). The Wooldridge test for serial correlation in linear panel data models (Wooldridge 2002, pp. 274-276) strongly rejects the null hypothesis of no serial correlation ($p=0.00$) for the specification of Table 5, column 2. This might be due to omitted dynamics.

Regardless of these considerations, the standard approach of the literature on the determinants of international reserves uses static models. There are only two exceptions (Bordo and Eichengreen 2001 and Dreher and Vaubel 2009).

3.2.3 Homogeneous versus heterogeneous parameters

A further property that warrants careful consideration before the estimation is carried out concerns the homogeneity of the cross-section units. One has to raise the question whether the behaviour of all cross-section units can be captured by one equation with common parameters.

The workhorse of macroeconometric panel data models are fixed effects estimators in their static or dynamic versions. These models with unobserved effects allow for some country heterogeneity, which is modelled by country-specific fixed effects. Hence it is assumed that the heterogeneity is time-constant and independent of the explanatory variables. Concerning the slope coefficients, they are set constant over time and over all cross sections. Thus, one assumes that the postulated economic relationship is constant over time and that the effect of the explanatory variables is equal over all units of observation.

The assumption of homogeneous slopes might be reasonable – both on theoretical and empirical grounds – for the analysis of microeconomic units like households or firms. For macroeconomic comparisons of countries, however, it is less likely to hold since countries differ for reasons that cannot adequately controlled for in the empirical analysis (i.e. institutions, laws, habits and social norms). For example, the effect of openness – trade as well as financial openness – on a country's level of reserves might depend on the country-specific experiences with openness. To be more precise, if a country had been hit by a balance of payments crisis in the past, it might evaluate the risk of openness differently than a country without this experience. In addition, if reserves had been used in the past to cushion the negative effects of openness, economic agents would expect the central bank to do so in the future, too. This creates moral hazard in the sense that economic agents do not evaluate risks properly. The central bank might simply respond to these expectations and hold a higher level of reserves than another country with the same degree of openness. Finally, the effect of a given degree of openness might depend on the history of this variable. Countries that liberalised their current and capital account just recently might behave differently than countries that have a long history of openness.

Thus, heterogeneity between countries might not be solely due to fixed country effects but also to different responses with respect to changes in the explanatory variables.

With respect to the demand for reserves, there are even fewer reasons to believe that countries are homogeneous than in other macroeconomic fields. So far, there exists no canonical consensus model that provides a formula for the optimal amount of reserves. The adequacy of reserves is usually assessed by means of indicators. However, there exists a variety of indicators with different indicators often leading to conflicting assessments of the adequacy of reserves. Finally, the "optimal value" of indicators is not time-independent but changes from time to time. Therefore, even if countries hold the optimal amount of reserves according to their own assessment, there will be differences in behaviour since decisions are not taken on the basis of a common model.
With respect to the speed of adjustment (δ), there exists no theoretical argument why all countries should converge to the equilibrium value with the same speed.

Figure 1 illustrates the cases of homogeneous and heterogeneous slopes using two extreme examples of two countries: one in which the fixed effects estimator is appropriate and another in which countries behave so differently that pooling may not lead to reasonable results.

Since the majority of empirical studies on the determinants of international reserve holdings rely on fixed effects estimation of static panel data models, the question arises whether their results are robust to possibly neglected heterogeneity across countries.

Theoretically, the estimators from a pooled model are more efficient than those based on individual models if the conditions for pooling are fulfilled. Pooled estimators are consistent as long as all regressors are strictly exogenous and all parameters are random and distributed independently of the regressors. Pooling presumes that there are similarities or linkages in the data generating processes of the different units of observation. They are assumed to belong to one population.

In practice, however, the strong assumption of common slopes might be violated. Countries behave differently and the results for one country are not completely transferable to other countries. The following section illustrates the consequences of neglecting parameter heterogeneity.

Country behaviour might be modelled according to the following heterogeneous specification, which allows for country-specific parameters β and δ, indicated by the index i:

$$y_{it} = \delta_i y_{i,t-1} + x_{it}\beta_i + c_i + v_{it} \tag{4}$$

where v is the error term and δ is set equal to zero in the static case. Let us assume that the coefficients β_i and δ_i vary across countries but are fixed over time. They consist of a component that is common for all countries and a country-specific random deviation:

$$\delta_i = \delta + \eta_i$$
$$\beta_i = \beta + \alpha_i$$

η_i and α_i are identically independently distributed, independent of x_{it} and v_{it} and have a zero mean and a constant variance. If this heterogeneity is neglected and estimation based on a restricted homogeneous model specified by (2), the heterogeneity terms become part of the error term:

$$u_{it} = v_{it} + \eta_i y_{i,t-1} + x_{it}\alpha_i \tag{5}$$

Given the assumptions that all regressors x_{it} are strictly exogenous and that all parameters are random and distributed independently from the regressors x_{it}, v_{it} and $x_{it}\alpha_i$ are independent of x_{it}. Therefore, in the static case ($\delta_i = \eta_i = 0 \quad \forall i$) the composite error term u_{it} is independent of the regressors and the fixed effects estimator is consistent.[23] This result originates from Zellner (1969). However, the error u_{it} is heteroskedastic and serially correlated if x_{it} is serially correlated. This makes the estimates inefficient but does not affect their consistency.

These results for static cases, however, do not apply to dynamic models. Since y_{it} is serially correlated, the composite error term is serially correlated as well and not independent of the lagged dependent variable. Therefore, in the dynamic case, pooling gives inconsistent estimates of the coefficients. The bias persists regardless of the size of N, T and of any choice

[23] Wooldridge (2004) shows that for consistency of the static fixed effects estimator it suffices that β_i is independent of the time-demeaned explanatory variables x_{it}. In particular, β_i may depend on the time averages of x_{it}.

of instruments. This inconsistency was first noted by Robertson and Symons (1992) and examined more rigorously by Pesaran and Smith (1995).
The large sample bias of δ will be positive if the serial correlation of x_{it} is larger than zero.[24] The estimator of β will be downward biased. The size of the bias increases with the degree of parameter heterogeneity (i.e. the variance of β_i).

If the explanatory variables x_{it} are serially correlated – which is the empirically relevant case – the bias persists even if the only source of heterogeneity comes from variations in β_i across groups whereas the adjustment parameter δ_i is the same across all countries.

Monte Carlo studies presented in Pesaran, Smith and Im (1996) investigate the small sample properties of various estimators in heterogeneous panels. They indicate that the mean group estimator – an estimator based on individual country regressions – generally outperforms pooled estimators (fixed effects estimator, Anderson-Hsiao estimator) by far. A comparative study of the bias of the GMM-type estimators and the mean group estimator, however, remains a task for future research.

Correlations between explanatory variables and the error term are usually dealt with by instrumental variables methods. A valuable instrument must be correlated with the endogenous explanatory variable but uncorrelated with the error term. However, given the composite error (5), all variables that are correlated with $y_{i,t-1}$ or x_{it} are also correlated with u_{it}. Hence, there are no suitable instruments and the instrumental variables approach is not helpful in this case.

In face of this theoretical argument against pooling, the neglect of slope heterogeneity in other studies can be explained by several arguments, some depending on the objective of the empirical study, others on the statistical inability to consider heterogeneous slopes.
First, when the main panel data estimators were developed, the time-series dimension of available panels was relatively short. Estimation of an individual regression for each country was not feasible because of the limited number of degrees of freedom. Hence, the scope for analysing slope heterogeneity was limited.

[24] Since in dynamic fixed effects estimations based on pooled OLS δ is biased upwards due to the presence of the lagged dependent variable, the two biases attenuate each other.

Second, slope heterogeneity does not matter if one is interested in obtaining an unbiased estimator of the average effect of exogenous variables. However, as shown in this section, this result is not valid in the case of a dynamic relationship.
Third, long run effects are less likely to be affected by slope heterogeneity. If, however, the primary interest is on the short run impact or adjustment process, heterogeneity might be important.

For the theoretical economist it is plausible that all countries behave equally according to the predictions of a theoretic model, especially if the model is derived from an optimisation procedure. If countries behaved differently, the theory would be questioned. For the empirical economist it is convenient to pool over countries: If he estimated the relationship individually for each country, the results would be complex and it would be difficult to draw general conclusions.[25]

These arguments might explain why the assumption of homogeneity is seldom questioned and rarely tested. This stands in sharp contrast to the decision whether the individual-specific effects are fixed or random, which is usually taken on the basis of a Hausman test. However, if the underlying assumption of homogeneity is erroneous, the decision between fixed and random effects is of second-order relevance. The degree of heterogeneity has to be determined before one decides whether the heterogeneity is systematic (fixed) or random.

Since the neglect of heterogeneity may cause misleading results with respect to the size of the coefficients and the significance of the variables, it is important to test for heterogeneity in the slope parameters and, if heterogeneity is significant, to employ estimators that take account of different slopes across countries. Since our data set spans over a sufficiently long period, separate regressions for each country can be estimated. Rather than assuming equal parameters for all countries, one can estimate individual parameters and than test the hypothesis that the parameters are equal (poolability hypothesis).

[25] Robertson and Symons (1992, p. 181) conclude that "it is tempting to pool these regressions to achieve an overall summary".

3.2.4 Tests for the poolability of the data

The poolability over countries can be tested by a Chow test that is extended to N linear regressions. Like a standard Chow test, it compares the residual sum of squares of a restricted model with that of an unrestricted model. The restricted model is the pooled model with the same parameters for all countries and over all periods except a country-specific intercept (fixed effects model, equation (2)). The unrestricted model consists of the same behavioural equation, which is, however, estimated individually for each country, thereby allowing for different parameters across countries (equation (4)). Intuitively, the Chow test rejects the hypothesis of poolability if the reduction in the residual sum of squares is relatively large when individual parameters are allowed for.
The standard Chow test is only valid for disturbances that meet the twin assumption of homoskedasticity and no serial correlation. A modified test statistic that allows for both heteroskedasticity and serial correlation of the errors is available. It is a special application of the Roy-Zellner test for aggregation bias in a set of seemingly unrelated regressions.

However, there is a problem with the standard F test in large samples: As the sample size grows, classical testing at a fixed level of significance increasingly favours the alternative hypothesis. When the sample size increases, the probability of accepting a false hypothesis (type II error) converges to zero whereas the probability of rejecting a true hypothesis (type I error) remains at its predefined level. If one is willing to reduce the two types of errors simultaneously, the critical value should be an increasing function of the sample size.[26] Leamer (1978) proposes such a correction to the critical value of the F statistic, which will be presented as an alternative to the standard Chow test.

These tests evaluate exclusively the validity of the hypothesis of common parameters across countries. They do not take into account that pooling data has the advantage that the variance-covariance matrix of the pooled model always has smaller entries than in the unrestricted model. The restricted model might hence be preferred if one accepts some bias in trade for a gain in precision. This trade-off between bias and variance is captured by the mean square error (MSE)[27] criteria for poolability, which were proposed by Toro-Vizcarrondo and Wallace (1968) and Wallace (1972). Strictly speaking, the MSE criteria do not test the hypothesis of

[26] This idea is in line with the Bayesian viewpoint that the critical value is an increasing function of the sample size.
[27] The mean square error of an estimator is defined as its variance plus the square of its bias.

equal parameters across countries but allow to choose between two estimators pragmatically trading off bias and variance.

The strong MSE criterion only favours the estimator of the pooled model if the MSE of every linear combination of the estimator of the pooled model is smaller than the MSE of each corresponding linear combination of the estimator of the unrestricted model with an individual regression for each country. It can be shown that this condition holds if and only if the noncentrality parameter of the F distribution is equal or smaller than one half.
The second weak MSE criterion[28], which was proposed by Wallace (1972), requires that the sum of the MSE of the parameter vector of the pooled model is smaller than that of the unrestricted model. Geometrically this means that the average squared distance of the estimator of the pooled model is smaller than that of the estimator of the unrestricted model. It can be shown that this condition is met if the noncentrality parameter of the F distribution is equal or smaller than the denominator degrees of freedom[29] of the F statistic divided by two.

These MSE tests are operational only if the variance-covariance matrix of the disturbances were known. In our case it is replaced by a consistent estimate. McElroy (1977) has shown that the limiting distribution of F is unaffected by this change and the tests can be applied by the same manner as described above.

The results of the poolability tests are presented in Table 2. The evidence is mixed. For our data set, three out of the four described tests reject the hypothesis of poolability. Only the Chow test with the corrected F statistic according to Leamer's formula accepts the hypothesis of common parameters across countries.

This result, however, comes as no surprise. Previous studies found that the hypothesis of common slope parameters is very often rejected (see for example Pesaran and Smith 1995). This tendency of overrejection in finite samples was also attested by Monte Carlo studies conducted by Bun (2004). Nevertheless, it indicates that heterogeneity in international reserve determination among individual central banks is considerable. As described in the previous section, while static models are still unbiased, the neglect of heterogeneity may lead to misleading results in dynamic models.

[28] There exists also a first weak MSE criterion which is not considered in the present context.
[29] The denominator degrees of freedom of the F statistic are calculated as (N - 1)(K + 1) where N is the number of countries and K the number of parameters excluding the intercept.

Table 2: Poolability tests across countries

	Large sample (93 countries)	Small sample (72 countries)
Observed F statistic	15.36	14.99
Chow test		
a) Generalized (Roy-Zellner)[1] H_0 of same slope coefficients across countries	$F_{crit} = 1.11$ rejected	$F_{crit} = 1.13$ rejected
b) Leamer critical values[2] H_0 of same slope coefficients across countries	$F_{crit} = 20.00$ accepted	$F_{crit} = 15.72$ accepted
Mean square error criteria		
a) strong MSE criterion Pooling better?	$F_{crit} = 1.15$ rejected	$F_{crit} = 1.15$ rejected
b) 2nd weak MSE criterion Pooling better?	$F_{crit} = 2.34$ rejected	$F_{crit} = 2.34$ rejected

Notes:

The large sample of 93 countries includes all those countries of the benchmark regression (Table 5, column 2) for which data for at least 10 years are available. The small sample consists of the same countries but requires at least data over 20 years. Since regression (2) of Table 5 also includes countries with data over fewer years, the samples are smaller. This restriction is necessary since the calculation of the test statistic is based on the estimation of the behavioural equation individually for each country. So it is guaranteed that the estimation country by country is based on at least 10 or 20 data points, respectively.

All critical values of the F statistic are based on a level of significance of 5%.

[1] The generalized Chow test allows for both heteroskedasticity and serial correlation of the errors.
[2] The critical values are calculated according to the following formula which is given in Leamer (1978, p.114):

$$F_{crit} = \frac{N(T-K-1)}{(N-1)K} \cdot \left((NT)^{(N-1)K/NT} - 1 \right)$$

where N is the number of countries, T the number of time periods and K the number of estimated parameters excluding the intercept.

Nevertheless, following the literature, the results of pooled models will be presented despite the presence of country heterogeneity. The purpose of this chapter is precisely to present the results of pooled as well as individual models and to highlight the differences.

3.3 Estimators for static and dynamic panel data models

The following section provides a review of estimators for static and dynamic panel data. Appendix E summarises their main characteristics and emphasises the different degrees of heterogeneity they account for.

3.3.1 Static models

This section presents different estimators for static models of panel data, which will be used for estimation. It summarises their characteristics and possible shortcomings.

Fixed effects model: The standard model for the analysis of macroeconomic panel data is the fixed effects model, which takes into account individual country effects. For estimation, the original equation is transformed by time-averaging the model equation for each country and subtracting it from the original equation. This removes the individual specific effect and allows for estimation by pooled OLS. For consistency it has to be assumed that the explanatory variables are independent of the error term for all countries and over all time periods (strict exogeneity assumption). The fixed-effects estimator is also called within estimator because only the variation over time within each country is used to estimate the coefficients. All cross sectional variation is absorbed by the fixed effect.

However, the fixed effects estimator is only efficient if the errors are homoskedastic and serially uncorrelated. These assumptions are likely to be violated in a panel data context. Since countries differ considerably in their absolute level of international reserves, they may also exhibit different variations in their reserve level and hence be subject to country-specific heteroskedasticity. Serial correlation – temporal dependence of the error terms – is also likely since unobserved shocks might affect the relationship over various periods. Therefore, a robust variance matrix is estimated, which allows for general forms of heteroskedasticity and serial correlation. This was suggested by Arellano (1987) and is equivalent to a White-corrected variance matrix.

Random coefficient model: A model that allows for additional parameter heterogeneity is the random coefficient model (RC). Rather than just the intercept varying across groups, all coefficients and the intercept vary randomly across groups but share a common mean and the

same variance-covariance matrix. It can be interpreted as an extension of the random effects model where not only the intercept but also the slope parameters are random.
The coefficient vector is estimated by GLS. It can be shown that the GLS estimator is a matrix-weighted average of the least-squares estimator for each cross-sectional unit, with the weights inversely proportional to their covariance matrices.

The coefficients can be interpreted as the sum of two effects: a direct effect of the explanatory variable on the dependent variable and an indirect effect due to the fact that the explanatory variables affect omitted variables which, in turn, affect the dependent variable.

In our sample of countries where the differences between countries are not random but rather systematic, the random model seems to be inappropriate. The arguments put forward against the random effects model are equally valid for the random coefficient model. Despite these caveats, the random coefficient model will be included in the econometric analysis because interest centres on the effect of permitted heterogeneity.

Mean group estimator: The mean group estimator (MG), which was proposed by Pesaran and Smith (1995), allows for slope heterogeneity between groups. For each country, it estimates an individual regression by OLS and averages the coefficients over groups. We may write the general model including a lagged dependent variable (and comprising the static model as the special case $\delta = 0$) as

$$y_{it} = \delta_i y_{i,t-1} + x_{it}\beta_i + c_i + u_{it}$$

which, written more compactly, reduces to

$$y_{it} = c_i + \gamma_i w_{it} + u_{it}$$

where $w_{it} = (y_{i,t-1}, x_{it})$ and $\gamma_i = (\delta_i, \beta_i)$.

The mean group estimator of γ, the population mean of γ_i, is then defined as

$$\hat{\gamma}_{MG} = \frac{1}{N}\sum_{i=1}^{N}\hat{\gamma}_i$$

This estimator leads to consistent estimates of the coefficients. It is unbiased if N and T are sufficiently large.[30]

[30] For small N outliers might affect the results. T must be sufficiently large in order to make individual regressions for each country feasible.

The variance-covariance matrix of the mean group estimator can be estimated from the individual estimates $\hat{\gamma}_i$, i=1,.., N

$$\hat{\text{var}}(\hat{\gamma}_{MG}) = \frac{1}{N(N-1)} \sum_{i=1}^{N} (\hat{\gamma}_i - \hat{\gamma}_{MG})(\hat{\gamma}_i - \hat{\gamma}_{MG})'$$

$$= \frac{1}{N^2} \sum_{i=1}^{N} \text{var}(\hat{\gamma}_i) + \frac{1}{N(N-1)} \delta$$

where δ represents the small sample "bias" term, which is zero in the static case, but disappears only asymptotically as T→∞ in the dynamic case.

3.3.2 Dynamic models

In a dynamic specification, the lagged dependent variable enters as an explanatory variable on the right hand side of the equation. In this setting, the assumption of strict exogeneity of the explanatory variables is violated since the lagged dependent variable is correlated with the error term by construction. Previously discussed fixed effects estimators (within estimators) are downward biased and inconsistent for N → ∞ and fixed T.[31]

The literature proposes two different solutions: a correction for the bias or, alternatively, estimation by the Generalized Method of Moments (GMM).

Bias-corrected fixed effects estimator: For dynamic panel data models with serially uncorrelated errors and strongly exogenous regressors, Kiviet (1995) derives an approximation for the bias of the fixed effects estimator. He proposes a corrected fixed effects estimator that subtracts a consistent estimate of this bias from the standard fixed effects estimator. In Kiviet (1999), a more accurate bias approximation is derived. Bun and Kiviet (2003) reformulate the approximation with simpler formulae for each term. Bruno (2005) extends these results to unbalanced panels. Simulation studies, which are included in the articles on bias approximation cited in this paragraph, show that this correction is an efficient method and can even be more efficient in finite samples than instrumental variables estimators.

[31] For N → ∞ and T → ∞ the estimator would be consistent. However, a Monte Carlo study, conducted by Judson and Owen (1999), reveals that even for a relatively large time dimension (T=30) the bias may be equal to as much as 20% of the true value of the coefficient of interest.

Instrumental variables estimators are proposed as an alternative solution. This class of estimators eliminates the country-specific effects by first differencing. It then applies instrumental variables to the transformed equation.

Anderson and Hsiao (1981) propose the lagged level $y_{i,t-2}$ or the lagged difference $(y_{i,t-2} - y_{i,t-3})$ as instruments for $y_{i,t-1}$. The use of the lagged difference has two drawbacks: it reduces the effective number of observations available for estimation and generally produces higher variances. Therefore, in practice, the lagged level is usually the preferred instrument. A valuable instrument must be correlated with the variable that it replaces and uncorrelated with the error term. These conditions should be fulfilled in our case where the lagged level of the reserves-to-GDP ratio is instrumented by its level lagged by two periods. Since the series of reserves is highly persistent, it is correlated over time. Moreover, whereas its lagged level is correlated with the error term by construction, it is reasonable to assume that it is uncorrelated with the error term of the period ahead.

This estimation leads to consistent estimates of the coefficients. However, it is not necessarily efficient because it does not make use of all available moment conditions and hence uses not all available instruments.

Difference GMM estimator: Arellano and Bond (1991) note that the number of instruments can be extended by using all feasible lagged values of the dependent variable as instruments. More precisely, beginning with $y_{i,t-2}$ all lagged levels of y until $y_{i,0}$ can be used as instruments. Hence, the number of instruments varies with t since with each forward period an extra instrument is added.

Whereas the Anderson-Hsiao estimator imposes only one moment condition, the Arellano-Bond estimator is based on a set of (T(T-1)/2) moment conditions. All these moment conditions can be exploited in a Generalized Method of Moments (GMM) framework.[32] This estimator is also known as the difference GMM estimator because it is based on the first-differenced equations.
Estimation is executed by a two-step procedure. In the first step, an arbitrary weighting matrix – usually the identity matrix – is applied and, in the second step, the optimal weighting matrix – based on the inverse of the covariance matrix of the sample moments – is used. Since the

[32] 2SLS cannot be applied since it demands that the dimension of the matrix of instruments is constant for all t.

two-step standard errors tend to be biased downward in small samples, the one-step standard errors are used for inference. Alternatively, a finite sample correction that provides more accurate estimates of the standard errors is proposed by Windmeijer (2005).

While the Arellano-Bond estimator has been widely used in dynamic empirical studies, various authors have extended this estimator by additional moment conditions with intent to further improve its efficiency.
First, Ahn and Schmidt (1995) show that the assumptions of Arellano and Bond imply further (T-2) moment restrictions, which are not used in their GMM framework.
Second, additional moment conditions can be exploited if further assumptions are imposed. Ahn and Schmidt (1990) show that the additional assumption of homoskedastic errors allows previously nonlinear moment conditions to be expressed linearly and adds (T-1) new moment conditions. As shown by Ahn and Schmidt (1995) the efficiency gain is small. Moreover, if the assumption of homoskedasticity is not valid, it may introduce inconsistency. For these reasons, we shall not use this estimator.

When the individual series are highly persistent and the number of time periods is moderately small, the Arellano-Bond estimator has been found to have poor finite sample properties. In this case, lagged levels of the series provide weak instruments for first differences. Particularly, the instruments become less informative as the value of δ increases towards unity[33] and as the relative variance of the fixed effects c_i increases $\left[\left(\sigma_c^2/\sigma_u^2\right)\to\infty\right]$. Simulation results reported in Blundell and Bond (1998) show that the first-differenced GMM estimator may be subject to a large downward finite-sample bias in these cases.

A further shortcoming of the Arellano-Bond estimator – just as of the fixed effects estimator – consists in the fact that it makes use only of the time variation within each cross section, whereas the cross-sectional variation is not used for estimation. However, we are not only interested in the time-series relationship between the level of reserves and its determinants, but also in their cross-country relationship.

This loss of information is avoided and the bias due to persistent series can be reduced by an alternative estimator, the so-called System GMM estimator.

[33] Bond (2002) notes that in this case the series are close to being random walks, so that their first-differences are close to being innovations.

System GMM estimator: This estimator, which was proposed by Arellano and Bover (1995) and fully developed by Blundell and Bond (1998), combines, in a system, the regression in differences with the regression in levels. The regression in differences, the first part of the system, and its instruments are the same as those of the Arellano-Bond estimator. For the regression in levels, the second part of the system, lagged first-differences of the corresponding variables are used as instruments. For consistency of this estimator, an additional stationarity assumption on the initial value of the level of reserves is required. If one can assume that the same process has generated the series for a long time, the condition will hold automatically.

Hence, the system estimator basically extends the Arellano-Bond estimator by adding the regression in levels.

Tests for the validity of the moment conditions in GMM estimation: The GMM model is overidentified by construction since there are several instruments, namely all lagged levels of a variable, for each explanatory variable. In such a context testing whether the additional instruments are valid in the sense that they are uncorrelated with the error term is indicated. This is implemented by the Sargan test of overidentifying restrictions, which evaluates the null hypothesis that the overidentifying restrictions are valid. The Sargan test statistic is not robust to heteroskedasticity. Arellano and Bond report that the one-step Sargan test over-rejects in the presence of heteroskedasticity. Therefore, the Hansen J statistic is preferred since it is robust to heteroskedasticity.

A further test of the consistency of the GMM estimator is given by the Arellano-Bond test for autocorrelation in the residuals. The consistency of the GMM estimator hinges on the assumption that the residuals are uncorrelated over time. This implies that the differenced residuals (the residuals of the regression in differences) are first-order serially correlated by construction unless the residual in the level equation follows a random walk. Second-order serial correlation, however, implies that the original residual is also serially correlated. Therefore, we test the null hypothesis that second-order serial correlation is absent.

Mean group estimator: Alike in the case of static models, the mean group estimator allows for parameter heterogeneity specifying an individual regression for each country.

This estimator leads to consistent estimates of the coefficients if N and T tend to infinity. For small T, however, there is the small-sample downward bias (Hurwicz bias) in the coefficient of the lagged dependent variable. Since each of the country estimates are subject to this bias, it will not be reduced by averaging across groups. The magnitude of the bias depends on 1/T and is less of concern if T and N are of the same order of magnitude. Hence, if one estimates a dynamic model for heterogeneous data, one has the choice between two biased estimators: an instrumental variables estimator à la Arellano-Bond, which is biased because of the neglect of slope heterogeneity, and the mean group estimator, which is subject to the Hurwicz bias.

3.4 Stationarity

For our case of a data field, characterized by a relatively long time-period under consideration, the time-series properties of the variables deserve more attention. From the time-series literature it is well-known that regressions based on nonstationary data may lead to misleading inferences due to non-standard distributions of the estimators. This is the problem of spurious regression where variables are statistically significant but without economic meaning. An important result in the context of panel data is that nonstationarity is not so much a topic of concern. Phillips and Moon (1999, 2000) and Kao (1999) show that panels make it possible to obtain consistent estimators as the number of cross-section units goes towards infinity. A long-run average parameter can be estimated consistently even when each of the individual time-series regressions is spurious. The averaging over N attenuates the noise in the individual estimators and thus facilitates a consistent estimator of the mean effect. This is especially true if one uses cross-sections, pooled or averaged estimates across countries.

Despite this result, we opt to consider the issue of stationarity and nonstationarity of our variables. Although testing for unit roots in panels is recent, a number of different tests were proposed. Examples are Im, Pesaran and Shin (2003), Levin, Lin and Chu (2002) and Hadri (2000). In comparison with unit root tests on single time-series, which lack power relative to the alternative hypothesis of a persistent but stationary process, these panel unit root tests increase the power of the test by combining information across units. However, these tests require a balanced panel and can therefore not be applied in our case of an unbalanced panel. One exception is the Fisher test, which was developed by Maddala and Wu (1999). It combines the p-values of independent unit root tests on each time-series. It tests the null hypothesis that all time-series are nonstationary against the alternative that at least one time-

series of the panel is stationary. Maddala and Wu find in a Monte Carlo study that the Fisher test performs the best compared to the three other panel unit root tests mentioned above.
Our findings are the following (see Table 3): For our dependent variables reserves over GDP as well as reserves over base money the hypothesis of nonstationarity can be rejected at the 1% level. Originally, real reserves defined as reserves deflated by the GDP deflator was also considered as a possible dependent variable. Since the nonstationarity hypothesis cannot be rejected, its use in the regression analysis was disregarded. The explanatory variables seem to be stationary with two inconclusive cases: The hypothesis of a nonstationary process cannot be rejected at reasonable levels of significance for GDP per capita in two out of eight specifications and for total external debt divided by GDP in five of a total of eight test specifications.
To test for the robustness of these results, Table 4 reports the results of the Levin-Lin-Chu unit root test. Since this tests requires a balanced panel, it is performed on a balanced subsample of our entire sample. Previous results are confirmed: Real GDP per capita and total external debt divided by GDP cannot always reject the hypothesis of a unit root. Moreover, lagged short-term debt and reserves over GDP now also lead to ambiguous results. With respect to the importance of these results one has to remember that the alternative hypothesis states that all series are stationary. Therefore, variables that fail to reject the null hypothesis might be characterized by a small fraction of series that follow nonstationary processes. This explanation is especially plausible for the variable reserves over GDP since it is well know that some countries (i.e. China, India, Mexico) accumulated large amounts of reserves in the recent past.
Despite their possible nonstationarity we include these variables in the econometric analysis since the results of Phillips and Moon suggest that the problem of spurious regression can be avoided by using pooled data. Moreover, we will check for spurious results in the section on robustness.

3.5 Special considerations for macroeconomic data fields

The use of data fields, which are characterized by both a large number of units of observation (N) and a large number of time periods (T), calls for a reassessment of the applicability of standard panel data methods. In particular, one has to investigate whether panel data estimators originally developed for micro panels are also suitable for macro panels. More precisely, the properties for estimators have to be checked for alternative asymptotics and

possible heterogeneity. Unit-specific as well as time-varying heterogeneity have to be considered more concisely.

The econometric theory for panel data was originally developed for panels where T is small in comparison with N. Therefore, the asymptotic characteristics of estimators (i.e. standard fixed effects estimator, Difference GMM estimator, System GMM estimator) were derived by letting N go to infinity for fixed T.

However, due to the increased availability of data and the continuous extension of time series, macroeconometric settings like the one considered here feature now fairly long time-series for a limited number of countries. Since the number of countries is more or less fixed, the asymptotic behaviour of estimators for $T \to \infty$ and fixed N becomes more relevant. Therefore, we have to analyse the properties of our proposed estimators under these asymptotics.

This reasoning moves panel data econometrics towards the traditional time-series literature which covers the case of $T \to \infty$. While traditionally restricted to the analysis of one single cross-section, there are alternative approaches that combine the time-series of various cross-sections in one system. The traditional approach stacks the equations of different cross-sections in a system of seemingly unrelated regression equations (SURE) and estimates it by GLS. This approach, however, is not feasible if $N>T$ since the disturbance covariance matrix is rank deficient. A more recent example is the multi-country vector autoregressive model – called Global VAR in Dees et al. (2007) – which is well suited to analyse interdependencies between countries like the transmission of shocks, spillover effects or the contagion of financial crises. Since our analysis of international reserves does not focus on common dynamics between countries, but tries to explain individual country behaviour, this method is not appropriate for our purposes.

Finally, if N and T are of comparable size, an adequate asymptotic analysis considers the behaviour of estimators for N and T going jointly to infinity. While consistent under fixed T asymptotics, instrumental variables estimators like the Anderson-Hsiao estimator and the difference GMM estimator exhibit finite-sample biases when T is moderate relative to N.

Alvarez and Arellano (2003) show for a simple autoregressive process for panel data without exogenous variables that the fixed effects estimator and the GMM methods are consistent

when both N and T tend to infinity and follow the expansion path $T/N \rightarrow c$ with $0 < c \leq 2$.[34] To be more precise, the limit on how slow N can tend to infinity relative to T is given by the condition $(\log T)^2/N \rightarrow 0$. For N>T the asymptotic bias of the GMM estimator is then always smaller than the bias of the fixed effects estimator.[35] Moreover, a Monte Carlo study suggests that this asymptotic result provides a good approximation of the small sampling characteristics of the estimators. More precisely, it is found that for N>T the bias of the GMM estimator is always smaller than the bias of the fixed effects estimator.

Since the GMM estimator proposed by Arellano and Bond uses all the available lags at each period as instruments, the number of instruments grows at a rate of T(T-1)/2. However, it is doubtful how much efficiency gain one can achieve by using a huge amount of instruments in a finite sample. Based on simulation studies (see Ziliak 1997 or Kiviet 1995), the strategy of exploiting all instruments for estimation is actually not recommended ("overfitting") when the cross-sectional sample size is considered to be too small relative to the number of instruments. Given the findings of Alvarez and Arellano (2003), this reluctance to use all moment conditions when T goes to infinity is theoretically unfounded. They show that the GMM estimator of Arellano and Bond is consistent even when the number of instruments is growing to infinity.

Since in practice N and T are both limited, the asymptotic analysis can only be regarded as a reasonable approximation of the finite sample properties of estimators. Wooldridge (2002, pp. 250-251) argues that even in cases where N is practically fixed and T can grow, N asymptotics with fixed T should provide suitable finite sample approximations if N is still sufficiently large relative to T and if cross-sectional independence can be assumed. Therefore, one can conclude that in our applications where N is at least twice as large as T, standard estimators for micro panels are still the best choice. Nevertheless, bias-corrected OLS estimators might not be a bad idea if T is not small. Judson and Owen (1999) show that the bias-corrected fixed effects estimator outperforms all viable alternatives for N=100 and T between 5 and 30. The bias-corrected estimator of Hahn and Kuersteiner (2002) also dominates the GMM estimators in terms of bias for large N and T.

[34] In order to get tractable results, generally one has to define the relative rate of expansion of N and T.
[35] The GMM and fixed effects estimators can be directly compared for $0<\lim(T/N)<\infty$. In this case, they show the same asymptotic variance and similar expressions for their asymptotic biases. Since the order of magnitude of the bias is $(1-\delta)/N$ for the GMM and $(1-\delta)/T$ for the fixed effects estimator, the asymptotic bias of GMM is always small for N>T [δ is the coefficient of the lagged dependent variable].

The large N and T data fields also allow for the consideration of kinds of heterogeneity which have to be assumed to be absent in the small T literature. First, unit-specific heterogeneity can be allowed for by estimating a separate regression for each cross-section unit. In our application, the mean group estimator follows this approach. Second, there may be unobserved time-varying heterogeneity from global shocks that influence all cross-section units. Such heterogeneity leads to correlation between the errors of different units. As a result, standard estimators will be biased and inconsistent if the common omitted variables are correlated with the unit-specific regressors.[36] Therefore it is important to test for cross section dependence. Tests have been proposed, among others, by Frees (1995) and Pesaran (2004). Unfortunately, these tests cannot be applied to our dataset of international reserves and their determinants since the dataset is highly unbalanced, resulting in insufficient common observations across the panel. Nevertheless, it is reasonable to assume that cross section dependence is not a major problem in our application. First, our dataset is not restricted to countries of a certain geographical region, which might be affected by common shocks. Second, our determinants of reserves show a relatively stable behaviour over time and do not seem to be heavily affected by shocks. Finally, Sarafidis et al. (2006) find in a Monte Carlo study that the bias due to cross section dependence is especially strong in short panels (T = 5), implying that our panel with T = 30 is already relatively long. All estimators do better if T grows.[37] These considerations allow us to suspect that the possible bias due to neglected cross section dependence is small in our application.

4 Estimation results

4.1 Static models

Table 5 presents the results of the estimation of a static fixed effects model. The dependent variable is reserves over GDP. The level of short-term external debt is lagged by one period since the sale of reserves and the issuance of debt are substitutes implying that both variables are determined simultaneously. Column 1 only includes the traditional, current account based determinants of reserves. It is a test of the classical buffer stock model.

[36] See Phillips and Sul (2003) for the fixed effects estimator in dynamic models and Sarafidis et al. (2006) for GMM-type estimators.
[37] This leads to the unsatisfactory situation that testing for cross section dependence becomes especially important when tests are not feasible (namely in the small T cases).

Real GDP per capita, the proxy for the stage of development, has no significant impact on reserves.

More open economies are associated with higher ratios of reserves to GDP, and this effect is statistically significant at the 1% level. This result is in line with the hypothesis that countries use reserves to protect the economy from external shocks.

An increase in the external volatility significantly lowers the level of reserves. This effect is inconsistent with our theoretical considerations, but in line with the findings of another empirical study (Dreher and Vaubel 2009). It also persists if nominal volatility is replaced by real volatility (see column 4): the effect is still negative and significant. Apparently, countries do not behave as hypothesized by the theoretical models. One explanation could be that countries with high external volatility deviate from the desired or "recommended" level of reserves. So far, it was assumed that changes in the amount of international reserves reflect a movement towards their desired level. This is the idea of the partial adjustment model. Countries, however, might deviate deliberately from the desired level of reserves because of poor macroeconomic management.

In this context it might be helpful to go further into the question why some countries are exposed to higher external volatility than others. The reasons might be local – economic crisis, political instability, natural disasters – or global – terms of trade shocks and volatile prices of natural resources in economies whose export sector is not well diversified. Hence, both low reserves and high volatility might be the outcome of poor macroeconomic management (common cause interdependence). Hence, it is not volatility that determines the demand for reserves on the basis of an optimising model, but volatility rather constrains the central bank's level of reserves. In that case, the regression analysis should include a variable that controls for macroeconomic management. Since the quality of macroeconomic management is difficult to measure, the analysis abstains from controlling for it.

Concerning the exchange rate system, a de-jure fixed exchange rate significantly lowers the level of reserves. Although this is also contrary to our expectations, it is in line with the findings of similar empirical studies (e.g. Dreher and Vaubel 2009). The category of fixed exchange rates includes currency unions and dollarized economies. Both might contribute to the negative sign of the fixed exchange rate dummy. Currency unions might actually have a floating exchange rate with respect to countries outside the union – like the Eurosystem. Therefore, they do not have to defend any exchange rate peg. Similarly, dollarized economies do not need any foreign exchange reserves for intervention purposes because they do not have an independent monetary and exchange rate policy. A further explanation for lower reserves

in our category of fixed exchange rate regimes might be that these regimes are supported by accompanying policies. Capital controls are an example of a distortionary policy that supports a fixed exchange rate and lowers the risk of a financial crisis caused by capital flight.
Interestingly, even intermediate exchange rate systems hold fewer reserves than flexible ones, although the difference is not statistically significant.

In column 2 capital account-based explanatory variables are added: Total external debt (in per cent of GDP) increases the level of reserves, whereas short-term external debt (as per cent of GDP) decreases reserves. Both effects are significant at the 1% level. This is in line with the hypothesis that reserves are considered as a means to protect the economy from negative repercussions associated with a sudden withdrawal of foreign capital. However, since capital flight primarily concerns short-term external debt, one would expect that reserves increase even more if the share of short-term debt in total external debt rises. This is the argument of precautionary reserves. However, a high share of short-term in total external debt might be an indication of an evolving crisis. The fraction of short-term in total external debt rises if the average maturity of external loans declines. The shortened maturity might be caused by international creditors who are reluctant to lend long-term because they are less confident with respect to the long-run performance of the economy. This can be the starting point of a financial crisis that eventually leads to capital flight. Therefore, the central bank's demand for reserves is no longer determined by precautionary motives. It aims at preventing a financial crisis selling reserves. This explains why a large share of short-term external debt is associated with lower reserve levels.
The sign and significance of the traditional variables remain unchanged, with two exceptions. Real GDP per capita has now a significant positive effect, and the sign of the intermediate exchange rate system changes from negative to positive.
When the real opportunity cost is added (column 3), the effects of the other explanatory variables are qualitatively unchanged. Real opportunity cost itself is not significant. This finding was also prevalent in the early literature and led to the disregard of the opportunity cost variable in many empirical studies (see Lane and Burke 2001). The interest elasticity of the demand for reserves seems to be low. A central bank might simply not bother about opportunity costs since it is blamed for not having sufficient reserves in times of crisis but is not accused of paying a too high opportunity cost in good times when reserves are not needed.

The results are also robust to the replacement of the standard volatility measure (nominal volatility) by the standard deviation of export growth as a capacity to import (real volatility). As well as the original volatility measure, this variable has the wrong sign.

Table 6 reports the regression results using alternative estimators, which account for different slope parameters across countries. This allows determining whether the results are robust to the consideration of parameter heterogeneity. Since the mean group estimator is based on individual regressions for each country, the sample is restricted to countries for which at least 20 common observations for each variable are available. This reduces the sample to 63 countries. As explanatory variables the core variables, which turned out to be significant in Table 5, are included. For comparison, column 1 contains the fixed effects estimation of the reduced sample. Significance and sign of the parameters mostly correspond to those found in Table 5. An exception is real volatility, which is no longer significant. Column 2 presents the results of the mean group estimator. Significance and sign of the variables are very similar to those of the fixed effects estimator. In general, significance of the effects is reduced (coefficients are now significant at higher levels of significance). Total external debt is no longer significant. However, quantitatively, the effects vary considerably, with the coefficients of volatility and short-term debt more than twice as large as those reported by the fixed effects estimates. This is in line with the theoretical finding in section 3.2.3 that the neglect of heterogeneity implies a downward bias of the coefficients. The results of the random coefficient model (column 3) once again confirm the sign of the effects. Nevertheless, only the effects of real openness and a fixed exchange rate are significant.

From a theoretical perspective, the mean group estimator is expected to provide the most reliable results because it explicitly accounts for country heterogeneity. This is important in our analysis since the hypothesis of poolability is rejected. Whereas the fixed effects estimator controls for country fixed effects, the random coefficients model is, at least on theoretical grounds, the less appropriate model. It assumes that intercepts and slope parameters are random, whereas the differences between countries are probably systematic.
The reported coefficient of determination R^2 does not have all the properties of the simple OLS R^2. It is calculated as the squared correlation between the actual and predicted values of the dependent variable. According to this measure of goodness-of-fit, the random coefficient model outperforms the other two models. A Hausman-type test between the mean group estimator and the fixed effects estimator cannot reject the hypothesis that the difference

between these two estimation methods is not systematic. This favours the fixed effects estimator and contradicts to some degree the finding that the dataset is not poolable. The choice of the preferred estimator therefore depends on the purpose of the estimation: For prediction one might choose the random coefficients estimator, whereas the mean group estimator illustrates the average behaviour of a country.

As a test for robustness, the exercises of Table 5 and Table 6 were replicated for a different specification where the dependent variable is not reserves over GDP but reserves over base money. By and large, the previous findings are confirmed.[38]

In sum, the traditional buffer stock model of the demand for reserves is confirmed. However, the inclusion of variables related to the international financial integration – total and short-term external debt – is important. These variables are significant determinants of reserve holdings and increase the explanatory power of the regression.[39] Moreover, the results confirm the theoretical finding that the neglect of heterogeneity leads to a downward bias in the coefficients.

4.2 Dynamic models

In this section the results from the dynamic specifications are presented. As expected, the lagged level of reserves is highly significant in all specifications and for all applied estimators.

Table 7 provides the results for different estimators for homogeneous panel data. The differences are striking: The coefficient of the lagged endogenous variable (δ) ranges from 0.76 to 0.96. The coefficient of adjustment, which equals (1-δ), is very low. Central banks adjust the level of reserves over a long time period. However, the high value of the coefficient of the lagged dependent variable does not indicate that our dependent variable has a unit root. The 95% confidence interval of this coefficient does not – with the exception of the System GMM estimator – include the value one.

[38] The results are available on request from the author.
[39] The coefficient of determination (R^2) is only 0.03 if the model of Table 5, column 1 is replicated for a reduced sample of 125 countries, which is the sample of column 2 including the debt variables. The inclusion of the debt variables increases the R^2 to 0.09.

The quantitative effects for the other explanatory variables also vary considerably. Concerning the qualitative results, the estimates are more homogeneous. Independently of the estimator, the coefficients of openness and external debt are positive and significant. This is in line with the findings from the static models. Moreover, the effect of short-term debt is significant and negative for all estimators, which is again in line with the results from the static models.

The three tests of consistency of the GMM estimators – the Sargan, Hansen and Arellano-Bond test – clearly accept the specification.

Which of the three estimation methods provides the most reliable results? While the System GMM estimator improves the asymptotic efficiency by adding additional moment conditions, simulation studies show that this might not be the case in finite samples. Moreover, since our series are highly persistent, the available instruments are weak and might lead to poor finite sample properties. Since simulation studies confirm the efficiency of the bias-corrected fixed effects estimator in samples of comparable size, this estimator provides the most reliable results in our application.

Like Table 6, Table 8 compares the restricted models characterized by homogeneous slope parameters with the mean group estimator. Again the sample is restricted to countries for which at least 20 common observations for all variables are available. This reduces the sample to 70 countries. The findings in column 1 to 3, which replicate the estimation of columns 1, 3 and 4 from Table 7 for the reduced sample, are similar to those described before. However, the results of the mean group estimator differ considerably from the homogeneous parameter methods: The coefficients of total external debt and short-term external debt are no longer significant. The coefficient of volatility, until now mostly insignificant, becomes significant at the 10 per cent level. Concerning the exchange rate dummies, at least the sign and significance do not change. The effect of the lagged endogenous variable is much smaller. This finding is in line with the theoretical prediction that this coefficient is upward biased when heterogeneity is neglected and when the serial correlation of the other explanatory variables is positive. The effects of the control variables obtained with the mean group estimator are without exception larger than those identified with the standard GMM methods. This again confirms the theoretical result that the neglect of heterogeneity biases the coefficients of the explanatory variables downwards. Apparently, the neglect of heterogeneity

affects the conclusions with respect to magnitude and significance of the coefficients. Since the tests for poolability reject the hypothesis of common slope parameters, the mean group estimator is expected to provide the most reliable results and is our preferred estimator.

4.3 Models controlling for monetary disequilibrium

The empirical analysis that has been presented so far explores the research question why central banks hold international reserves from a demand-driven perspective. The level of reserves is assumed to be the outcome of a demand for reserves, which depends on certain characteristics of an economy. The level of reserves, however, might be a by-product of other policies. In particular, section 3.2 of chapter 1 shows that a disequilibrium in the domestic money market translates into reserve changes. This section presents the empirical results of a test of the explanatory power of the monetary approach to the balance of payments.

According to the balance sheet of the central bank, changes in reserves must equal the difference between changes in the monetary base and changes in domestic credit. I investigate whether this relationship also holds on the level of the banking sector, namely whether changes in a money aggregate and changes in domestic credit provided by the central bank and commercial banks are associated with changes in reserves. Table 9 presents the results.
Column 1 uses M1 as money aggregate and column 2 tests the hypothesis for M2. As expected, an increase in money supply raises the level of reserves. The provision of domestic credit reduces the level of reserves. However, the coefficients of both explanatory variables are much smaller than the theoretically predicted value of one.

In a second step, the effect of a disequilibrium in the domestic money market is examined. The difference between money supply and money demand is calculated for M1 (column 3) and M2 (column 4). In line with the monetary approach to the balance of payments, we find that an excess supply of money reduces the level of reserves. This effect is only significant if the disequilibrium is defined for M2. Trade openness is included as an additional control variable.

Table 10 provides the results for a static model that combines the theory of the demand for reserves with the hypothesis of the monetary approach to the balance of payments. Column 1 presents the results for a simple fixed effects model. Magnitude and significance of the

coefficients of the control variables are similar to those of Table 5, column 2, which does not account for monetary disequilibrium. Only the fixed exchange rate dummy is no longer significant. The monetary disequilibrium has the expected effect: It is negatively associated with the level of reserves. Since this effect is expected to be the stronger, the more rigid the exchange rate system is, an interaction term is included that captures the effect of a monetary disequilibrium in fixed exchange rate regimes. Its coefficient is highly significant (at the 1 per cent level), negative and in absolute value much larger than the coefficient of a monetary disequilibrium without interaction. The latter effect then turns out to be insignificant.
When the mean group estimator is applied (columns 3 and 4), many control variables – including monetary disequilibrium – become insignificant.
These results highlight that the level of reserves is not only demand driven, but also follows the pattern implied by the monetary approach to the balance of payments. When there is an excess supply of money, reserves tend to decrease and thereby bring actual money supply closer to its demand. This effect is especially relevant under fixed exchange rate regimes since an excess supply of domestic money tends to depreciate the nominal exchange rate.

Dynamic models including monetary disequilibrium (see Table 11) confirm the results of the static model. When the Difference GMM estimator is used, an excess supply of money reduces the level of reserves. This effect is especially strong under fixed exchange rate arrangements. The coefficients of the other control variables are similar to those found without controlling for monetary disequilibrium. The mean group estimator again suggests that most control variables are insignificant.

In sum, as hypothesised by the monetary approach to the balance of payments, a disequilibrium in the domestic money market translates into changes of reserves. Its explanatory power measured as the marginal R^2, however, is limited. Moreover, its neglect – the rule in the literature explaining reserve holdings – does not bias the results regarding the other control variables.

4.4 Robustness

In this section the robustness of our results is examined with respect to the choice of the sample and the definition of the variable controlling for the exchange rate regime.

Alternative samples: During the period under consideration (1975-2003) China has become the world's largest reserve holder. Whereas China accounted for less than 1% of the world's international reserves in 1975, its share exceeded 12% in 2003. Until 2007, China has continued its accumulation of reserves, which then made up almost one quarter of worldwide reserve holdings. Despite the size of its economy and population, this reserve accumulation – although a worldwide phenomenon – is not comparable to other countries. China is an outlier. To ensure that our results are not driven by the Chinese accumulation, the estimation of the demand for reserves is also carried out for a sample excluding China. By and large, the results are unchanged.

Since there might be regional patterns of reserve demand driven by herding and imitation, the estimation is carried out for regional sub-samples. Table 12 presents the results for 28 Latin American and Caribbean, 11 Asian and 42 African countries separately. For the first two country groups the corrected fixed effects estimator is used and for the last the Difference GMM estimator. While the latter is asymptotically more efficient, it is not suited for cases where the number of time periods exceeds the number of countries. The results for Latin America and the Caribbean correspond very closely to the findings of the full sample. The estimates for Asia and Africa, however, are characterised by many insignificant coefficients. In these regions, the demand for reserves depends only positively on trade openness and in Africa additionally on the monetary disequilibrium in economies with fixed exchange rate regimes. The adjustment measured by $(1-\delta)$ is in Africa significantly slower than in the other two regions. The fact that the two external debt variables are only significant in the Latin American and Caribbean sample might be due to the negative experiences of this region during the debt crisis in 1981.

Since the full sample contains developing and industrial countries, one might also be interested in the results of the two subsamples. However, since data on short-term external debt is only available for developing countries, all regressions including short-term debt as explanatory variable are already restricted to the subsample of developing countries.

Alternative definition of exchange rate regime: So far the estimations accounted for the effect of the exchange rate regime by the inclusion of dummy variables according to the IMF's de-jure classification. This classification is based on what countries officially declare to be their exchange rate regime. However, the exchange rate policy that countries follow in practice might differ from what they claim to do. An example are countries that have a de-jure flexible exchange rate regime but intervene frequently in the market for foreign exchange. This is the

so-called phenomenon of "fear of floating". Central banks' demand for reserves is expected to depend rather on the actual than on the announced exchange rate regime. Therefore, we replace the de-jure exchange rate dummy variables by dummies of two different de-facto classifications.[40]

Reinhart and Rogoff (2004) apply a classification algorithm that examines both the variability of the exchange rate and the possible presence of multiple exchange rate regimes. They consider that the official exchange rate might be fixed whereas it is de-facto floating in a parallel market.

An alternative de-facto classification is provided by Levy-Yeyati and Sturzenegger (2005). They base their classification of the exchange rate regime on the behaviour of three variables: changes in the nominal exchange rate, the volatility of these changes and the volatility of international reserves. For the classification, the authors use a cluster analysis methodology that groups countries according to similarity. Countries with a low exchange rate volatility and a high volatility of international reserves form the group of de-facto fixers.

Table 13 provides the results for dynamic models when dummies for these de-facto regimes are used. Columns 1 (Difference GMM estimator) and 2 (mean group estimator) make use of the classification of Reinhart and Rogoff. Since both exchange rate dummies are insignificant one may conclude that the de-facto exchange rate regime has no effect on the demand for reserves. Although the level of reserves is unaffected, one might suspect that the volatility of reserves is higher under de-facto fixed exchange rate regimes. With respect to the other control variables one notices that the two external debt variables – total and short-term debt – are no longer significant. The only exogenous variable that is significant in both estimation methods is trade openness. When the classification of Levy-Yeyati and Sturzenegger is used (columns 3 and 4) the Difference GMM estimator shows that intermediate exchange rate regimes are correlated with a higher level of reserves than the corner solutions of fixed and floating exchange rates. Whereas the results for de-jure exchange rate regimes indicate that fixed exchange rate regimes are associated with lower reserves than the other two regimes, in the de-facto case reserves are lower in both fixed and flexible exchange rate regimes. This allows to draw two conclusions: First, in line with theory, central banks committed to freely

[40] The IMF has realized this shortcoming of its own classification and changed this towards a de-facto classification in 1998. It is no longer based on official country reports but on the evaluation of IMF staff. It may differ from the officially announced arrangements.

(de facto) floating exchange rates hold fewer reserves. Second, the fact that this cannot be shown for de-jure flexible exchange rates supports the hypothesis of fear of floating. The difference between de-jure and de-facto regimes is especially pronounced for flexible regimes. With respect to the other control variables, the Difference GMM and the mean group estimator lead to contradictory results concerning the significance of the effects. Only the coefficient of trade openness is significant and positive independently of the estimation method.

5 Conclusions

The goal of this chapter is twofold: First, the determinants of central banks' international reserve holdings are examined empirically. Second, the appropriateness of different panel data estimators for our data field of reserves and their determinants is assessed. In particular, the effects of omitted dynamics and neglected heterogeneity are examined.

With respect to the application of a variety of estimation techniques to the research question why central banks hold international reserves, the findings show that a country's level of reserves is positively correlated with its integration through goods and capital flows with the rest of the world. Obviously, countries do not only enjoy the advantages of their openness but also take precautionary measures against the downside risks of the increasing international financial integration. Country-specific time-series of reserves are characterized by a high degree of persistence and reserves are adjusted only gradually. However, the level of reserves is not only demand-driven, but also the by-product of other policies. We confirm the result of the monetary approach to the balance of payments that domestic monetary policy affects the level of reserves.

The comparison of different estimation approaches reveals that omitted dynamics and neglected heterogeneity do not only theoretically cause biased results, but may even lead to erroneous inferences in macroeconometric applications with a moderate number of observations. Therefore, the possibility of dynamic processes and tests of the poolability of the data might be considered more important in future cross-country time-series studies.

Dynamic and heterogeneous regression results differ from their static and homogeneous counterparts with respect to magnitude and significance of the effects. Whereas the differences between the static and dynamic models for homogeneous data regard primarily the estimated magnitude of the effects, the comparison of the estimates of homogeneous versus heterogeneous models reveals conflicting results concerning the significance of the effects. These inconsistencies are especially pronounced in the dynamic specification. The results confirm the theoretical finding that the neglect of heterogeneity affects inferences in dynamic models.

In sum, we could identify a set of variables that determine a central bank's international reserve holdings. The results are robust for a wide range of different specifications and estimation methods. Nevertheless, these models cannot explain the enormous accumulation of reserves in recent years, especially since the East Asian financial crisis of 1996. This will be the task of the following two chapters, which present possible explanations for this increase, namely the experience of currency crises and a fear of capital mobility.

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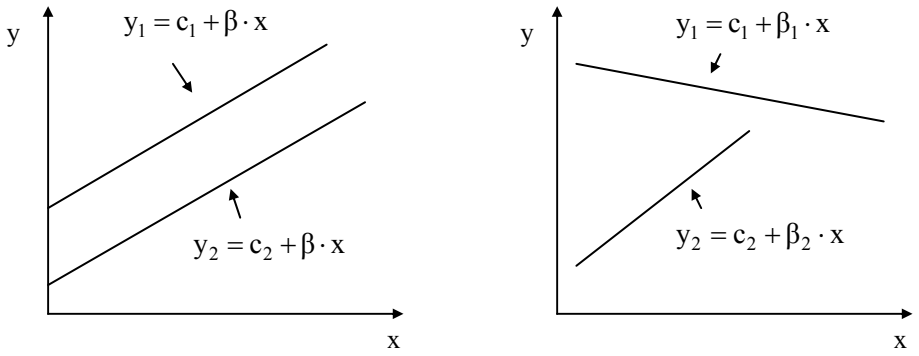
Figure 1: Homogeneous versus heterogeneous data



The left-hand-side graph illustrates the case of two countries that differ in their intercepts (fixed effects) but have the same slope parameters. This behaviour conforms with the implicit assumptions of the fixed effects estimator. The two countries of the right-hand-side graph, however, differ in both intercept and slope parameters. If the slope parameter heterogeneity is neglected, the estimation results will be biased (as shown in section 3.2.3). Estimation of individual regressions for both countries is the appropriate econometric approach.

Table 1: Money demand

Dependent variable	M1		M2	
	(1)	(2)	(3)	(4)
Real GDP	1.0201 (24.83***)	0.9511 (27.84***)	1.2892 (28.47***)	0.9716 (31.48***)
Interest rate (money market)	0.0006 (1.64)	-0.0079 (-0.19)	0.0009 (1.06)	-0.012 (-0.31)
Number of countries	158	158	159	159
Number of observations	3080	3080	3108	3108
Method of estimation	OLS (fixed effects)	OLS (between regression)	OLS (fixed effects)	OLS (between regression)
R^2	0.40	0.83	0.56	0.86

Notes:

The dependent variable and real GDP are used in log-form.
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 3: Fisher P_λ unit root test

Variable	Lags	Trend	ADF-Test χ^2	ADF-Test p-value	Phillips-Perron-Test χ^2	Phillips-Perron-Test p-value
Reserves/GDP	1	no	449.41	0.00	559.92	0.00
	1	yes	460.02	0.00	511.00	0.00
	2	no	408.27	0.03	607.25	0.00
	2	yes	394.96	0.08	534.47	0.00
Real GDP per capita	1	no	405.08	0.00	405.06	0.00
	1	yes	536.18	0.00	496.13	0.00
	2	no	321.41	0.62	400.92	0.00
	2	yes	317.21	0.68	523.16	0.00
Trade openness	1	no	625.89	0.00	722.95	0.00
	1	yes	725.10	0.00	681.10	0.00
	2	no	383.75	0.08	738.25	0.00
	2	yes	520.57	0.00	628.27	0.00
Volatility (nominal)	1	no	772.39	0.00	744.72	0.00
	1	yes	602.88	0.00	702.10	0.00
	2	no	712.72	0.00	775.08	0.00
	2	yes	553.92	0.00	792.16	0.00
Total external debt/ GDP	1	no	422.29	0.00	341.94	0.21
	1	yes	415.57	0.00	315.06	0.60
	2	no	333.58	0.24	360.43	0.07
	2	yes	287.82	0.87	336.53	0.28
Short-term external debt/GDP	1	no	572.72	0.00	600.51	0.00
	1	yes	451.65	0.00	496.25	0.00
	2	no	610.95	0.00	610.55	0.00
	2	yes	511.06	0.00	504.20	0.00

Note: The Fisher-type unit root test pools the results of independent unit root tests on each individual time-series. The table reports the results for the cases where the individual time-series are examined by the Augmented Dickey Fuller (ADF) and the Phillips-Perron test. The null hypothesis is that all series follow a nonstationary process.
The results are sensitive to the number of lags included and to the choice of specification (trend). The inclusion of lags of the dependent variables accounts for serial correlation in the errors. Therefore, results for different numbers of lags - with and without tend - are reported. The minimum of the Schwarz Bayesian information criterion and the modified Akaike's information criterion suggest a lag length of one or two for the majority of country-specific time-series.

Table 4: Levin-Lin-Chu unit root test

Variable	# CS	Lags	Without trend		With trend	
			Coefficient	p-value	Coefficient	p-value
Reserves/GDP	98	1	-0.1290	0.89	-0.2583	0.00
		2	-0.1303	0.97	-0.2683	0.02
Real GDP per capita	105	1	0.0060	1.00	-0.1799	0.00
		2	0.0044	1.00	-0.1878	0.00
Trade openness	85	1	-0.1350	0.00	-0.3551	0.00
		2	-0.1283	0.00	-0.3571	0.00
Volatility (nominal)	94	1	-0.2691	0.00	-0.3338	0.00
		2	-0.2861	0.00	-0.3592	0.00
Total external debt/ GDP	75	1	-0.1087	0.00	-0.1523	0.79
		2	-0.1071	0.01	-0.1419	0.99
Short-term external debt/GDP	74	1	-0.1596	0.00	-0.2071	0.63
		2	-0.1679	0.00	-0.2237	0.52

Note: The Levin-Lin-Chu test requires a balanced panel. Therefore, for each variable a subsample is constructed that contains only those countries, for which data on all 30 time periods is available. # CS indicates the number of countries included in each subsample. Since any systematic relationship between the availability of data and the characteristics of the time-series is improbable, the subsample can be considered as a random sample of the population of all countries.
As for the Fisher-type test, the results are reported for different lag lengths and specifications – with and without trend. Coefficient reports the value of the coefficient of the AR(1) process, which is assumed to be equal for all countries. The p-value shows the level of significance at which the null hypothesis of a unit root in each individual time-series can be rejected. The alternative hypothesis is that all individual series are stationary.

Table 5: Static models: Fixed effects estimation

Dependent variable: Reserves/GDP

	(1)	(2)	(3)	(4)
Real GDP per capita	0.0001 (-0.19)	0.0324 (8.21***)	0.0363 (6.83***)	0.0284 (6.31***)
Trade openness	0.1022 (8.97***)	0.0644 (4.70***)	0.0713 (4.15***)	0.0734 (4.45***)
Volatility (nominal)	-0.0269 (-5.96***)	-0.0167 (-4.06***)	-0.0205 (-4.18***)	
Volatility (real)				-0.0096 (-3.27***)
Total external debt (per cent of GDP)		0.0363 (7.18***)	0.342 (5.50***)	0.0378 (6.87***)
Short-term external debt, lagged (per cent of GDP)		-0.1838 (-8.57***)	-0.1813 (-7.80***)	-0.1905 (-8.22***)
Real opportunity cost, lagged			0.0000 (-0.37)	
Fixed exchange rates, dummy	-0.0242 (-6.47***)	-0.0092 (-1.95*)	-0.0130 (-2.27**)	-0.0082 (-1.63)
Intermediate exchange rates, dummy	-0.0011 (-0.28)	0.0056 (1.33)	0.0025 (0.48)	0.0070 (1.54)
Number of countries	162	125	117	119
Number of observations	3411	2518	1694	2221
Method of estimation	OLS	OLS	OLS	OLS
Adjusted R^2 (overall)	0.17	0.09	0.12	0.12

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 6: Static models: Alternative estimators allowing for parameter heterogeneity

Dependent variable: Reserves/GDP

	(1)	(2)	(3)
Real GDP per capita	0.0329 (5.92***)	0.0360 (1.66*)	0.0286 (1.26)
Trade openness	0.0535 (2.67***)	0.0929 (3.54***)	0.1058 (3.63***)
Volatility (real)	-0.0144 (-0.64)	-0.0629 (-1.15)	-0.0292 (-0.50)
Total external debt (per cent of GDP)	0.0409 (6.66***)	0.0311 (1.07)	0.0084 (0.28)
Short-term external debt, lagged (per cent of GDP)	-0.1983 (-8.04***)	-0.5262 (-1.65*)	-0.2937 (-0.90)
Fixed exchange rates, dummy	-0.0145 (-2.82***)	-0.0262 (-3.80***)	-0.0216 (-2.93**)
Intermediate exchange rates, dummy	0.0069 (1.37)	0.0024 (0.49)	0.0019 (0.36)
Number of countries	63	63	63
Number of observations	1743	1743	1743
Method of estimation	OLS	MG	RC
Adjusted R^2 (overall)	0.10	0.12	0.15

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
OLS: pooled OLS including fixed country effects
MG: mean group estimator
RC: random coefficient estimator

Table 7: Dynamic models: Homogeneous parameters

Dependent variable: Reserves/GDP

	(1)	(2)	(3)	(4)
Lagged endogenous variable	0.7605 (16.52***)	0.7846 (16.52***)	0.9639 (47.22***)	0.9316 (69.29***)
Real GDP per capita	-0.0064 (-2.29**)	-0.0066 (-2.37**)	0.0004 (1.39)	-0.0013 (-1.10)
Trade openness	0.0495 (3.60***)	0.0491 (3.52***)	0.0124 (5.45***)	0.0314 (5.74***)
Volatility (nominal)	-0.0053 (-1.29)		-0.0026 (-2.70***)	-0.0041 (-1.89*)
Volatility (real)		-0.0039 (-1.27)		
Total external debt (per cent of GDP)	0.0145 (4.55***)	0.0177 (4.35***)	0.0105 (4.26***)	0.0136 (6.20***)
Short-term external debt, lagged (per cent of GDP)	-0.0580 (-2.67***)	-0.0705 (-2.62***)	-0.0371 (-3.51***)	-0.0361 (-3.52***)
Fixed exchange rates, dummy	-0.0115 (-2.36**)	-0.0105 (-2.37**)	-0.0054 (-2.39**)	-0.0016 (-0.58)
Intermediate exchange rates, dummy	0.0048 (1.14)	0.0052 (0.96)	0.0009 (0.39)	0.0011 (0.40)
Number of countries	125	118	125	
Number of observations	2317	2036	2446	
Method of estimation	Difference GMM (two step)	Difference GMM (two step)	System GMM (two step)	LSDV (corrected)
Sargan Test (p-level)	1.0	1.0		
Hansen Test (p-level)			1.0	
Arellano-Bond-Test (p-level)	0.95	0.93	0.90	

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
LSDV: least-squares dummy variable estimator (= fixed effects estimator)

Table 8: Dynamic models: Alternative estimators allowing for parameter heterogeneity

Dependent variable: Reserves/GDP

	(1)	(2)	(3)	(4)
Lagged endogenous variable	0.7946 (20.84***)	0.9678 (40.59***)	0.9314 (71.88***)	0.5449 (14.09***)
Real GDP per capita	-0.0041 (-1.28)	0.0001 (0.42)	-0.0014 (-1.05)	0.0106 (0.84)
Trade openness	0.0485 (3.64***)	0.0121 (3.80***)	0.0301 (4.85***)	0.0800 (4.90***)
Volatility (nominal)	-0.0021 (-0.21)	-0.0052 (-0.85)	-0.0060 (-0.80)	-0.0421 (-1.90*)
Total external debt (per cent of GDP)	0.0140 (3.67***)	0.0088 (3.28***)	0.0129 (5.10***)	0.0205 (1.25)
Short-term external debt, lagged (per cent of GDP)	-0.0567 (-2.23**)	-0.0332 (-3.00***)	-0.0324 (-3.24***)	-0.0599 (-0.65)
Fixed exchange rates, dummy	-0.0115 (-3.04***)	-0.0060 (-2.47**)	-0.0050 (-1.70*)	-0.0123 (-3.72***)
Intermediate exchange rates, dummy	0.0014 (0.70)	0.0011 (0.40)	0.0001 (0.05)	0.0040 (0.54)
Number of countries	70	70	70	70
Number of observations	1824	1896		
Method of estimation	Difference GMM (two step)	System GMM (two step)	LSDV (corrected)	MG
Sargan Test (p-level)	1.0			
Hansen Test (p-level)		1.0		
Arellano-Bond-Test (p-level)	0.92	0.95		

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
LSDV: least-squares dummy variable estimator (= fixed effects estimator)
MG: mean group estimator

Table 9: Simple tests of the monetary approach to the balance of payments

	(1)	(2)	(3)	(4)
Dependent variable	Δ Reserves	Δ Reserves	Reserves over GDP	Reserves over GDP
Δ M1	0.0515 (1.66*)			
Δ M2		0.0616 (2.65***)		
Δ Domestic credit	-0.0011 (-0.19)	-0.0163 (-2.08**)		
Trade openness			0.0858 (6.28***)	0.0860 (6.30***)
Monetary disequilibrium (M1) (excess money supply)			-0.0011 (-0.73)	
Monetary disequilibrium (M2) (excess money supply)				-0.0006 (-2.27**)
Number of countries	177	175	152	153
Number of observations	3839	3828	2760	2782
Method of estimation	OLS	OLS	OLS	OLS
Adjusted R^2 (overall)	0.19	0.18	0.14	0.17

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
All regressions include country fixed effects.

Table 10: Static models including monetary disequilibrium

Dependent variable: Reserves/GDP

	(1)	(2)	(3)	(4)
Real GDP per capita	0.0467 (7.75***)	0.0467 (7.75***)	0.0648 (2.27**)	0.0612 (2.09**)
Trade openness	0.0552 (2.96***)	0.0556 (2.99***)	0.0659 (2.08**)	0.0617 (2.08**)
Volatility (nominal)	-0.0175 (-3.57***)	-0.0175 (-3.56***)	-0.0779 (-1.51*)	-0.0838 (-1.67**)
Total external debt (per cent of GDP)	0.0490 (6.64***)	0.0484 (6.56***)	0.0548 (2.08**)	0.0557 (2.10**)
Short-term external debt, lagged (per cent of GDP)	-0.2370 (-7.99***)	-0.2353 (-7.96***)	-0.5762 (-2.43**)	-0.5585 (-2.38**)
Fixed exchange rates, dummy	0.0031 (0.43)	0.0036 (0.49)	-0.0185 (-2.37**)	-0.0152 (-1.27)
Intermediate exchange rates, dummy	-0.0024 (-0.45)	-0.0025 (-0.47)	0.0063 (1.09)	-0.0078 (-1.34)
Monetary disequilibrium (excess money supply)	-0.0018 (-1.75*)	0.00005 (0.17)	0.0971 (0.32)	0.0651 (0.21)
Monetary disequilibrium in fixed exchange rate regimes		-0.0064 (-7.55***)		0.0845 (-0.63)
Number of countries	115	115	41	41
Number of observations	1816	1816		
Method of estimation	OLS	OLS	MG	MG
Adjusted R^2 (overall)	0.08	0.08		

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
OLS includes country fixed effects.
MG: mean group estimator

Table 11: Dynamic models including monetary disequilibrium

Dependent variable: Reserves/GDP

	(1)	(2)	(3)	(4)
Lagged endogenous variable	0.7391 (12.11***)	0.7381 (12.12***)	0.4547 (7.68***)	0.4375 (7.49***)
Real GDP per capita	0.0004 (-1.05)	-0.0004 (-1.04)	0.0274 (1.39)	0.0304 (1.47)
Trade openness	0.0556 (3.21***)	0.0549 (3.20***)	0.0328 (1.09)	0.0347 (1.15)
Volatility (nominal)	-0.0027 (-1.13)	-0.0031 (-1.16)	-0.0370 (-1.03)	-0.0383 (-1.07)
Total external debt (per cent of GDP)	0.0214 (4.54***)	0.0214 (4.52***)	0.0698 (2.43**)	0.0709 (2.51**)
Short-term external debt, lagged (per cent of GDP)	-0.0611 (-3.56***)	-0.0628 (-3.57***)	-0.0656 (-0.66)	-0.0755 (-0.79)
Fixed exchange rates, dummy	-0.0001 (-0.02)	0.0008 (0.11)	-0.0075 (-1.65*)	-0.0099 (-0.92)
Intermediate exchange rates, dummy	0.0043 (0.93)	0.0050 (0.98)	0.0047 (1.32)	0.0037 (1.05)
Monetary disequilibrium (excess money supply)	-0.0003 (-1.72*)	-0.0002 (-1.68*)	-0.0300 (-0.15)	-0.0577 (-0.29)
Monetary disequilibrium in a fixed exchange rate system		-0.0023 (-1.85*)		0.0829 (0.62)
Number of countries	114	114	40	40
Number of observations	1651	1651		
Method of estimation	Difference GMM (two step)	Difference GMM (two step)	MG	MG
Sargan Test (p-level)	1.0	1.0		
Arellano-Bond-Test (p-level)	0.90	0.91		

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
MG: mean group estimator

Table 12: Dynamic models: Robustness checks using different (geographical) samples

Dependent variable: Reserves/GDP

	(1) Latin America and the Caribbean	(2) Asia	(3) Africa
Lagged endogenous variable	0.7785 (27.97***)	0.7359 (12.46***)	0.8658 (14.34***)
Real GDP per capita	0.0003 (1.69*)	-0.0003 (-0.68)	-0.0002 (-0.89)
Trade openness	0.0648 (7.14***)	0.0677 (3.46***)	0.0280 (2.07**)
Volatility (nominal)	-0.0092 (-0.42)	0.0122 (0.48)	-0.0012 (-0.90)
Total external debt (per cent of GDP)	0.0149 (4.92***)	0.0273 (1.55)	0.0120 (0.52)
Short-term external debt, lagged (per cent of GDP)	-0.0379 (-3.25***)	0.0573 (1.05)	-0.0329 (-1.17)
Fixed exchange rates, dummy	-0.0139 (-2.55**)	-0.0064 (-0.53)	-0.0041 (-1.44)
Intermediate exchange rates, dummy	0.0001 (0.03)	-0.0103 (-1.00)	0.0034 (-0.11)
Monetary disequilibrium	0.0118 (1.46)	-0.0007 (-0.54)	-0.0001 (-0.23)
Monetary disequilibrium in a fixed exchange rate system	-0.0033 (-0.74)	-0.0008 (-0.24)	-0.0005 (-1.69*)
Number of countries	28	11	42
Number of observations	379	239	792
Method of estimation	LSDV (corrected)	LSDV (corrected)	Difference GMM (two step)

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
LSDV: least-squares dummy variable estimator (= fixed effects estimator)

Table 13: Dynamic models: Robustness checks using de-facto exchange rate regimes

Dependent variable: Reserves/GDP

	(1)	(2)	(3)	(4)
Lagged endogenous variable	0.8135 (21.24***)	0.5680 (12.88***)	0.7918 (15.69***)	0.5840 (13.17***)
Real GDP per capita	-0.0097 (-2.47**)	0.0086 (0.64)	-0.0087 (-2.72***)	0.0007 (0.05)
Trade openness	0.0519 (3.14***)	0.0737 (4.83***)	0.0572 (3.31***)	0.0856 (4.87***)
Volatility (nominal)	-0.0116 (-0.52)	-0.0783 (-2.55**)	-0.0103 (-0.66)	-0.0424 (-1.69*)
Total external debt (per cent of GDP)	0.0213 (1.54)	0.0256 (1.22)	0.0156 (3.60***)	0.0266 (1.52)
Short-term external debt, lagged (per cent of GDP)	-0.0891 (-1.56)	-0.0809 (-0.82)	-0.0828 (-2.53*)	0.0167 (0.17)
Fixed exchange rates, dummy	-0.0201 (-0.87)	-0.0061 (-1.48)	0.0017 (0.13)	-0.0044 (-1.14)
Intermediate exchange rates, dummy	-0.0215 (-1.00)	-0.0050 (-0.80)	0.0059 (2.25**)	0.0030 (1.38)
Number of countries	53	53	61	61
Number of observations	1286		1475	
Method of estimation	Difference GMM (two step)	MG	Difference GMM (two step)	MG
Sargan Test (p-level)	1.0		1.0	
Arellano-Bond-Test (p-level)	0.73		0.89	

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
MG: mean group estimator
Columns 1 and 2 use the measure for de-facto exchange rate regimes based on Reinhart and Rogoff (2004) and columns 3 and 4 that of Levy-Yeyati and Sturzenegger (2005).

Appendix A: Features of major recent empirical studies on the demand for international reserves[41]

Author (year)	Regression type (estimation method)	Countries	Time period (Frequency)	Motivation	Findings
Badinger (2000)	Pooled cross-country time-series (restricted SUR with fixed country effects)	10 Euro-area countries	1981-1997 (annually)	Implications of the introduction of the Euro for the demand for reserves in the Eurosystem	The introduction of the Euro has generated excess reserves.
Bordo and Eichengreen (2001)	Pooled cross-country time-series	21	1882-1995 (annually)	Role of gold as part of international reserves	The persistence of gold holdings can be explained by inertia, network externalities and laws.
Lane and Burke (2001)	Cross-section (pooled OLS)	102	1981-1995 (averaged annual data)	Demand for reserves; focus on cross-section to abstract from cyclical fluctuations	Trade openness is the most important factor explaining reserves; financial integration is associated with an increase of reserves.
Flood and Marion (2002)	Pooled cross-country time-series (GMM with fixed country effects)	22 36	1971-1997 1988-1997	Replication of the buffer stock model based on Frenkel and Jovanovic (1981)	Buffer stock model works well but explains only about 10-15% of reserve changes.
Aportela, Gallego and García (2003)	Cross country analysis Individual time series for 6 countries (OLS)	115 6 industrialized countries	1970-1997 > 1977-1997 depending on country	Effect of a switch to a floating exchange rate and inflation targeting regime.	Adoption of inflation targeting regime is associated with a reduction of reserves.
World Economic Outlook (2003)	Pooled cross-country time-series (includes country fixed effects)		1980-1996 (annually)	Identification of the determinants of the demand for reserves	Fundamentals cannot explain upsurge in Asia's reserve accumulation beginning in 2002.
Aizenman and Marion (2004)	Pooled cross-country time series (fixed country effects)	122 developing countries	1980–1999 (annually)	Political-economy considerations in the holdings of international reserves	Political factors like probability of leadership change and political corruption influence reserve holdings.
Badinger (2004)	Vector error correction model	1 (Austria)	1985-1997 (quarterly)	Effect of monetary disequilibrium on reserve holdings	Support for the monetary approach to the balance of payments: excess money demand leads to an inflow of reserves.

[41] Similar tables summarizing the features of earlier empirical studies on the demand for reserves can be found in Bahmani-Oskooee (1984) and Lehto (1994).

Author (year)	Regression type (estimation method)	Countries	Time period (Frequency)	Motivation	Findings
Polterovich and Popov (2004)	Pooled cross-country time-series (OLS)	95-172	1960-1999 (data averaged over the period)	Effect of accumulation of foreign exchange on long-term growth	Accumulation of reserves enhances growth in developing countries, increases investment and raises exports.
Soto et al. (2004)	Pooled cross-country time-series (GLS with fixed country effects)	31 emerging countries	1990-2001 (annually)	Determinants of the demand for reserves	
Gosselin and Parent (2005)	Cointegration relationship	8 Asian emerging-market economies	1980-2003 (annually)	Explanation of the accumulation of foreign reserves in emerging Asia in the aftermath of the Asian financial crisis in 1997	Positive structural break in the demand for reserves after the 1997 financial crisis.
Cifarelli and Paladino (2006)	Cointegration relationship	10 emerging markets	1985-2004 (monthly)	Investigation of excess reserves	Size of excess reserves is usually overstated.
Levy Yeyati (2006b)	a) Pooled cross-country time-series b) Cross-section of group averages (both OLS including fixed effects)	131	1975-2004 (annually)	Effect of deposit dollarization on reserves	Dollarization is associated with higher reserve levels; crisis episodes increase reserves.
Redrado et al. (2006)	Pooled cross-country time-series (bias-corrected OLS including fixed effects and system GMM)	139	1973-2003 (annually)	Explanation of the demand for reserves (importance of development and competitive hoarding)	Economic development follows an inverted-U shaped relationship with reserves; countries of a certain region imitate each other.
Aizenman and Lee (2007)	Pooled cross-section time-series (fixed country effects)	≤53	1980-2000 (annually)	Precautionary versus mercantilist views	Reserve accumulation cannot be explained by mercantilist motives but rather by precautionary purposes.
Aizenman, Lee and Rhee (2007)	Time-series	1 (Korea) case study	Pre-crisis: 1992-1997 Post-crisis 1998-2003 (quarterly)	Relationship between reserves and integration into international financial markets	Financial crisis led to a structural change in the hoarding of reserves.
Choi et al. (2007)	Pooled cross-country time-series (OLS, instrumental variables and GMM)	60	1980-2005 (annually)	Interaction of capital flows and reserve holdings	Since the Asian financial crisis, capital inflows to emerging markets and their level of reserves are positively correlated; correlation increased with globalisation.

Author (year)	Regression type (estimation method)	Countries	Time period (Frequency)	Motivation	Findings
Dominguez (2007)	Pooled cross-section time-series	53	1983-2004	Reserves in underdeveloped capital markets	Countries with less developed financial markets and higher levels of private sector liabilities hold more reserves.
Elhiraika and Ndikumana (2007)	Pooled cross-country time-series (including fixed effects) after cointegration analysis	21 African countries	1979-2005	Determinants of the demand for reserves	Reserve accumulation cannot be explained by portfolio optimisation or stabilization objectives.
Obstfeld et al. (2007)	Pooled cross-section time-series (OLS)	135	1980-2004 (annually)	Test of the explanatory power of a financial stability model	Financial openness and financial development are key variables to explain the recent accumulation of reserves.
Choi and Baek (2008)	Pooled cross-country time-series (OLS)	137 countries	1980-2000 (annually)	Effect of exchange rate regime on international reserves	Intermediate exchange rate regimes are correlated with higher reserve levels than polar regimes (fix and float).
Cheung and Ito (2009)	Cross-section analysis of period averages	Developing countries (≤74)	1975-1981 1983-1993 1999-2004 (period averages)	Varying explanatory power of determinants of reserves across different time periods	Macroeconomic variables' explanatory power diminished over time whereas financial variables have become more important as determinants of reserves.
Dreher and Vaubel (2009)	Pooled cross-country time-series (OLS and GMM, both including fixed country and period effects)	≤158	1975-2001	Foreign exchange intervention and the political business cycle	Sale of reserves supports a monetary business cycle and is especially likely before elections.

Appendix B: Theoretical motivation for a dynamic model specification: The state dependence or partial adjustment model

This appendix illustrates the so-called state dependence or partial adjustment model. It justifies the inclusion of a lagged dependent variable in the regression equation. The basic idea is that the level of reserves is not always equal to its desired level, but follows a process of gradual convergence to this level.
The desired level of reserves R_{it}^* might be given by the expression:

$$R_{it}^* = \alpha + x_{it}\beta + u_{it} \qquad (1)$$

The partial adjustment process relates the (unobserved) desired level of reserves to the observed level. Adjustment to the desired level of reserves is assumed to follow the simple process:

$$R_{it} - R_{i,t-1} = \lambda(R_t^* - R_{i,t-1}) + \varepsilon_{it} \qquad 0 \le \lambda \le 1 \qquad (2)$$

Hence, the actual change in reserves in any given time period t is only a fraction λ of the desired change. Substituting equation (1) into (2) produces the following linear dynamic demand model:

$$R_{it} = \lambda \cdot \alpha + (1-\lambda)R_{t-1} + x_{it}\beta\lambda + v_{it}$$

where $v_{it} = \varepsilon_{it} + \lambda \cdot u_{it}$

But why might countries adjust only partially to the desired level of reserves? The rationale for this behaviour might be that adjustment is costly. Hence, the country faces two types of costs: the cost of making the adjustment and the cost of being in disequilibrium. In optimum, total costs must be in minimum. If the two costs are quadratic and additive, we can write total cost C_t as:

$$C_t = a_1(R_t - R_{t-1})^2 + a_2(R_t^* - R_t)^2$$

where the first term on the right hand side of the equation is the cost incurred by the adjustment and the second term represents the cost of the deviation from the desired level R^*.

Given R_{t-1} and R_t^*, we have to choose R_t so that total cost C_t is minimized:

$$\frac{dC_t}{dR_t} = 0 \qquad \text{gives} \qquad 2a_1(R_t - R_{t-1}) = 2a_2(R_t^* - R_t)$$

$$2a_1(R_t - R_{t-1}) = 2a_2\left[R_t^* - R_{t-1} - (R_t - R_{t-1})\right]$$

$$(R_t - R_{t-1}) = \lambda(R_t^* - R_{t-1})$$

where $\lambda = \dfrac{a_2}{a_1 + a_2}$

This expression is equivalent to the assumed adjustment process given by equation (2).

Appendix C: Country list

Afghanistan
Albania
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia
Aruba
Australia
Austria
Azerbaijan
Bahamas, The
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Cape Verde
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo, Dem. Rep.
Congo, Rep.
Costa Rica
Cote d'Ivoire
Croatia
Cyprus
Czech Republic
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt, Arab Rep.
El Salvador
Equatorial Guinea
Eritrea
Estonia
Ethiopia
Fiji
Finland
France
Gabon
Gambia, The
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hong Kong, China
Hungary
Iceland
India
Indonesia
Iran, Islamic Rep.
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Korea, Rep.
Kuwait
Kyrgyz Republic
Lao PDR
Latvia
Lebanon
Lesotho
Liberia
Libya
Lithuania
Luxembourg
Macao, China
Macedonia, FYR
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Mauritania
Mauritius
Mexico
Micronesia, Fed. Sts.
Moldova
Mongolia
Morocco
Mozambique
Myanmar
Namibia
Nepal
Netherlands
Netherlands Antilles
New Zealand
Nicaragua
Niger
Nigeria
Norway
Oman
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russian Federation
Rwanda
Samoa
San Marino
Sao Tome and Principe
Saudi Arabia
Senegal
Seychelles
Sierra Leone
Singapore
Slovak Republic
Slovenia
Solomon Islands
Somalia
South Africa
Spain
Sri Lanka
St. Kitts and Nevis
St. Lucia
St. Vincent and the Grenadines
Sudan
Suriname
Swaziland
Sweden
Switzerland
Syrian Arab Republic
Tajikistan
Tanzania
Thailand
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Vanuatu
Venezuela, RB
Vietnam
Yemen, Rep.
Zambia
Zimbabwe

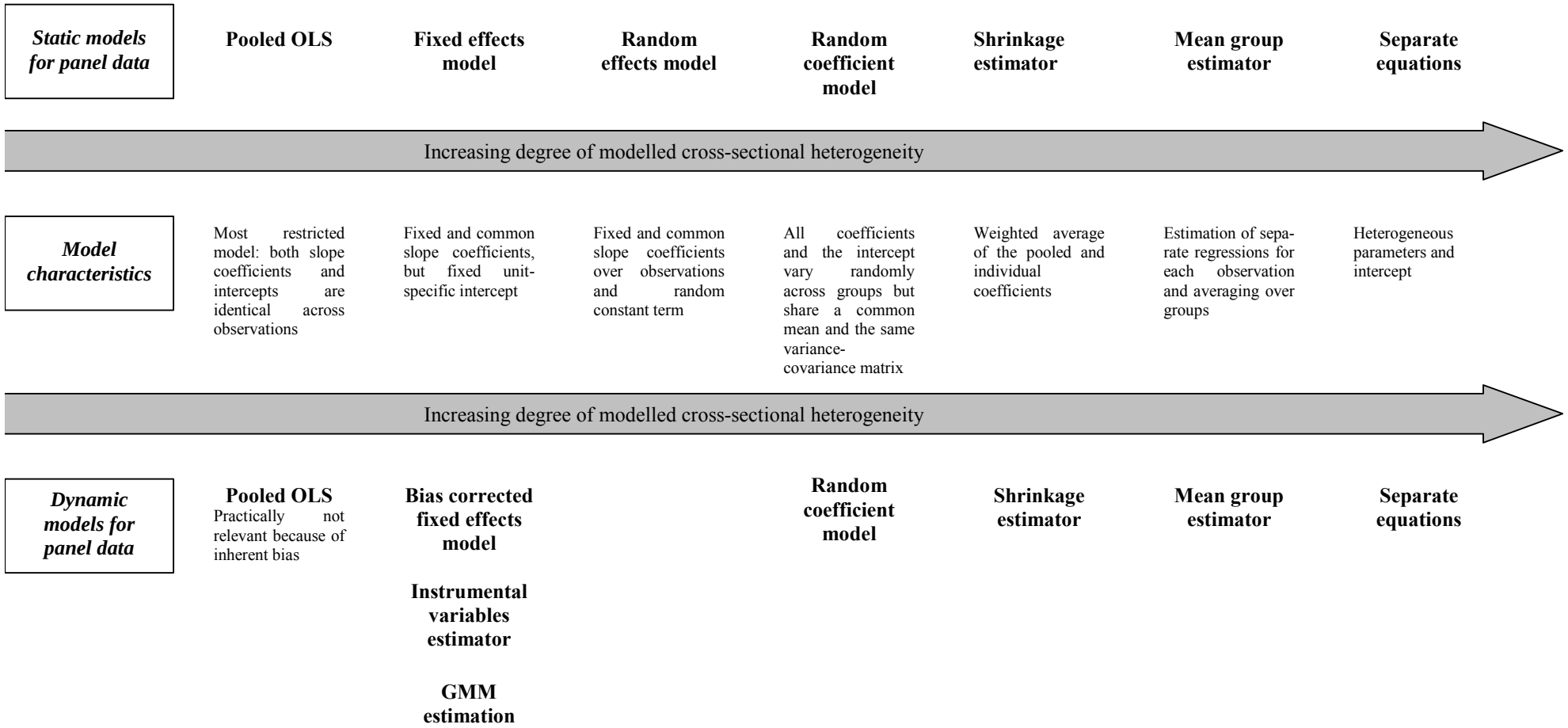
Appendix D: Summary statistics (estimation sample of 125 countries)

Variable	Observations	Minimum	Maximum	Mean	Std. Dev. (overall)	% of variance across countries	% of variance over time
Reserves/GDP	2928	-0.0048	1.254	0.1062	0.1152	54.02	45.98
Real GDP per capita	3123	0.4532	18.6858	3.7914	2.9566	75.48	24.52
Trade openness	3064	0.0632	2.8240	0.7303	0.3911	67.01	32.99
Volatility (nominal)	2847	0.0068	9.0484	0.1883	0.3900	45.28	54.72
Volatility (real)	2491	0.0129	16.4027	0.1841	0.7286	63.40	36.60
Total external debt (divided by GDP)	2965	0	10.6441	0.6854	0.6654	51.29	48.71
Short-term external debt (divided by GDP)	2965	0	2.0453	0.0773	0.1262	42.49	57.51
Real opportunity cost	1917	-26365.93	108291.1	21.9787	2572.738	22.35	77.65
Fixed exchange rates, dummy	3106	0	1	0.5969	0.4906	50.60	49.40
Intermediate exchange rates, dummy	3106	0	1	0.2411	0.4278	45.31	54.69

Notes: The calculation of the summary statistics is based on a sample of 125 countries. For these countries data are jointly available for eight of the above listed variables. These countries also correspond to the sample used in column 2 in Table 5. For the following variables data are only available for a smaller number of countries and the summary statistics are calculated for the respective maximal number of countries: Volatility (real) 118 countries and real opportunity cost 117 countries.

The negative number of the minimum of reserves over GDP is due to the data for Guinea-Bissau. In 1986 total reserves for Guinea-Bissau are negative, probably due to the fact that the central bank had a negative net position of foreign-currency bonds.

Appendix E: Model specification: Varying degrees of cross-sectional heterogeneity



Chapter 3

Does Experience Make a Difference?

The Behaviour of Central Banks' Reserve Holdings in the Aftermath of Currency Crises

1 Introduction

While the previous chapter identified determinants of international reserve holdings and applied econometric estimators that have not been used in this literature before, it could not offer an answer to a question that is puzzling standard economic theory: What are the underlying reasons for the enormous increase in international reserve holdings by central banks, particularly in developing and transition economies, since the demise of the Bretton Woods system?

Between 1975 and 2006, the absolute value of worldwide official reserve holdings increased by a factor of 17.[42] This build-up of reserves is mainly due to developing and transition economies. Their share in total worldwide reserves has risen from 40% in 1975 to more than 70% in 2006. Although the increase of the absolute level of reserves is driven by a small number of countries, e.g. China, Japan, Russia, Korea (Figure 1), the phenomenon of reserve accumulation is not restricted to a small number of outliers, but rather observable in the majority of countries (see Figure 2). The number of systematic accumulaters has even increased in the recent past. Whereas from 1973 to 1996 on average 57% of all countries increased their real reserves in a given year, this share amounted to 65% over the period from 1997 to 2006 (Figure 3).

As was already illustrated in Figures 2a and 2b of chapter 1, the increase is also observable in commonly used indicators of reserve adequacy, which consider the level of reserves in relation to a scaling variable like imports, GDP or external debt. This shows that the increase cannot be explained by simple rules of thumb: Whereas traditionally a level of reserves that covers three to four months of imports was considered to be adequate, in 2006 reserves covered on average more than six months of imports. Even recent models of the optimal amount of reserves fail to explain the actual accumulation. According to Jeanne and Rancière (2006) the optimal level of reserves for a benchmark economy amounts to 10% of GDP. However, in 2006 central banks' reserves averaged 18% of GDP.

This unexpected increase in reserves gave rise to a series of papers that investigate two main research questions. The first group of papers analyses the optimality of reserve holdings given that reserves exceed traditional indicators of reserve adequacy. The second group aims at finding rationales for this unprecedented reserve accumulation.

[42] All data in the introduction are obtained from calculations based on the International Financial Statistics (IMF 2008).

This paper contributes to the latter strand of the literature. It proposes a new explanation for reserve accumulation, namely that central banks revise their reserve policy after they have experienced a currency crisis and significantly increase their reserves after a crisis. Questions of the optimality and adequacy of this reserve policy are not touched.

Existing papers explaining the reserve accumulation can be grouped into two lines of argumentation: The first argues that the accumulation of reserves is driven by mercantilist motives and the result of an export-led growth strategy (Dooley et al. 2003). The second highlights the precautionary motive of reserve hoardings. Reserves are seen as a form of self-insurance against financial crises. Examples of the latter are Jeanne and Rancière (2006) and Mendoza (2004). Aizenman and Lee (2007) contrast both motives and test their empirical relevance. Their results confirm the relevance of a precautionary reserve demand, whereas the mercantilist motive turns out to be economically insignificant.

This article contributes to both lines of argumentation: If the experience of a currency crisis alters a central bank's reserve policy, the additional hoardings might be precautionary. The central bank changes its assessment of the country-specific crisis probability and fears future currency crises. It wants to be better prepared to defend the currency and manage a crisis after a future attack. The reserve accumulation after a crisis might also be driven by mercantilist motives. Since the accumulation of reserves depreciates the currency and may foster exports, it might be regarded as an instrument to ease the negative growth effects of the crisis.

Empirical tests of the proposed relationship between economic crises and reserves are rare. Typically, studies confirm that reserves decrease during a currency crisis whereas the long-run effects of a crisis are disregarded. To my knowledge there is only one exception, namely Aizenman and Lee (2007) who test for the long-run effect of crises on reserve holdings. However, their approach is rather simple and some refinement is warranted. They include two dummies in their specification, one for the Mexican Tequila crisis in 1994 and another for the Asian financial crisis of 1997-98. These are applied to all developing and emerging market countries independently whether they were directly affected by these crises or not. The findings suggest that these crises have increased the level of reserves in the long run.

This chapter extends the existing literature in several ways, both with respect to theory and empirics. First, it proposes a model of currency crises that motivates central banks'

accumulation of reserves. Second, on empirical grounds it identifies crises for each country individually and hence allows to test whether countries change their reserve holdings after they have suffered from a crisis. To confirm the robustness of the findings, the results of three different estimators are compared. Finally, and most importantly, it tests the hypothesis that reserve holdings are significantly higher in countries that have experienced a currency crisis. To this end, a panel data set of a maximum of 114 countries over the period 1975 – 2003 is analysed.

To anticipate the results: We find that the experience of a speculative attack – successful or unsuccessful – alters the reserve policy of a central bank. The long-run level of reserves is significantly higher in countries that have experienced currency crises. This holds for crises during the 1980s and 1990s, but not for crises in the years after the breakdown of the Bretton Woods system. This effect is permanent. The number of crises also matters. The more currency crises a country suffered from, the higher the level of reserves is. These findings are robust to different definitions of a currency crisis and across different estimation methods.

This chapter is organized as follows. Section 2 describes how reserves and currency crises are related and proposes a theoretical model explaining why central banks prefer to accumulate reserves than to loose them. It then postulates the hypothesis of the article. Section 3 presents the data which are used in the empirical analysis. After a description of the panel data estimators, section 4 presents and discusses the empirical results. The final section concludes.

2 How are reserves and currency crises related?

After a review of the relevance of international reserves in different models of currency crises, this section proposes a theoretical model of currency crises that emphasises the role of changes in reserves in investors' expectation formation. The final subsection states reasons why central banks might change their reserve policy after the experience of a currency crisis.

2.1 The role of reserves in models of currency crises

This section analyses the link between currency crises and reserves, both theoretically and empirically. First, the role of reserves in different models of currency crises is reviewed. Second, empirical evidence of the relationship between reserves and the probability of a currency crisis is presented.

In the first generation of currency crisis models[43] an inconsistency between fiscal and monetary policy on the one hand and the commitment to a fixed exchange rate on the other leads to a continuous loss of reserves and, consequently, to a change of the fixed parity or even free float when reserves have fallen below some critical value (e.g. Krugman 1979 and Flood and Garber 1984). Thus, a high level of reserves cannot avoid this type of currency crisis. It can only postpone its occurrence and provide a time buffer within which domestic policy can be reconciled with the exchange rate commitment.

Models of the second-generation type emphasise that a currency crisis might be the result of an optimising behaviour of the government. A government trades-off the costs of fiscal austerity – additional unemployment and a depressed economy – against the costs of losing its reputation for a credible exchange rate policy. The abandonment of an exchange rate peg is seen as a deliberate and active policy choice. In this class of models expectations can be self-fulfilling since the government's cost of maintaining the peg depends on the mass of individuals who attack. The more speculators attack, the more probable a crisis.

One of the pioneering works of the second-generation type is Obstfeld (1994). He affirms "that reserve losses certainly accompany a crisis, but they are not the factor that triggers it and not the factor that ultimately leads the authorities to devalue." (p. 211)

This view, however, neglects the relationship between individuals' expectations and the level of reserves. In models of the second generation the costs of a defence of the exchange rate depend on the expectations of the individuals. If individuals expect a devaluation because reserves are low, a defence of the exchange rate is more costly which, in turn, makes a

[43] These models are known as models of balance of payments crises. Balance of payments crises may only arise under fixed exchange rates, whereas currency crises may occur independently of the exchange rate system. Whereas a balance of payments crisis may be triggered by a continuous loss of reserves due to a deficit in the sum of current and capital account, a currency crisis is a wider concept that also encompasses sudden speculative attacks.

devaluation more probable. Hence, a low level of reserves – which is considered as inadequate – may be a contributing cause of a currency crisis.

The third generation approach to balance of payments crises was developed as a response to the Asian financial crisis in 1997-98 and highlights a variety of factors that might serve as explanations for a currency crisis. These factors include the following: weakly supervised financial systems and implicit government guarantees that lead to moral-hazard-driven overlending; an increase of the real debt service burden due to a large currency depreciation in the presence of a currency mismatch (foreign currency liabilities are backed by domestic currency assets); interactions with other kinds of financial crises, namely banking crises (twin crises); and contagion due to linked fundamentals or herding behaviour of investors. In these third-generation models the role of reserves is ambiguous: On the one hand, a high level of reserves might be interpreted by investors that the government is ready to intervene in a crisis situation. If creditors and borrowers expect the government to provide public loans and subsidies in the case of a crisis and if reserves are considered to be part of that government guarantee, they may foster moral-hazard-driven overlending. On the other hand, reserves lower public net debt in foreign currency and thereby reduce the probability of a debt crisis.

An additional source of balance of payments crises, which is not considered in the three generations of crisis models, are terms of trade shocks under a fixed exchange rate regime. If domestic prices are sticky and a negative terms of trade shock affects the economy, the central bank has to sell reserves in order to maintain the peg. If the shock is temporary, the loss of reserves continues until the terms of trade revert to their pre-shock level. If the shock is permanent, the central bank has to sell continuously reserves until domestic prices have adjusted. Hence, a sufficiently high level of reserves strengthens a central bank's commitment to defend the exchange rate and may prevent a currency crisis.

Real world crises generally do not follow one of the above-mentioned patterns; they are rather a combination of them. Therefore, it is important to analyse the role of reserves in all three models jointly.
It can be concluded that the level of international reserves plays a prominent role in models of currency crises. High levels may reduce the probability of a currency crisis from a theoretical perspective (second and third generation models) or postpone its occurrence (first generation).

This is especially relevant for countries that are financially integrated in the world capital market. Whereas financial integration facilitates private financing of current account deficits in good times, open capital markets increase the exposure to external financial disturbances and speculative flows in crisis periods. Crises may arise from the capital account with no change in the current account. Therefore, the more recent literature considers reserves as a precautionary cushion against the risks of capital account liberalization, namely sudden stops, reversals of capital flows and financial volatility. The empirical analysis will account for these effects by the inclusion of measures of financial integration.

In sum, the models suggest that the function of precautionary reserves includes both crisis prevention and crisis management. The former refers to the role of reserves in reducing the probability of a crisis. A high level of reserves may signal the central bank's ability to act as a seller of last resort in a financial crisis. This perceived guarantee might prevent the outset of a speculative run, which leads to a self-fulfilling crisis. Crisis management refers to the role reserves may take in the case that a crisis has erupted. The sale of reserves can reduce and smoothen the adjustment of the exchange rate and of output. Moreover, it can avoid the costly liquidation of assets and the abandonment of profitable investment projects in a crisis.

The empirical relationship between reserves and currency crises has been studied extensively.[44] Kaminsky, Lizondo and Reinhart (1998) present a review of studies on indicators of currency crises and report that losses of international reserves belong to the leading indicators. A high level of reserves reduces the probability of a currency crisis significantly in 12 out of a sample of 13 studies. The estimation results of Bussière and Mulder (1999) even suggest that high liquidity (defined as international reserves over short-term external debt) can offset weak fundamentals and reduce contagion. In an extensive probit analysis of crisis probability, Frankel and Wei (2005) find that the ratio of short-term external debt to international reserves together with an expansionary monetary policy are the most likely contributors to a crisis. In a historical comparison of the causes of currency crises in two periods (1880-1913 vs. 1972-1997) Bordo and Meissner (2005) show that a strong reserve position relative to money decreased the probability of a crisis in both periods. The conclusions of these studies, however, have to be interpreted with caution: The negative correlation between the level of reserves and the incidence of a crisis might be due to the loss of reserves preceding a crisis.

[44] Reserves are usually one of the leading indicators to forecast a currency crisis in the literature of early warning systems of financial crises.

2.2 A model of currency crises for emerging and developing countries with heterogeneous agents

The following section presents a model of currency crises in the spirit of the second generation of currency crisis models (Morris and Shin 1998). In these models, economic agents base their decision whether to attack the currency or to refrain from doing so on the state of fundamentals given that the central bank only defends the currency if the benefits of a fixed exchange rate exceed its costs. Beliefs turn out to be self-fulfilling in a certain range of fundamentals.

This section expands these models by allowing for a different mechanism that determines how beliefs are formed. In particular, agents are not only guided by the level but also by the change in the fundamentals. Agents' behaviour at a certain state of fundamentals might depend on the change in fundamentals with respect to the previous period. The strength of their action in the presence of improving fundamentals might differ from its strength if fundamentals deteriorate.

Existing models assume that agents are risk neutral and rational. The state of fundamentals is the only criterion that determines their decision to sell or maintain a unit of domestic currency. Our specification, in contrast, is more general. It includes rational speculators as a special case, but also allows for agents who consider changes of fundamentals to provide additional information. Deteriorating fundamentals can be regarded as a negative signal. It is assumed that agents overreact to negative signals and underreact in the presence of positive signals.

To some extent the experimental findings in behavioural finance – especially prospect theory (Kahnemann and Tversky 1979) – are applied to a model of currency crises.[45] According to prospect theory agents focus on changes rather than levels. Their evaluation of an outcome is based on its deviation from a reference point. Agents are loss averse: They attach a higher value to losses than to gains with respect to the reference point.

[45] It should be noted that prospect theory is concerned with choices of states rather than the evaluation of one given state. Therefore, this application is only in the spirit of prospect theory. The relevant variable in prospect theory is some measure that generates utility like wealth or income. In our setting, however, a change in the fundamentals does not affect agents' utility in the first place. Nevertheless, since worsening fundamentals increase the probability of a currency crisis, the expected loss of a devaluation rises. Hence, if agents are loss averse, they might overreact in the presence of worsening fundamentals.

We transfer these ideas to a second generation model of currency crises with incomplete information. The reference point is the state of fundamentals of the previous period. Agents evaluate fundamentals with respect to two dimensions: current and expected future level of fundamentals. Analogously to the property of loss aversion, worsening fundamentals may have a larger impact on agents' decisions than improving fundamentals. In particular, we will examine the effects if individuals are pessimistic in the sense that they overreact to bad news and underreact to good news.

Besides this possible deviation from rational expectations, the model reconsiders the role of reserves in currency crises. Whereas in the first generation approach to currency crises the level of reserves takes a central role in determining the timing of the devaluation, in the models of the second generation reserves do not constrain economic policy. It is assumed that the central bank either owns sufficient reserves to defend the peg or can borrow reserves in the case they are needed.[46] Its decision whether to defend or abandon the peg is taken independently of the level of reserves.

While this assumption is reasonable for industrial countries, in emerging and developing countries the level of reserves usually still matters.[47] With liberalised capital movements, central banks in emerging and developing countries usually do not have enough reserves to defend a fixed exchange rate. A characteristic of financial crises in emerging markets is that foreign capital sources dry up and foreign investors refuse to roll over maturing loans. This may even be the case when central banks try to attract capital by raising interest rates.

Hence, central banks of emerging and developing countries may devalue their currency if at least one of the following two conditions is fulfilled: Either the net profits from maintaining the peg are smaller than zero or the level of reserves reached its lower bound. Hence, devaluation expectations and actual devaluations are related to the level of reserves. Moreover, the level of reserves is part of the state of fundamentals. Therefore, a fall in reserves can deteriorate the state of fundamentals such that expectations become self-fulfilling based on a cost-benefit analysis.

[46] Obstfeld (1994, p. 200) states this assumption explicitly: "Assume that foreign reserves can be freely borrowed in the world capital market, subject only to the government's consolidated intertemporal budget constraint. Neither model assumes additional reserve constraints, nor assigns to reserve levels per se a special role in generating balance-of-payments crises."

[47] Indeed, the second generation of currency crisis models was developed as a response to the crisis of the European Monetary System in 1992.

The model presented below combines these two extreme views and hypothesizes that reserves do play a role in self-fulfilling currency crises. This might especially be true in emerging and developing countries.

In general, the fundamental state of an economy is assessed on the basis of various variables like the real exchange rate, the public budget deficit, the inflation rate and the soundness of the banking system, just to give some examples. Since this chapter focuses on the role of international reserves, attention is restricted to changes in fundamentals caused by changes in reserves. This is consistent with a broader definition of fundamentals provided that reserves are either exogenous to the crisis or moving in the same direction as the overall fundamental index. Worsening fundamentals are equivalent to a reduction in the level of reserves.

2.2.1 The distinction between improving and deteriorating fundamentals

The following section explains why it might be important to consider the role of changes in fundamentals in investors' expectation formation and to allow for asymmetric responses with respect to improving and deteriorating fundamentals.

Agents might attribute a fall in reserves to other investors' strategy to sell domestic currency units in exchange for foreign currency. If these investors are rational, they expect a positive payoff from this transaction, that is, their expected probability of a devaluation is relatively high. Hence, this reveals those investors' private information. Agents, who still hold domestic currency units, might update their beliefs by giving a special weight to the observed change in reserves.

This reasoning is related to models of herding and information cascades described in a more general context in Banerjee (1992). These models consider sequential actions of economic agents. The standard currency crisis models, however, only regard one period. The model presented below at least considers two consecutive periods.
In these models agents imitate the action of those investors who move first and ignore their private information. In the words of Douglas Gale (1996, p. 620) "imitation dominates private information" since the other agents are supposed to be better informed. Hence, falling reserves might be regarded by investors as the result of the actions of the first movers, who in

sum substituted foreign currency for domestic currency. They might simply imitate this behaviour causing a bandwagon effect.
Dasgupta (2000) shows in a game theoretic model with sequential actions of investors that agents' optimism grows in the number of predecessors who choose to invest. He notes that "it turns out that such optimism can take excessive forms" (p. 3).

There exists also a link to the literature on economic bubbles. Bubbles are characterised by high prices, which are sustained by investors' enthusiasm rather than rational expectations of the real value of an asset. Price increases trigger the expectation that prices will rise in the future, too. In the case of reserves, a fall in reserves might be interpreted as the beginning of a period of falling reserves.

Asymmetric responses with respect to improving and deteriorating fundamentals can also be explained by the uncertainty about the threshold level of reserves. Economic agents do not know the reserve floor that induces a central bank to devalue. Moreover, it is difficult to anticipate the volume of capital flight in a speculative attack. Hence, an exogenous fall in reserves entails the risk that the level of reserves approaches its floor.

Research in cognitive psychology has shown that individual decision-making may deviate from the assumption of perfect rationality. Experiments reveal that the most recent information receives too much weight.
In line with these findings, empirical studies of foreign exchange markets find evidence for asymmetric news effects on prices: Laakkonen and Lanne (2008) find that negative macro news increase exchange rate volatility more in good times than in bad times of the business cycle whereas the effect of positive news does not depend on the state of the economy. Markets overreact to news in the short run, especially in emerging markets (Larson and Madura 2001). For stock markets it is a well-established fact (de Bondt and Thaler 1985) that markets overreact to a series of good or bad news. Hence, the postulated overreaction to bad news might be amplified if fundamentals move in the same direction during several periods. This may induce cycles of pessimism and optimism. Pigou (1929, p. 89) describes the links between economic agents "as conducting rods along which an error of optimism or pessimism, once generated, propagates itself about the business world. By their joint action they exert a powerful influence, in favour of actions in droves." Angeletos et al. (2007) show in a dynamic version of the currency crisis model of Morris and Shin (1998) that the

accumulation of information by agents may lead to alternating phases of tranquility and distress.

The importance attached to changes in fundamentals is reflected in the way media report on financial news. They typically emphasise changes rather than levels. This is important since a news report is a kind of public signal that affects the decision process of many agents. If these reports are biased, they will most likely also lead to partisan reactions of economic agents. An example is South Korea whose central bank steadily increased its level of reserves since the 1997-98 Asian financial crisis until it hit a record value in March 2008. When reserves decreased in the seven following months, newspapers already warned about a possible repetition of a financial crisis like in the late 1990s despite the fact that South Korea's reserves were still the world's sixth largest.[48]

In sum, the importance of trend changes in fundamentals for investors' decision formation is confirmed by theoretical and empirical studies. According to theory, trend changes may induce herding behaviour. Empirical studies focus on the effects of news on prices. Since news are typically expressed as changes with respect to previous news, news focus on changes rather than levels.

2.2.2 The basic model

The following section summarizes briefly the structure of the model. It is based on the model of Morris and Shin (1998) and uses the information structure and the graphical representation of Metz (2002).[49]

The model considers a small open economy with a fixed exchange rate. It examines the strategic interaction between the central bank and domestic and foreign agents who hold domestic currency units. There is a continuum of agents uniformly distributed over [0, 1]. Agents move simultaneously. The country is characterised by a state of fundamentals θ with high values of θ indicating good fundamentals. The value of the fundamental index θ is

[48] This view is embodied in the following two news extracts: "This year's steady decline, however, has raised alarm bells in South Korea, where memories of the economic turmoil of the late 1990s remain fresh." (Associated Press, 2 December 2008). "The nation's foreign exchange reserves dropped for the fifth consecutive month in August, fanning worries over the level of national emergency funds." (The Korea Times, 2 September 2008).

[49] For a detailed description of the model setup and the assumptions and conditions, refer to one of these references.

chosen by nature from a uniform distribution over the set of real numbers. Its value can be observed by the central bank, but not by the economic agents.

The cost of maintaining a fixed exchange rate at a predetermined level depends on the demand for and supply of domestic and foreign money. Our model of currency crises is based on the idea that these costs increase ceteris paribus if the demand for foreign currency units increases at the expense of domestic money holdings. This might be due to domestic agents – the domestic component of capital flight – who sell domestic currency to the central bank in exchange for foreign currency. Additionally, foreign investors might suddenly withdraw their investment, substituting their position in domestic currency by foreign currency units – the external component of capital flight. Hence, the group of actors comprises both domestic and foreign agents who have invested part of their wealth in domestic currency units.

We assume that each agent holds one unit of the domestic currency. She can convert this unit into foreign currency at the cost t, which comprises the transaction costs and the interest rate differential between the two countries. If the domestic currency is then devalued, she gets a fixed payoff D.

In the canonical second generation model of currency crises without uncertainty (Obstfeld 1996), where the value of the state of fundamentals is common knowledge, one can distinguish three cases:

At a low level of the fundamental ($\underline{\theta}$) the central bank is indifferent between defending the peg and abandoning it. Hence, if $\theta < \underline{\theta}$, a rational central bank abandons the peg independently of the agents' decision to attack or not.

At high levels of the fundamental $\theta > \overline{\theta}$, the benefits from maintaining the peg exceed its cost for the central bank independently of the speculators. Moreover, the expected depreciation after an attack is so low that the costs of an attack exceed its benefits for the agents. Hence, the peg is stable.

In the interval $[\underline{\theta}, \overline{\theta}]$ - the ripe for attack zone - the central bank's decision depends on the behaviour of the speculators: If all speculators attack the currency, the central bank's costs of defending the currency are higher than the benefits of the peg. As a consequence, the central bank devalues the exchange rate. The behaviour of the speculators drives the action of the central bank. If no speculator attacks, the central bank's trade-off is in favour of maintaining the peg. Therefore, in this interval of fundamentals speculators' expectations are self-fulfilling

and the state of fundamentals makes a currency crisis possible, but does not generate it. It is generated by investors' actions. Agents' actions are strategic complements in the sense that individual payoffs depend on the actions of the other investors. The equilibrium depends on the actors' expectation about other actors' expectations.

Morris and Shin (1998) show that this tripartition depends on the assumption of complete information. If agents do not know the value of the fundamental with certainty, the interval with multiple equilibria disappears and there exists one value that separates the unique equilibria of abandoning and defending the peg. Whereas Morris and Shin assume that agents receive a noisy public signal, Metz (2002) additionally introduces a noisy private signal. She shows that the probability of a currency crisis depends on the relative precision of the two signals. The equilibrium is unique if the precision of the private signal is high in comparison to the precision of the public signal.

2.2.3 The model with incomplete information

Agents evaluate the state of fundamentals on the basis of two noisy signals, a public and a private one. The central bank disseminates a public signal of the form $y_t = \theta_t + \upsilon_t$ with $\upsilon_t \sim N(0,\ 1/\alpha)$, $\alpha > 0$ and $E(\nu\theta) = 0$ such that the noise is uncorrelated with the true value of the fundamental. This signal is the same for all agents. It is common knowledge in the sense that each agent knows that everybody else received the same signal. Additionally, each agent *i* receives a private signal $x_{it} = \theta_t + \varepsilon_{it}$ with $\varepsilon_{it} \sim N(0,\ 1/\beta)$, $\beta > 0$. The noise parameters ε_{it} are assumed to be independent of the fundamental state θ_t and of the noise parameter υ_t in the public signal. All agents know the distribution of the noise parameters υ and ε.

According to Bayesian updating, the posterior about θ conditional on the public and private information is normal with expected value

$$E(\theta_t \mid x_{it}, y_t) = \frac{\alpha}{\alpha+\beta} \cdot y_t + \frac{\beta}{\alpha+\beta} \cdot x_{it}$$

This expectation is a weighted average of the two signals where the more precise signal receives a higher weight.[50]

It is assumed that the central bank reveals the true value of the fundamental once it decided whether to defend or to abandon the peg. Hence, the fundamental of the previous period θ_{t-1} is common knowledge. The expected value of the fundamental of the current period θ_t equals its value of the previous period plus the expected change:

$$\begin{aligned}\tilde{\theta}_t &= \theta_{t-1} + \lambda \cdot [E(\theta_t) - \theta_{t-1}] \\ &= (1-\lambda) \cdot \theta_{t-1} + \lambda \cdot E(\theta_t)\end{aligned}$$

where λ is the weight attached to the expected change. We refer to $\tilde{\theta}_t$ as the *perceived* value of the fundamental index. For $\lambda = 1$, $\tilde{\theta}_t$ equals $E(\theta_t)$ and the model reduces to that of Metz (2002). However, if $\lambda \neq 1$, economic agents not only care about the state of fundamentals but attach special importance to its changes. More precisely, they overreact to changes if $\lambda > 1$ and they undervalue changes if $\lambda < 1$.

The current state of fundamentals can be expressed as a function of the previous period's state:

$$E(\theta_t) = \gamma \cdot \theta_{t-1} \qquad \text{such that} \qquad \theta_{t-1} = \frac{E(\theta_t)}{\gamma}$$

It follows that

$$\gamma = \begin{cases} < 1 & \text{if } E(\theta_t) < \theta_{t-1} \\ > 1 & \text{if } E(\theta_t) > \theta_{t-1} \end{cases}$$

Hence, the expected value of $\tilde{\theta}_t$ can be expressed as:

$$\begin{aligned}E(\tilde{\theta}_t) &= \frac{1-\lambda+\gamma\cdot\lambda}{\gamma} \cdot E(\theta_t) \\ &= \frac{1-\lambda+\gamma\cdot\lambda}{(\alpha+\beta)\cdot\gamma} \cdot [\alpha \cdot y_t + \beta \cdot x_{it}]\end{aligned}$$

[50] In the limiting case where one signal is disseminated without noise, the agents base their decisions only on that signal whereas the noisy signal is disregarded in the decision process.

Its time-constant variance is given by the expression

$$\mathrm{Var}\left(\tilde{\theta}\right)=\left(\frac{1-\lambda+\gamma\cdot\lambda}{\gamma}\right)^{2}\cdot\frac{1}{\alpha+\beta}$$

In the remaining formulae the time index *t* is skipped since only contemporaneous variables enter the equations.

The equilibrium (θ^{*}, x^{*}) consists of a unique value of the state of fundamentals θ^{*} such that the central bank's best response is to abandon the peg whenever the realized θ is smaller than this threshold level, and of a unique value of the private information x^{*} such that each speculator receiving a signal x_i smaller than x^{*} attacks. So far we assume that the unique equilibrium exists and will state the condition for its uniqueness later.

After having received the private and public signal, each agent has to decide whether to keep the domestic currency unit or to sell it. If an domestic agent keeps the domestic currency, her net profit is zero with certainty. If she sells the currency, she faces costs of t and an uncertain payoff D.[51] An agent is indifferent between these two actions if both lead to the same expected net profit:

$$0 = D\cdot\mathrm{Prob}\left(\text{successful attack}\mid x\right)-t$$

Since per definition the central bank abandons the peg when θ is smaller or equal to its trigger value θ*, the probability of a successful attack evaluated by the economic agents is given by the probability that their perceived $\tilde{\theta}$ is smaller or equal to θ*:

$$t = D\cdot\mathrm{Prob}\left(\tilde{\theta}\le\theta^{*}\mid x\right)$$

$$t = D\cdot\Phi\left[\frac{\sqrt{\alpha+\beta}\cdot\gamma}{1-\lambda+\gamma\cdot\lambda}\cdot\left(\theta^{*}-\frac{\alpha\cdot\left(1-\lambda+\gamma\cdot\lambda\right)}{\left(\alpha+\beta\right)\cdot\gamma}\cdot y-\frac{\beta\cdot\left(1-\lambda+\gamma\cdot\lambda\right)}{\left(\alpha+\beta\right)\cdot\gamma}\cdot x\right)\right] \qquad (1)$$

[51] A foreign investor faces the same trade off, which, however, can be expressed in terms of costs: If she retains the domestic currency, she faces uncertain costs D if the money finally is to be converted into foreign currency units. If she sells its domestic money, she faces costs of t, which comprise the transaction costs and the interest rate differential between both countries. The condition for indifference between both actions turns out to be identical to that of the domestic agent.

If we solve equation (1) for x, the resulting relationship states all combinations of x and θ, for which agents are indifferent between selling and holding the domestic currency unit:

$$x^{SP} = \frac{(\alpha+\beta)\cdot\gamma}{(1-\lambda+\gamma\cdot\lambda)\cdot\beta}\cdot\theta - \frac{\alpha}{\beta}\cdot y - \frac{\sqrt{\alpha+\beta}}{\beta}\cdot\Phi^{-1}\left(\frac{t}{D}\right)$$

To simplify the exposition, set

$$A = \left(\frac{\gamma}{1-\lambda+\gamma\cdot\lambda}\right)$$

We call this term reaction parameter. For A=1, investors are rational. If A > 1 investors are pessimistic and for A < 1 they are optimistic.

After the central bank has observed the action of the agents, it decides whether to maintain or to abandon the peg. This decision is based on the central bank's cost-benefit analysis: On the one hand, the central bank derives benefits from a fixed exchange rate, whose value is assumed to be exogenously given. On the other hand, it faces a cost of defending the peg, which decreases in the state of fundamentals and increases in the proportion of agents who sell the currency. Without loss of generality we assume that the central bank devalues the peg if the proportion of attacking agents *p* is larger or equal to the state of fundamentals. The proportion of attacking agents, however, equals the proportion of agents that receive a private signal smaller or equal to x*. This proportion, in turn, equals the probability with which any single agent receives a private signal smaller or equal to x*. Hence

$$\begin{aligned} p &= \text{Prob}(x \le x^* \mid \theta) \\ &= \Phi\left[\sqrt{\beta}(x^* - \theta)\right] \end{aligned}$$

The central bank is indifferent between defending and abandoning the peg if

$$\theta = \Phi\left[\sqrt{\beta}(x^* - \theta)\right] \qquad (2)$$

If we solve equation (2) for x, the resulting equation states all combinations of x and θ, for which the central bank is indifferent:

$$x^{CB}(\theta) = \frac{1}{\sqrt{\beta}}\Phi^{-1}(\theta) + \theta$$

The switching equilibrium (θ^*, x^*) is given by the intersection of the two indifference curves x^{SP} and x^{CB}. It is illustrated in Figure 4.

The graph illustrates a situation for given precision of the public and private signal, α and β respectively, and for one possible value of the reaction parameter A. Hence it depicts the special case for which A is the same on both sides of θ_{t-1}, although its parameters γ and λ change per definition.

In the more general case that A differs for points to the left and to the right of the previous period's state of fundamentals θ_{t-1}, the indifference curve would be discontinuous in θ_{t-1} with a jump and a change of the slope.

The indifference curves x^{CB} and $x^{SP(rational)}$ correspond to those of the reference model. Their intersection marks the changeover from an equilibrium with a stable currency peg to an equilibrium with currency crisis (moving towards lower values of the fundamental index). The difference with respect to the reference model lies in the location of the indifference curve of pessimistic agents $x^{SP(pessimistic)}$. Its slope is given by the slope of $x^{SP(rational)}$ multiplied by the reaction parameter A. For $\lambda = 1$ this term takes the value one and $x^{SP(pessimistic)}$ falls on $x^{SP(rational)}$. However, for our analysis we can distinguish the following cases if economic agents are pessimistic:

(1) Economic agents overreact in the presence of a negative signal. They overvalue a decrease in the fundamental index.
$\lambda > 1,\ \gamma < 1 \Rightarrow A > 1$

(2) Economic agents are cautious in the presence of positive signals. They underreact to improvements in the fundamental index.
$\lambda < 1,\ \gamma > 1 \Rightarrow A > 1$

Hence, if agents base their decision not only on the expected value of the fundamental, but attach an additional weight on changes in the fundamental such that they overreact to a fall in

the fundamental index and underreact to improvements, their indifference curve is steeper than in the reference model.

This implies that the intersection with the indifference curve of the central bank moves upward and to the right. It is characterized by a higher value of the fundamental θ and a higher private signal x. This means that the economy is hit by a currency crisis already at a higher state of the fundamental. Since the probability of a currency crisis is proportional to the size of the interval [-∞, θ*], this increases the probability of a currency crisis.

In the range of fundamentals $[\theta^{*RA}, \theta^{*PE}]$ or equivalently of the private signal $[x^{*RA}, x^{*PE}]$, the economy faces a currency crisis although these values guarantee a stable peg in the reference model.

Analytically, the equilibrium value of θ can be expressed as

$$\theta^* = \Phi\left[\frac{1}{\sqrt{\beta}}\left(\frac{(\alpha+\beta)\cdot\gamma - \beta\cdot(1-\lambda+\gamma\cdot\lambda)}{(1-\lambda+\gamma\cdot\lambda)}\cdot\theta^* - \alpha\cdot y - \sqrt{\alpha+\beta}\cdot\Phi^{-1}\left(\frac{t}{D}\right)\right)\right]$$

Until now it was assumed that there exists only one intersection of the two indifference curves such that there is a unique switching point. Along the lines described in Metz (2002) it can be shown that the sufficient condition for a unique equilibrium is satisfied if

$$\alpha < \frac{\beta + \sqrt{2\cdot\beta\cdot\pi}}{A} - \beta$$

Hence, for a given precision of the private signal β and the reaction parameter A, a unique equilibrium exists as long as the precision of the public signal α is low enough. Moreover, this condition restricts the range of A. Given β, the range of A is restricted to values such that the right hand side of the above expression is positive.

2.2.4 Comparative statics

This section examines the influence of λ on the switching value θ* under the assumption that the equilibrium is unique.

Proposition: The probability of a currency crisis rises in comparison to the reference model

(1) after a decrease of the fundamental state whenever λ increases and

(2) after an increase of the fundamental state whenever λ decreases.

Proof: The partial derivative of the switching point θ* with respect to λ is given by

$$\frac{\partial\theta^*}{\partial\lambda} = \phi(\cdot)\cdot\left[\frac{1}{\sqrt{\beta}}\cdot\frac{(\alpha+\beta)\cdot\gamma - \beta\cdot(1-\lambda+\gamma\cdot\lambda)}{(1-\lambda+\gamma\cdot\lambda)}\cdot\frac{\partial\theta^*}{\partial\lambda} + \frac{1}{\sqrt{\beta}}\cdot\frac{(1-\gamma)\cdot(\alpha\cdot\gamma+\beta\cdot\gamma)}{(1-\lambda+\gamma\cdot\lambda)^2}\cdot\theta^*\right]$$

$$\frac{\partial\theta^*}{\partial\lambda} = \frac{\frac{1}{\sqrt{\beta}}\cdot\frac{(1-\gamma)\cdot(\alpha\cdot\gamma+\beta\cdot\gamma)}{(1-\lambda+\gamma\cdot\lambda)^2}\cdot\theta^*\cdot\phi(\cdot)}{1-\phi(\cdot)\cdot\left(\frac{1}{\sqrt{\beta}}\cdot\frac{(\alpha+\beta)\cdot\gamma - \beta\cdot(1-\lambda+\gamma\cdot\lambda)}{(1-\lambda+\gamma\cdot\lambda)}\right)}$$

If the parameters α, β and λ fulfil the condition for a unique equilibrium, the denominator is larger than zero. Therefore, the sign of the partial derivative depends on the sign of $(1-\gamma)$.

If the fundamental index has decreased with respect to the previous period $(\gamma<1)$, the partial derivative of θ* with respect to λ is positive. If λ rises, the switching point θ* rises and the probability of a currency crisis is higher. The explanation for this result is the following: If economic agents are pessimistic and overweight worsening fundamentals, the interval of fundamentals where agents attack includes higher values of θ: A currency crisis materialises at a higher state of fundamentals than in the reference model.

If fundamentals have improved $(\gamma>1)$, the partial derivative becomes negative. If λ falls below its starting value of one, θ* increases and the probability of a currency crisis increases. If economic agents are pessimistic and undervalue improvements in the fundamentals (λ<1), the value of θ* is larger than in the reference model.

2.2.5 A model with heterogeneous agents

So far it was assumed that all investors are homogeneous: They are all pessimistic. This assumption might be too strong. However, for the above results to hold we do not have to assume that all economic agents are pessimistic. Economic agents might simply be heterogeneous. They differ in how their beliefs are formed. Some are pessimistic, others are optimistic, such that the average agent is rational.

Assume that each agent is assigned a type λ. Types are drawn from a uniform distribution over $[1 - \delta, 1 + \delta]$ for some small $\delta > 0$. If $\lambda > 1$, the agent overreacts. She is pessimistic with regard to worsening fundamentals and optimistic in the presence of improving fundamentals. For $\lambda < 1$ she undervalues given changes.[52] Assume that agents neither know their own type nor that of other agents.

Since half of the investors are pessimistic, their individual indifference curves are steeper than in the reference model. As a consequence, they attack at higher states of the fundamental whereas optimistic investors refrain from attacking.

If $\theta^* = 0.5$, this does not influence the results. 50% of investors attack already at higher states of fundamentals, whereas the optimistic 50% start attacking at lower states of fundamentals. Since for an attack to be successful, the proportion of attacking investors must equal the state of fundamentals, an attack will only be successful if $\theta \leq \theta^*$. Hence, the heterogeneity of agents does not make any difference.

In general, each realization of $\theta > \theta^*$ is associated with a higher proportion of attacking investors than in the reference model, whereas for $\theta < \theta^*$ this proportion is smaller than in the reference model.

Hence, if in the reference model $\theta^* < 0.5$, the sufficient proportion of attacking investors for a successful attack is reached at a higher state of fundamentals. For $\theta^* > 0.5$, the reverse happens: Since the pessimistic investors alone cannot bring about a currency crisis (p must be larger than the 50% pessimistic investors), the optimistic investors decide upon the timing of a successful speculative attack. Hence, an attack materializes at a lower state of fundamentals than in the reference model.

In sum, the heterogeneity in investors' sentiment increases the probability of a currency crisis at bad states of fundamentals and reduces this probability at good states of fundamentals.

[52] Since agents might "exchange" types when the change in the fundamental changes its sign, this specification is compatible with agents who are always optimistic or always pessimistic.

2.2.6 Summary and implications

The model introduces investor sentiment into a model of currency crises of the second generation approach. It shows that the probability of a currency crisis increases when investors are pessimistic. There exists a range of fundamentals where a currency attack occurs although the peg would be stable in a model where investors base their decision only on the expected value of fundamentals and do not consider changes in fundamentals to convey additional information.
For heterogeneous investors the model shows that conclusions based on a representative agent may be misleading. The heterogeneity of agents has to be considered explicitly. A sample of pessimistic and optimistic investors increases the probability of a currency crisis in low states of fundamentals whereas for good fundamentals the reverse holds. If investors' sentiment follows cycles such that phases of a majority of pessimistic agents alternate with phases of a majority of optimistic agents, these conclusions are amplified.

The model highlights the effects if changes in reserves (or more generally of the fundamentals) are perceived as an important signal of the stability of a fixed exchange rate system. This may explain the observation that central banks prefer to accumulate reserves instead of selling them. Central banks want to disseminate positive signals of the state of the economy. This is especially effective if fundamentals are in the interval of self-fulfilling crises.

Morris and Shin (2001) formulated this argument verbally: "But taking into account the strategic analysis, we see that the true benefit of accumulating reserves is a confidence building measure. If the accumulation of reserves is publicly observed, speculators will anticipate that other speculators will be less aggressive in attacking the currency. So in regions of fundamentals where a self-fulfilling attack is in fact feasible, it will not occur." (p. 154). By implication, falling reserves are especially harmful if their reduction is common knowledge.
Investors will be especially pessimistic if they suffered from a recent crisis. Therefore, central banks might be tempted to disseminate positive signals (= accumulate reserves) especially after currency crises. This hypothesis will be tested in the empirical part of this chapter.

This, however, is not to say that central banks are recommended to accumulate reserves. This strategy is costly in the long run and might even contribute to a future currency crisis. Since reserves are low-yielding assets or – if they are borrowed – even generate future interest payments, their increase might deteriorate the state of fundamentals in the long run and end in a currency crisis. Central banks might do better if they explained why reserves increase or decrease in a certain period. Thereby they might prevent that changes are understood as positive or negative signals.

2.3 The hypothesis

We hypothesise that central banks accumulate international reserves after they have experienced a currency crisis.[53] There might be several reasons why a central bank changes its reserve policy after a currency crisis has occurred.

First, the experience of a currency crisis might lead to a re-examination of the optimal amount of reserves. A central bank might want to signal international investors and speculators that it is disposed to defend the currency. In the framework of the model elaborated in section 2.2 central banks are concerned to disseminate positive signals. This might reduce the probability of speculative attacks. If a currency crisis cannot be avoided, the central bank might at least wish to be endowed with the resources for a better crisis management.

Second, a central bank might change its evaluation of risks linked to the integration into the international financial market. The occurrence of a crisis highlights the risks and costs of sudden stops of capital flows and contagion. These risks might have been undervalued in good times of financial tranquillity.

Third, central bankers might not only be more vigilant concerning possible risks. Even more important, they might become more risk averse after they have been blamed for the severe effects of a crisis by politicians and the public. Central bank governors might be concerned about the loss of reputation – of their person and of the institution as a whole – and fear to be fired. Whereas the empirical findings of Frankel (2005) suggest that this fear is justified – he finds that the turnover rate of the central bank governor or finance minister is significantly higher in the year after a currency crash – Dreher et al. (2006) cannot confirm this relationship.

Fourth, currency crises usually depress economic growth. Governments might intend to accelerate the recovery from low growth and return to the pre-crisis growth path on the basis

[53] In this chapter a broad concept of currency crisis is used. The term currency crisis encompasses successful speculative attacks on a currency as well as unsuccessful ones.

of an export-led growth strategy. Central banks may contribute to this strategy by maintaining the exchange rate undervalued. This can be facilitated if reserves are accumulated.
Finally, the accumulation of reserves after a crisis can be explained by political economy considerations. According to the theory of bureaucracy, bureaucrats try to maximize their power through increases in their budget, staff and discretion. International reserve interventions are both powerful and often discrete instruments. Incumbent politicians like high reserves for political business cycles: expansionary monetary policy before election and selling reserves to avoid depreciation (see Dreher and Vaubel 2009). Central bankers might use a crisis episode to justify a further increase of reserves. In the moment when the costs of a crisis are evident, the costs of reserve holdings might be underestimated by the public.

To test this hypothesis a dynamic panel data model is estimated. It expands traditional models of the demand for reserves by the inclusion of a dummy variable that accounts for currency crises.

3 Empirical strategy

The following section sets the foundations for the empirical analysis: It describes the data set, presents the standard control variables and explains how currency crises are identified.

3.1 Data

The empirical analysis is carried out on the basis of the pooled data set of cross-country and time-series observations from the previous chapter. It contains annual data from 1975 to 2003 for a maximum of 181 countries. Since data for several explanatory variables are missing for some countries, the number of countries used in the econometric analysis depends on the particular specification and is indicated in the respective tables. It ranges from 40 to 114 countries. As before, with a few exceptions, data are taken from the International Financial Statistics of the IMF and the World Development Indicators of the World Bank. Appendices C and D of chapter 2 list the countries that are included in the sample and provide summary statistics of the variables. A list of data sources and empirical definitions of the variables is provided in the appendix at the end of this dissertation.

For the identification of currency crises, annual observations may lack the necessary precision. Therefore, an additional data set is constructed that contains monthly observations of the relevant variables (international reserves, nominal exchange rate and interest rate) for the same sample of countries. It covers the period 1970-2003 such that also currency crises in the five years before the period of the main empirical analysis (1975-2003) can be identified.
The set of control variables consists of those variables that were identified as important determinants of the level of reserves in the previous chapter. Since these variables are rather standard and described in chapter 2, I abstain from a detailed discussion here.

3.2 Definition of a currency crisis

Actual currency crises are characterized by sharp devaluations, depreciations or instances where a peg is completely abandoned. Hence, they can be identified by large nominal depreciations of the exchange rate. Frankel and Rose (1996) define a currency crash as a nominal depreciation of the currency of at least 25% during one year that is also at least an increase of 10% in the rate of depreciation in comparison with the previous year.

Alternatively, a speculative attack may be unsuccessful if a currency crisis can be avoided. It can be identified indirectly by counteractive measures taken by a central bank: The currency may be defended by the sale of reserves. Alternatively, an increase of the interest rate may intend to stop massive capital outflows and thereby reduce the pressure on the currency. Therefore, unsuccessful speculative attacks can be identified by large reserve losses and/or sharp increases of the interest rate.

The existing empirical literature uses two alternative ways to identify a crisis episode: event-based methods and index methods.
The event-based method dates crisis episodes on the basis of events that attract the attention of the general public: As an event might qualify a sharp depreciation, a drastic interest rate hike or news referring to a crisis situation that are reported by newspapers or international organizations.
In this analysis, the event-based method will not be applied due to its conceptual shortcomings. Both the definition of an event – what is a sharp depreciation? – and its timing are likely to be arbitrary. Moreover, a given rate of depreciation might qualify as a crisis in one country whereas it is regarded as normal in another country.

According to the index method, a currency crisis is defined to occur if an index of exchange market pressure (EMPI) exceeds a threshold. Methods differ in the choice of a threshold and in the variables that are included in the index.

Whereas the event-based method only identifies currency crises that are perceived as a crisis by a wide public, the index method reveals both successful and unsuccessful speculative attacks.

Eichengreen et al. (1996) propose an index that summarizes the changes of the nominal exchange rate, reserves and the interest rate, each weighted by the inverse of its standard deviation. All changes are computed relative to a reference country, namely Germany or the US. Hence, the index is calculated as:

$$EMPI_{it} = \frac{1}{\sigma_e}\frac{\Delta e_{it}}{e_{it}} - \frac{1}{\sigma_r}\frac{\Delta R_{it}}{R_{it}} + \frac{1}{\sigma_i}\Delta\left(i_{it} - i_{US,t}\right)$$

where e is the nominal exchange rate, R are reserves, and i is the nominal interest rate. The index t indicates the time period and the index i denotes a certain country. The standard deviation σ is calculated individually for each country over the whole period. In our application changes in e and i are calculated relative to the U.S. Changes in reserves are not compared with a reference country since a simultaneous fall of reserves in many countries might signal a global crisis.
A currency crisis is defined to occur if the index exceeds its mean plus two standard deviations.[54] In comparison with the event methods where the threshold is fix over all countries and periods – e.g. a depreciation of 25% in the case of Frankel and Rose – the index method calculates country-specific thresholds. This has the merit that it takes into account different institutional settings. A devaluation in a fixed exchange rate regime is much more costly than the same devaluation under a floating exchange rate since in the latter economy agents are used to be exposed to a higher exchange rate volatility and might be better prepared for such situations.

A different approach proposed by Zhang (2001) analyses the time-series of reserves and exchange rates individually. It is a combination of the event-based and the index method. It

[54] I also used smaller and larger threshold values. The choice of a threshold, however, does not change the number of identified currency crises significantly.

postulates that a currency crisis is identified if the rate of change of at least one of the variables exceeds a certain threshold. I extend Zhang's approach by including changes of the interest rate as a third variable.

A speculative attack is defined as a period when changes of at least one of the variables take extreme values. In particular, a speculative attack is identified if one or more of the following conditions are fulfilled:

$$\Delta e_t > 3\sigma_{\Delta e_t} + \mu_{\Delta e_t}$$
$$\Delta R_t < -3\sigma_{\Delta_{R_t}} + \mu_{\Delta_{R_t}}$$
$$\Delta i_t > 3\sigma_{\Delta_{i_t}} + \mu_{\Delta_{i_t}}$$

The standard deviation σ and the mean μ are calculated for each country individually over the preceding three years, namely over the monthly sample of (t-36, t-1). This implies that the threshold is time-varying. This time-varying feature has several virtues: First, the threshold adapts automatically to periods where a country – or the world as a whole – is subject to higher or lower volatility. Second, regime changes are less likely to be misinterpreted as a crisis.

In order to avoid double-counting, the three years that follow a currency crisis are discarded.

In the empirical analysis, the results of both methods to identify a currency crisis will be presented. Figures 5 and 6 show the distribution of currency crises for both methods. The pressure index succeeds in identifying the two periods of numerous crises at the beginning of the 1980s and at the end of the 1990s. The distribution of crises according to the methodology of Zhang is quite different. This might be due to the fact that it puts higher weight on unsuccessful attacks – a large interest rate increase or a heavy loss of reserves are interpreted as a crisis. Moreover, if the exchange rate is defended by a combination of policy actions, the pressure index identifies crises more often than the Zhang criterion.

In contrast to the literature on early warning systems for currency crises, which try to identify the date of the beginning of a currency crisis, we focus on the end of a currency crisis. The end of a currency crisis is defined as the moment where – at least from the point of view of the central bank – the economy is stabilized again.

The following time path of reserves is assumed: Reserves decrease during a currency crisis and reach a lower point. After the disorder of the crisis passed and the economy is stabilized, the central bank restocks reserves. It is natural to assume that the central bank aims at accumulating reserves in the post-crisis period. Therefore, we expect that reserves grow in the first months or years after a currency crisis. If our currency crisis dummy variable took the value one beginning in the first crisis month, a positive relationship between crisis and reserves would be natural. However, it would not indicate a revised reserve policy but, in contrast, affirm that the central bank replenishes its reserves. Conclusions would be misleading.

Therefore, I use another approach. After a currency crisis has been identified I determine in which month reserve restocking is completed. The dummy for currency crises takes the value one in that year and all following years. Hence the crisis dummy only evaluates if reserves exceed their pre-crisis level.

Figure 7 illustrates the construction of the crisis dummies and the hypothesised time path of reserves before and after currency crises. According to the hypothesis, reserves are expected to increase in the aftermath of currency crises and to rise above their pre-crisis level. This increase is permanent.

There are two different views how to determine when pure restocking is completed. First, the central bank might end its policy of reserve accumulation once reserves reach their pre-crisis level. However, for a given reserve strategy of the central bank, the desired post-crisis level usually differs from the desired pre-crisis level. During a crisis typical determinants of reserves like the amount of external debt, the economy's trade openness and even the exchange rate system may be affected by important changes. Therefore, as a second approach, I calculate the fitted values of reserves over GDP in a bias-corrected dynamic fixed effects estimation, which includes the same control variables as the majority of the subsequent regressions except the crisis dummies. In the year when actual reserves exceed their fitted value, the currency crisis dummy takes for the first time the value one. To test for the robustness of the findings, the empirical analysis will make use of both approaches. They are referred to as methods based on the pre-crisis level and fitted values, respectively.

Given this currency crisis dummy I use two different approaches to employ it in the estimation.
First, I use all dummies individually in their chronological order. That is to say, the effect from the first until the last identified crisis is examined. The dummy "first crisis" then analyses the impact of the first crisis during 1973-2003 independently of the year of its occurrence. The first crisis might hit one country in 1973 whereas another country suffers its first crisis in 2003.

As a second approach, I distinguish three periods: Crises between 1973 and 1981, between 1982 and 1996 and between 1997 and 2003. The partition in episodes is justified by the occurrence of important crises: the breakdown of the Bretton Woods system in 1973, the debt crisis of 1982 and the East Asian financial crisis of 1997. These crises might have changed the general perception of a crisis since these crises can be regarded as prototypes of crises. Moreover, these three crises periods also coincide with the theoretical distinction of three generations of currency crises (see section 2.1). The crisis dummy takes the value one after a country experienced its first currency crisis within this period. Relevant is the year in which reserve restocking is completed. The dummy makes no difference whether this was the only currency crisis for a certain country in this period or whether a country suffered several crises in the same period.

In a nutshell (see Figure 8), crisis dates are identified according to two different approaches. On the basis of these dates, two different methods are applied to determine the year when reserve restocking is completed. The dates of completed restocking are used in two versions of crisis dummies in the empirical analysis: absolute number of crises and categorized in periods of crises.

3.3 Financial liberalization and economic globalisation

Financial liberalization and economic globalisation both allow a country to profit from international capital flows. However, they also make countries more vulnerable to sudden stops and capital flow reversals. Therefore, capital account liberalization and economic globalisation might go along with increasing self-insurance in the form of reserve hoardings. More importantly, the question arises whether this planned self-insurance was adequate or if a central bank revises its reserve policy after the occurrence of a currency crisis although it had already taken precautionary measures before the crisis. If we did not control for these effects,

the currency crisis dummy variable might simply proxy increased economic integration. This, however, does not foreclose that the occurrence of a crisis may be correlated with financial integration.

We rely upon the index of capital account openness developed by Chinn and Ito (2002). This index embodies four binary dummy variables on restrictions on international financial transactions, which are reported in the IMF´s Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). The index measures de jure financial openness and makes no attempt to include de facto openness. Higher values indicate that countries are more open to cross-border financial transactions.

As a proxy for the integration of an economy in the international markets we use an index of economic globalisation. It is a sub-index of the KOF index of globalisation proposed by Dreher (2006). The index of economic globalisation has two main components, which are weighted equally: actual flows of goods and capital and restrictions to these flows. The index takes values between one and hundred where higher values denote greater globalisation.

4 Empirical evidence

4.1 Statistical evidence

As a nonparametric test of our hypothesis, Figures 9 and 10 plot in a scatter diagram the relationship between the largest annual reserve loss during 1975-2003 and the subsequent change in the level of reserves. The diagram includes those countries of our sample that experienced an annual reserve loss of at least 25%. Analogously to Frankel and Rose's (1996) definition of a currency crisis (nominal devaluation larger than 25%), this is our indicator of a successful or unsuccessful speculative attack. The ordinate depicts the level of reserves relative to its pre-crisis level five (Figure 9) and eight (Figure 10) years after the reserve loss, respectively. The horizontal line at the value zero divides the diagram in two parts: in countries below the line, reserves did not reach their pre-crisis level whereas in countries above the line reserves are larger than before the crisis. It is evident that the majority of countries increases its reserves well above the pre-crisis level. Whereas five years after a crisis there is still a minority of countries with lower reserves than before the crisis, eight years after the crisis in only six countries reserves are below their pre-crisis level. At least

three of these countries suffered from (civil) wars during those years.[55] The diagram illustrates that already after five years the reserves of the majority of countries are twice their pre-crisis level (values larger than one on the vertical axis). The downward sloping line of fitted values indicates that there is a positive link between the absolute loss of reserves (severity of a crisis) and the subsequent accumulation of reserves. These correlations, however, are not significant. In sum, the figures show first evidence that central banks accumulate reserves in the years after a currency crisis until reserves are significantly higher than before the crisis.

4.2 Method of estimation

Since the level of reserves is partly determined by its level of the previous period, I use a dynamic specification where the lagged dependent variable enters as an explanatory variable. Since the lagged level of reserves is correlated with the error term the assumption of strict exogeneity is violated. Fixed effects estimators - which are the standard estimation technique in static models - are biased and inconsistent for the number of units of observation going to infinity and a fixed number of time periods.

The literature proposes two different solutions to the problem: a correction for the bias or, alternatively, estimation by the Generalized Method of Moments (GMM). In order to check for the robustness of the results, the empirical analysis will make use of both methods.

For dynamic panel data models with serially uncorrelated errors and strongly exogenous regressors, Kiviet (1995) derives an approximation for the bias of the fixed effects estimator. He proposes a corrected fixed effects estimator that subtracts a consistent estimator of this bias from the standard fixed effects estimator.

Instrumental variables estimators are proposed as an alternative solution. This class of estimators eliminates the country-specific effects by first differencing and then applies instrumental variables to the transformed equation.

[55] These six countries with a lower reserve level than before the crisis are Afghanistan (crisis in 1981 during the civil war between 1979 and 1989), Bahamas (1987), Burkina Faso (1994), Nicaragua (1984, in the year of the first free elections after the Sandinista revolution), Paraguay (1992) and Sri Lanka (1980, beginning civil war in 1983).

The difference GMM estimator, also known as Arellano-Bond estimator (Arellano and Bond 1991), uses all feasible lagged values of the dependent variable as instruments. Hence, the number of instruments varies with each time period since with each forward period an extra instrument is added. All these moment conditions can be exploited in a Generalized Method of Moments (GMM) framework.[56] Estimation is executed by a two-step procedure. Since the two-step standard errors tend to be biased downward in small samples, the one-step standard errors are used for inference.

The consistency of the GMM estimator depends on the validity of the instruments. To address this issue, two specification tests are used: The Sargan test of overidentifying restrictions evaluates the overall validity of the instruments. The Arellano-Bond test for autocorrelation in the residuals assesses the assumption that the residuals are uncorrelated over time. It tests the null hypothesis that second-order serially correlation is absent. This implies that the original residuals are uncorrelated, too. The results of both tests are reported at the bottom of the output tables.

These estimators assume that the slope parameters are constant over time and over all countries. The previous chapter highlighted the theoretical result that the estimation coefficients may be biased if this assumption does not hold. Tests of the poolability of the dataset rejected the hypothesis of common slope parameters. Therefore, one has to check whether the results are robust to neglected country heterogeneity. On this account, the mean group estimator, proposed by Pesaran and Smith (1995), is employed. It estimates an individual regression for each country by OLS and averages the coefficients over countries.

4.3 Estimation results

Table 1 presents the estimation results for the individual currency crisis dummies in their chronological order. The definition of a currency crisis is based on the methodology of Zhang. As described above, the crisis dummies switch from zero to one when the central bank finishes to restock reserves after a currency crisis. Columns (1) and (2) assume that this is the case when reserves have reached their pre-crisis level. The determination of crisis dummies in columns (3) to (5), however, is based on an auxiliary regression: The dummies take the value one beginning in the period when actual reserves exceed their fitted values from the auxiliary

[56] 2SLS cannot be applied since it demands that the dimension of the matrix of instruments be constant for all t.

regression. We employ three different estimation techniques: the difference GMM estimator, the bias-corrected fixed effects estimator and the mean group estimator.

With respect to the traditional determinants of reserves, the results confirm previous findings. Independently of the chosen estimator, the effects of trade openness and total external debt are positive and significant. More open and more indebted countries hold higher levels of reserves. Short-term external debt has a significant negative effect on reserves. This supports the hypothesis that an increase in short-term external debt is an indication of an emerging financial crisis – investors prefer to lend short-term –, which is reflected in a fall of central banks' reserves. The lagged level of reserves is highly significant. The effects of the remaining variables are not significant. In particular, the level of development (proxied by real GDP per capita), external volatility and the exchange rate system do not significantly influence the level of reserves. The results with respect to the significance of the effect of a disequilibrium in the domestic money market are ambiguous and depend on the estimation method.

With respect to the impact of currency crises, we can record the following: Currency crises lead to a subsequent permanent increase in the level of reserves. In the different specifications, a minimum of one and a maximum of four currency crises have a significant positive effect on the level of reserves. This implies that countries revise their reserve policy after the experience of a currency crisis. The level of reserves is a positive function of the number of crises they suffered from during the period of consideration.

Table 2 replicates the regressions of Table 1 with the difference that the identification of a currency crisis is based on the exchange market pressure index of Eichengreen et al. (1996). Columns (1) and (2) determine the date of a central bank's successful completion of reserve restocking by a comparison with the pre-crisis level, whereas columns (3) to (5) use fitted reserve levels. By and large, the results of the previous table are confirmed. The lagged level of reserves divided by GDP, trade openness, total and short-term external debt determine the level of reserves. Whereas only one crisis dummy is positive and significant when restocking of reserves is defined by comparison with their pre-crisis level, up to four consecutive crises increase the level of reserves significantly if fitted values are used. The fifth crisis may significantly reduce the level of reserves. Hence, central banks do not increase the level of reserves after each crisis. However, the cumulative effect of the first five crises is still positive. In sum, the level of reserves depends positively on the occurrence of currency crises.

Table 3 shows the results when currency crises are categorized by their incidence in three different periods. Columns (1) and (2) use the crisis definition of Zhang, whereas columns (3) and (4) define crises according to the exchange market pressure index. All crisis dummies are constructed on the basis of a comparison of reserves with their pre-crisis level. In the case of crisis periods, the alternative use of fitted values is disregarded since in this specification the errors are serially correlated (Arellano-Bond test has a very low p-value), which might lead to misleading inferences.

Countries that suffered from a currency crisis in the years between 1973 and 1981 do not significantly differ in their reserve policy in comparison to countries that were not hit by a crisis. In this period, the new financial order was still evolving after the breakdown of the Bretton Woods system. Countries might have used crisis episodes to reduce their reserve overhang from the period of fixed exchange rates. Moreover, they might have been over optimistic in assuming that the crisis was only an isolated event due to the changeover to a new international financial order and which would not be repeated once the teething problems of the new system have been overcome.
For crises in the wave of the Latin American debt crisis in 1982 until 1996, the results are inconclusive. In one of the four different estimations, the effect is positive and significant. This picture seems to change with the East Asian financial crisis in 1997. Countries that were hit by a speculative attack after 1996 increased significantly their level of reserves if the crisis definition of Zhang is considered. Countries increased their reserve holdings independently of whether they already had accumulated reserves due to a crisis in the periods before 1997. The magnitude of the effect is even stronger: the coefficient of the dummy almost doubled in comparison with the crisis dummy of the period 1982-1996.

Table 4 replicates column 3 of Table 1 (number of currency crises) where capital account openness and economic globalisation are added to control for the effects of international financial integration. The results concerning currency crises are robust to this change: Crises imply an increase in the level of reserves. The effects are slightly smaller in magnitude than without the additional control variables but still highly significant. The fifth crisis again leads to a significant reduction in the level of reserves, which, however, does not question the cumulative positive effect of crises. The effects of capital account openness and economic globalisation are not significant.

The robustness checks for currency crisis periods are presented in Table 5. It replicates column 3 of Table 2 after adding the control variables for international financial integration. The 1973-81 crisis dummy is still insignificant, the effect of the 1982-1996 dummy ambiguous and the 1997-2003 dummy is again positive and significant. Capital account openness and economic globalisation again do not significantly affect the level of reserves.

Table 6 additionally includes interaction terms between the crisis dummies and a fixed exchange rate system. It tests whether central banks' reserve policies in the aftermath of currency crises depend on the exchange rate system. One might expect that the increase in reserves after a crisis is especially strong in countries with a commitment to a fixed exchange rate. The results, however, are not clear-cut. If currency crises are defined according to Zhang (column 1), the increase in reserves under fixed exchange rate systems was lower during 1982-1996, but larger between 1997 and 2003 in comparison with the remaining exchange rate systems. The effects of fixed exchange rates for currency crises identified by the exchange market pressure index (column 2) are not significant. However, independently of the exchange rate regime, both crises between 1982 and 1996 and crises between 1997 and 2003 now significantly increase central banks' international reserves.

5 Conclusions

The widespread accumulation of international reserves by central banks in recent years is often explained as a precautionary buffer against the risks of international financial integration. Although theoretically plausible, empirical tests of this argument are still scarce. This chapter enhances research on the links between reserve accumulation and currency crises on two main fronts.

First, it reviews the role of reserves in different models of currency crises. It develops a model of currency crises in the spirit of the second-generation approach that accounts for heterogeneous agents. As a result, the probability of a speculative attack increases in comparison to homogeneous agents' models provided that a part of the investors is pessimistic. As a consequence, central banks might accumulate reserves in order to disseminate positive signals with respect to the evolution of the state of the fundamentals of the economy.

Second, it analyses empirically whether currency crises have an effect on countries' level of reserves. It is especially interesting to investigate central bank behaviour after crises when the risks of international financial integration are not only represented by a probability measure, but when they have become real in the form of a speculative attack with or without ensuing devaluation of the national currency.

It tests the hypothesis that central banks increase their holdings of international reserves after they have experienced a currency crisis. A dynamic model is estimated for a large panel data set of developing and industrial countries covering the period from 1975 to 2003. The evidence shows that currency crises induce a permanent increase of reserves. This effect is particularly strong for recent currency crises since the Asian financial crisis. The more currency crises a country suffered from, the higher the level of reserves is. These findings are robust for different definitions of a currency crisis and across different estimation methods.

Central banks revise their reserve policy after the experience of a currency crisis and accumulate reserves in its aftermath.

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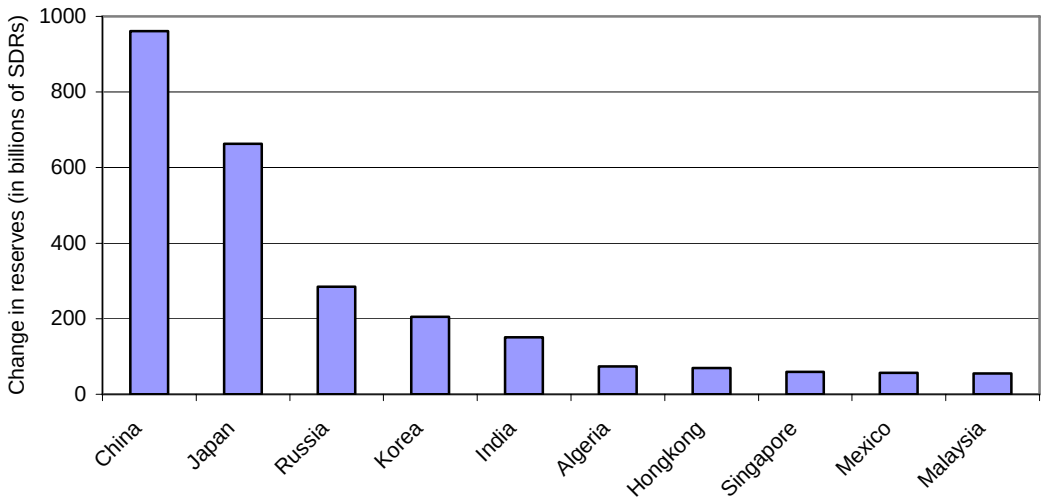
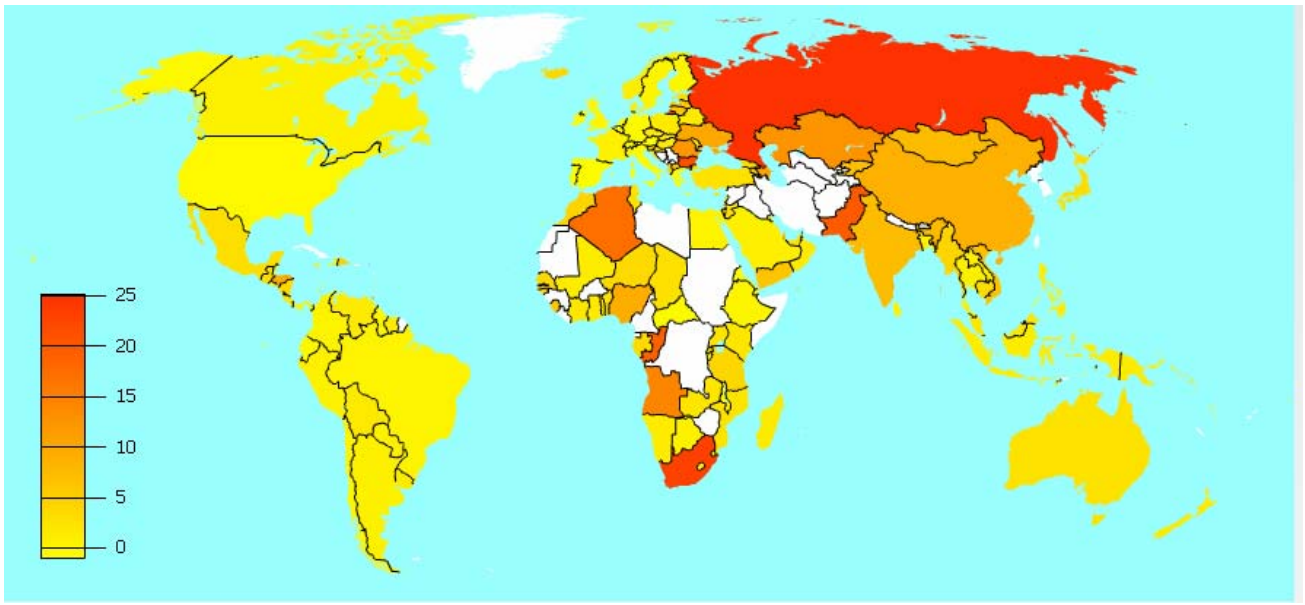
Figure 1: Countries with largest absolute increase of reserves (1996-2006)



Data source: International Monetary Fund (2007)

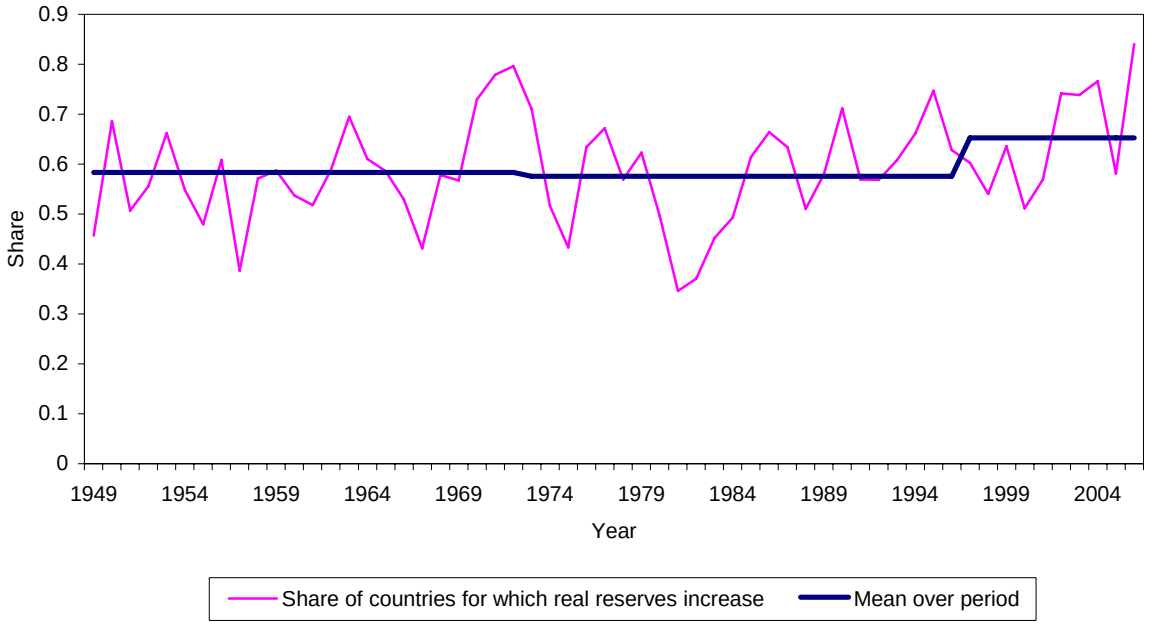
Figure 2: Relative increase of international reserves (1996-2006)



Data source: International Monetary Fund (2007)

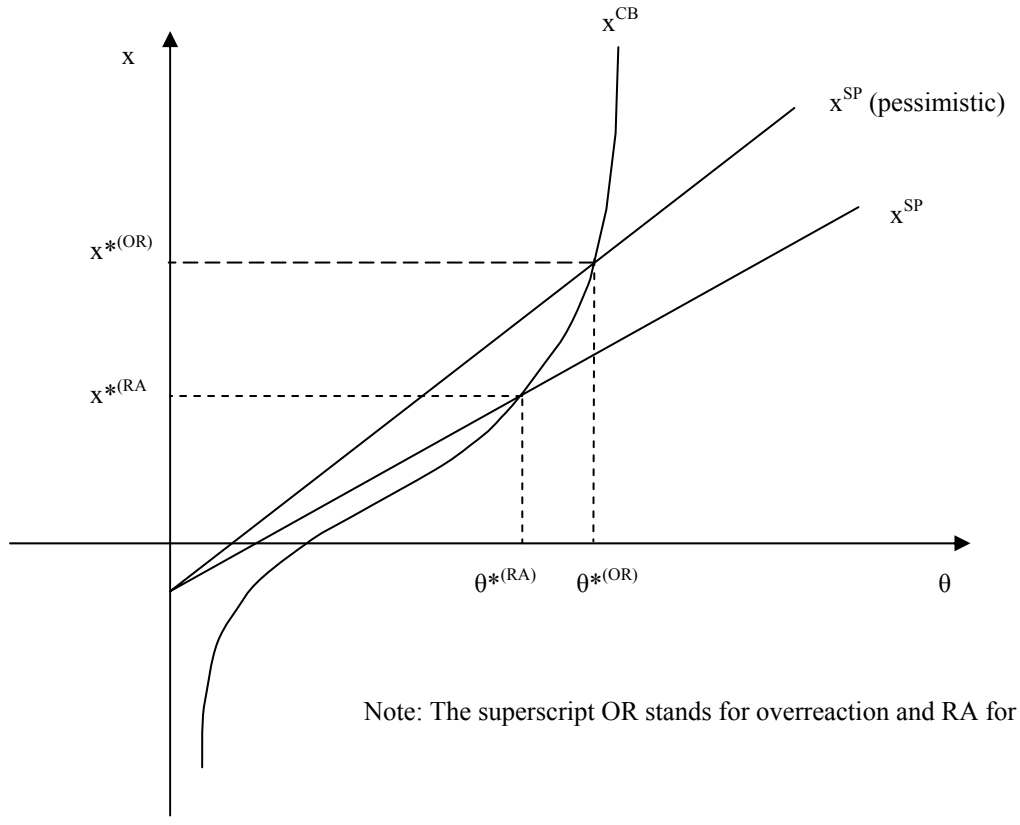
Notes: The relative increase of reserves is calculated as the ratio of the level in the year 2006 and the level in 1996.
Countries with missing data are marked white. Moreover, the following outliers (very large increase) are disregarded: Cameroon, Equatorial Guinea, Liberia and Sudan.

Figure 3: Share of countries with positive reserve accumulation



Source: Author's computations based on International Monetary Fund (2007).
Note: Real reserves are defined as total international reserves (in dollars) divided by the GDP deflator for the US. The chosen periods and calculated mean values for the share of countries are the following: 1949-1972: 58.3%; 1973-1996: 57.6%; 1997-2006: 65.3%.

Figure 4: Determination of the equilibrium



Note: The superscript OR stands for overreaction and RA for rational.

Figure 5: Identified currency crises by the exchange market pressure index

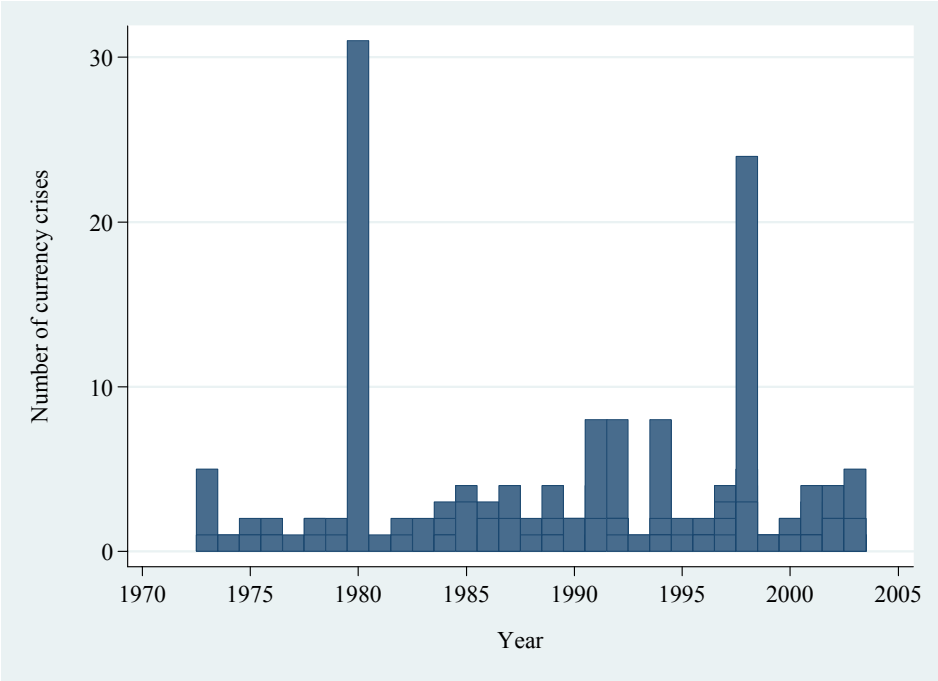


Figure 6: Identified currency crises by the expanded methodology of Zhang

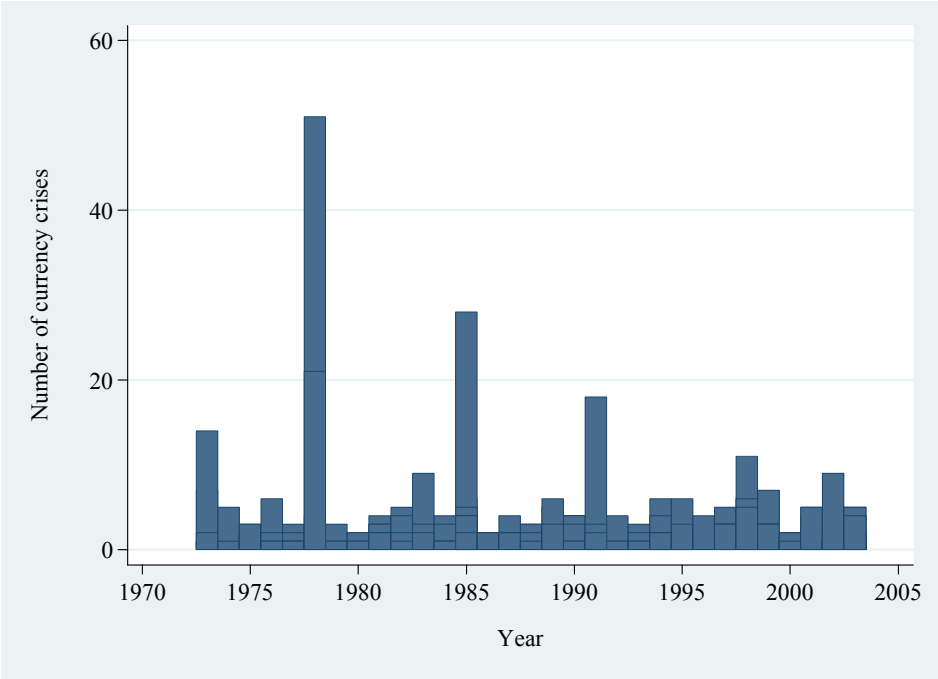


Figure 7: Stylized time path of reserves according to the hypothesis

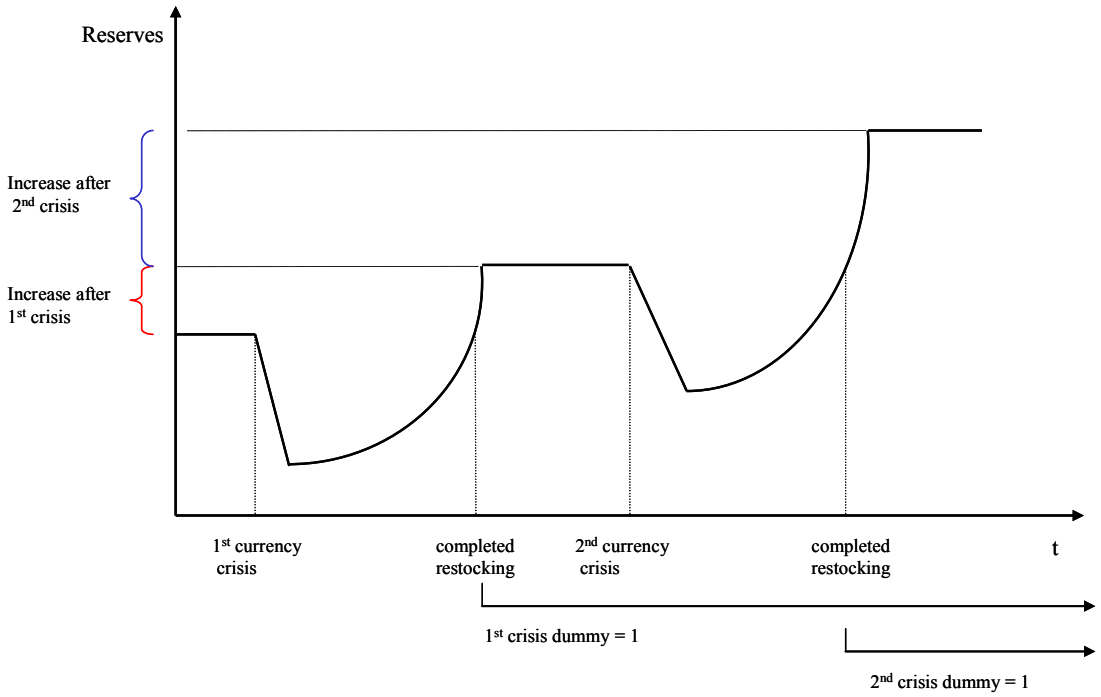


Figure 8: Construction of currency crises dummies

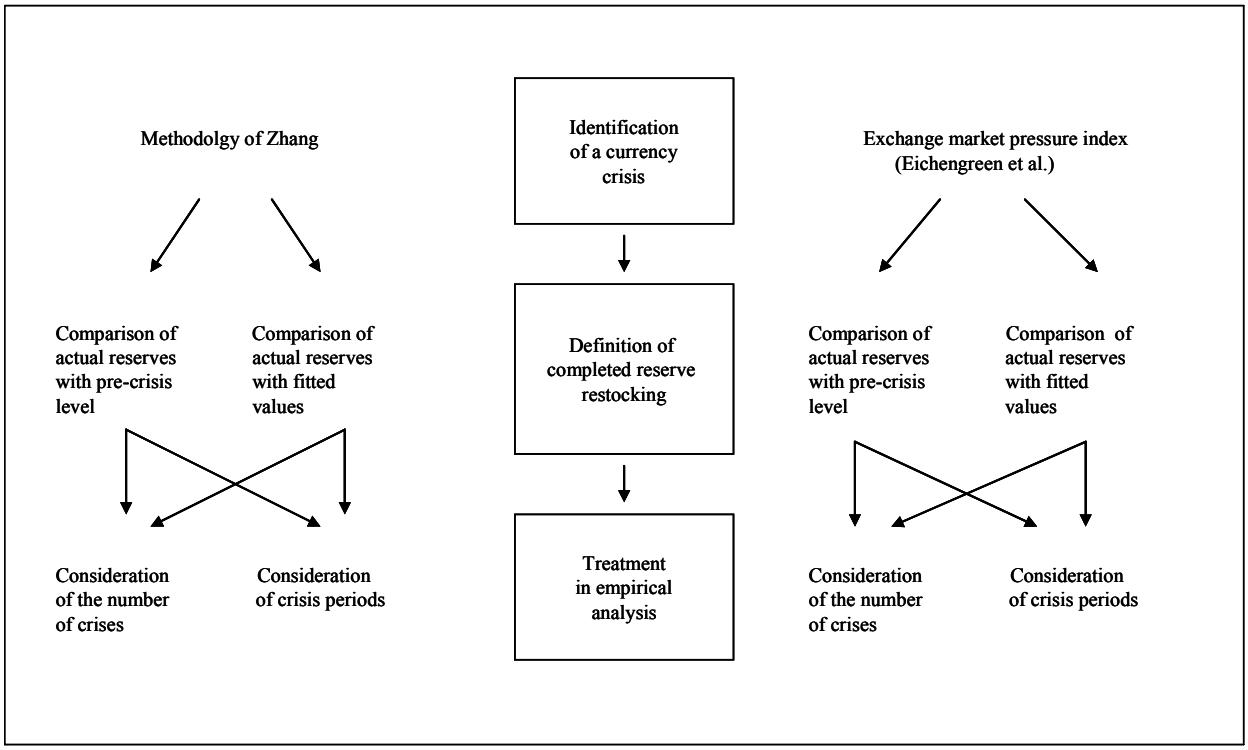


Figure 9: Reserve losses and subsequent reserve accumulation (five-year period)

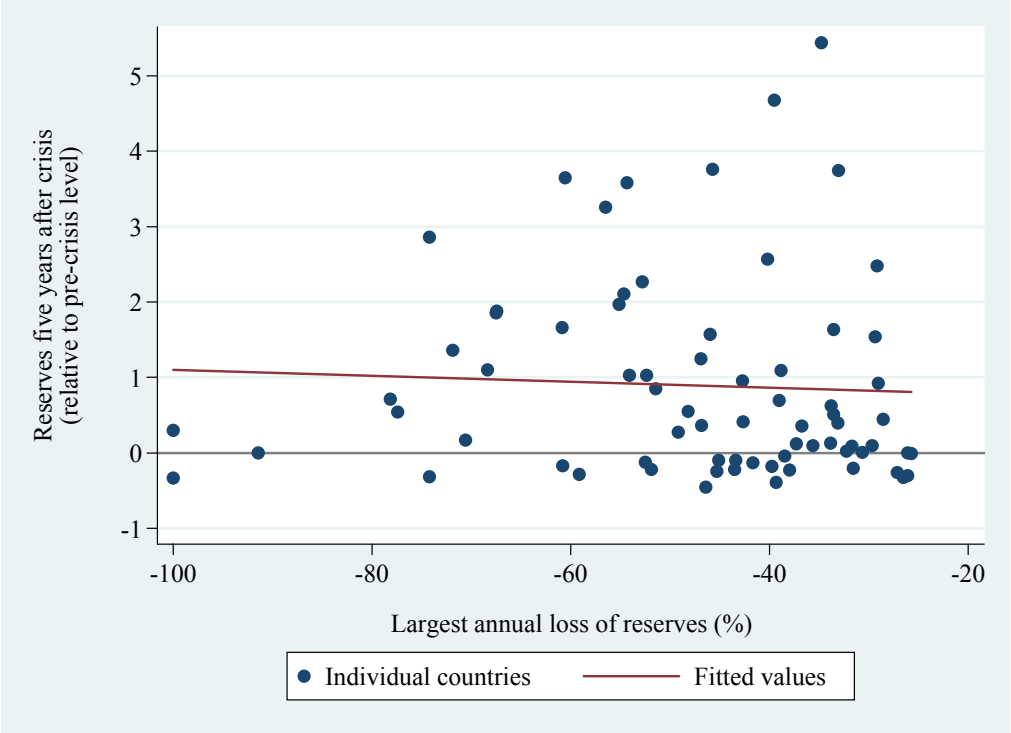


Figure 10: Reserve losses and subsequent reserve accumulation (eight-year period)

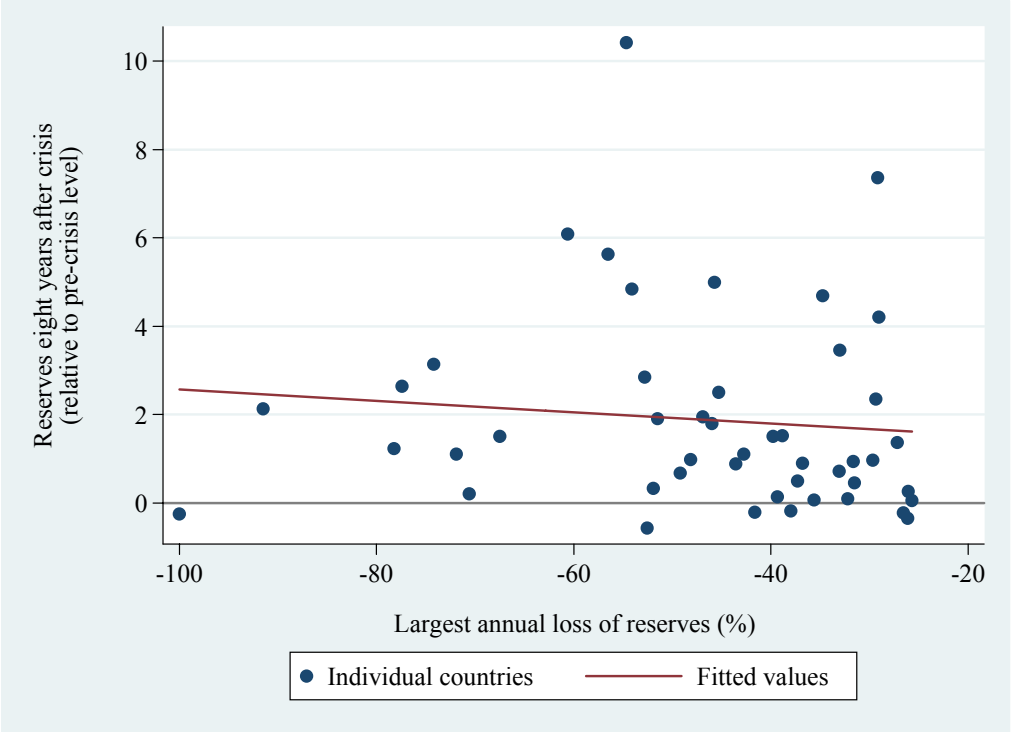


Table 1: International reserves and currency crises: fine classification
(definition of currency crises based on Zhang)

Dependent variable: Reserves/GDP	(1)	(2)	(3)	(4)	(5)
Lagged endogenous variable	0.7237 (12.48***)	0.9198 (57.59***)	0.6936 (11.30***)	0.9123 (55.91***)	0.3196 (5.31***)
Real GDP per capita	-0.0035 (-1.11)	-0.0016 (-0.91)	-0.0027 (-0.90)	-0.0024 (-1.37)	0.0354 (1.41)
Trade openness	0.0548 (4.09***)	0.0373 (5.45***)	0.0495 (3.05***)	0.0353 (5.05***)	0.0378 (1.64*)
Volatility (nominal)	-0.0022 (-1.08)	-0.0051 (-1.84*)	-0.0001 (-0.96)	-0.0040 (-1.46)	-0.0149 (-0.40)
Total external debt (per cent of GDP)	0.0189 (4.13***)	0.0185 (4.95***)	0.0160 (3.80***)	0.0158 (4.21***)	0.601 (1.50)
Short-term external debt, lagged (per cent of GDP)	-0.0542 (-3.90***)	-0.0375 (-3.15***)	-0.0541 (-4.72***)	-0.0303 (-2.50**)	-0.1795 (-1.97*)
Fixed exchange rates, dummy	-0.0013 (-0.21)	0.0052 (1.20)	0.0033 (0.75)	0.0084 (1.93*)	-0.0072 (1.39)
Intermediate exchange rates, dummy	0.0027 (0.70)	0.0003 (0.07)	0.0055 (1.43)	0.0007 (0.18)	0.0044 (0.59)
Monetary disequilibrium (excess money supply)	-0.0003 (-1.86*)	-0.0005 (-0.65)	-0.0002 (-1.53)	-0.0002 (-0.34)	0.1066 (2.75**)
First crisis	0.0199 (3.35***)	0.0035 (0.49)	0.0401 (7.59***)	0.0078 (2.27**)	0.0147 (3.80***)
Second crisis	0.0140 (0.71)	0.0144 (2.35*)	0.0446 (4.92***)	0.0126 (3.79***)	0.0345 (2.63**)
Third crisis	0.0175 (3.34***)	0.0047 (1.26)	0.0335 (4.48***)	-0.0011 (-0.32)	0.0130 (1.84*)
Fourth crisis	0.0100 (1.57)	-0.0012 (-0.42)	0.0332 (4.42***)	0.0081 (1.85*)	0.0107 (0.81)
Fifth crisis	0.0061 (0.71)	0.0030 (0.47)	0.0028 (0.26)	-0.0109 (-1.28)	0.0027 (1.00)
Sixth crisis	0.0117 (1.02)	0.0072 (1.59*)	0.0207 (0.95)	0.0102 (0.27)	
Seventh crisis	0.0189 (1.65*)	-0.0016 (-0.20)			

Eighth crisis	0.0567 (1.13)	0.0225 (1.69*)			
Number of countries	114	114	114	114	40
Number of observations	1651	1651	1651	1651	
Method of estimation	Difference GMM (two step)	LSDV	Difference GMM (two step)	LSDV	MG
Sargan Test (p-level)	1.0		1.0		
Arellano-Bond-Test (p-level)	0.96		0.81		

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
LSDV: least-squares dummy variable estimator (= fixed effects estimator)
MG: mean group estimator
Since the mean group estimator is based on individual regressions for each country, the sample is restricted to countries for which at least 20 common observations for each variable are available. This explains the reduced number of countries.
As described in the text, the crisis dummies of columns (1) and (2) take the value one after reserves have reached their pre-crisis level. The crisis dummies in columns (3) to (5) are based on an auxiliary regression: The dummies take the value one beginning in the period when actual reserves exceed their fitted values from the auxiliary regression.

Table 2: International reserves and currency crises: fine classification
(definition of currency crises based on exchange market pressure index)

Dependent variable: Reserves/GDP	(1)	(2)	(3)	(4)	(5)
Lagged endogenous variable	0.7339 (12.52***)	0.9335 (57.68***)	0.6973 (11.92***)	0.9122 (55.47***)	0.3911 (7.18***)
Real GDP per capita	-0.0046 (-1.10)	-0.0015 (-0.82)	-0.0040 (-1.08)	-0.0019 (-1.04)	0.0197 (0.97)
Trade openness	0.0563 (3.62***)	0.0356 (5.11***)	0.0577 (3.72***)	0.0324 (4.55***)	0.0460 (2.04*)
Volatility (nominal)	-0.0028 (-0.94)	-0.0048 (-1.72*)	-0.0016 (-0.89)	-0.0034 (-1.23)	-0.0246 (-0.69)
Total external debt (per cent of GDP)	0.0193 (3.89***)	0.0196 (5.28***)	0.0164 (4.02***)	0.0172 (4.66***)	0.0365 (1.61)
Short-term external debt, lagged (per cent of GDP)	-0.0570 (-3.55***)	-0.0353 (-2.91***)	-0.0602 (-3.67***)	-0.0318 (-2.60***)	-0.1702 (-2.25**)
Fixed exchange rates, dummy	-0.0002 (0.14)	0.0035 (0.79)	0.0030 (0.55)	0.0064 (1.47)	-0.0071 (-2.06*)
Intermediate exchange rates, dummy	0.0044 (1.01)	-0.0002 (-0.05)	0.0067 (1.59)	0.0004 (0.09)	0.0077 (1.57)
Monetary disequilibrium (excess money supply)	-0.0003 (-1.66*)	-0.0004 (-0.51)	-0.0002 (-1.29)	-0.0002 (-0.22)	0.1033 (0.61)
First crisis	0.0084 (1.37)	0.0062 (2.19**)	0.0397 (4.92***)	0.0122 (4.32***)	0.0230 (3.13***)
Second crisis	0.0153 (1.36)	0.0025 (0.71)	0.0348 (2.88***)	0.0041 (1.11)	0.0304 (3.62***)
Third crisis	0.0180 (1.47)	-0.0038 (-0.98)	0.0374 (3.46***)	0.0053 (0.97)	0.0140 (1.92*)
Fourth crisis	0.0098 (0.63)	0.0023 (0.28)	0.0078 (0.31)	0.0130 (0.76)	-0.0015 (-1.35)
Fifth crisis	-0.0194 (-1.40)	-0.0036 (-0.24)	-0.0233 (-2.27**)	-0.0349 (-1.76*)	0.0012 (0.37)
Sixth crisis			0.0110 (0.27)	0.0192 (n.a.)	

Number of countries	114	114	114	114	40
Number of observations	1651	1651	1651	1651	
Method of estimation	Difference GMM (two step)	LSDV	Difference GMM (two step)	LSDV	MG
Sargan Test (p-level)	1.0		1.0		
Arellano-Bond-Test (p-level)	0.91		0.85		

Notes:

t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
LSDV: least-squares dummy variable estimator (= fixed effects estimator)
MG: mean group estimator
Since the mean group estimator is based on individual regressions for each country, the sample is restricted to countries for which at least 20 common observations for each variable are available. This explains the reduced number of countries.
As described in the text, the crisis dummies of columns (1) and (2) take the value one after reserves have reached their pre-crisis level. The crisis dummies in columns (3) to (5) are based on an auxiliary regression: The dummies take the value one beginning in the period when actual reserves exceed their fitted values from the auxiliary regression.

Table 3: International reserves and currency crises: classification in periods of crises

Dependent variable: Reserves/GDP	(1)	(2)	(3)	(4)
Lagged endogenous variable	0.7348 (11.69***)	0.9295 (59.93***)	0.7407 (12.19***)	0.9350 (59.04***)
Real GDP per capita	-0.0047 (-1.28)	-0.0018 (-1.07)	-0.0046 (-1.23)	-0.0012 (-0.70)
Trade openness	0.0544 (3.48***)	0.0354 (5.10***)	0.0516 (3.26***)	0.0355 (5.21***)
Volatility (nominal)	-0.0036 (-1.27)	-0.0043 (-1.54)	-0.0036 (-1.39)	-0.0047 (-1.70*)
Total external debt (per cent of GDP)	0.0198 (3.86***)	0.0191 (5.12***)	0.0193 (3.63***)	0.0209 (5.53***)
Short-term external debt, lagged (per cent of GDP)	-0.0604 (-3.78***)	-0.0346 (-2.84***)	-0.0580 (-4.02***)	-0.036 (-2.94***)
Fixed exchange rates, dummy	-0.0038 (-0.50)	0.0047 (1.09)	-0.0011 (-0.08)	0.0043 (0.97)
Intermediate exchange rates, dummy	0.0027 (0.53)	-0.0001 (-0.02)	0.0045 (0.95)	0.0002 (0.04)
Monetary disequilibrium (excess money supply)	-0.0003 (-1.80*)	-0.0003 (-0.47)	-0.0003 (-1.76*)	-0.0003 (-0.49)
Crisis 1973-81	0.0044 (0.35)	0.0022 (0.31)	-0.0045 (-0.26)	-0.0064 (-1.24)
Crisis 1982-96	0.0136 (1.66*)	0.0044 (1.41)	0.0147 (1.04)	0.0040 (1.21)
Crisis 1997-03	0.0210 (2.28**)	0.0079 (2.40**)	0.0124 (1.56)	0.0038 (1.13)
Method of estimation	Difference GMM (two step)	LSDV	Difference GMM (two step)	LSDV
Sargan Test (p-level)	1.0		1.0	
Arellano-Bond-Test (p-level)	0.85		0.86	

Notes:

Estimation is based on a sample of 114 countries comprising a total of 1651 observations.
Definition of currency crises is based on Zhang (columns (1) and (2)) and the exchange market pressure index (columns (3) and (4)).
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
LSDV: least-squares dummy variable estimator (= fixed effects estimator)

Table 4: Robustness checks: Inclusion of measures of financial integration

Dependent variable: Reserves/GDP	(1)	(2)
Lagged endogenous variable	0.6942 (10.34***)	0.7196 (11.49***)
Real GDP per capita	-0.0057 (-0.92)	-0.0010 (-0.37)
Trade openness	0.0612 (5.14***)	0.0395 (2.43**)
Volatility (nominal)	-0.0015 (-0.85)	-0.0150 (-0.86)
Total external debt (per cent of GDP)	0.0168 (3.50***)	0.0197 (4.95***)
Short-term external debt, lagged (per cent of GDP)	-0.0521 (-3.58***)	-0.0636 (-4.10***)
Fixed exchange rates, dummy	0.0013 (0.58)	0.0072 (0.90)
Intermediate exchange rates, dummy	0.0063 (1.80*)	0.0064 (1.02)
Monetary disequilibrium (excess money supply)	-0.0002 (-1.29)	-0.0001 (-0.83)
First crisis	0.0352 (6.56***)	0.0368 (4.23***)
Second crisis	0.0307 (4.39***)	0.0347 (2.48**)
Third crisis	0.0322 (3.19***)	0.0453 (4.42***)
Fourth crisis	0.0106 (0.46)	0.0238 (1.21)
Fifth crisis	-0.0261 (-1.89*)	-0.0457 (-3.21***)
Sixth crisis	0.0807 (0.55)	0.0201 (0.83)
Capital account openness	0.0019 (0.42)	
Economic globalisation		0.0009 (1.20)
Number of countries	114	70
Number of observations	1606	1150
Method of estimation	Difference GMM (two step)	Difference GMM (two step)
Sargan Test (p-level)	1.0	1.0
Arellano-Bond-Test (p-level)	0.79	0.66

Table 5: Robustness checks: Inclusion of measures of financial integration

Dependent variable: Reserves/GDP	(1)	(2)
Lagged endogenous variable	0.7321 (11.70***)	0.7542 (12.31***)
Real GDP per capita	-0.0070 (-1.49)	-0.0014 (-0.51)
Trade openness	0.0633 (5.12***)	0.0555 (4.16***)
Volatility (nominal)	-0.0019 (-1.34)	-0.0157 (-1.34)
Total external debt (per cent of GDP)	0.0203 (3.30***)	0.0247 (3.51***)
Short-term external debt, lagged (per cent of GDP)	-0.0505 (-3.62***)	-0.0494 (-5.08***)
Fixed exchange rates, dummy	-0.0017 (-0.25)	0.0049 (0.57)
Intermediate exchange rates, dummy	0.0039 (1.03)	0.0069 (0.95)
Monetary disequilibrium (excess money supply)	-0.0003 (-1.78*)	-0.0003 (-1.57)
Crisis 1973-81	-0.0149 (-1.11)	-0.0010 (-0.12)
Crisis 1982-96	0.0065 (0.91)	0.0163 (1.72*)
Crisis 1997-03	0.0119 (1.74*)	0.0187 (2.55**)
Capital account openness	-0.0014 (-0.33)	
Economic globalisation		0.0009 (0.91)
Number of countries	114	70
Number of observations	1606	1150
Method of estimation	Difference GMM (two step)	Difference GMM (two step)
Sargan Test (p-level)	1.0	1.0
Arellano-Bond-Test (p-level)	0.78	0.63

Table 6: Robustness checks: Interactions between crises and fixed exchange rate system

Dependent variable: Reserves/GDP	(1)	(2)
Lagged endogenous variable	0.5228 (7.63***)	0.7426 (11.72***)
Real GDP per capita	-0.0042 (-0.39)	-0.0038 (-1.04)
Trade openness	0.0624 (2.11**)	0.0503 (3.41***)
Volatility (nominal)	-0.0105 (-0.44)	-0.0031 (-1.23)
Total external debt (per cent of GDP)	0.0189 (2.05**)	0.0186 (3.65***)
Short-term external debt lagged (per cent of GDP)	-0.0464 (-1.90*)	-0.0611 (-4.26***)
Fixed exchange rates, dummy	0.0054 (0.37)	0.0097 (1.07)
Intermediate exchange rates, dummy	0.0045 (0.65)	0.0037 (0.96)
Monetary disequilibrium (excess money supply)	-0.0021 (0.007)	-0.0002 (-1.71*)
Crisis 1973-81	0.0509 (1.68*)	0.0079 (0.36)
Crisis 1973-81 and a fixed exchange rate system	0.0019 (0.49)	-0.0118 (-1.13)
Crisis 1982-96	0.0427 (4.83***)	0.0219 (2.12**)
Crisis 1982-96 and a fixed exchange rate system	-0.0110 (-1.89*)	-0.0112 (-0.72)
Crisis 1997-2003	0.0274 (4.10***)	0.0184 (1.74*)
Crisis 1997-2003 and a fixed exchange rate system	0.0195 (1.91*)	-0.0117 (-1.11)
Number of countries	108	114
Number of observations	772	1651
Method of estimation	Difference GMM (two step)	Difference GMM (two step)
Sargan Test (p-level)	1.0	1.0
Arellano-Bond-Test (p-level)	0.49	0.88

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively:

Chapter 4

The Accumulation of Foreign Exchange by Central Banks: Fear of Capital Mobility?

1 Introduction

As discussed in the previous chapters, recent years witnessed an enormous increase in central banks' foreign exchange holdings. Whereas average foreign exchange holdings amounted to 5.1% of GDP in 1975, they reached 18% of GDP in 2006. This increase is a puzzle for the standard literature on the demand for international reserves. Since during the same period exchange rates have become more flexible and countries more integrated in the international capital market, standard theory predicts a decline in foreign exchange holdings.

The existing literature usually explains the demand for foreign exchange as a buffer stock to defend the exchange rate. Whereas traditional approaches argue that reserves are needed to finance imbalances in the balance of payments under a fixed exchange rate system, the more recent literature, which emerged after the series of financial crises during the 1990s, focuses on the stock of reserves, which is seen as a lifejacket against financial crisis. Both approaches coincide in the view that there exists an adequate level of reserve holdings, which is the outcome of an optimising behaviour of the central bank.

Chapter 3 of this dissertation puts forward an alternative explanation: It shows empirically that countries revise their reserve policy after they were affected by a currency crisis. Currency crises induce a permanent increase in reserves. While this effect helps to explain the accumulation of reserves for crisis-ridden countries, it cannot account for the accumulation in countries that did not suffer from major currency crises.

This chapter takes a different approach: It explains the accumulation of reserves as a side effect of the liberalization of national capital markets and, more particularly, of the integration of emerging and developing economies in the world capital market. According to this hypothesis, central banks suffer from a "fear of capital mobility". The increasing capital mobility goes along with growing levels of reserves. The accumulation of foreign exchange is a response to capital inflows. It aims at reducing the interdependence of an open economy from developments in the rest of the world.

Two different lines of argumentation will be presented: First, it is hypothesised that a central bank's reserves increase in the degree of capital mobility. The motive for this behaviour might be the central bank's desire to protect the economy from potentially detrimental effects of sudden stops of capital flows and flow reversals. Second, a central bank might accumulate reserves in order to manage net capital flows in the absence of capital controls. The

management of capital inflows allows the central bank to preserve some leeway for the conduct of an independent monetary policy despite the classic policy trilemma. Furthermore, the central bank can limit the real effects of capital inflows, which might interfere with domestic policy objectives.

In the first case, the central bank supports the open capital account but takes precautionary measures. According to the second motive, it intends to insulate the domestic economic policy from the world capital market under a fixed exchange rate. In either case the accumulation of reserves can be regarded as a management of capital flows by the central bank.

This chapter is organized as follows. Section 2 describes the magnitude of capital flows to developing and transition economies in the recent past and shows how capital mobility has changed over time. Section 3 derives the hypothesis that central banks suffer from a fear of capital mobility and presents different theoretical approaches to this concept. It explains why the accumulation of reserves can be regarded as a substitute for capital controls. Section 4 presents and discusses the empirical results and the final section draws the conclusions.

2 Capital flows and capital mobility - stylised facts

This section describes the changing patterns of capital flows[57] since the 1970s and presents different measures of capital mobility, which shall be applied in the empirical analysis.

2.1 Capital flows - magnitude and effects

Until the early 1970s official loans were the most important source of external financing for developing countries. However, this pattern changed when the liberalization of the capital account and the increased macroeconomic stability in some emerging and developing

[57] Capital flows are always measured as private flows excluding changes in official reserves.
The empirical literature distinguishes two concepts of capital flows: In the terminology of the IMF (see World Economic Outlook) total net capital flows comprise direct investment, portfolio investment and other long- and short-term investment flows. In the standard balance of payments presentation total net capital flows are equal to the balance on the financial account minus the change in reserve assets. Other publications (see UNCTAD 1999, p. 100) define net capital flows as the sum of the balance on capital and financial accounts, that is to say they additionally include transfers like debt forgiveness, official grants and migrants' transfers as well as services like the acquisition or disposal of nonproduced, nonfinancial assets (patents, trademarks etc.). For the purpose of this chapter I prefer the first concept because it focuses on the financial account, which is the origin of the volatility of capital flows. Transfers, in contrast, are fairly stable or even countercyclical.

economies led to a shift of private capital flows towards these economies in the second half of the 1970s. Flows expanded rapidly, but collapsed suddenly in 1982, the year of the debt crisis. After almost one decade of modest flows, capital imports to developing countries resumed at the beginning of the 1990s (see Figure 1). They reached unprecedented levels and were devoted to a small number of developing countries, mainly to the emerging markets. As a result of the opening of capital accounts, private agents became the principal borrowers in international markets. In the aftermath of the East Asian financial crisis capital inflows collapsed again in 1998. However, flows resumed rapidly reaching unprecedented levels.
The liberalization of outward movements of capital flows led also to an increase of capital outflows. An increasing proportion of private capital inflows has been offset by capital outflows. One important source of capital export is the accumulation of foreign exchange by central banks. Its explanation is the challenge of this article.

International capital flows enable countries to invest more or less at home than they save. They contribute to an efficient allocation of capital both in geographic and intertemporal terms.

However, despite their obvious benefits, capital flows have aroused concern. First, capital flows have been proven to be cyclical and volatile and therefore might have detrimental effects on macroeconomic stability. Second, capital flows have real effects on the domestic economy that might interfere with domestic policy objectives. The instrument of an independent monetary policy is lost in a fixed exchange rate regime with capital mobility.
Therefore, the central bank might have an interest in managing these inflows. The management of capital inflows can either be in the form of a reduction of the amount of capital inflows or a channelling of inflows towards certain uses, e.g. through a taxation of capital inflows that discriminates between short- and long-term investment. One way of reducing net capital inflows is the accumulation of reserves because it partially offsets capital inflows (see Figure 2).
Both concerns linked to capital flows that were described above can be addressed by the accumulation of reserves.
The first concern that the instability of capital flows gives rise to an instability of the economy only arises when private borrowers do not take sufficient precautionary measures against sudden reversals of capital inflows. The central bank might fill this gap and substitute official reserves for private ones.

The second concern refers to the real effects of capital inflows. Capital inflows lead to an appreciation of the real exchange rate because a surge in capital supply raises domestic investment and consumption.[58] In a fixed exchange rate regime, the increase in the price level leads to a real exchange rate appreciation. If the exchange rate is flexible, a nominal appreciation due to the high demand for the domestic currency translates into a real appreciation.

This appreciation is necessary to maintain equilibrium in the balance of payments. That is to say, the real exchange rate adjusts until the capital account surplus is matched by the current account deficit. This appreciation, however, might interfere with domestic policy objectives if a fixed nominal exchange rate regime is in place, if the economy pursues a development strategy of export-led growth or if a reallocation of resources towards the nontradable sector is not desired for other reasons. To prevent the exchange rate appreciation, a central bank might increase the domestic component of the monetary base. This supply of domestic money can be brought about either by the purchase of domestic bonds or the purchase of foreign exchange. The increase of the money supply, however, might raise the price level interfering with the objective of price level stability. Alternatively, the central bank may intervene in the foreign exchange market, accumulate reserves and sterilize the effects on the domestic monetary base.[59] As a consequence, it distorts the balance of payments.

Although this chapter restricts its attention to the relationship between foreign exchange holdings and capital mobility, it has to be mentioned that the accumulation of foreign exchange is only one among a variety of potential policy responses to volatile capital inflows. A country can impose controls on capital inflows or relax controls on capital outflows. It can pursue a contractionary fiscal policy, which will reduce domestic interest rates and diminish the incentive for capital inflows. Or, it can increase the reserve ratio that applies to bank deposits and remove guarantees on deposits. All these policy responses have in common that they are expected to reduce net capital inflows. A relaxation of controls on capital outflows, however, might have the perverse effect of stimulating net capital inflows because it reassures foreign investors that they can withdraw their capital without restrictions. A contractionary fiscal policy, in turn, may be incompatible with domestic policy objectives. This chapter

[58] Some authors call the appreciation of the real exchange rate as a response to capital inflows the "Dutch disease". In analogy to the natural resource boom in the Netherlands, a capital inflow boom causes a real appreciation that jeopardizes the prospects of the tradables sector of the economy.

[59] The literature on foreign exchange intervention usually covers the case in which a central bank sells foreign exchange in order to prevent a devaluation of its currency. In this article, I focus on the opposite situation: A central bank buys reserves in order to "defend" its currency, that is to say, to prevent an appreciation.

restricts its attention to the accumulation of foreign exchange and controls on capital inflows as policy responses to volatile capital inflows.

2.2 Capital mobility – definitions and measures

Capital mobility has two dimensions: de jure and de facto capital mobility. De jure capital mobility corresponds to the extent and nature of regulations governing capital account transactions. It can be measured by the existence of legal restrictions of cross-border capital flows. Theoretically, it is a pre-condition for de facto capital mobility.[60] De facto capital mobility refers to the actual mobility of capital measured by stocks and flows of cross-border assets and liabilities.

For our analysis of the links between capital mobility and the accumulation of reserves both concepts of de jure and de facto capital account openness are relevant.[61] The empirical analysis uses different measures of capital mobility, which allow to differentiate between the effects of de jure and de facto capital mobility.

Capital account openness may be limited by legal restrictions. These include direct controls on capital inflows and capital outflows, quantitative limits and prohibitions. Multiple exchange rate systems and the taxation of capital flows are forms of indirect capital controls.

Most indices of de jure capital account openness are based on the information provided in the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). It offers a binary variable that informs about the existence of controls in different categories of restrictions. The information is available for a large number of countries and for many different categories of controls. Whereas originally only six binary variables of different forms of controls were provided, the Annual Report has used a more detailed and disaggregated classification since 1996. However, the data set also has some shortcomings. It neither provides information about the intensity of controls – are limits binding? – nor about their effectiveness and enforcement. Moreover, these variables are too aggregated. For example, they do not distinguish between controls on capital inflows and controls on capital outflows.

[60] In practice, the private sector may circumvent capital controls.
[61] In this chapter, the terms capital mobility and financial openness are used as synonyms.

An index of capital account openness that is based on this information was developed by Chinn and Ito (2002, 2006). It embodies four binary dummy variables on restrictions on international financial transactions, namely the presence of multiple exchange rates, restrictions on current account transactions, restrictions on capital account transactions and the requirement of the surrender of export proceeds. The index value is given by the first principal component of these four dummy variables. Higher values indicate that countries are more open to cross-border financial transactions. In the empirical analysis I refer to this index as de jure capital mobility (Chinn-Ito).

An alternative index of de jure capital mobility is provided by Edwards (2007). He combines the information of the indices of Quinn (2003) and Mody and Murshid (2005), which are based on data from the IMF. Country-specific information is used to revise and refine the index. The index is scaled over the range from zero to one hundred where a score of one hundred is equivalent to free capital mobility. Since the index provides data only until the year 2000, regressions including the index cover a reduced period ending in 2000. This variable is called de jure capital mobility (Edwards) in the empirical analysis.

A measure of de facto capital mobility is constructed from data on external capital stocks. As proposed by Lane and Milesi-Ferretti (2007) an index is given by the sum of total external assets and total external liabilities as a proportion of GDP. To some extent, this index mimics the traditional measure of trade openness, which is calculated as the sum of exports and imports divided by GDP. However, whereas the latter measure is based on flows – exports and imports – the index of de facto capital mobility is based on stocks of assets and liabilities. A higher value of this index implies that the country is more financially integrated in the international capital market.

Additionally, as a proxy for the integration of an economy in the international markets we use an index of economic globalisation. It is a sub-index of the KOF index of globalisation proposed by Dreher (2006). The index of economic globalisation has two main components, which are weighted equally: actual flows of goods and capital and restrictions to these flows. Hence, this index combines information of de jure and de facto capital mobility with information of trade openness. The index takes values between one and a hundred where larger values denote a higher degree of globalisation.

Figure 3 illustrates the evolution of capital mobility over time. All four measures indicate a trend of increasing capital mobility. This trend was temporarily halted by the Latin American debt crisis, the Mexican Tequila crisis in 1994 and the East Asian financial crisis. This overall trend is independent of a country's capital mobility at the beginning of our period of consideration: The trend is observable in industrial, emerging and developing countries (see Figure 4 for an illustration of the Chinn-Ito index of de jure capital mobility for different country groups). Whereas on average industrial countries are in every single year more open than the other two country groups, capital mobility in emerging markets does not differ much from that in developing countries. Emerging markets are characterised by a higher volatility of capital mobility over time.

3 The hypothesis: Fear of capital mobility

The following section describes the hypothesis that central banks suffer from a fear of capital mobility. This fear of capital mobility arises in two different forms: Central banks fear the openness of the capital account and tend to manage private capital inflows.

3.1 Capital mobility and the level of reserves

Financial liberalization and economic globalisation both allow a country to profit from international capital flows. However, they also make countries more vulnerable to sudden stops and capital flow reversals. Hence, capital account liberalization and economic globalisation may be associated with an increasing buffer stock in the form of reserve hoardings.

On theoretical grounds the effect of the liberalization of the capital account on the level of reserves is ambiguous. On the one hand, the eased access to external credit sources reduces the importance of reserves in financing international transactions. Any balance of the current account can, at least theoretically, be financed by proportionate capital flows. On the other hand, open capital markets increase the exposure to external financial disturbances and speculative flows. Especially emerging and developing countries are subject to sudden stops of capital flows and flow reversals. In periods of increased risk or risk aversion of international investors – changes that often cannot be influenced by domestic actors –

countries might have difficulties to roll-over their debt and get new financing. They may suffer from capital flight.

The risk of capital flight originates from two sources: First, foreign investors might suddenly withdraw their capital invested in the domestic economy. Second, domestic agents might prefer to invest their wealth in foreign currency. This form of currency substitution may be restricted to currency in circulation or can comprise bank deposits. The savings, in turn, can be deposited in domestic or foreign commercial banks. These possibilities of capital flight also increase the risk of speculative attacks and ensuing currency crises.

As pointed out in section 2.2, capital mobility has two dimensions: de jure and de facto capital mobility. Central banks might fear both forms of capital mobility: Countries which have liberalised their capital account but whose cross-border capital flows and stocks are limited, might fear that domestic investors prefer to invest abroad, leading to large capital outflows. Countries with substantial financial linkages to the rest of the world might fear a double outflow of capital, namely of domestic and foreign investors.

In sum, an open capital account entails the risk of sudden swings of the supply of capital in the domestic economy. A central bank that fears these potentially detrimental effects might accumulate a stock of reserves in order to protect the economy in a situation of capital flight. This reasoning leads to the following hypotheses:

Hypothesis 1: The higher the degree of capital mobility, the more foreign exchange a country hoards.

Hypothesis 1a: Central banks fear a de jure open capital account independently of the country's actual degree of integration in the international capital market.

Hypothesis 1b: Central banks fear the potentially negative effects of a country's financial integration. They accumulate foreign exchange in order to protect the economy from potential sudden stops of capital flows and capital flight.

The empirical analysis in section 4 examines the empirical validity of these hypotheses.

3.2 Capital flows and changes in reserves: Management of capital inflows

This section is devoted to the hypothesis that central banks actively manage capital flows. Different theoretical approaches are used to show that the accumulation of reserves has the same effects as capital controls. Changes in reserves are evidence for a "fear of capital mobility" if they are a countermovement to the removal of capital controls.

3.2.1 Foreign exchange accumulation as a substitute for capital controls

Changes in foreign exchange reserves can be regarded as an imperfect substitute for capital controls because both have to a certain extent the same macroeconomic effects.[62] In the following paragraphs the common effects of capital controls and reserve accumulation will be analysed from different perspectives.

Monetary policy independence

In the context of a fixed exchange rate, capital controls and the accumulation of reserves preserve some room for the conduct of an independent monetary policy despite the classic policy trilemma.

More precisely, capital controls loosen the interest rate parity. If capital flows are prohibited or restricted by quantitative controls, the domestic interest rate can be set independently of the world interest rate. If capital controls are imposed in the form of a tax – an explicit tax or an implicit one like an unremunerated reserve requirement –, the domestic interest rate can move within bands without inducing capital movements. It can lie between the international interest rate and the international interest rate plus the equivalent tax of the capital control. Within this band, interest rate changes do not induce any capital movements, that is to say, monetary policy is independent.

Similarly, foreign exchange interventions give a government some leeway for domestic monetary policy in spite of exchange rate fixity. If the central bank sells foreign exchange,

[62] Their degree of substitutability is imperfect because the accumulation of reserves cannot accomplish all effects, which may be attained by capital controls. For instance, whereas capital controls, in the form of a fixed-term unremunerated reserve requirement, aim at changing the composition (from portfolio to direct investment flows) and maturity structure of capital inflows, the accumulation of foreign exchange cannot bias the nature of capital inflows. Moreover, whereas capital controls can be designed to target specific capital flows (prohibitions, requirement of special permission for pre-defined types of flows), the accumulation of reserves cannot prohibit certain kinds of capital movements. In this sense, the accumulation of reserves is a simple instrument that cannot be designed to achieve specific objectives concerning the nature of capital flows. Finally, capital controls and the accumulation of foreign exchange are costly distortions of the efficient allocation of capital. However, they differ in the distribution of these costs: whereas the costs of capital controls have to be borne by lender and borrower, the costs of foreign exchange reserves fall on the society as a whole.

there is a tendency towards appreciation in the exchange rate. The central bank can at least restore the monetary base while holding the exchange rate fixed. A nonsterilized intervention is compatible with a larger increase in money supply than a sterilized one. Moreover, if bonds in different currencies are imperfect substitutes, the central bank can pursue an expansionary policy even if the interventions are sterilized at home and abroad (see Branson 1977, Claassen 1985, Dreher and Vaubel 2009). Conversely, an accumulation of reserves allows the central bank to pursue a contractionary monetary policy while holding the exchange rate fixed. More precisely, for a given money demand at home and abroad the growth rate of the monetary base at home may be lower than that abroad. In the case that domestic and foreign-currency bonds are imperfect substitutes this is still true for a sterilized intervention.

The equivalence between an unremunerated reserve requirement at the central bank and its accumulation of foreign exchange becomes also apparent if one considers their effects on the allocation of foreign capital in the domestic economy (see Figure 5). The unremunerated reserve requirement obliges foreign investors to deposit a specified fraction of their investment at the central bank. Analogously, the accumulation of foreign exchange withdraws foreign currency from the market for foreign exchange. The central bank exports capital.

Both the reserve requirement and the accumulation of foreign exchange bias the allocation of capital. The central bank invests abroad. Both measures differ only with respect to their status in the central bank's balance sheet: Whereas the reserve requirement enters as a liability, the foreign exchange reserves are assets, which are acquired in the domestic money or bond market.

Balance of payments implications

The balance of payments restriction implies that both capital controls and the accumulation of reserves (ceteris paribus) may lead to an increase in the current account balance. Both policy actions may distort the current account balance because they reduce net private capital inflows (see Figure 5).

If private capital is perfectly mobile, the accumulation of reserves, which is a form of official capital export, will be offset by an equal import of private capital. Hence, the capital account balance including official reserve changes is unaffected while the gross sum of capital flows increases.

In the case of imperfect capital mobility, the balance of payments restriction implies that the accumulation of foreign exchange has to increase the current account balance. To increase the current account balance, the real exchange rate has to depreciate; in the case of a fixed

nominal exchange rate domestic prices have to fall relative to the foreign price level. In any case, the current account is distorted towards less domestic investment and consumption. Exports are driven up and imports are depressed.
If controls are used to reduce capital inflows, they distort the current account towards a surplus. So capital controls and the accumulation of foreign exchange are substitutes in the sense that both allow the government to increase the current account balance.

The policy trilemma

The relationship between capital mobility and reserve accumulation can be analysed in the framework of the macroeconomic policy trilemma. The trilemma imposes a constraint on the choice of macroeconomic policies. It states that the objectives of exchange rate stability, monetary independence and capital mobility are mutually inconsistent. Only two out of these three possible objectives can be attained jointly.
Figure 6 illustrates the trilemma. The corners of the triangle show three possible goals of economic policy and the sides indicate the policy regimes which meet (pairs of) these goals. Since at most two goals can be reached at the same time, the side connecting the two chosen corners excludes the attainment of the third goal. If, for example, a country opts for an independent monetary policy under an open capital account, it cannot pursue an active exchange rate policy. It has to cede the determination of the exchange rate to the market forces. The demand for and supply of domestic and foreign currency, which result from the interest rate set by monetary policy and the open capital account, determine the level of the exchange rate.

The policy trilemma, however, constrains economic policy only in the long run. Standard theories overlook that all three objectives are jointly attainable in the short run if they are supported by accompanying policies. Changes in reserves are such a policy to reconcile the trilemma. If net private capital flows are temporary and bonds are imperfect substitutes, it even holds in the long run.

The accumulation of reserves allows a country to reach the three goals of the trilemma simultaneously. It, however, neglects a fourth potential goal, namely an optimal allocation. The accumulation of reserves alike restrictions on capital movements distort the allocation of capital. The trilemma is only a partial analysis. Since it disregards the consequences of

reaching all three goals jointly, it might be considered as an inadequate illustration of the restrictions of economic policies.

To illustrate the mechanisms how the three goals can be attained jontly, consider the example from above in which a country opts for an independent monetary policy and capital mobility. According to the trilemma, policy cannot stabilize the exchange rate. This, however, is not true in the short run. Assume that some shock causes an outflow of capital such that the real exchange rate tends to depreciate. The central bank can stabilize the real exchange rate if it offsets the outflow of capital by the sale of foreign exchange reserves. This is the policy of exchange rate defence through an exchange market intervention. It allows to achieve all three objectives of the trilemma if domestic and foreign bonds are imperfect substitutes or if the foreign central bank does not sterilize the increase in its monetary base.

Whereas this policy configuration has been extensively analysed by economists, the opposite case of a foreign exchange intervention aimed at preventing an exchange rate appreciation is usually disregarded. According to the trilemma, in the presence of net capital inflows an independent monetary policy and a fixed exchange rate system are incompatible. However, if the central bank offsets the capital inflow with the accumulation of reserves, it can reconcile an open capital account with an independent monetary policy and a fixed exchange rate.

In general, if the central bank offsets capital inflows and outflows with proportional changes of reserves, it can neutralise the effects of an open capital account on the current account. This is possible as long as capital is not perfectly mobile.
According to the monetary approach to the exchange rate, exchange rate changes can be explained by changes of the money supply M, changes of real income y and changes of the interest rate i:

$$\hat{E} = \hat{M} - \hat{M}^* - \eta \cdot (\hat{y} - \hat{y}^*) + \varepsilon \cdot \Delta(i - i^*)$$

where foreign variables carry an asterisk. η denotes the income elasticity of money demand and ε the semi-elasticity of money demand with respect to the interest rate.

In the case of direct currency substitution, net capital inflows increase the relative demand for domestic currency. The demand for foreign money decreases and the demand for domestic money increases. According to the monetary approach, the exchange rate appreciates. The

exchange rate is stable in the presence of net capital inflows if for a given output and interest rates at home and abroad domestic money supply increases and foreign money supply decreases. A non-sterilized accumulation of foreign reserves satisfies the increased demand for domestic currency and reduces the supply of foreign currency. Technically, a central bank can influence the supply of domestic and foreign currency such that the exchange rate remains unchanged.

In comparison with the opposite policy of exchange rate defence in the face of capital outflows, this policy has the merit that there exists no upper reserves bound above which this policy is no longer feasible. The recent experience of reserve accumulation shows that this policy is sustainable over a long time period.

Nevertheless, this policy entails costs. To fund the purchase of reserves, the central bank has to increase the monetary base or sell domestic bonds, which sterilizes the effects on the monetary base. The increase of the monetary base may lead over time to inflation pressures. A central bank can offset these effects on the monetary base by the sale of domestic bonds or by the issue of central bank bonds. This implies a fiscal cost since the return paid on domestic assets is generally higher than the return earned on foreign exchange. Moreover, the increasing supply of bonds may require an increase in the interest rate.

Since this chapter focuses on the explanation of the recent period of reserve accumulation, one has to question whether the choices countries have made with respect to the trilemma in the recent past might have favoured systematic central bank interventions to prevent the exchange rate from appreciating. Since the demise of the Bretton Woods system, countries have moved towards greater exchange rate flexibility and financial openness (see Figures 3 and 7). Nevertheless, according to the IMF classification of exchange rates (Annual Report on Exchange Arrangements and Exchange Restrictions) the majority of exchange rates are still managed or fixed. Hence, monetary policy autonomy is still limited in many countries. However, the accumulation of reserves by central banks reverses this trend. As has been described in the preceding paragraphs, in this configuration the accumulation of reserves may be seen as an instrument to restore monetary independence. Although capital is mobile, the central bank intervention can manage capital flows such that both a fixed exchange rate and an independent monetary policy can be attained jointly if bonds are imperfect substitutes. Dreher and Vaubel (2009) show in a large sample that the level of reserves and the monetary

base are negatively correlated. This indicates that countries sterilize the effects of reserve changes on the monetary base and that reserve changes do not restrict monetary autonomy.

Empirical evidence in support of the trilemma is provided by Obstfeld et al. (2005) and Aizenman et al. (2008). The latter show empirically that a move towards one goal of the trilemma induces a shift away from at least one of the other two policy objectives. They note that the accumulation of reserves may be related to the changing configuration of the trilemma over time, but do not analyse its role in detail. Levy-Yeyati and Sturzenegger (2007) suggest that in the 2000s foreign exchange interventions increasingly aimed at depressing the domestic currency rather than defending it. They ascribe this behaviour to a "fear of appreciation".

The foregoing analysis leads to the following hypothesis:

Hypothesis 2: The accumulation of foreign exchange is a response of central banks to the removal of capital controls. Central banks aim at managing capital inflows.

3.2.2 Explanations for the substitution of capital controls by the accumulation of foreign exchange

This hypothesis, however, raises the question why governments abolish controls on capital movements even though they still have an interest in managing capital flows.
It could be that they had to liberalize their capital account due to conditions associated with IMF lending or external consultants advised them to do so. Joyce and Noy (2008) find empirical evidence that the participation in an IMF programme during the 1990s is correlated with capital account liberalization. A country is more likely to liberalize its capital movements after an agreement with the IMF was initiated. Perhaps countries could not resist the general market development (bandwagon effects) and liberalized their capital account after neighbouring countries or members of their peer group had done so. This pattern could be interpreted as "policy imitation" in the sense that governments are influenced by the initiatives of their neighbours.[63] When neighbours relax capital controls it becomes harder to justify them politically and economically. At the same time, relative to its neighbours, the

[63] Recent studies (e.g. Simmons and Elkins 2004) show empirically that countries are more likely to open their capital account when members of their peer group have done so.

country may become a less attractive destination for foreign capital.[64] Countries that resist the tendency to relax capital controls fall behind countries that do remove controls. Finally, the relaxation of capital controls could be the result of some kind of bargaining between industrialized and emerging economies where the first loosened their trade barriers and, in return, the second had to open up their capital markets.

The removal of capital controls can be in the proper interest of the central bank. The abandonment of capital controls, it is true, means that the central bank loses one of its instruments of financial policy. However, there are several reasons why a central bank could be willing to give up capital controls anyway. First, capital controls are not an instrument that can be set independently by the central bank; on the contrary, the imposition of capital controls either has to be explicitly permitted by the central bank's statute or be specified by other laws, which, in turn, have to be approved by government. In most cases, the central bank constitution defines a maximum percentage that can be required as mandatory reserves from capital importers. So, in principle, the central bank only enforces and administers the pre-defined capital controls. The accumulation of reserves, in contrast, is a policy that is independently set by the central bank. Capital controls are an inflexible instrument whereas the accumulation of reserves can be adjusted easily and without time lag to changing economic conditions and objectives of financial policy.

Consistent with these considerations, an empirical study (Alesina, Grilli and Milesi-Ferretti 1993) comes to the result that capital controls are an instrument of financial policy that is more likely to be used by strong governments with dependent central banks. Countries with independent central banks impose fewer restrictions on capital movements. This observation, however, might be due to a common-cause-interdependence: Countries, whose economic policy follows the classical liberal paradigm, are more likely to establish an independent central bank and to desire free capital movements.

Capital controls can lead to revenues for the central bank (for example if unremunerated reserves have to be held at the central bank), whereas reserves tend to entail quasi-fiscal costs because of the interest differential between domestic bonds and bonds denominated in the reserve currency.[65] In sum, central banks are financially worse off if capital controls are

[64] This does not hold if capital flows are prohibited and if these prohibitions can be circumvented.
[65] This argumentation assumes that the effect of the accumulation of reserves on the domestic monetary base is sterilized by the issue of domestic bonds.

replaced by foreign exchange reserves. However, this might not bother the central bankers. The economic theory of bureaucracy assumes that public officials are primarily interested in their power, prestige and independence (see Vaubel 1997), but not in the profits of their institution, which have to be delivered to the Treasury. In fact, large reserve holdings may be preferred by the central bank because they increase its power and independence from government.

4 Empirical evidence

This section first presents statistical evidence in support of the hypotheses and then tests empirically whether the degree of capital mobility has an effect on the level of reserves (hypothesis 1) and whether capital inflows are managed through changes in reserves (hypothesis 2).

4.1 Statistical evidence

In the case that a central bank does not intervene in the foreign exchange market or intervenes only temporarily, the current account and the capital account excluding reserve changes are the main components of the balance of payments. Changes in official reserves are only a residual entry that brings about the overall balance under a fixed exchange rate. Every international transaction leads to two offsetting entries in the balance of payments. Since the balance of the current account equals the change in a country's net foreign liabilities, a current account deficit is offset by a surplus of the capital account, namely net capital inflows.

This picture has changed dramatically since the Asian financial crisis (see Figure 1). The current account deficits of the developing countries as a group have been replaced by surpluses in 1999. At the same time, these countries still registered net capital inflows (excluding changes in reserves) despite an initial fall in capital inflows. This joint incidence of net capital inflows (excluding changes in reserves) and a current account surplus is somewhat unusual. Capital inflows cannot be explained as the counterpart of a current account deficit, that is to say, they do not finance the current account deficit.

The puzzle can be solved when we include the change in official reserves in the analysis. In fact, since 1999 the developing countries registered net financial outflows including official reserves. Hence, they have increasingly become net exporters of capital. The increase of

reserves equals the sum of current account surplus and net capital inflows (plus errors and omissions).

The statistical evidence suggests that since the 1990s developing countries are increasingly managing capital inflows by the accumulation of foreign exchange reserves (see Figure 2). Since 1999 they more than offset all capital imports turning the net capital flow into an outflow that finances their current account surpluses, i.e., the increase in reserves is larger than net private capital inflows.

A large part of net private capital inflows is offset by national central banks, which accumulate official foreign exchange. Total investment of domestic residents abroad is increased by the public sector exporting capital.

Table 1 shows the absolute values of net capital inflows and changes in reserves as well as changes in reserves expressed as a percentage of inflows over different time periods and for different country groups. The variable of primary interest is the change in reserves expressed as a percentage of capital inflows. In the second half of the 1970s, changes in reserves accounted for a relatively large part of capital inflows. This is primarily due to the low level of cross-border capital flows during this period. Since the second wave of capital account liberalization, which took place in the late 1980s and early 1990s, this has changed fundamentally: In the 1980s, capital flows increased such that the accumulation of reserves only offset a minor part of capital inflows (between 7.7% in the world and 13.1% in developing countries). Since then, these figures have increased steadily. Between 2000 and 2003, more than half the capital inflows to emerging and developing countries was reversed via the accumulation of reserves, namely 86.5% and 76.3%, respectively. This means that in developing countries only 23.7% of capital inflows (emerging markets 13.5%) could be used for domestic investment. Central banks in emerging and developing countries increasingly offset net capital flows. Both country groups show the same pattern, which, however, is more pronounced in emerging markets.

This is also a first indication that central banks seem to have replaced capital controls by a policy of reserve accumulation, thereby still pursuing the objective of regulating capital flows. In comparison with developing countries, emerging markets as a group are characterised by both less capital account restrictions (see Figure 4) and a larger extent of capital inflow management.

Figure 8 shows the Chinn-Ito index of capital mobility. It compares the average value of the index over all countries with its value for the ten countries that accumulated the largest absolute value of reserves over the period 1996-2006. It is striking that until the East Asian financial crisis these ten countries were characterised by a significantly higher degree of de jure capital mobility than the average country. This is first evidence that countries which have had few capital controls tend to hoard reserves. In 1998, capital mobility of the reserve accumulaters fell to the level of an average country and has not differed significantly from the average country since then.

Finally, Figure 9 presents some country examples that illustrate the effects of a removal of capital controls. The graphs show the time-series of capital inflows, reserve changes and de jure capital mobility for India, Korea, Russia and the Slovak Republic. Despite some downward outliers in crisis years, capital inflows increased after the liberalization of the capital account. Changes in reserves increased simultaneously. The reserve changes were larger than the capital inflows.

These country cases may be regarded as first evidence that the accumulation of foreign exchange in the presence of capital inflows and capital controls are substitutes. It supports the hypothesis that despite the removal of capital controls governments still want to control net capital flows. They now do it in a disguised way by accumulating foreign exchange reserves. Non-market barriers to capital movements – capital controls in the form of taxes, administrative controls, prohibitions and quantitative controls – have been replaced by a policy of reserve accumulation of a non-market actor – the domestic central bank. To put it differently: Methods have changed, but the objective of regulating net capital flows remained the same.

4.2 Regression analysis

The remaining task consists in testing econometrically the hypothesis that the accumulation of foreign exchange is a response of central banks to the removal of capital controls and to net capital inflows. This section presents the results of a regression analysis.

4.2.1 Data

The empirical analysis is carried out on the basis of the pooled data set of cross-country and time-series observations from chapter 2. It contains annual data from 1975 to 2003 for a maximum of 181 countries. Since data for several explanatory variables are missing for some countries, the number of countries used in the econometric analysis depends on the particular specification and is indicated in the respective tables. It ranges from 70 to 174 countries. With a few exceptions data are taken from the International Financial Statistics of the IMF and the World Development Indicators of the World Bank. A detailed description of the variables and their data sources are provided in the appendix at the end of this dissertation. Information about the country sample and summary statistics of the variables can be found in Appendices C and D of chapter 2.

To approach the hypotheses of this chapter, measures of de jure and de facto capital mobility are added. These were described in detail in section 2.2.

4.2.2 Traditional control variables

In the following section the control variables are presented. The set of control variables consists of those variables that were identified as significant determinants of the level of reserves in chapter 2. Since these variables are rather standard and described in chapter 2, I abstain from a detailed discussion.

Trade openness is included to control for the effects of real linkages with other economies. The more open the economy, the more vulnerable it is to external shocks and is expected to hold more reserves for precautionary motives. External debt is another source of vulnerability. Empirical studies show that both a high level of external debt and a low level of reserves increase the probability of a financial crisis. Reserves might offset this vulnerability. Therefore, it is expected that countries with a high level of external debt hold more reserves for precautionary reasons. Additionally, short-term external debt is included.

Since the time-series of reserves are characterized by a high degree of persistence, the determination of the level of reserves is a natural candidate for a dynamic specification that includes the lagged level of reserves as one of its determinants. This specification can be motivated by a partial adjustment or habit-persistence model.

The dependent variable international reserves is measured net of gold holdings and scaled by GDP.

4.2.3 Estimation results

We first test the hypothesis that foreign exchange holdings are larger, the higher the degree of capital mobility is (hypothesis 1). Table 2 presents the results for a static specification where the dependent variable is reserves over GDP. Country fixed effects are included in all regressions. Column (1) contains the benchmark regression, which includes the control variables that were found to be significant determinants of reserve holdings in chapter 2. The results confirm previous findings: The more open countries are with respect to trade of goods and services, the more reserves they hold. Reserve holdings increase with the amount of total external debt, but decrease in short-term external debt. The latter effect supports the hypothesis that for a given external indebtedness an increase in short-term borrowing is an indication of an emerging financial crisis. Hence, under these circumstances short-term debt increases and reserves fall. The measure for a disequilibrium in the domestic money market is not significant. The overall explanatory power of the included covariates is low (R^2=0.04)[66].
Columns (2) to (6) add different measures of capital mobility to test the hypothesis that countries increase their reserve holdings in the face of increasing capital mobility. Columns (2) and (3) examine the hypothesis 1a and columns (4) to (6) hypothesis 1b.
Column (2) analyses the effect of de jure capital mobility proxied by the index of Chinn and Ito (2002, 2006). The coefficient is significant and positive implying that countries with fewer restrictions on capital flows hold a larger amount of reserves. Sign and significance of the control variables are unchanged with respect to column (1) , which does not control for capital mobility. The effect of a monetary disequilibrium is now significant with the expected sign. The adjusted R^2 doubles due to the inclusion of de jure capital mobility.
Column (3) examines the robustness of these results. It uses an alternative measure of de jure capital mobility, namely the index of Edwards (2007). The effect of capital mobility is again positive and significant. In comparison with the Chinn-Ito index, Edwards uses a wider set of information to construct this index. It shows that the results of column (2) are insensitive with respect to the definition of de jure capital mobility. The smaller magnitude of the effect comes from the fact that both indices use different scales with the Edwards index usually being larger than the Chinn-Ito index.
We now turn to the question whether de facto capital mobility has an effect on reserve holdings (hypothesis 1b). To this end, column (4) adds a measure of de facto capital mobility defined as the sum of external assets and liabilities divided by GDP. This measure is named

[66] This R^2, however, is due to the covariates. A simple regression with fixed effects but without covariates leads to a R^2 of zero.

financial openness. The effect is positive and significant. Countries with a large stock of cross-border assets relative to their economic size hold more international reserves. However, the inclusion of this measure of de facto capital mobility affects the results with respect to the standard control variables. Trade openness and short-term external debt are no longer significant and total external debt is significant, but with a negative sign. This might be due to the fact that total external debt and the measure for de facto capital mobility are correlated since the construction of the latter contains total external debt. Hence, the assumption of exogenous regressors is violated and the results might be biased. Therefore, I re-estimate the effect of de facto capital mobility after dropping total external debt and the proxy for a monetary disequilibrium (see column (5)). Trade openness and short-term external debt have the expected effects. A country's reserves increase with the degree of its de facto openness to the world capital market.

Economic globalisation, which is added in column (6), is a combined measure of capital mobility and trade openness. It confirms the previous results that openness – both de jure and de facto – increases a country's reserve holdings. This specification has the highest explanatory power if the misspecified results of column (4) are disregarded.

Table 3 replicates the regressions of Table 2 in a dynamic specification that includes the lagged level of reserves as one of the explanatory variables. The dynamics imply that central banks adjust their reserve holdings gradually to the desired level. As a consequence, the fixed effects estimator is asymptotically biased. Therefore, the difference GMM estimator, also known as the Arellano-Bond estimator, is used. The tests of the validity of instruments support these specifications.

Two of the four measures of capital mobility are significant and positive, namely the de jure index of Edwards and the measure of financial openness. The effects of the control variables have the expected sign. Hence, although with reduced significance, the dynamic specification also supports the hypothesis of a positive relationship between capital mobility and the level of foreign exchange holdings to some extent.

So far it was shown that there exists a fear of capital mobility in the sense that central banks increase their holdings of foreign exchange when capital controls are dismantled and when their exposure to the international financial market deepens (hypothesis 1). We now analyse the related but different question whether central banks' accumulation of foreign exchange is a direct response to capital flows. The accumulation of reserves is a form of managing net

capital flows and allows a central bank to influence the amount of capital channelled to domestic uses even in the absence of capital controls. Hence, the accumulation of foreign exchange might be a substitute for capital controls.

Table 4 tests whether net capital flows cause changes in reserves. According to the hypothesis, higher net capital inflows imply that central banks absorb a part of these inflows via the accumulation of reserves. The dependent variable is nominal changes in reserves net of gold, measured in US$. Net capital flows are measured by the balance of the financial account of the balance of payments, i.e., excluding the central bank. It equals the difference between capital inflows and capital outflows. It encompasses the categories direct investment, portfolio investment, financial derivatives and other investment. As possible other determinants of reserve changes, changes in money supply, a disequilibrium in the domestic money market and a dummy for a currency crisis are included. Given a central bank's balance sheet, an increase in money supply implies a decrease in domestic bonds in private hands or an increase in international reserves. According to the monetary approach to the balance of payments, any disequilibrium in the domestic money market implies a reduction of reserves of equal size. Finally, we control for the effect that reserves generally fall during a currency crisis. The dummy for currency crises takes the value one in years where a speculative attack – unsuccessful or successfully leading to a crisis – is identified by an exchange market pressure index.[67] Additional control variables, derived from the regressions in Table 2 where the level of reserves is the dependent variable, are changes of trade openness, of total external debt and of short-term external debt. However, they all turn out to be insignificant in regressions explaining changes in reserves.

In all specifications of Table 4, net capital flows have no significant impact on reserve changes. Their explanatory power is zero (R^2=0). The other three possible determinants, however, are significant and have the expected signs: An increase in money supply is associated with a positive change in reserves whereas an excess money supply reduces reserves. Reserves are significantly lower in years with a currency crisis.

The missing influence of net capital flows on reserve changes might be due to the fact that central banks react with a very long lag to net capital flows (see Table 1) or that they respond asymmetrically to capital flows. The action of a central bank in the face of capital inflows (= positive net capital flows) might differ from its response to capital outflows (= negative net capital flows). We hypothesise that central banks manage capital inflows via the accumulation

[67] For details how currency crises are identified, refer to section 3.2 of chapter 3.

of reserves since capital inflows cause an appreciation of the exchange rate and imply an increasing external indebtedness of the country. If there are capital outflows, the central bank does not intervene in the foreign exchange market as long as these outflows do not lead to a systemic crisis.

Table 5 shows the results. The variable capital inflows equals the amount of capital inflows and is set to zero if capital inflows are zero or negative. The variable capital outflows, respectively, equals capital outflows and zero otherwise.

The results fully support the hypothesis. In all specifications (columns (1) to (4)) capital inflows lead to a significant increase in reserves. Although capital flows cannot explain reserve changes ($R^2 = 0$), reserves increase significantly when capital flows are positive. The latter result suffices to support the hypothesis that central banks manage capital inflows. Central banks offset a fraction of capital inflows via the accumulation of foreign exchange and thereby export capital. In the face of capital outflows, central banks do not adjust their reserves. An increase in money supply affects reserve changes positively (column 2) whereas a disequilibrium in the domestic money market leads to a fall of reserves (column 3). Currency crises are associated with losses of reserves (column 4).

Finally, Table 6 investigates whether central banks react to changes in net capital flows by accumulating more reserves. Changes in net capital inflows are defined as changes of the balance of the financial account on a year-to-year basis. Independently of the specification, this variable has a positive and significant effect on reserve changes. A positive change in capital flows with respect to the previous year is counteracted by an increase in reserves. The effects of the control variables are in line with previous findings.

5 Conclusions

The accumulation of foreign exchange may be regarded as an indication of a "fear of capital mobility" suffered by central banks. First, central banks fear that capital inflows are volatile and subject to sudden reversals. Therefore, they demand reserves as a buffer stock against potential capital flight. Second, central banks accumulate reserves in order to manage net capital flows in the absence of capital controls because they fear the real effects which these capital flows might have on the real exchange rate and thus on the domestic economy.

The second argument differs in an important way from the standard analysis concerning the accumulation of reserves. If the holding of foreign exchange reserves is explained as a buffer stock, which will be used to defend the exchange rate in a period of crisis, what matters is the level of reserves. The timing of the reserve accumulation is irrelevant. However, if the objective of the foreign exchange accumulation consists in managing net capital flows, the accumulation itself – and its effects – is the target of the central bank policy. The level of reserves does not matter. Only changes in reserves have macroeconomic effects.

This chapter emphasises a supply side explanation for the accumulation of reserves. First, as a response to the increased supply of foreign capital, central banks demand foreign exchange in order to protect the economy from potential detrimental effects of flow reversals on the domestic economy. Second, they offset part of the capital inflow in order to limit the real effects of the increased supply of foreign capital.

In sum, the accumulation of foreign exchange has to be analysed in a broader context. Central banks might deliberately distort the balance of payments. Foreign reserves are not only used to defend the exchange rate in periods of crisis but also to manage net capital flows even in periods without major economic disturbances. The liberalization of capital markets is to a certain extent compensated by the accumulation of official reserves. A microeconomic policy distortion – capital controls – is replaced by a macroeconomic one – the accumulation of foreign exchange.

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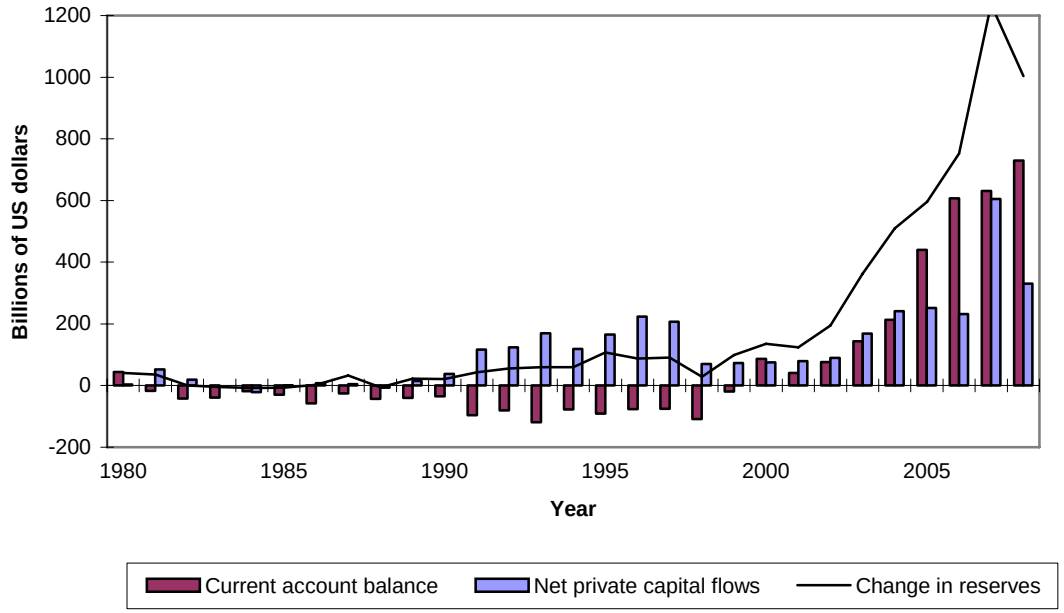
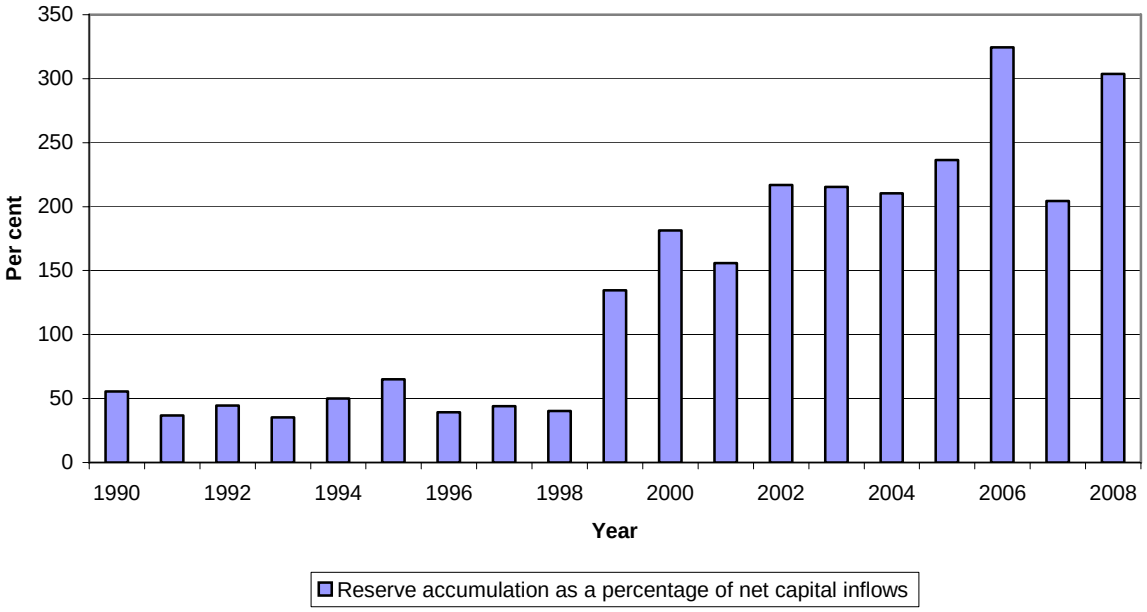
Figure 1: Balance of payments of emerging and developing countries



Data source: World Economic Outlook database, April 2008

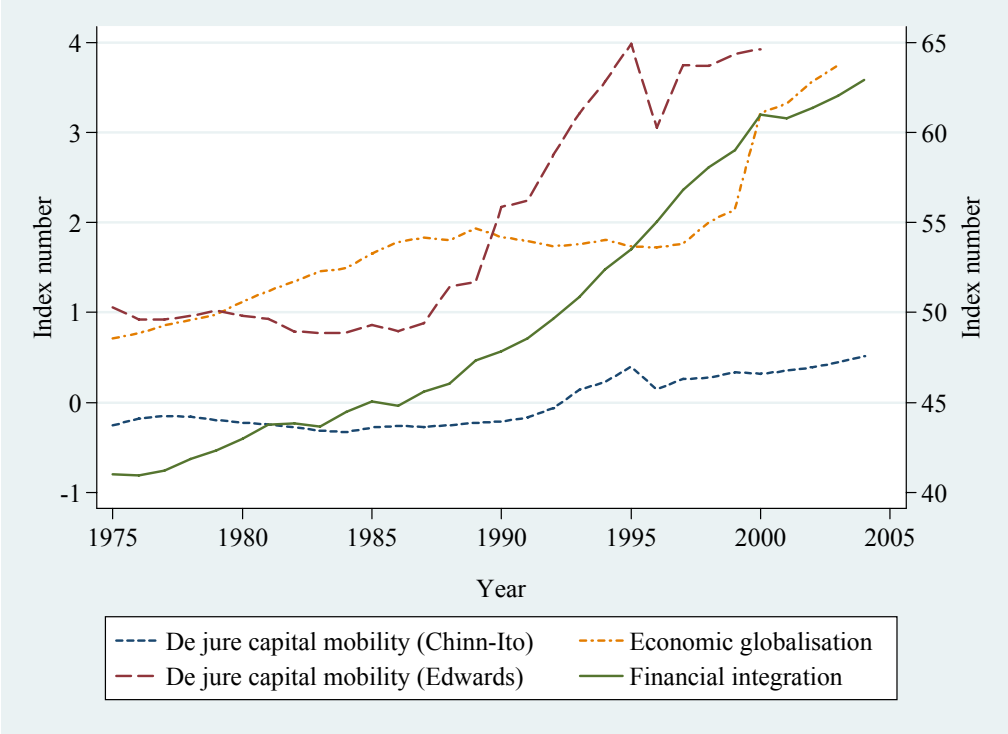
Notes: A poitive sign in the change of reserves indicates an increase in foreign exchange holdings.
Net capital flow is equal to the balance of the financial account.
The data cover 146 emerging and developing countries as well as selected advanced economies (Hong Kong, Israel, Korea, Singapore, and Taiwan Province of China).

Figure 2: Reserve accumulation in emerging and developing countries



Data source: World Economic Outlook database, April 2008

Figure 3: Measures of capital mobility over time



Note: The scale on the left-hand side axis corresponds to the Chinn-Ito index and the measure for financial integration. For the index of Edwards and economic globalisation the right-hand axis applies.

Figure 4: De jure capital mobility in different country groups (Chinn-Ito index)

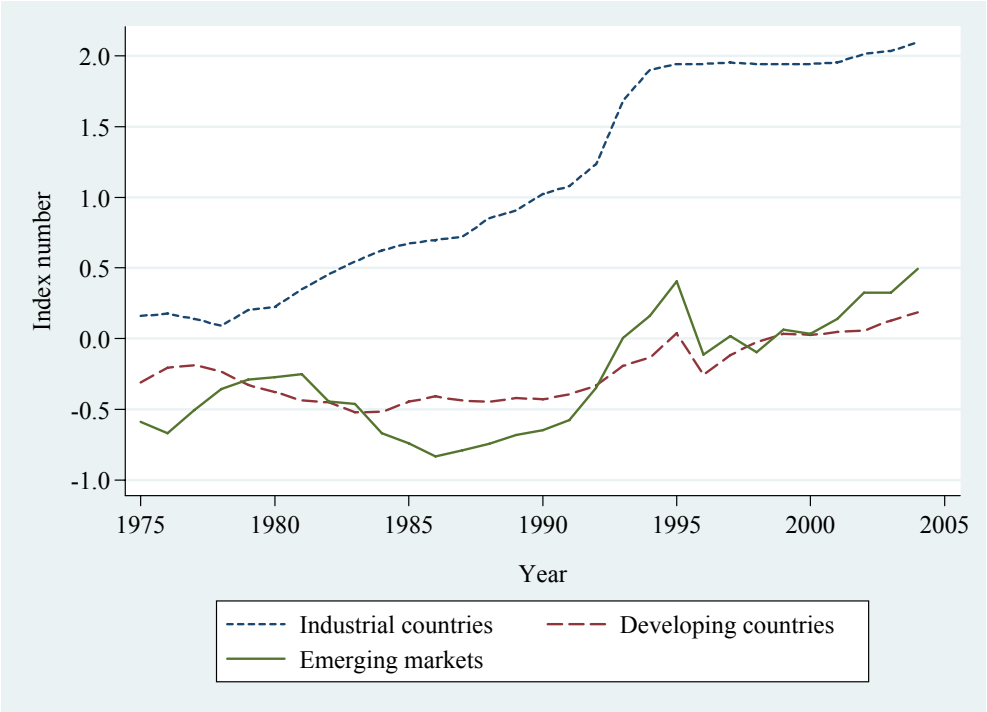
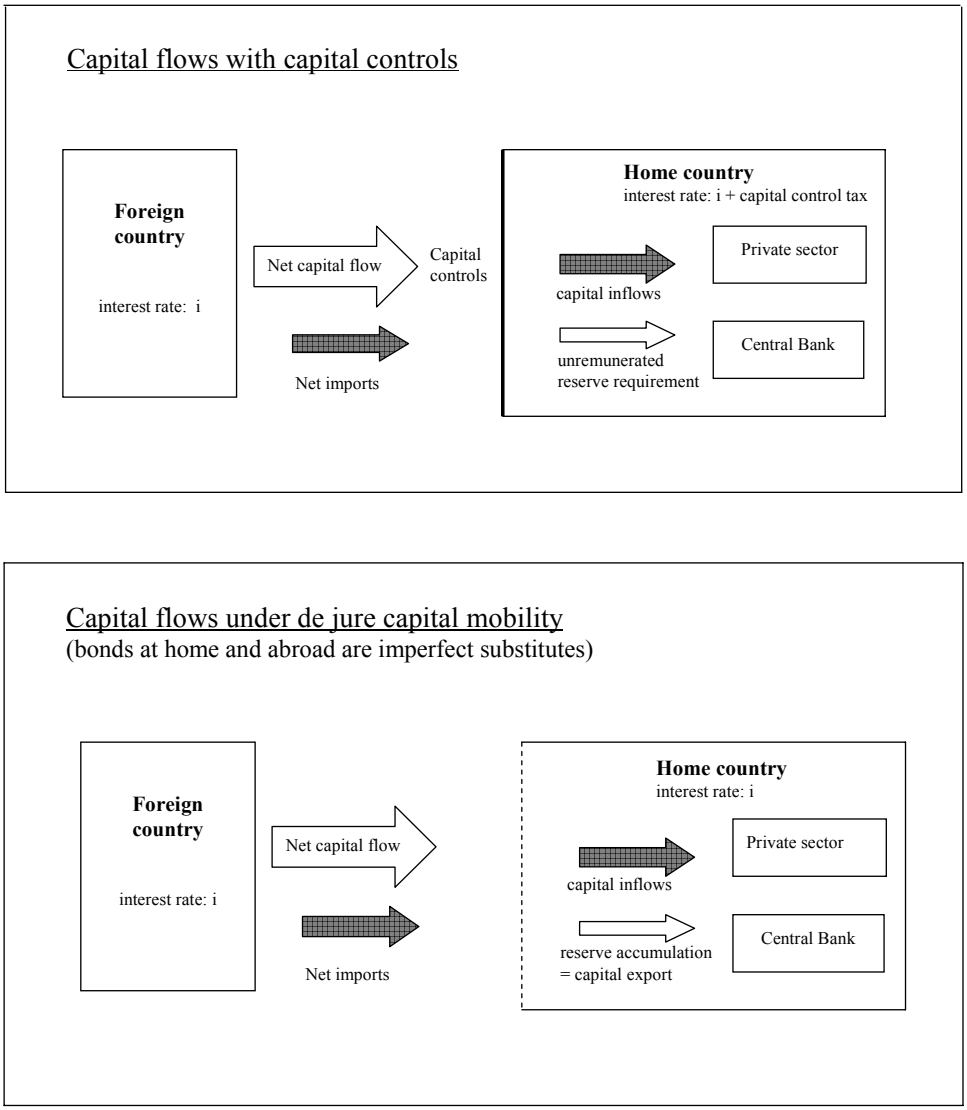


Figure 5: Comparison of capital flows in a system with capital controls and under de jure capital mobility



Notes: The grey arrows represent nominal flows of equal size.
According to the balance of payments identity, net imports and net capital flows (comprising both private and official flows) are identical.
The graph illustrates that capital controls (upper panel) and reserve accumulation (lower panel) have similar effects on capital flows to the domestic private sector: Original capital inflows are larger than those finally channelled to the private sector. Both capital controls and reserve accumulation bias the current account towards fewer net imports.

Figure 6: Reconciliation of the classic policy trilemma in the short run

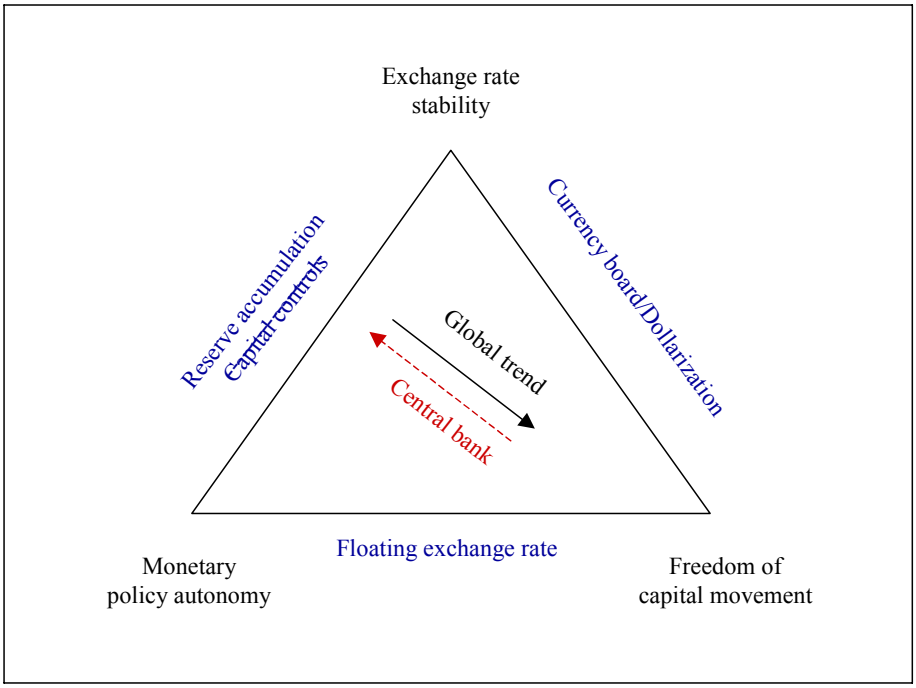
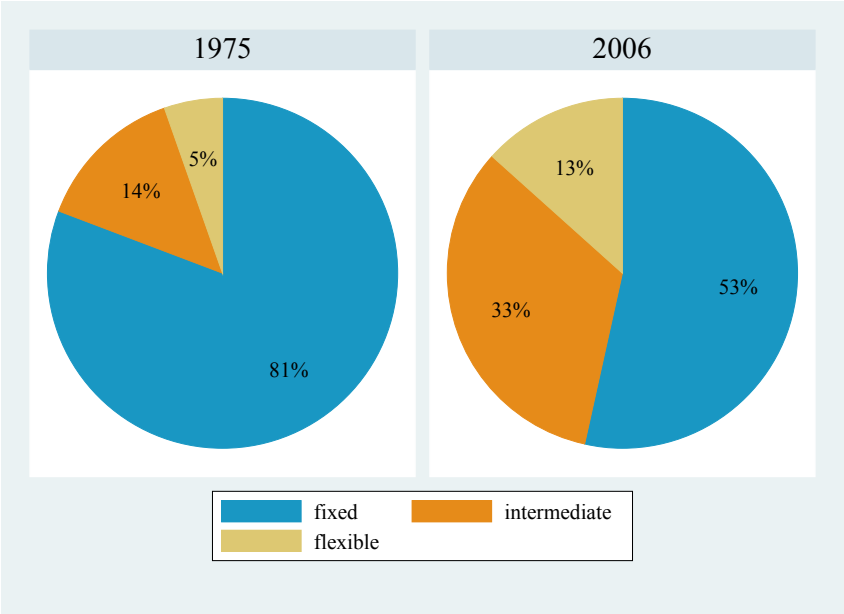


Figure 7: Classification of exchange rate regimes



Data source: Annual Report on Exchange Arrangements and Exchange Restrictions, IMF.

Figure 8: Index of de jure capital mobility (Chinn-Ito) and reserve accumulation

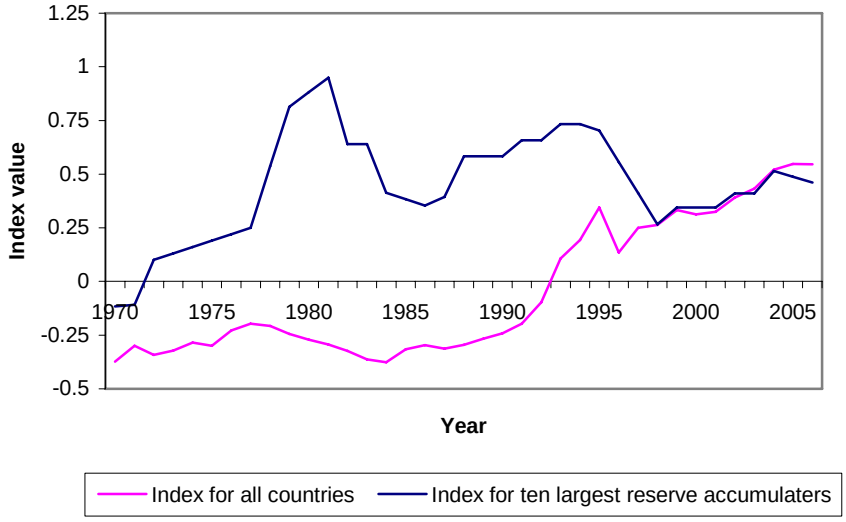


Figure 9: Capital account openness, capital flows and reserve accumulation: Country examples

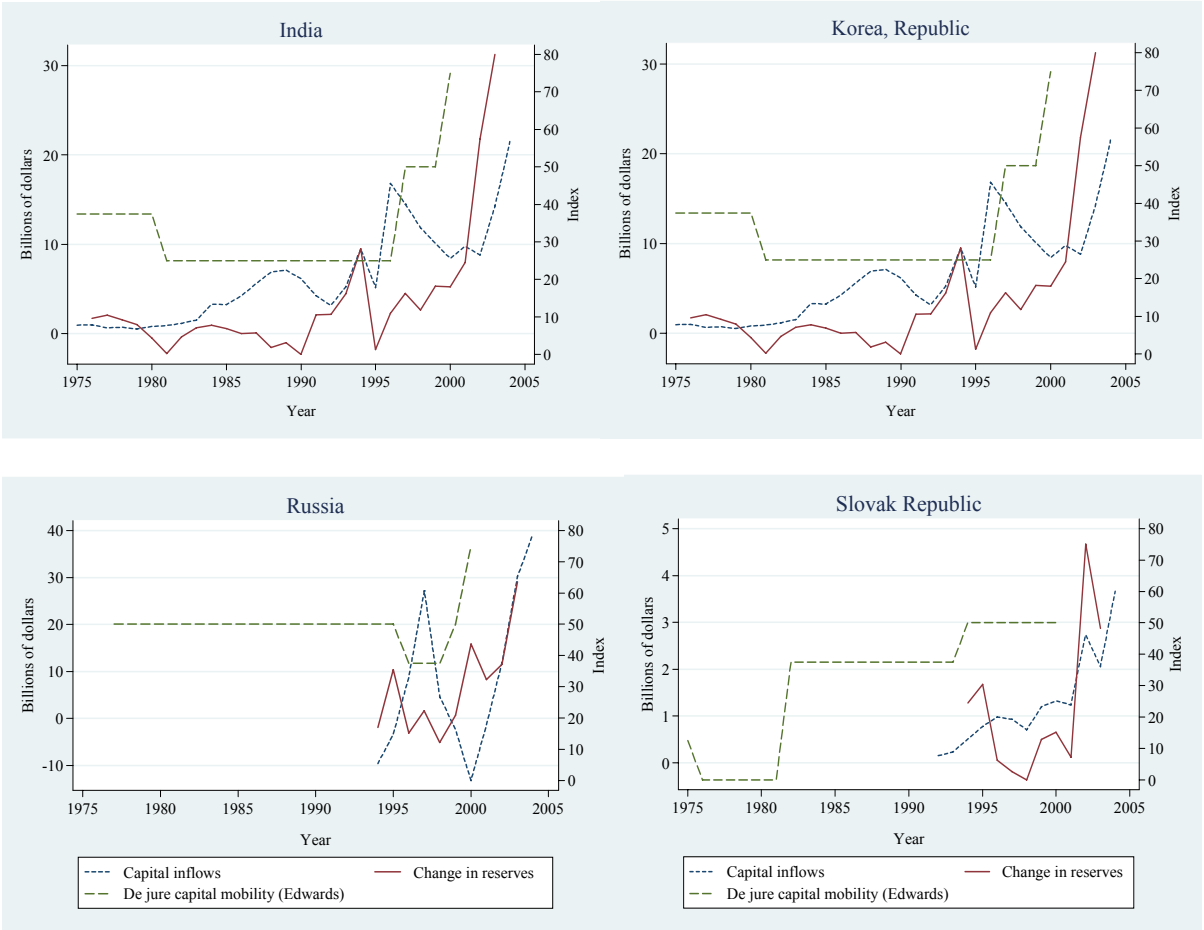


Table 1: Net capital inflow and change in reserves

		World	Emerging-market countries	Developing countries
1975-79			Billions of dollars	
	Net capital inflow	608.0	44.0	103.9
	Change in reserves	120.4	21.4	34.9
			Percentage of net capital inflow	
	Change in reserves	19.8	48.6	33.6
1980-89			Billions of dollars	
	Net capital inflow	4093.9	178.7	257.5
	Change in reserves	316.6	22.9	33.9
			Percentage of net capital inflow	
	Change in reserves	7.7	12.8	13.1
1990-99			Billions of dollars	
	Net capital inflow	13033.8	1389.9	1573.9
	Change in reserves	838.4	368.0	551.3
			Percentage of net capital inflow	
	Change in reserves	6.4	26.5	35.0
2000-2003			Billions of dollars	
	Net capital inflow	12467.0	623.2	911.4
	Change in reserves	1121.6	539.2	695.6
			Percentage of net capital inflow	
	Change in reserves	9.0	86.5	76.3

Note: Net capital inflows are defined as changes of the investment position of foreigners in the domestic economy in the categories direct investment, portfolio investment and other investment. Due to data limitations, investment in financial derivatives is not included although it is a component of the financial account. Since this definition only considers transactions of foreigners, it differs from the financial account (= net capital flows), which additionally takes the transactions of domestic residents into account.

Table 2: Reserves and capital mobility: Static models

Dependent variable: Reserves/GDP
Estimation method: Fixed effects estimator

	(1)	(2)	(3)	(4)	(5)	(6)
Trade openness	0.0969 (7.54***)	0.1111 (8.45***)	0.0743 (5.16***)	-0.3343 (-1.49)	0.0751 (6.15***)	0.1079 (6.27***)
Total external debt (per cent of GDP)	0.0389 (6.19***)	0.0378 (5.99***)	0.0468 (6.67***)	-0.1721 (-5.67***)		0.0147 (1.97**)
Short-term external debt, lagged (per cent of GDP)	-0.1880 (-8.16***)	-0.1722 (-7.31***)	-0.1926 (-7.63***)	-0.0497 (-1.31)	-0.1341 (-5.19***)	-0.1336 (-6.17***)
Monetary disequilibrium (excess money supply)	-0.0020 (-1.53)	-0.0020 (-1.88*)	-0.0030 (-1.18)	-0.0007 (-0.32)		-0.0014 (-0.85)
De jure capital mobility (Chinn-Ito)		0.0134 (5.46***)				
De jure capital mobility (Edwards)			0.0006 (3.71***)			
Financial openness				0.1606 (6.74***)	0.0240 (4.38***)	
Economic globalisation						0.0021 (7.11***)
Number of countries	119	119	112	95	103	72
Number of observations	2007	1911	1475	1570	2253	1313
Adjusted R^2 (overall)	0.04	0.08	0.08	0.31	0.13	0.17

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 3: Reserves and capital mobility: Dynamic models

Dependent variable: Reserves/GDP
Estimation method: Difference GMM estimator (Arellano-Bond)

	(1)	(2)	(3)	(4)
Lagged endogenous variable	0.7156 (10.89***)	0.7307 (10.69***)	0.7697 (18.45***)	0.7750 (15.10***)
Trade openness	0.0620 (4.42***)	0.0521 (2.92***)	0.0107 (0.77)	0.0515 (3.33***)
Total external debt (per cent of GDP)	0.0211 (4.17***)	0.0232 (3.87***)		0.0229 (5.10***)
Short-term external debt, lagged (per cent of GDP)	-0.0601 (-3.41***)	-0.0525 (-2.32**)	-0.1074 (-2.90***)	-0.0552 (-4.24***)
Monetary disequilibrium (excess money supply)	-0.0002 (-0.76)	-0.0013 (-0.82)	-0.0002 (-0.85)	-0.0002 (-1.45)
De jure capital mobility (Chinn-Ito)	-0.0020 (-0.54)			
De jure capital mobility (Edwards)		0.0003 (1.93*)		
Financial openness			0.0346 (3.58***)	
Economic globalisation				0.0007 (0.91)
Number of countries	118	109	94	70
Number of observations	1740	1318	1428	1194
Sargan Test (p-level)	1.0	1.0	1.0	1.0
Arellano-Bond-Test (p-level)	0.97	0.96	0.79	0.66

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
As recommended by Arellano and Bond in the case of finite samples, the coefficients are obtained from a two-step estimation, whereas the t-statistics are based on the one-step standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 4: Management of capital flows

Dependent variable: Changes in reserves
Estimation method: Fixed effects

	(1)	(2)	(3)	(4)
Net capital flows (excluding central bank)	0.0054 (1.06)	0.0059 (1.17)	0.0058 (1.12)	0.0059 (1.18)
Δ M1		0.0452 (1.98**)		0.0351 (2.02**)
Monetary disequilibrium (excess money supply)			-0.0027 (-3.01***)	-0.0024 (-3.13***)
Currency crisis, dummy				-700.17 (-1.67*)
Number of countries	174	168	159	158
Number of observations	3479	3220	2660	2618
Adjusted R^2 (overall)	0.00	0.14	0.26	0.30

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 5: Management of capital inflows: Asymmetric effects

Dependent variable: Changes in reserves
Estimation method: Fixed effects

	(1)	(2)	(3)	(4)
Capital inflows (excluding central bank)	0.0095 (1.96**)	0.0081 (1.67*)	0.0094 (1.91*)	0.0097 (2.04**)
Capital outflows (excluding central bank)	-0.0251 (-0.92)	-0.0106 (-0.38)	-0.0227 (-0.77)	-0.0216 (-0.73)
Δ M1		0.0451 (1.97**)		
Monetary disequilibrium (excess money supply)			-0.0027 (-3.01***)	-0.0027 (-3.00***)
Currency crisis, dummy				-730.05 (-1.69*)
Number of countries	174	168	159	159
Number of observations	3479	3220	2660	2660
Adjusted R^2 (overall)	0.00	0.14	0.26	0.26

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 6: Management of capital flows: Changes in net capital flows

Dependent variable: Changes in reserves
Estimation method: Fixed effects

	(1)	(2)	(3)	(4)
Δ net capital flows	0.0209 (1.88*)	0.0182 (1.70*)	0.0197 (1.76*)	0.0186 (1.77*)
Δ M1		0.0445 (1.95*)		0.0343 (1.98**)
Monetary disequilibrium (excess money supply)			-0.0027 (-3.00***)	-0.0024 (-3.13***)
Currency crisis, dummy				-768.81 (-1.96**)
Number of countries	174	168	159	158
Number of observations	3383	3133	2611	2573
Adjusted R^2 (overall)	0.00	0.14	0.26	0.30

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Chapter 5

Does the Accumulation of International Reserves Spur Inflation? A Panel Data Analysis

1 Introduction

The current accumulation of international reserves by central banks is part of the vividly debated phenomenon of global imbalances. One possible consequence of the accumulation of reserves, however, has been disregarded so far: The effect of rising reserves on the price level. A rise in reserves increases the monetary base as long as it is not fully sterilized. The increased monetary base, in turn, leads through the functioning of the money multiplier to an expansion in the total amount of money. Finally, according to the quantity theory of money, the growth of money causes prices to rise after some delay. This argument is due to Heller (1976) and was confirmed by Khan (1979).

There is an additional argument: under fixed exchange rates monetary policy may be constrained by a lack of reserves. If all countries have more reserves, they may choose more expansionary policies.

Since these seminal papers, the relationship between reserves and inflation has not been reconsidered. Even though the risks of reserve accumulation for monetary policy have been recognized (see for example ECB 2006)[68], a deep theoretical and empirical study on the topic is missing. Moreover, since the studies of Heller and Khan, the international financial system has changed fundamentally and their conclusions of the Bretton Woods period might not be valid in a financial system with flexible exchange rates and a high degree of capital mobility. It is therefore warranted to reconsider whether the current accumulation of reserves creates inflationary pressures.

The uncertainty with respect to the inflationary consequences of the ongoing reserve accumulation is amplified by the fact that recent empirical studies disagree in the assessment of the extent of de-facto sterilization. Whereas Aizenman and Glick (2009) find that the extent of sterilization has risen after the Asian financial crisis, Reinhart and Reinhart (2008) show that recent years have been characterised by less sterilization.

If the accumulation of reserves were not fully sterilized, inflation rates in many emerging and developing countries would be expected to rise further in the near future. This might require a change in central banks' sterilization policy since their goals of maintaining price stability and

[68] The authors point out that the accumulation of reserves might challenge monetary policy: "Particularly in the presence of continuous net capital inflows, intervention on currency markets […] may lead to an excessive easing of domestic monetary conditions which could then threaten price stability." (ECB 2006, p.36)

preventing currency crises via reserve accumulation can only be attained simultaneously if the effects on the monetary base are sterilized. .

The article is organized as follows: The following section summarises the existing empirical findings on the relationship between reserve accumulation, global liquidity and inflation. Section 3 reviews the theoretical links between reserves, the monetary base and inflation. Section 4 investigates the relationship empirically in a panel data set that covers a large number of countries over the period 1970-2006. Static and dynamic panel data models are applied to test whether increasing reserves create inflation. The final section concludes.

2 Literature review

2.1 Reserves and inflation in fixed exchange rate regimes

The seminal paper exploring the links between changes in international reserves and inflation is due to Heller (1976). A regression analysis covering the period 1958-1975 (Heller 1979) shows that prices react with a mean lag of three years to changes in international reserves. This lag tends to be much shorter in developing than in industrial countries. A one per cent increase in reserves is estimated to result in a cumulative price increase of about 0.4 per cent. This effect is larger in developing than in industrial countries.

Khan (1979) challenges these results arguing that the empirical tests of Heller do not allow the conclusion that changes in international reserves caused inflation. One could as well argue in favour of a reversed causality argument, namely that nominal international reserves respond to inflation. However, Khan's causality tests confirm Heller's results for the whole period of observation (1957-77). Conversely, tests for the floating rate period (1973-77) show that the two series are independent and that the relationship between them is rather contemporaneous than causal.

Rabin and Pratt (1981) question the generality of Heller's results. They argue that his results are driven by a short episode of reserve accumulation and rising inflation in the 1970s and cannot be generalised.

2.2 Inflation as a global phenomenon

According to global monetarism, inflation is a global monetary phenomenon. Under floating exchange rates, however, the central bank can pursue an independent monetary policy such that the inflation rate is determined domestically. The question to which extent inflation is due to local and global factors has attracted increasing interest in recent years.

Neely and Rapach (2008) decompose a cross-section of inflation rates into their global, regional and country-specific components. They find that changes in global inflation explain a high proportion of domestic inflation variability, namely 34% of the total variability. This is especially true for developed and open economies with independent central banks.

Ciccarelli and Mojon (2005) consider inflation to be a global phenomenon in the sense that the international comovement of inflation rates is high. For 22 OECD countries changes of their average inflation explain 70% of the country-individual inflation variance. These common fluctuations are found to stem from commodity price changes and the international business cycle in the short run, and changes in the monetary policy regime and the tolerated inflation rate in the long run.

A related literature considers the inflationary consequences of global excess liquidity, defined as the amount of global liquidity that cannot be explained by a global money demand function including income and short-term interest rates. One possible source of global excess liquidity is the worldwide accumulation of international reserves. Rüffer and Stracca (2006) find that global excess liquidity conveys important information about future inflation at the global level.
The mentioned studies, however, disregard the accumulation of reserves as a possible source of excess liquidity. This study shall fill this gap and examine whether inflation can partly be attributed to the growth in international reserves.

3 Reserve accumulation and inflation: Theoretical aspects

Since the inflationary consequences of the reserve accumulation may depend on the exchange rate arrangement, the theoretical section considers fixed and floating exchange rates separately.

3.1 Fixed exchange rates: Global monetarism

Standard monetarist theory states that inflation is a monetary phenomenon. Inflation can be explained by the rate of change of domestic money supply. This theory is formalised by the quantity equation of money:

$$M^S \cdot V = P \cdot Y$$

where M^S is the nominal money supply, V the velocity of money, P the price level and Y real output. After taking natural logarithms and differentiating with respect to time this can be expressed in rates of change as:

$$\hat{P} = \hat{M}^S + \hat{V} - \hat{Y}$$

where a hat on a variable denotes its rate of change. If one assumes that the velocity of money is constant and real output growth is constant[69], changes of the price level depend on the supply of money.

Global monetarism states that under fixed exchange rates this relation also holds at the global level: The worldwide inflation rate is determined by changes in the global supply of money.

Under fixed exchange rates the relative value of national currencies is stable and the world money supply, defined as the sum of domestic money supplies converted into a numeraire, is a meaningful concept. The balance of payments mechanism distributes the world money supply across countries such that the monetary market is in equilibrium in each country. If a country creates an excess supply of domestic money, its balance of payments turns into

[69] The effect of money on the price level is a long-run effect. Over this period, output is not constant, but output growth may be close to constant.

deficit: It looses reserves until the relative supply of domestic to foreign currency is again compatible with the value of the fixed exchange rate. As a result, the world money supply increases unless the foreign country sterilizes the increase in its monetary base.

If – as stated by global monetarism – global money supply determines global inflation, small open economies cannot control their inflation rate. Inflation may be generated by equal rates of money growth across countries or by the monetary policy of one single country.

The link between the money supply and the accumulation of international reserves can be illustrated by the money supply process. Money supply depends on two major factors: the money multiplier (m) and the monetary base (B):

$$M^S = m \cdot B$$

The monetary base equals a central bank's liabilities, namely the sum of currency (C) and deposits of commercial banks at the central bank (R). Alternatively, it can be defined by the assets of the central bank's balance sheet as the sum of net domestic assets (NDA) and net foreign assets (NFA):

$$M^S = m \cdot (C + R) = m \cdot (NDA + NFA) \tag{1}$$

Hence, the rate of change of money supply can be expressed as

$$\hat{M}^S = \hat{m} + \frac{NDA}{B} \cdot N\hat{D}A + \frac{NFA}{B} \cdot N\hat{F}A \tag{2}$$

Combining this specification of the money supply process with the quantity theory of money and assuming a constant velocity of money results in

$$\hat{P} = \hat{m} + \frac{NDA}{B} \cdot N\hat{D}A + \frac{NFA}{B} \cdot N\hat{F}A - \hat{Y} \tag{3}$$

This equation highlights the links between changes in international reserves and the price level. One can distinguish two extreme cases: If the central bank accumulates international reserves and fully sterilizes the effects on the monetary base through an open-market operation reducing its holdings of domestic bonds in exchange for money, $\frac{NDA}{B} \cdot \hat{NDA} = -\frac{NFA}{B} \cdot \hat{NFA}$, the price level is unaffected. If, however, the central bank does not sterilize, the increase in international reserves directly translates into an increase of the price level.

This argument holds for any individual country. If the assumptions of global monetarism are fulfilled – a world under a system of fixed exchange rates without sterilization ($\Delta NDA = 0$) – this equation also holds for world aggregates:

$$\hat{P}^W = \hat{m}^W + \frac{NFA^W}{B} \hat{NFA}^W - \hat{Y}^W$$

where the superscript w denotes world variables. If the world money multiplier is constant, world inflation equals the weighted rate of net foreign asset creation minus the growth rate of world output.

3.2 Floating exchange rates: National monetarism

Under floating exchange rates, the central bank can pursue an independent monetary policy such that the inflation rate may vary substantially between countries. There are no monetary restrictions that make domestic inflation rates interdependent. Differences in the growth rate of the monetary base can be maintained permanently as the resulting differences in inflation rates are accommodated via changes in the exchange rate. Hence, inflation is a national phenomenon under floating exchange rates. This, however, does not foreclose that inflation rates show some co-movement due to common non-monetary factors.

With inflation rates being independent, the concept of a worldwide inflation rate determined by world money supply is no longer meaningful. Consequently, the implications of the quantity theory of money cannot be applied to the world as an aggregate. In the words of Niehans (1976, p. 179) under floating exchange rates “international reserves have lost their

significance for inflation or deflation in the world economy, each country now controlling its own price trend." However, for each individual country, the quantity theory still applies.

Given the above reasoning (see equation (3)), the effect of an accumulation of international reserves on the inflation rate depends on the degree of sterilization. If countries do not offset the expansionary effect of accumulating international reserves, this might raise the domestic inflation rate. If, on the contrary, they fully sterilize, the accumulation of reserves has no impact on money supply and is not inflationary. To be more precise, only the direct monetary effects of the reserve accumulation are not inflationary in this case. There are, however, political economy reasons why sterilized purchases of foreign exchange might raise inflation. Since a sterilization operation expands the stock of domestic debt, policymakers might be tempted to reduce the nominal value of the debt through surprise inflation. Hence, increasing domestic debt aggravates the commitment problem of the central bank and inflation expectations might rise (see Calvo 1991).

4 Empirical analysis

The empirical analysis tests two hypotheses: 1. global reserve growth drives global inflation, and 2. reserve accumulation is inflationary within each country. The latter hypothesis is based on fewer assumptions since it does not require a fixed exchange rate regime.

4.1 Data

The empirical analysis is carried out on the basis of a pooled data set of cross-country and time-series observations. It contains annual data from 1970 to 2006. Data for international reserves are available for 191 countries. After dropping small countries (population smaller than 3 millions in the year 2000), the sample contains 126 countries, which are listed in Appendix A. Since data for several explanatory variables are missing for some countries, the number of countries used in the econometric analysis depends on the particular specification and is indicated in the respective tables. It ranges from 66 to 118 countries. With a few exceptions data are taken from the International Financial Statistics of the IMF and the World Development Indicators of the World Bank. A detailed description of the variables and their data sources can be found in Appendix B.

In line with equation (2) the growth rates of reserves and domestic central bank assets are weighted by their fraction in the total monetary base.

4.2 Statistical evidence

This section presents statistical evidence with respect to the correlation between the growth rate of reserves and monetary variables.

Figure 1 plots the relationship between the growth rate of world reserves and the world inflation rate. Each data point relates to a specific year between 1975 and 2006. The world inflation rate is calculated as the weighted mean of individual countries' inflation rates where a country's fraction of world GDP is used as its weight. Weights are calculated for each year individually such that changes in the relative size of an economy are accounted for. This is a test of global monetarism.

The graph visualises two patterns: First, data points are not agglomerated in a data cloud but rather distributed over a large range of inflation rates and growth rates of reserves. This points to the fact that both rates varied considerably during the period under consideration. This variability might be due to factors not considered in the graph.

Second, the downward sloping line of fitted values suggests a negative relationship: Higher growth rates of reserves are correlated with lower inflation rates. This correlation, which is not in line with our hypothesis, is statistically insignificant. The missing positive correlation might stem from the fact that the scatter diagram only considers two variables. Hence, additional factors that affect one of the variables are implicitly assumed to be constant. In our case, inflation rates in many emerging and developing countries have fallen since the beginning of the 1990s while at the same time countries increasingly accumulated reserves. However, the fall in inflation is usually attributed to a trend for more prudent macroeconomic policies and increased central bank accountability. This might bias the scatter diagram. Therefore, the relationship warrants a finer analysis by means of a regression analysis, which accounts for additional determinants of the inflation rate.

After this time-series analysis of world averages, Figure 2 presents the relationship between the growth of reserves and the inflation rate in the cross section. Each data point represents an individual country displaying its average growth rate of reserves and its average inflation rate over the period 1970-2006. The left-hand side graph shows that both rates are positively

correlated. This supports the hypothesis that the accumulation of reserves is correlated with higher inflation rates. Since this relationship might be driven by some outliers with very high inflation rates and/or high growth rates of reserves, the right-hand side is based on a reduced sample after dropping countries with an average growth rate of reserves and/or inflation exceeding 50%. In this case, reserve growth and inflation are not correlated.

According to the theory developed in section 3, the link between the growth of reserves and inflation works through an indirect transmission channel. It is assumed that the growth of reserves increases the monetary base, which, in turn, leads to an increase in money supply (M1) ultimately causing the inflation rate to rise. Therefore, the correlation between reserve growth on the one hand and the growth rate of base money and M1 on the other is depicted in two additional graphs (Figures 3 and 4). Each data point represents the average growth rates of both variables over the period from 1970-2006 for an individual country. Whereas the left-hand side graph is based on the full sample, the graph on the right hand displays the relationship for a reduced sample excluding outliers, namely countries with a growth rate of reserves and/or a growth rate of base money or M1, respectively, larger than 50%. All four graphs show that countries' growth rates of the monetary base and M1 are the higher, the higher their growth rate of international reserves is. All effects are significant at the 5%-level. This is first evidence that the inflationary impact of reserve accumulation works through an increase of domestic money supply.

4.3 Estimation results

4.3.1 Global monetarism

The regression analysis first replicates the analysis of Heller (1976, 1979). It investigates whether inflation is a global phenomenon in the sense that the growth of the stock of worldwide reserves causes global inflation. Global inflation is calculated as the geometric mean of country-specific inflation rates, which are weighted by a country's fraction of world GDP. Whereas Heller regresses the inflation rate on current and lagged changes of reserves, I prefer to use a vector autoregression (VAR) of reserves and inflation that (1) includes also lagged values of the dependent variable, (2) does not a-priori assume variables to be endogenous or exogenous and (3) allows to test for the direction of causality. Thereby I can directly approach Khan's reversed causality argument. The VAR consists of the following two equations:

$$\pi^W = \alpha_1 + \sum_{j=1}^{p} \beta_j \cdot \pi^W_{t-j} + \sum_{j=1}^{p} \gamma_j \cdot \hat{R}^W_{t-j} + u_{1t}$$

$$\hat{R}^W = \alpha_2 + \sum_{j=1}^{p} \theta_j \cdot \pi^W_{t-j} + \sum_{j=1}^{p} \lambda_j \cdot \hat{R}^W_{t-j} + u_{2t}$$

where π^W and $\hat{R}^W$ denote world inflation and the growth rate of world reserves, respectively. p is the number of included lags. This model can be estimated by OLS.

The number of included lags is determined by the minimization of information criteria, namely the Akaike information criterion and the Schwarz-Bayes criterion. The preferred specification includes two lags.

Table 1 presents the estimation results. The growth of reserves significantly increases the inflation rate with a lag of two years. However, this effect is economically small and not comparable to the magnitude reported by Heller: An increase of world reserves by 10% raises inflation two years later by about 0.7%. To check the causality of this relationship, a Granger test is applied. The hypothesis that the growth of reserves does not cause inflation cannot be rejected at the 10%-significance level (it can be rejected at a level of significance of 11%).

The lower panel of the table tests for reversed causality: Inflation has no significant impact on reserve growth. Moreover, inflation does not Granger-cause reserves to grow.

Figure 5 shows the impulse-response function for an expansionary reserve growth shock. Reserve growth reduces inflation in the year following the shock, but has a positive impact on inflation two years later. This effect only decreases slowly over time. The negative impact in the first year is unexpected. It might be due to the fact that reserves are often replenished after a crisis has occurred (see chapter 3). Therefore, rising reserves might coincide with lower inflation rates due to the implementation of macro stabilization programmes.

As discussed in the theoretical section, the conclusion of global monetarism - global reserve growth causes world inflation - is based on the assumption of a world of fixed exchange rates. Therefore, I replicate the vector autoregressions of Table 1 for a reduced sample. The subsample contains only those annual observations for which a de jure fixed exchange rate was in place.[70] Based on these observations, world inflation and world reserve growth are calculated. Vector autoregressions examine the relationship between both variables. The

[70] This classification is flawed for our purposes and may be sharpened in future research: Global monetarism makes its statements for countries whose currencies are fixed with respect to one common currency. The empirical group of pegged exchange rates, however, consists of various blocs of fixed exchange rates with respect to different currencies, i.e. the Dollar, Euro or Yen.

results are presented in Table 2. Reserve growth significantly reduces inflation after one year and significantly raises inflation with a lag of two years. The total effect is positive: If reserves grow by 1%, two years later inflation will have increased in sum by almost 0.25%. The Granger test supports the hypothesis that the growth of reserves causes inflation. Although the lags of inflation significantly affect the growth in reserves, the hypothesis of reversed causality can be rejected.

4.3.2 National monetarism

The following tables examine the hypothesis that inflation is rather a national than global phenomenon. To this end, a panel data set is analysed that contains individual country data for the period 1970-2006. The regressions estimate the extent to which the foreign and domestic components of the monetary base determine the inflation rate independently of the evolution of global liquidity and of the inflation rate in other countries.

Column (1) of Table 3 tests for the effect on the contemporaneous inflation rate. Both growth rates are weighted by their fraction in the total monetary base (see equation (3)). While the growth rate of domestic central bank assets significantly increases the inflation rate, the effect of foreign assets (= international reserves) is insignificant.

According to the money market equilibrium condition, monetary expansion raises inflation only to the extent to which it exceeds the growth of money demand, e.g., real GDP growth. Column (2) shows that real GDP growth indeed significantly lowers inflation for a given monetary base. The effects of the two components of the monetary base on inflation are basically unchanged.

Economic theory suggests that inflation reacts with some time lag to increases in money supply. Existing evidence shows that monetary factors feed into inflation with a lag of two to three years. Therefore, column (3) adds three lags of both the growth rate of reserves and the growth rate of domestic central bank assets. With respect to the growth of domestic central bank assets, the contemporaneous and the previous period's growth rate raise inflation. The growth of international reserves, however, feeds into inflation with a lag of three years. This effect is economically small (on average 0.02%).

The effect of monetary factors on inflation might be different during currency crises than in normal times. During crises the expected deflationary impact of reserve losses might be overcompensated by other factors like a devaluation of the currency. Therefore, column (4) adds a dummy for currency crises that takes the value one in years where a currency crisis was identified by an exchange market pressure index. Its effect, however, is not significant.

The importance of monetary factors in the inflation process may depend on the level of inflation. A reduced sample that disregards high inflation periods might offer additional insights how moderate inflation rates are determined. To this end, Table 4 replicates the estimations of Table 3 for a reduced sample that disregards all observations with an inflation rate exceeding 50%.

Column (1) includes the growth rates of the domestic and foreign component of the monetary base and column (2) adds real GDP growth. Whereas domestic central bank assets do not significantly affect moderate inflation, the growth of international reserves significantly increases inflation and the growth of real GDP significantly decreases it. Column (3), which investigates if inflation reacts to monetary factors with some time lag, shows that the effect of the growth rate of international reserves lasts for two years. With an average growth rate of the weighted nominal reserves of 16% in the whole sample, the inflation is expected to be on average 0.4% higher than without reserve growth. This marginal effect of reserve increases implicitly assumes that all other factors are constant, particularly that the reserve growth is not sterilized by the central bank.

In sum, reserve growth significantly raises moderate inflation rates. However, monetary factors do not explain moderate inflation rates well as the low levels of the coefficients of determination (R^2) indicate. This general result is in line with the findings of De Grauwe and Polan (2005).

4.3.3 Robustness

To test the robustness of the results, the effects of the growth rate of reserves on the inflation rate are investigated for different time periods. To this end, the sample is divided into three periods of equal size (twelve years). The results are presented in Table 5. Columns (1) and (2) show the results for the first period from 1970 to 1982. Both the growth of domestic central bank assets and the growth of reserves have a positive and significant impact on inflation. Whereas the effect of domestic assets is distributed over three years, the effect of reserve growth is only contemporaneously significant. With an average weighted growth rate of nominal reserves during 1970-1982 of 17%, reserve growth raises the inflation rate on average by 1.6% if the effect on the monetary base is not sterilized (marginal effect).

During 1983-1994 (columns (3) and (4)) reserve growth significantly raises the inflation rate with a lag of three years. This effect is much smaller than in the previous period. The inflationary impact of domestic asset growth, in turn, is larger compared to 1970-1982. For the last period from 1995 to 2006 (columns (5) and (6)), reserve growth contemporaneously raises inflation. This effect, however, becomes insignificant when three lags are included.
Results differ between periods. This might be due to changes in the variability of the variables: Whereas the highest variability of inflation can be observed between 1983 and 1994, the variability of the growth rate of reserves in 1995-2006 is larger than in the other two periods. The variability of the growth rate of domestic central bank assets has declined over the three periods of consideration.

Table 6 replicates the analysis of temporal subsamples for the restricted sample of moderate inflation rates. Whereas the growth of domestic central bank assets is insignificant, reserve growth raises inflation in all three periods.

Table 7 tests whether the results are robust to the use of a different estimator. It uses the between regressor, which is based on country averages over the whole period. It tests whether countries with higher growth rates of the components of the monetary base are on average associated with higher inflation rates. For the full sample (columns (1) and (2)) and the sample of moderate inflation rates (columns (3) and (4)) inflation is significantly higher, the higher the growth rate of domestic central bank assets. The growth rate of reserves, however, does not significantly affect the inflation rate.

Current inflation might not be time-independent but related to past inflation rates. This might be due to pricing policies and the formation of inflation expectations. If indexation mechanisms are in place such that prices like wages, tariffs and rents adjust automatically to past inflation rates, the change of the current price level depends on the past inflation rate. Adaptive expectations imply that the expected future inflation rate is the higher, the higher the inflation in the past was. This theory can be tested in the form of a dynamic regression analysis that includes the lagged level of the inflation rate as one of its determinants. The results for moderate inflation rates are presented in Table 8.
The lagged level of inflation is significant. Part of the previous period's inflation rate is passed to the next period. This inertia, however, is relatively small. The growth of domestic

central bank assets raise the inflation rate whereas the current growth rate of reserves does not significantly affect inflation.

4.3.4 Sterilization policies

As pointed out in the theoretical section, the effect of an increase in international reserves on the inflation rate depends on the degree of sterilization of these purchases by the central bank. If the effect of the accumulation of international reserves on the monetary base is fully sterilized through the sale of domestic bonds, the inflationary impact of the accumulation of reserves, for which the previous tables offer weak evidence, is cushioned.

To measure the extent of sterilization, I estimate sterilization coefficients. Along the lines of Aizenmann and Glick (2008) I regress the growth rate of domestic central bank assets on the growth rate of reserves and the growth rate of nominal GDP. The sterilization coefficient is defined as the coefficient of reserve growth in this regression. A sterilization coefficient of minus one represents full sterilization while a coefficient of zero implies no sterilization. Nominal GDP growth is included to control for increases in nominal money demand. Hence, with full sterilization the central bank prevents an expansion of the monetary base due to changes in reserves, but domestic credit may grow due to other reasons, namely increases in money demand.
The results of a cross-section analysis are presented in Table 9. The estimation assumes by definition that the sterilization coefficient is constant over time and over all countries. It equals –0.26 (column (1)). This indicates that the effect of reserve growth on the monetary base was partially offset by the sale of domestic central bank assets. However, the coefficient is relatively small implying that sterilization is far from complete.

Sterilization policies of central banks might change over time. They depend on the primary objectives of central bank policy, economic circumstances and the policies of other central banks. To investigate the stability of the relationship over time, I estimate the regression for different time periods. The sample is divided into three time periods of equal size. Columns (2) to (4) of Table 9 present the results. The sterilization coefficient amounts to –0.43 in the 1970s, decreases (in absolute terms) first to –0.22 between 1983 and 1994 and falls further to –0.15 between 1995 and 2006. This indicates that the sterilization of the effect of reserve changes on the monetary base has decreased over time.

Given this instability of sterilization coefficients, it might be appropriate to focus on shorter time periods. To this end, I use a rolling regression over a period of five years. The first regression covers the period from 1970 to 1974, the second from 1971 to 1975 and the last uses data between 2002 and 2006. Figure 5 plots the sterilization coefficients. Sterilization is relatively small in the first half of the 1970s but increases after the end of the Bretton Woods System. The effect of reserve changes on the monetary base are at least cut by half. Until the late 1980s sterilization further increases but then falls abruptly to very low levels. During the 2000s sterilization remains low, both in absolute terms and in comparison with other periods.

An explanation for the decreasing sterilization efforts of central banks might be given by the increase of capital mobility. Private capital flows may render central banks' sterilization policies ineffective. If a central bank sterilizes its accumulation of reserves, the interest rate is higher than without sterilization. Hence, foreign capital flows might continue and challenge the central bank to further accumulate reserves, thereby offsetting its sterilization policies.

5 Conclusions

This chapter examines the inflationary consequences of reserve accumulation, both at the global and the country level.

Global reserve growth significantly raises the world inflation rate with a lag of two years. This effect is especially strong for countries with fixed exchange rate regimes. In a world of mutually fixed exchange rates, reserve growth is found to Granger-cause inflation. A rate of reserve growth of 1% causes an increase of the price level of 0.25% over a period of two years.

On the level of individual countries, the growth of domestic central bank assets is the major monetary determinant of inflation. If domestic central bank assets increase by 1%, inflation rises during the current and subsequent year by more than 0.5%. Changes in international reserves do not significantly affect inflation. These effects are reversed if only moderate inflation rates are to be explained. The growth of international reserves then significantly contributes to higher moderate inflation rates.

Further results suggest that the growth of reserves contributed to higher inflation rates during the 1970s and between 1995-2006, but was insignificant during the 1980s. Hence, the results

of Heller (1976) that the accumulation of reserves has inflationary effects can be confirmed for the 1970s and for the period between 1995 and 2006.

The estimation of sterilization coefficients shows that the degree of sterilization of the effects of reserve growth on the monetary base varies considerably over time. The observation that sterilization is relatively low during the 2000s allows two concluding remarks. First, sterilization policies of central banks might be increasingly offset by private capital flows in a financially integrated world. Second, since the recent accumulation of reserves is sterilised to a lower extent than in previous periods, its inflationary impact in the future might be larger.

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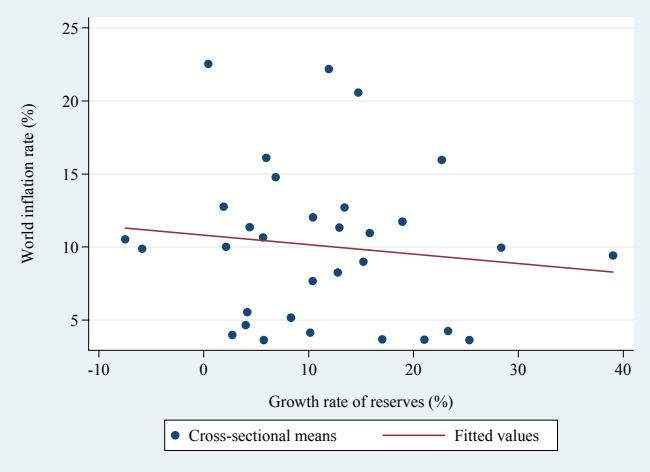
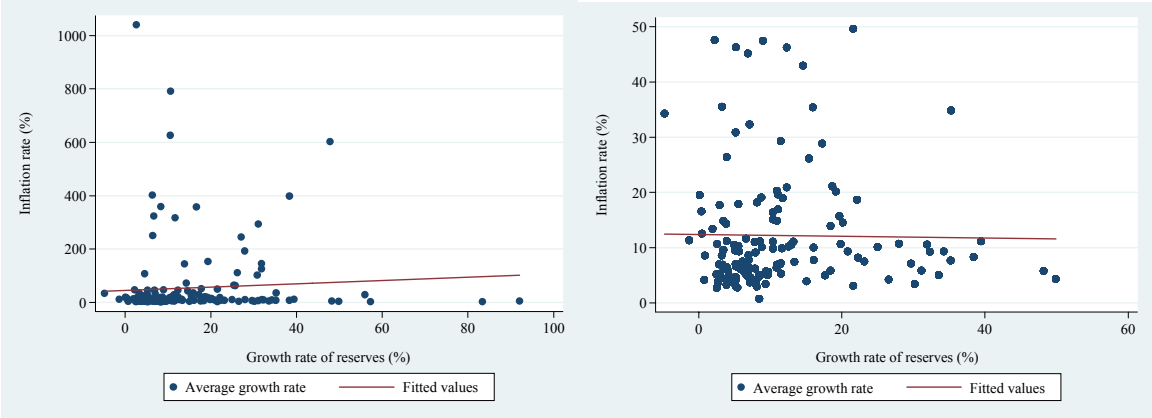
Figure 1: World inflation and growth of world reserves (1975-2006)



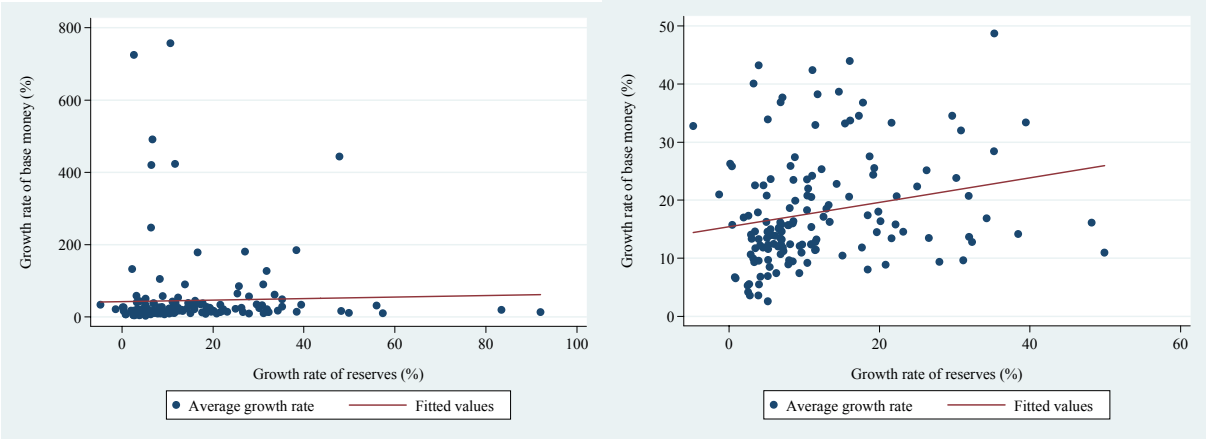
Note: The graph displays annual combinations of the growth rate of world reserves and world inflation calculated as a weighted average of individual country's inflation rates.

Figure 2: Growth of reserves and inflation (country averages)



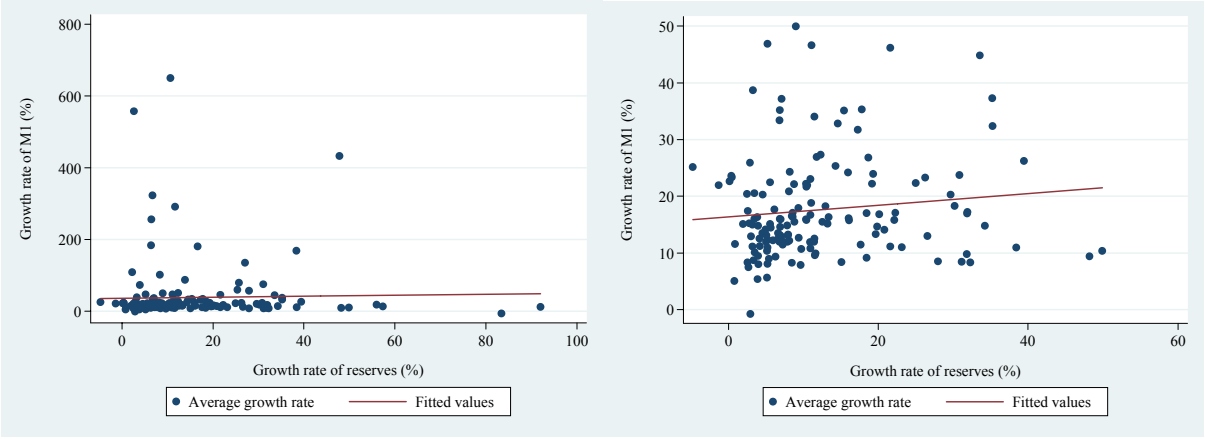
Note: Each data point displays the average growth rate of reserves and the average inflation rate over the period 1970-2006 for an individual country. The left-hand side graph includes all countries for which data are available with the exception of three extreme outliers. The right-hand side graph is based on a reduced sample after countries with an average inflation rate and/or growth rate of reserves exceeding 50% have been dropped.

Figure 3: Reserves and monetary base



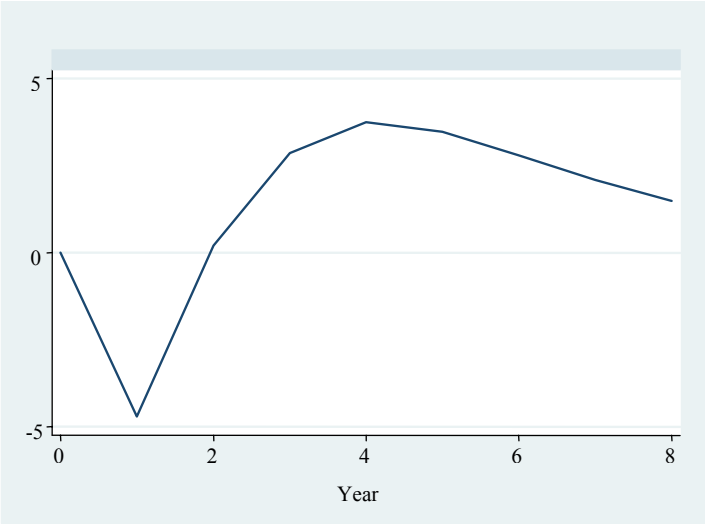
Note: Whereas the left-hand side graph is based on the full sample, the graph on the right hand displays the relationship for a reduced sample excluding outliers, namely countries with a growth rate of reserves and/or a growth rate of base money larger than 50%.

Figure 4: Reserves and money (M1)



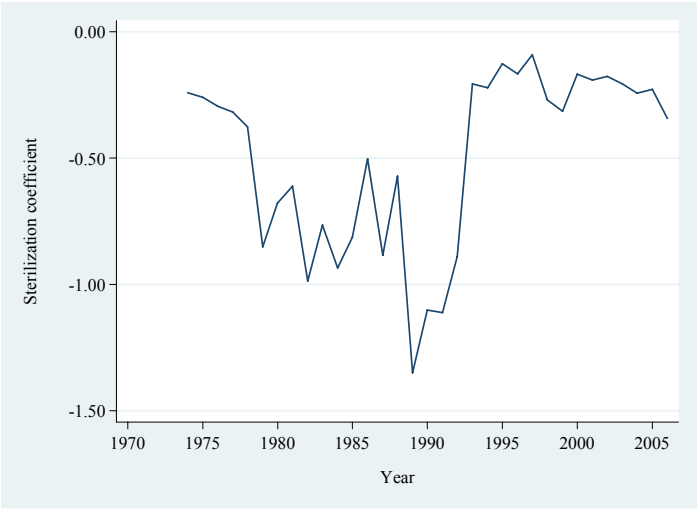
Note: Whereas the left-hand side graph is based on the full sample, the graph on the right hand displays the relationship for a reduced sample excluding outliers, namely countries with a growth rate of reserves and/or a growth rate of money (M1) larger than 50%.

Figure 5: Impulse-response function for expansionary reserve growth shock



Note: The graph displays the time path of the response of the inflation rate to reserve growth.

Figure 6: Sterilization coefficients



Note: This graph is based on rolling regressions of the rate of growth of domestic central bank assets on the growth rate of international reserves. A total of 33 regressions is estimated, each covering 5 years. The graph plots the resulting coefficients attributed to international reserve growth. The year on the x-coordinate marks the last year of the respective regression, e.g. the coefficient in 1975 is based on the regression over 1971-1975.

Table 1: World reserves and world inflation (1970-2006)

Estimation method: Vector autoregression

Dependent variable: World inflation (%)

	Lags	1	2
World inflation		1.1480 (7.44***)	-0.3136 (-2.00**)
World reserves (growth rate)		-0.0471 (-1.05)	0.0668 (2.06**)
H_0: World reserve growth does not cause world inflation.		p-value: 0.11	

Dependent variable: World reserve growth (%)

	Lags	1	2
World inflation		-0.4436 (-0.74)	0.3144 (0.52)
World reserves (growth rate)		0.2287 (1.32)	0.0073 (0.06)
H_0: World inflation does not cause world reserves to grow.		p-value: 0.75	

Table 2: World reserves and world inflation under fixed exchange rate regimes

Estimation method: Vector autoregression

Dependent variable: World inflation (%)

Lags	1	2
World inflation	0.3268 (2.59***)	0.3861 (3.04***)
World reserves (growth rate)	-0.3260 (-2.38**)	0.5568 (4.80***)
H_0: World reserve growth does not cause world inflation.	p-value: = 0.00	

Dependent variable: World reserve growth (%)

Lags	1	2
World inflation	0.1427 (1.04)	-0.1560 (-1.12)
World reserves (growth rate)	0.3480 (2.33**)	-0.2468 (-1.95*)
H_0: World inflation does not cause world reserves to grow.	p-value: = 0.47	

Table 3: Determinants of inflation

Dependent variable: Inflation (%)
Estimation method: Fixed effects estimator

	(1)	(2)	(3)	(4)
Domestic central bank assets (weighted growth rate)	0.5285 (3.13***)	0.5271 (3.13***)	0.8507 (4.62***)	0.4152 (1.78*)
- lagged by one year			0.1200 (2.59***)	0.3310 (2.03**)
- lagged by two years			0.0403 (0.57)	0.1005 (1.39)
- lagged by three years			0.0233 (1.03)	0.0902 (1.21)
International reserves (weighted growth rate)	0.0022 (1.33)	0.0021 (1.35)	0.0018 (1.62)	0.1127 (1.82*)
- lagged by one year			-0.0002 (0.62)	-0.0006 (-0.20)
- lagged by two years			0.0004 (1.26)	-0.0033 (-1.17)
- lagged by three years			0.0006 (1.71*)	-0.0016 (-0.57)
Real GDP (growth rate)		-3.8150 (-2.44**)	-1.1426 (-1.02)	-0.9509 (-1.34)
Currency crisis, dummy				-0.4343 (-0.04)
Number of countries	116	115	115	100
Number of observations	3145	3118	2762	1356
Adjusted R^2 (overall)	0.30	0.30	0.32	0.54

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 4: Determinants of moderate inflation

Dependent variable: Inflation (%)
Estimation method: Fixed effects estimator

	(1)	(2)	(3)	(4)
Domestic central bank assets (weighted growth rate)	0.0063 (1.29)	0.0058 (1.28)	0.0042 (1.27)	0.0032 (2.54***)
- lagged by one year			0.0047 (1.06)	0.0032 (1.66*)
- lagged by two years			0.0022 (0.51)	0.0005 (0.35)
- lagged by three years			0.0008 (0.28)	0.0005 (0.46)
International reserves (weighted growth rate)	0.0062 (4.77***)	0.0061 (4.81***)	0.0261 (3.01***)	0.0226 (2.11**)
- lagged by one year			0.0008 (1.75*)	0.0009 (1.82*)
- lagged by two years			0.0000 (0.11)	0.0001 (0.20)
- lagged by three years			0.0001 (0.34)	0.0002 (1.34)
Real GDP (growth rate)		-0.1222 (-4.02***)	-0.1517 (-4.69***)	-0.0914 (-1.83*)
Currency crisis, dummy				2.4711 (3.82***)
Number of countries	116	115	113	97
Number of observations	2912	2889	2383	1235
Adjusted R^2 (overall)	0.02	0.02	0.04	0.04

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 5: Determinants of inflation (temporal subsamples)

Dependent variable: Inflation (%)
Estimation method: Fixed effects estimator

	(1)	(2)	(3)	(4)	(5)	(6)
	1970-1982		1983-1994		1995-2006	
Domestic central bank assets (weighted growth rate)	0.2291 (2.73***)	0.2133 (2.82***)	0.4880 (2.78***)	0.8725 (4.47***)	0.3681 (1.03)	0.3764 (1.06)
- lagged by one year		0.2176 (1.79*)		0.1287 (2.58***)		0.0360 (0.95)
- lagged by two years		0.1126 (3.43***)		0.0713 (0.74)		0.0172 (0.55)
- lagged by three years		0.1603 (2.60***)		0.0606 (1.21)		-0.0099 (-0.34)
International reserves (weighted growth rate)	0.1041 (3.44***)	0.0915 (4.59***)	0.0015 (1.10)	0.0012 (1.33)	0.2951 (2.79***)	0.1397 (1.25)
- lagged by one year		0.0206 (1.18)		-0.0012 (-1.43)		-0.0018 (-0.77)
- lagged by two years		0.0024 (0.17)		0.0004 (1.32)		-0.0013 (-0.55)
- lagged by three years		0.0050 (0.39)		0.0005 (1.67*)		0.0004 (0.37)
Real GDP (growth rate)	-0.1103 (-5.47***)	0.0755 (0.50)	-9.3253 (-2.18**)	-5.0961 (-1.81*)	0.4019 (0.21)	0.8904 (0.45)
Number of countries	78	78	103	88	113	113
Number of observations	892	814	996	935	1230	1167
Adjusted R^2 (overall)	0.30	0.46	0.31	0.33	0.10	0.20

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 6: Determinants of moderate inflation (temporal subsamples)

Dependent variable: Inflation (%)
Estimation method: Fixed effects estimator

	(1)	(2)	(3)	(4)	(5)	(6)
	1970-1982		1983-1994		1995-2006	
Domestic central bank assets (weighted growth rate)	0.0108 (1.15)	-0.0003 (-0.06)	0.0061 (0.81)	-0.0002 (-0.03)	0.0015 (1.04)	0.0010 (0.65)
- lagged by one year		0.0019 (0.14)		0.0130 (1.22)		0.0016 (0.70)
- lagged by two years		0.0097 (1.47)		0.0066 (0.44)		-0.0016 (-1.02)
- lagged by three years		-0.0010 (-0.13)		0.0099 (1.05)		-0.0017 (-1.09)
International reserves (weighted growth rate)	0.0292 (3.55***)	0.0402 (5.45***)	0.0056 (7.66***)	0.0346 (5.87***)	0.0220 (1.74*)	0.0213 (1.66*)
- lagged by one year		0.0168 (2.78***)		0.0007 (0.07)		0.0009 (2.28**)
- lagged by two years		-0.0010 (-0.16)		-0.0029 (-0.38)		0.0002 (0.62)
- lagged by three years		-0.0006 (-0.13)		-0.0056 (-0.76)		0.0001 (0.62)
Real GDP (growth rate)	0.0744 (1.29)	-0.0363 (-0.61)	-0.0763 (-1.20)	-0.0727 (-1.04)	-0.1647 (-3.56***)	-0.1044 (-1.94*)
Number of countries	78	73	93	78	112	111
Number of observations	835	572	876	771	1178	1040
Adjusted R^2 (overall)	0.02	0.05	0.02	0.03	0.02	0.02

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 7: Determinants of inflation: cross-country analysis

Dependent variable: Inflation (%)
Estimation method: Between regression (country averages)

	(1)	(2)	(3)	(4)
	whole sample		moderate inflation	
Domestic central bank assets (weighted growth rate)	1.6406 (11.62***)	1.6342 (11.44***)	0.1442 (4.06***)	0.1473 (4.21***)
International reserves (weighted growth rate)	0.0087 (0.20)	0.0132 (0.29)	-0.0008 (-0.08)	-0.0015 (-0.15)
Real GDP (growth rate)		-3.3556 (-0.60)		0.5650 (2.32**)
Number of countries	92	91	92	91
Number of observations	2502	2475	2311	2288
Adjusted R^2 (overall)	0.60	0.60	0.16	0.20

Notes: Columns (1) and (2) are based on the whole sample, whereas columns (3) and (4) disregard episodes of annual inflation rates exceeding 50%.

Table 8: Determinants of inflation: dynamic model

Dependent variable: Inflation (%)
Estimation method: Arellano-Bond estimator (GMM)

	(1)
Lagged inflation	0.1410 (2.16**)
Domestic central bank assets (weighted growth rate)	0.0018 (3.08***)
International reserves (weighted growth rate)	0.0216 (1.61)
Real GDP (growth rate)	-0.1083 (-1.56)
Currency crisis, dummy	2.4264 (4.27***)
Number of countries	118
Number of observations	1003
Sargan Test (p-level)	1.0
Arellano-Bond-Test (p-level)	0.50

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 9: Sterilization

Dependent variable: Growth rate of domestic central bank assets (%)
Estimation method: Cross-section analysis (between regression)

	(1) 1970-2006	(2) 1970-1982	(3) 1983-1994	(4) 1995-2006
Growth rate of international reserves	-0.2558 (-3.28***)	-0.4285 (-4.97***)	-0.2160 (-1.81*)	-0.1529 (-1.73*)
Nominal GDP (growth rate)	0.0369 (6.91***)	0.4155 (11.69***)	0.0317 (6.03***)	0.0571 (5.37***)
Number of countries	94	66	83	90
Number of observations	2510	754	809	947
Adjusted R^2	0.39	0.72	0.34	0.27

Notes:
t-statistics (in brackets) computed with heteroskedasticity-consistent standard errors.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Appendix A: Country list (126 countries)

Albania
Algeria
Angola
Argentina
Armenia
Australia
Austria
Azerbaijan
Bangladesh
Belarus
Belgium
Benin
Bolivia
Bosnia and Herzegovina
Brazil
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Central African Republic
Chad
Chile
China
Colombia
Congo, Dem. Rep.
Congo, Rep.
Costa Rica
Cote d'Ivoire
Croatia
Czech Republic
Denmark
Dominican Republic
Ecuador
Egypt, Arab Rep.
El Salvador
Eritrea
Ethiopia
Finland
France
Georgia
Germany
Ghana
Greece
Guatemala
Guinea
Haiti
Honduras
Hong Kong, China
Hungary
India
Indonesia
Iran, Islamic Rep.
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Korea, Rep.
Kyrgyz Republic
Lao PDR
Lebanon
Liberia
Libya
Lithuania
Madagascar
Malawi
Malaysia
Mali
Mexico
Moldova
Morocco
Mozambique
Myanmar
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Pakistan
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Romania
Russian Federation
Rwanda
Saudi Arabia
Senegal
Serbia
Sierra Leone
Singapore
Slovak Republic
South Africa
Spain
Sri Lanka
Sudan
Sweden
Switzerland
Syrian Arab Republic
Tajikistan
Tanzania
Thailand
Togo
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Venezuela, RB
Vietnam
Yemen, Rep.
Zambia
Zimbabwe

Appendix B: List of variables and data sources

Variable	Source	Description
Reserves	World Bank (2008)	Net international reserves comprise special drawing rights, reserves of IMF members held by the IMF, and holdings of foreign exchange under the control of monetary authorities. Gold holdings are excluded. Data are in current U.S. dollars.
Inflation	World Bank (2008)	Inflation is measured as the growth rate of the GDP implicit deflator which is defined as the ratio of GDP in current local currency to GDP in constant local currency.
De jure fixed exchange rates, dummy	Ghosh, Gulde and Wolf (2002) and own update based on AREAER	Equals one if one of the following finer categories applies: dollarized, currency board, monetary union, single currency peg, published basket peg and secret basket peg.
Domestic central bank assets	IMF (2008)	Domestic central banks assets are defined as the sum of the following items: claims on central government, claims on deposit money banks, claims on state and local governments, claims on nonfinancial public enterprises, claims on the private sector, claims on other banking institutions and claims on nonbank financial institutions. Since the majority of countries only reports data for the first two categories, central banks assets are narrowly defined as the sum of these two categories. The variable central bank assets (all), however, is the sum of all seven categories.
Real GDP	World Bank (2008)	Real GDP is measured as gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. Data are in current international dollars.
Currency crisis, dummy	Own calculations (see chapter 3)	The identification of a currency crisis is based on the exchange market pressure index described in chapter 3. A currency crisis is defined to occur if the index exceeds its mean plus two standard deviations. The dummy takes the value one in years with a currency crisis.

Appendix to chapters 2 to 4[71]
List of variables and data sources

Variable	Source	Description
Reserves	World Bank (2005a)	Net international reserves comprise special drawing rights, reserves of IMF members held by the IMF, and holdings of foreign exchange under the control of monetary authorities. Gold holdings are excluded. Data are in current U.S. dollars.
Real GDP per capita	World Bank (2005a)	GDP is measured as gross domestic product in constant international dollars with the year 2000 as base. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. This measure of GDP is divided by the population which counts all residents regardless of legal status or citizenship.
Trade openness	World Bank (2005a)	Openness is defined as the sum of exports and imports divided by GDP. Data are expressed in per cent.
Volatility (nominal)	World Bank (2005a)	Volatility is measured as the standard deviation of the previous five years of the growth rate of exports.
Volatility (real)	World Bank (2005a)	The alternative proxy for volatility uses exports measured as a capacity to import as its base variable. Exports as a capacity to import equal the current price value of exports of goods and services deflated by the import price index. Data are in constant local currency. Volatility is then calculated as the standard deviation of the previous five years of the growth rate of this measure of exports.
Total external debt (divided by GDP)	World Bank (2005a)	Total external debt is the sum of public, publicly guaranteed, and private nonguaranteed long-term debt, use of IMF credit, and short-term debt. Data are in current U.S. dollars divided by GDP.
Short-term external debt (divided by GDP)	World Bank (2005b)	Short-term external debt includes all debt that has an original maturity of one year or less. Data are in current U.S. dollars divided by GDP.

[71] The complete references to the data sources can be found in the chapters where the data are used.

Appendix (continued)

Variable	Source	Description
Real opportunity cost		Real opportunity cost is defined as the national real interest rate minus the real return of U.S. treasury bills.
• Real interest rate	World Bank (2005a)	The national real interest rate is calculated as the difference between the lending interest rate charged by banks on loans to prime customers and the inflation rate measured by the annual growth rate of the GDP implicit deflator which shows the rate of price change in the economy as a whole. The GDP implicit deflator is the ratio of GDP in current local currency to GDP in constant local currency.
• Real return of U.S. treasury bills	World Bank (2005a), IMF (2005)	The real return of US treasury bills is calculated as the difference of the rate of return of U.S. treasury bills (IFS line 60c) and the U.S. inflation rate measured by the annual growth rate of the GDP implicit deflator.
Fixed exchange rates (de jure), dummy	Ghosh, Gulde and Wolf (2002) and own update based on AREAER	Equals one if one of the following finer categories applies: dollarized, currency board, monetary union, single currency peg, published basket peg and secret basket peg.
Intermediate exchange rates (de jure), dummy	Ghosh, Gulde and Wolf (2002) and own update based on AREAER	Equals one if one of the following finer categories applies: cooperative system, crawling peg, target zone, unclassified rule-based intervention, managed float with heavy intervention, unclassified managed float and other floats.
Fixed exchange rates (de facto), dummy	Levy-Yeyati and Sturzenegger (2005)	Equals one if the category “fix” of the three-way classification applies.
	Reinhart and Rogoff (2004)	Equals one if one of the following finer categories apply: no separate legal tender, pre announced peg or currency board arrangement, pre announced horizontal band that is narrower than or equal to +/-2%, de facto peg.

Appendix (continued)

Variable	Source	Description
Intermediate exchange rates (de facto), dummy	Levy-Yeyati and Sturzenegger (2005)	Equals one if the category "interm" of the three-way classification applies.
	Reinhart and Rogoff (2004)	Equals one if one of the following finer categories apply: pre announced crawling peg, pre announced crawling band that is narrower than or equal to +/-2%, de factor crawling peg, de facto crawling band that is narrower than or equal to +/-2%, pre announced crawling band that is wider than or equal to +/-2%, de facto crawling band that is narrower than or equal to +/-5%, moving band that is narrower than or equal to +/-2%, managed floating.
M1	IMF (2008)	Money (line 34 IFS) is the sum of currency outside banks and demand deposits (excluding those of the central government). Data are in millions of current national currency.
M2	IMF (2008)	M2 is the sum of M1 and quasi money. Quasi money (line 35 IFS) is defined as the sum of time, savings and foreign currency deposits of residents (excluding the central government). Data are in millions of current national currency.
Interest rate (money market)	IMF (2008)	Money market rate (line 60b IFS): interest rate on short-term lending between financial institutions, measured in per cent.
Domestic credit	IMF (2008)	Domestic credit (line 32 IFS) comprises claims on the government (net), public enterprises and the private sector in the hands of the monetary authority or commercial banks. Data are in millions of national currency.
De jure capital mobility (Chinn-Ito)	Chinn and Ito (2002, 2006)	Measure of the de jure openness of the capital account. Calculation is based on the binary dummy variables of the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER).

Appendix (continued)

Variable	Source	Description
De jure capital mobility (Edwards)	Edwards (2007)	Index that combines the measures from Quinn (2003) and Mody and Murshid (2005) [both are based on the information provided by the AREAER] and information from country-specific sources
Financial integration	Lane and Milesi-Ferretti (2007)	Sum of total external assets and liabilities divided by GDP.
Economic globalization	Dreher (2006)	Index based on actual flows of goods and capital and restrictions concerning these flows.
Net capital flows	IMF (2008)	Financial account (IFS line 78bjd) is defined as the difference of net capital inflows (investment from foreigners in the domestic economy) and net capital outflows (investment from domestic residents abroad). It comprises direct investment, portfolio investment, financial derivatives and other investment.
Currency crisis, dummy	Own calculations (see chapter 3)	The identification of a currency crisis is based on an exchange market pressure index as described in chapter 3. A currency crisis is defined to occur if the index exceeds its mean plus two standard deviations. The dummy takes the value one in years with a currency crisis.

L e b e n s l a u f

Persönliches

Name	Andreas Steiner
Geburtsjahr	1975
Geburtsort	Urach, heute Bad Urach
Familienstand	verheiratet, ein Kind
Staatsangehörigkeit	deutsch

Schulausbildung und Zivildienst

09/86-07/95	Graf-Eberhard-Gymnasium, Bad Urach, Abitur
08/95-08/96	Zivildienst auf Station der Medizinischen Universitätsklinik in Tübingen

Studienverlauf und Promotion

10/96-03/00	Diplomstudiengang Volkswirtschaftslehre mit Schwerpunkt Regionalstudien Südamerika an der Universität Tübingen; Vordiplom Oktober 1998.
04/00-09/02	Diplomstudiengang Volkswirtschaftslehre an der Universität Mannheim, Abschluß als Diplom-Volkswirt.
10/02-03/09	Promotionsstudent am Zentrum für wirtschaftswissenschaftliche Doktorandenstudien (CDSEM bzw. CDSE) der Universität Mannheim.
04/04-03/09	Wissenschaftlicher Mitarbeiter am Lehrstuhl von Professor Dr. Roland Vaubel.

Auslandsaufenthalte

09-12/98	Studium an der Faculty of Economics der University of Edinburgh/Schottland.
03-12/99	Studium an der Facultad de Economía der Pontifícia Universidad Católica in Santiago de Chile.

Ehrenwörtliche Erklärung

Hiermit erkläre ich ehrenwörtlich, dass ich die Dissertation selbständig angefertigt und mich anderer als der in ihr angegebenen Hilfsmittel nicht bedient habe. Entlehnungen aus anderen Schriften sind ausdrücklich als solche gekennzeichnet und mit Quellenangaben versehen.

Mannheim, den 05. März 2009