Reserve Accumulation and Financial Crises: From Individual Protection to Systemic Risk

Andreas Steiner*
University of Osnabrueck
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Abstract This paper provides a new perspective on the relationship between countries’ international reserve holdings and financial crises: While the local view holds that reserves may prevent domestic crises, their accumulation might destabilize the international financial system in the long run and cause a global crisis. The local view overlooks that the accumulation of reserves relaxes the financing constraint of the reserve currency country and may cause a financial crisis, which is transmitted globally. Since the crisis affects all countries alike, the accumulation of reserves imposes a negative externality on non-accumulating countries. We integrate this idea in a theoretical model of the optimal amount of reserves and illustrate the gap between local and global optimality: The consideration of systemic risk lowers the demand for reserves. Moreover, if a supranational authority determines the optimal level of reserves, it internalizes the negative externality and accumulates fewer reserves. A macroprudential tax on reserve hoardings might implement the socially optimal solution.

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*Address: University of Osnabrueck, Institute of Empirical Economic Research, Rolandostrasse 8, D-49069 Osnabrueck, Germany, e-mail: asteiner@uni-osnabrueck.de. The author would like to thank Joshua Aizenman and Joachim Wilde for their helpful comments and suggestions.
1 Introduction

Central banks’ hoardings of international reserves are considered as a form of self-protection against financial crises. They enable central banks to intervene in the foreign exchange market and help to cushion the economy from external shocks. This paper turns the tables and shows that the accumulation of reserves might also have a flip-side: Whereas large reserve holdings may indeed protect a country from domestic crises, their accumulation increases the instability of the international financial system and might cause a global crisis emanating from the reserve currency country. In the end, central banks’ attempt to insure against financial crises via the accumulation of reserves may be counterproductive. Good intentions may result in bad outcomes.

The idea is motivated by the global financial crisis that began as the US subprime crisis in 2007 and affected the rest of the world through trade and financial linkages. In this regard it has been noted that global imbalances have increased the vulnerability of the US (i.e. Ferguson and Schularick, 2011; IMF, 2009; Portes, 2009; Aizenman, 2010; Obstfeld and Rogoff, 2010). Global imbalances, in turn, have been partly sustained by central banks’ accumulation of reserves, especially in Asian emerging markets. By implication, the accumulation of reserves has contributed to developments in the US, that eventually turned into a global crisis.

The recurrence of financial crises in the recent past questioned the benefits of the increasing international financial integration and challenged countries to find ways how to protect the domestic economy from the downside risks of financial openness. Many countries faced this challenge by the accumulation of foreign reserves. Since the East Asian financial crisis of 1996-97 the worldwide level of real reserves has more than tripled. Reserves are considered as a precautionary cushion against the risks of financial openness, namely sudden stops of capital flows and contagious financial crises. Their function includes both crisis prevention and crisis management (see Aizenman and Lee, 2007; Obstfeld et al., 2010).

This unprecedented increase in international reserves also reflects previous advice given to emerging and developing countries by various sources. In the aftermath of the Asian financial crisis the IMF emphasised the importance of reserves as a means of crisis prevention and proposed new measures to evaluate their adequacy (IMF 2000). Feldstein (1999) advised emerging markets to rely on large foreign exchange reserves as a form of self-protection and to count less on assistance by the IMF. Finally, the burdensome conditionality and unpredictability of IMF assistance may have contributed that many countries prefer to self-

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1There exist other reasons why countries hoard reserves. The mercantilist approach, for example, argues that the accumulation of reserves is the by-product of an export-led growth strategy. This paper, however, focuses on the relationship between reserves and crises.
insure (see Bird and Mandilaras, 2011).

The accumulation of reserves, however, contains costs that have been neglected so far: While reserves might effectively protect the domestic economy from external shocks, their global and continuous accumulation might create systemic risks. Since the accumulation of reserves constitutes a capital inflow to the reserve currency country, it increases its external indebtedness. This may create the macroeconomic backdrop for a sovereign debt crisis, a currency crisis or a banking crisis. A crisis in the center country, however, destabilize the international financial system. Since the reserve currency country is per definition at the centre of the international financial system, a crisis originating there spreads to other countries and causes a global downturn. This crisis affects accumulating and non-accumulating countries alike. Hence, the accumulation of reserves has a negative externality.

This reasoning is related to the Triffin dilemma, which - in its original version - states that it is impossible for the US to fix the dollar value in terms of gold and to satisfy an increasing demand for dollar reserves. In its modern version, the Triffin dilemma implies that the objectives of providing sufficient reserves to the rest of the world and of maintaining a stable value of the reserve currency are mutually inconsistent.

The accumulation of reserves might induce two types of crises: First, it might lead to overborrowing and overinvestment in the reserve currency country and cause a financial crisis when expectations worsen or the reserve accumulation ends. Second, by steadily worsening the net foreign asset position of the reserve currency country, it might result in a currency crisis where the reserve currency country deliberately decides to devalue its currency. Whereas the first type of crisis follows the lines of the financial crisis of 2008-10, the second type also has its precedent, namely the breakdown of the Bretton Woods system.

A dilemma arises: On the one hand, the recent reserve accumulation is partly due to concerns for financial stability in a financially globalised world (see Obstfeld et al., 2010). On the other, policies of reserve accumulation exactly expose the system to additional risks and shocks. Hence, the blessing attributed to the accumulation of reserves might become a curse.

The relationship between reserve accumulation and systemic risk creation has been identified only recently (see Ferguson and Schularick, 2011; Gourinchas et al., 2010; IMF, 2010; Obstfeld and Rogoff, 2010). This paper extends the preceding literature in several dimensions: First, the line of causality from reserve accumulation to a global financial crisis is

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2Triffin (1960, p.87) concludes that "the use of national currencies as international reserves constitutes indeed a "built-in destabilizer" in the world monetary system".

3This is an example of the law of unintended consequences, which was popularised by Robert K. Merton: Any intervention - in our case a central bank intervention - creates unanticipated and undesired outcomes. In the end, the intended solution may aggravate the problem.
traced both on empirical and theoretical grounds. Second, the paper integrates the idea of negative feedback in a model of the demand for reserves and formalizes the difference between local and global optimality. It solves for the first best policy chosen by a social planner that internalises the externality associated with local optimality.

This paper is organized as follows. The next section elaborates on the link between reserves and financial crises, both on theoretical and empirical grounds. The model and its solution are presented in section 3. Section 4 discusses the policy implications of our findings. Concluding remarks are offered in Section 5.

2 Reserves and crises: the links

This section illustrates the links between central banks' international reserve holdings and the probability of financial crises. In this context it is important to distinguish between domestic and global crises. A global crisis is defined here as a crisis that originates in one country - the centre country - and spreads to a number of countries due to their real and financial linkages with the crisis country. As will be shown later, the reserve currency country is particularly vulnerable to trigger a global financial crisis.

2.1 Reserves and domestic crises

Theoretical models and empirical findings with respect to the link between the level of international reserves and currency crises show that reserves reduce both the probability and severity of domestic financial crises.

In the first generation of currency crisis models 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 devaluation crisis when reserves have fallen below some critical value (e.g. Krugman, 1979, and Flood and Garber, 1984). Hence, reserves can avoid a crisis when the policy inconsistency is transitory. Otherwise, reserves can postpone the occurrence of a crisis and provide a time buffer within which domestic policies can be reconciled with the exchange rate commitment. Models of the second generation emphasize that crisis expectations might become self-fulfilling. Reserves may signal government’s ability and willingness to defend the exchange rate and prevent a speculative attack. Another strand of the crisis literature stresses the fragility of balance sheets in the presence of currency mismatches. Reserves reduce these mismatches at the country level and might be used to support the banking and corporate sector during balance sheet crises.
Accordingly, the literature traditionally derives central banks’ demand for reserves from the benefits they provide in the face of shocks: Reserves might be used to smooth economic adjustment processes in the face of external shocks (Heller, 1966) and to prevent financial and sovereign crises (Ben-Bassat and Gottlieb, 1996). Theoretical models show that reserves help to smooth consumption intertemporally in the presence of productivity shocks (Aizenman and Marion, 2004) and mitigate the output effects of liquidity shock (Aizenman and Lee, 2007). Li and Rajan (2009) show in a theoretical model that high reserves may offset the negative impact of moderately weak fundamentals and prevent speculative attacks on the currency. According to Jeanne and Rancière (2011) the optimal amount of reserves for a small open economy increases with the probability and size of a sudden stop in capital flows.

Although these models differ considerably, they coincide in the view that reserves might be hoarded to reduce the incidence and the cost of financial crises. These theoretical results are confirmed by a series of empirical papers.

In a meta-analysis Frankel and Saravelos (2010) review more than 80 papers of the literature on early warning systems for currency crises. They find low central banks’ reserves to be the most reliable warning indicator including the crisis of 2008-10. Concerning the depth of a crisis once it materializes, De Gregorio and Lee (2004) and Aizenman et al. (2011) demonstrate that reserves reduce the output costs of a crisis. Obstfeld et al. (2009) and Fratzscher (2009) note that low reserves are associated with larger depreciations during the crisis of 2008-10.4

Based on these theoretical and empirical findings and in line with the literature (see Aizenman and Marion, 2004, and Jeanne, 2007) we assume that the probability of a local financial crisis \( p_L \) in country \( i \) decreases in the level of reserves \( R \). Since the effect of reserves depends on the potential volume of capital flight, reserves are scaled by the level of external debt \( B \) :

\[
p_L = \phi + \alpha_i \frac{B_i}{R_i}, \quad \alpha_i > 0, \quad 0 < p_L < 1
\]  

where the index \( i \) indicates that all variables and coefficients may be country-specific. \( \phi \) captures all other factors that influence the probability of a crisis and which, for the sake of simplicity, are taken as constant in our analysis. A crisis is defined in general terms as a fall in output as the consequence of a currency, banking or sovereign debt crisis.6

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4Frankel and Saravelos (2010, p.27) conclude that "the results lend credence to the usefulness of reserve accumulation policies as insurance during periods of crisis." Alike, Obstfeld et al. (2009, p.483) state that "international reserves did provide effective insurance against currency instability, for advanced and emerging countries alike."

5Besides the level of external debt, its maturity composition is found to be an important crisis indicator with a high level of short-term debt being considered to be harmful. Since our model focuses on one period, we do not make a distinction between long-term and short-term external debt.

6The output drop in a crisis may be explained by the costly liquidation of investment projects (see Chang
The same relationship holds for the reserve currency country, which is denoted by $C$. It is true that the reserve currency country suffers less from a currency mismatch because part of its foreign liabilities are denoted in its own currency. Confidence in the reserve currency, however, is linked to the amount of foreign liabilities relative to collateral in the form of reserves held by the reserve currency country.\(^7\) A loss of confidence may restrict the reserve currency country’s access to external credit, cause capital flight and end in a crisis in the center country.

Due to international business cycle correlation and contagion (see Eichengreen et al., 1996, and Kose et al., 2003), a crisis in the center country increases the crisis probability in the countries of the periphery.\(^8\) We assume that a crisis in the center is transmitted to the periphery with an impact coefficient of $\lambda$ with $0 < \lambda < 1$. Hence, the probability of both a local or globally-transmitted crisis $p^{LG}$ in country $i$ is given by

$$p^{LG}_i = p^L_i + \lambda p^{LC}_i = \phi^L_i + \alpha_i \frac{B_i}{R_i},$$

where $\phi^{LG}_i = \phi^L_i + \lambda \left( \phi^{LC}_i + \alpha_C \frac{B_i}{R_i} \right)$. In this stage of the analysis we assume that the decisions of the center country with respect to its level of external debt and reserves are exogenous variables for the periphery.

### 2.2 Reserves and crises in the reserve currency country

This section discusses the argument that the virtue of being the provider of the world’s reserve currency - often referred to as an exorbitant privilege \(^9\) - destabilizes the economy of the reserve currency country.

Changes in reserve hoardings in the rest of the world induce a counter entry in the balance of payments of the reserve currency country: Any dollar accumulated by the rest of the world represents external debt of the US. If the accumulation of reserves implied an increasing level of external debt of the reserve provider, it might endanger its financial stability. This section examines this concern.

According to the balance of payments constraint, the change in international reserves ($R$)

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\(^7\)Alternatively, one may argue that the reserve currency is backed by GDP or fiscal capacity of its issuer.

\(^8\)Reinhart and Kaminsky, 2008, and Reinhart and Rogoff, 2008, document that crises spread globally when they emanate from financial center countries.

\(^9\)Gourinchas et al. (2010) note that this privilege comes at the cost of an exorbitant duty: The United States provides insurance to the rest of the world during crisis episodes. This insurance comes in the form of a transfer of wealth since the United States suffers valuation losses in its assets during crises. The costs analysed in this paper, however, are of a different nature.
equals the sum of the current account balance (CA) and the capital account balance (KA):

\[ \Delta R = CA + KA \] (3)

Assume without loss of generality that the reserve currency country holds its stock of reserve assets constant. Then an increase of reserves in the rest of the world (\( \Delta R_{ROW} \)) increases external liabilities of the reserve currency providing central bank, which corresponds to a decrease of its reserves. For the reserve currency country, equation (3) can be reformulated as

\[ -\Delta R_{ROW} = CA_C + KA_C \] (4)

This expression shows that the accumulation of reserves in the rest of the world may be financed by a current account deficit or a deficit in the capital account. However, if reserves are accumulated via a deficit in the capital account (private capital outflows), external net positions of both countries are unaffected. Hence, this form of reserve accumulation might be ineffective in reducing country vulnerability in countries of the periphery. Consequently, it is true that the reserve-providing country has to run a current account deficit when the rest of the world wants to accumulate net dollar assets. A current account deficit, however, corresponds to an equal increase in external debt.

Empirically, the current account deficit of the US - the center of the current international monetary system - has been persistent and accounted for 56% of the global deficit over the period 1996-2009. Moreover, Figure 1 shows that a substantial part of her current account deficit has been financed through the purchase of reserves by foreign central banks. To this end, it compares the US current account deficit with the global change in dollar reserves.\textsuperscript{10}

Accordingly, if the rest of the world accumulates net reserves, the level of net external debt of the reserve currency country increases:

\[ \Delta B_C = \Delta B_C^{pr} + \Delta R_{ROW} \] (5)

\textsuperscript{10}Given that not all reserves are denoted in US dollars and that central banks disclose their reserve composition on a voluntary basis, the change in dollar reserves is estimated on the basis of data taken from the COFER database of the IMF. It provides the currency composition of official foreign exchange reserves of a fraction of total world reserves (57% in 2009). For any given year we assume that the sample is representative in the sense that the global reserve composition equals the reserve composition of those countries disclosing it. Hence, for a given year the amount of reserves denominated in dollars is calculated as the worldwide level of reserves excluding the US multiplied by that year’s dollar share in reserves. The change in this variable between two consecutive years is the change in dollar reserves.
where $B_{pr}^C$ denotes privately held external debt of the reserve currency country (outside of the central bank). As emphasized before we do not allow that any increased supply of reserve assets be offset by a decrease in $B_{pr}^C$ because we examine the case of a demand for net reserves. Hence, $B_{pr}^C$ can be set constant. After expressing (5) in levels and plugging it in (1), the crisis probability in the reserve currency country can be expressed as:

$$p_C^L = \phi_C^L + \alpha_C \frac{B_{pr}^C + R_{ROW}}{R_C} \quad (6)$$

As a result, the fragility of the reserve currency country is a positive function of the demand for reserves in the rest of the world.

Besides this direct effect, there exist additional arguments explaining why the accumulation of reserves may increase instabilities in the reserve currency country. Although these are not integrated explicitly in our model, we summarise them in the following section.

**Instability due to lower interest rates.** In comparison to the rest of the world, the reserve currency country faces an additional demand for its loans: Besides private foreign lenders, foreign central banks provide loans to the center country equal to the amount of hoarded reserves. In line with a simple demand-supply framework, both the amount of debt and the price of loans are higher than without the reserve currency characteristic.\(^{11,12}\) Low interest rates, in turn, create incentives for higher deficits and debt. Policy discipline is weakened and instabilities may result (see Daniel, 2001).

**Instability due to the relaxation of the sovereign credit ceiling.** The accumulation of international reserves in the form of Treasury bonds is basically a form of lending to the sovereign of a foreign country.\(^{13}\) In order to make repayment incentive compatible maximal lending is constrained by a credit ceiling. Under the special circumstances of a reserve currency country the credit ceiling might be eased for several reasons. First, lenders might disregard the ceiling because they do not consider the purchase of reserves as an investment. They rather think of reserve purchases as buying an insurance to prevent and manage financial crises. This behaviour is corroborated by the observation that the hoarding of reserves is insensitive to its return (see Krishnamurthy and Vissing-Jorgensen, 2010). Second, sequential

\(^{11}\)Korinek (2011) argues that the hoarding of reserves may be modelled as an increased supply of credit, which makes the world riskier in his model.

\(^{12}\)Warnock and Warnock (2009) and Krishnamurthy and Vissing-Jorgensen (2010) suggest a substantial reduction in US long-term interest rates due to official purchases of US government bonds by foreigners. The latter examine how US Treasury yields would react to a sale of all foreign official Treasury holdings. They estimate an increase of US Treasury yields between 41 and 60 basis points depending on the specification and maturity of the Treasuries. These findings are qualitatively confirmed by Kitchen and Chinn (2011). Using consensus projections for the US they find that the share of foreign holdings in total Treasuries has to rise from current 25% to 45% if interest rates are to be stabilized at around 5.5%.

\(^{13}\)The share of foreign official holdings in total Treasury debt securities outstanding has risen from 6% in 1970 to an unprecedented value of 40% in 2009.
lending from multiple sources involves the danger of overlending. Because countries continuously adjust their hoardings of international reserves, lending is rather sequential than a one-time operation. Sequential lending from multiple sources may lead to debt dilution, i.e. the devaluation of existing debt. Since each unit of additional debt increases the probability of default, it imposes a negative externality on overall external debt. Because this effect is not internalised in the price of debt, a social planner would restrict lending to lower levels. From the perspective of an individual country it is rational to neglect the credit ceiling. In this case, however, default is optimal for the borrowing country. This, however, might not hold for the reserve currency country since a default causes additional costs in the form of loosing its reserve currency status.

Instability due to a risk mismatch. Caballero and Krishnamurthy (2009) stress that global imbalances can be interpreted as the result of an imbalance in the supply of save assets: Capital inflows to the US have been sustained by the rest of the world’s demand for a safe store of value. This not only contributes to global imbalances, but also leads to a concentration of risky assets in the US.\footnote{See also Gourinchas and Rey (2007).}

\subsection{2.3 Reserves and global crises}

The previous section has shown that central banks’ desire for larger stocks of reserves increases the risk of a financial crisis in the reserve currency country. After plugging (6) in (2), one gets the revised probability for a local and globally-transmitted crisis in a non-reserve currency country as

\[ p_i^{LG} = \phi_i + \alpha_i \frac{B_i}{R_i} + \beta \frac{R_{ROW}}{R_C} \]

where \( \beta = \lambda \alpha_C \) and \( \phi_i = \phi_i^L + \lambda (\phi_C^L + \alpha_C \frac{R_{ROW}}{R_C}) \). As a consequence, besides their crisis-preventing effect at the domestic level, reserves increase the likelihood of a global crisis.\footnote{This is an example of a fallacy of composition: Policies that enhance the stability of each individual country need not necessarily benefit the stability of the entire system (Morris and Shin, 2009).} Analytically, the level of external debt of the reserve currency is a function of the demand for reserves by the rest of the world. The probability of a crisis in the center country is endogenous to the demand for reserves in the rest of the world.

The existing literature on the demand for reserves focuses on the benefits of reserves in the form of a lifejacket against crises. At the same time, it disregards the global effects of reserve accumulation. It does not take into account that exactly the desire for self-insurance might overturn the ship. The main arguments of this modified cost-benefit analysis are summarized in Figure 2. This paper is the first to incorporate the idea of rising official
reserves causing global financial crises in an existing model of the demand for reserves.

[Figure 2 about here.]

3 The optimal amount of reserves

This section presents a model of the demand for reserves, which will be used as the basis of our analytical considerations. The conclusions apply to a representative reserve-hoarding country. The basic structure follows the model introduced by Aizenman and Marion (2004) and its simplified version, which is provided by Cheung and Qian (2009). We introduce the notion of reserves causing systemic risk to this framework and compare the results with the benchmark model. Two effects are shown: First, if the accumulation of reserves causes global crises, the optimal level of reserves is lower than in the benchmark case, which disregards global crises. Second, the optimal amount of reserves is further reduced if the negative externality of reserve accumulation on other countries is internalised.

At this point it should be mentioned that the literature provides alternative approaches to determine the optimal amount of reserves. Examples are the cost-benefit approaches of Ben-Bassat and Gottlieb (1992) and Jeanne and Rancière (2011). All approaches share the characteristic that they focus on domestic variables and disregard interdependencies among countries’ reserve policies.\(^\text{16}\) While this paper has chosen the framework of Aizenman and Marion (2004) to illustrate the effect of interdependencies, their consideration within alternative approaches would lead to similar qualitative results.

3.1 Setup

We consider an extension of a standard model of a two-period economy, in which second period output is uncertain. The economy can intertemporally optimize its consumption path through borrowing and lending on the international capital market. In addition to the standard model there is a role for international reserves: They affect utility through an indirect transmission channel: Reserves determine the likelihood of a financial crisis and since a financial crisis depresses output, they indirectly influence income. Consumption smoothing via international debt has the negative side effect that international debt is positively related to the likelihood of a financial crisis. Hence, the level of foreign debt and the amount of reserves are the result of a joint decision.

\(^{16}\)An exception is Cheung and Qian (2009) who analyse the Joneses effect, namely that countries reserve levels depend positively on the level of their peers.
As long as we consider a representative economy, the country index $i$ is omitted. In the
first period, the economy’s output is $Y_1$ which is normalized to 1. The output of the second
period is uncertain: Either a positive productivity shock increases output by an amount of
$\delta$ or the economy suffers a financial crisis that depresses output by an amount of $\epsilon$. The
probability of a local financial crisis is given by $p^L$ as defined by (1). Hence,

$$Y_2 = \begin{cases} 1 + \delta & \text{with probability } 1 - p^L \\ 1 - \epsilon & \text{with probability } p^L \end{cases} \quad \delta, \epsilon > 0 \text{ and } 0 < p^L < 1. \quad (8)$$

In the first period the economy allocates output ($Y_1$) among consumption ($C_1$), interna-
tional borrowing ($B$) and international reserve accumulation ($R$):

$$C_1 = 1 + B - R \quad (9)$$

Since the economy may default in the second period, it faces a credit ceiling. The ceiling
is determined by the incentive compatibility condition: Lenders will only provide credits up
to an amount where the contractual repayment equals the expected cost of default. If the
repayment were larger than the penalty, lenders would have an incentive to default. Let us
assume that the international lender can confiscate a fraction of the output in period 2, given
by $\theta Y_2$ with $0 < \theta < 1$. Reserves, in turn, are beyond the reach of international creditors and
can be used even after a country has defaulted. The repayment in period 2 is then given by

$$S = \text{MIN}[(1 + r)B; \theta Y_2], \quad (10)$$

where MIN is the minimum operator. The country’s interest rate for international borrowing
($r$) is determined such that the expected return on international credits equals its risk-free
return:

$$E[S] = (1 + r^f)B \quad (11)$$

where $r^f$ is the risk-free interest rate.\(^{17}\) The credit ceiling $\bar{B}$ is hence given by the condition
that the expected repayment equals the confiscated output when the debt induces default

\(^{17}\)In this paper we do not model the effects of reserve demand on the interest rate and risk-taking behaviour
in the reserve currency country. If a foreign central bank accumulates reserves and sterilizes the effect on
the domestic monetary base, the accumulation of reserves constitutes a swap of domestic bonds for foreign
bonds. Hence, the interest rate of reserve currency bonds falls because bonds are imperfect substitutes. This
corresponds to the theoretical results of Korinek (2011) and Warnock and Warnock (2009). Lower interest
rates increase the credit ceiling $\bar{B}$, which again raises the probability of a currency crisis according to (1). As
a consequence, the accumulation might have an additional negative feedback effect. While we do not account
for this effect in our analysis, it would only strengthen our argument for lowering the level of reserves.
both after positive and negative output shocks:

\[
\bar{B} = \frac{(1 - p^L)\theta(1 + \delta) + p^L\theta(1 - \epsilon)}{1 + r^f} = \frac{\theta(1 + \delta) - p^L\theta(\delta + \epsilon)}{1 + r^f}
\] (12)

Assume that the economy does not default on its external debt obligations when it is hit by a positive productivity shock. The probability to default in the midst of a financial crisis is given by \(q\).\(^{18}\) Furthermore, reserves earn an interest rate of \(r^f\) and accumulated reserves are spent in period 2 since this is the last period. The budget constraint of period 2 then reads as

\[
C_2 = \begin{cases} 
C_{2,g} = 1 + \delta - (1 + r)B + (1 + r^f)R & \text{with probability } 1 - p^L \\
C_{2,c} = 1 - \epsilon - (1 + r)B + (1 + r^f)R & \text{with probability } p^L(1 - q) \\
C_{2,c,d} = (1 - \theta)(1 - \epsilon) + (1 + r^f)R & \text{with probability } p^Lq
\end{cases}
\] (13)

where the indices \(g, c\) and \(d\) stand for the good state, crisis state and default, respectively.

In order to focus on a single first order condition, we assume in line with Aizenman and Marion (2004) that foreign debt reaches the credit ceiling, \(B = \bar{B}\).\(^{19}\) As a consequence, \(B(1 + r)|_{B=\bar{B}} = \theta(1 + \delta)\). The expected utility is then given by

\[
U(.)|_{B=\bar{B}} = (1 + \bar{B} - R) + \frac{1}{1 + \rho} \left[ (1 - \theta)(1 + \delta) + (1 + r^f)R - p^L(1 - q\theta)(\delta + \epsilon) \right]
\] (14)

where \(\rho\) is the individual discount rate. Government chooses the levels of foreign debt and reserves such that the expected utility is maximised given the budget constraints (9) and (13) and the probability of a financial crisis (1). The first order condition with respect to \(R\) then reads as:

\[
1 - \frac{dB}{dR}|_{B=\bar{B}} = \frac{1}{1 + \rho} \left[ (1 + r^f) - (1 - q\theta)(\delta + \epsilon) \frac{dp^L}{dR} \right]
\] (15)

This equation can be interpreted as follows: The left-hand side represents the costs of a marginal unit of reserves which are given by the difference between the resources withdrawn from consumption and the additional external debt granted thanks to an increase of the credit ceiling. The right-hand side illustrates the benefits of a marginal unit of reserves,

\(^{18}\)It is assumed that \(q\) is not impacted by the level of reserves. If international creditors can confiscate reserves after default, higher reserves would raise the credit ceiling but not affect the probability of default (at the limit with \(B = \bar{B}\)). If reserves lower the probability of default for reasons not considered in the model, reserves had an additional benefit and their optimal level would be higher. This would increase the negative externality of reserves on other countries and strengthen our argument. The assumption that default occurs independently of the level of reserves might be a realistic assumption if one considers actual defaults like Greece 2011, where reserves were beyond the reach of international creditors.

\(^{19}\)This is the case for a high discount rate \(\rho\).
namely additional interest income and a reduced crisis probability. After calculating the partial derivatives and plugging them in, one obtains

\[
\left[ (1 + r^f)R + \alpha \theta (\delta + \epsilon) \right]^2 = \\
\frac{(\delta + \epsilon) \left[ (1 + r^f)(1 - q\theta) + \theta (\rho - r^f) \right] [\alpha \theta (1 + \delta) - \alpha \theta \phi (\delta + \epsilon)]}{(\rho - r^f)D}
\]

(16)

This equation can be solved for R. However, for following sections this representation turns out to be convenient as a benchmark for comparisons. In subsequent sections, the left-hand side term is referred to as A, the right-hand side term as D. This equation shows that the optimal amount of reserves depends positively on the output cost of a financial crisis \((\delta + \epsilon)\) and negatively on the opportunity cost of reserves \((\rho - r^f)\).

### 3.2 Behaviour of the reserve currency country

For simplicity we assume that the behaviour of the reserve currency country can be described by the equations in the previous section. Its status as reserve currency provider may be grounded on a low crisis probability \(\phi^L_C < \phi^L_I\) and strong rule of law with high contract enforceability such that entire output may be confiscated in a default \((\theta_C = 1)\). Consequently, its credit ceiling is higher as in the other economies and it can borrow on international markets at the risk free interest rate \(r^f\). Its crisis probability is given by (6).

Before we may conclude that the international demand for reserves increases the crisis propensity in the reserve currency country, two caveats have to be solved: (1) The reserve currency country might increase its reserves holdings such that the effect of an increase in external debt on the crisis probability is offset. While an accumulation of other reserve currencies is excluded by the assumption that the rest of the world wants to acquire net reserves, the reserve currency country might increase its gold holdings.\(^{20}\) (2) The credit ceiling, given by (12), equally applies to the reserve currency country. This ceiling corresponds to the maximum level of reserves, which the reserve currency country can provide to the rest of the world. If the worldwide demand for reserves exceeds the credit ceiling, a dilemma arises: Either the level of reserves in the rest of the world is sub-optimal or reserve-accumulating countries have to neglect the credit ceiling of the reserve provider.\(^{21}\)

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\(^{20}\)In this case, the current account deficit does not reflect the net import of consumption goods, but net imports of gold.

\(^{21}\)In fact, there was a vivid debate in the 1960s and early 1970s whether there is a lack of international liquidity (for a literature survey see Williamson, 1973). To increase the supply of reserves, SDRs were created.
To answer the first question, we derive the response of the optimal level of reserves to changes in external debt. For the benchmark case where the return of reserves \( (r_f) \) equals the time preference \( (\rho) \), the optimal level of reserves is independent of the level of external debt. Hence, if the rest of the world increases its reserves, the reserve currency country has no incentive to catch up. Consequently, the accumulation of reserves in the rest of the world increases the crisis probability in the center country.

To explore the question whether the provision of reserves is restricted by the credit ceiling, we investigate how the ceiling may be raised. It can be shown that \( \frac{dR}{dB} > 1 \). Hence, theoretically any demand for reserves can be satisfied if the reserve currency country invests part of the borrowed resources in reserve assets. However, as shown above, the reserve currency provider has no incentive to increase its own reserve assets in line with provided reserves to the rest of the world.

In sum, the stronger the demand for reserve assets, the higher the crisis probability in the center country. One may argue that in a rational model of reserve accumulation, the rising default risk of the center country is reflected by an increase in the interest rate on reserves. Given this price signal, the accumulating countries demand even more reserves because their opportunity cost has fallen (decrease in \( (r - r_f) \)). As a consequence, the price mechanisms does not work in this case and an endogenous response in \( r_f \) would even strengthen the negative externality argument of the model.

### 3.3 Local and global crises

Besides local crises, output may also be depressed by a global financial crisis. Whereas the probability of a local crisis depends on domestic fundamentals (as described by equation (1)), a global crisis is assumed to have its origin in the reserve currency country.

For the sake of simplicity it is assumed that there exist only two countries besides the reserve currency country.\(^{22}\) These countries, home and foreign, are identical and denoted by \( H \) and \( F \), respectively.

The modified probability of a financial crisis in the home country, both a local and a global one is given by (7):

\[
p_H^{LG} = \phi_H + \alpha_H \frac{B_H}{R_H} + \beta(R_H + R_F),
\]

where the change in reserves in the rest of the world is replaced by the reserve demand in

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\(^{22}\) An extension that allows for more countries would only inflate the mathematical presentation, but not affect our basic results. Alternatively, if one relaxes the assumption of equal size, the second country may be regarded as the rest of the world except the reserve currency country.
our two reserve-accumulating countries \( R_{ROW} = R_H + R_F \) and the level of reserves in the reserve currency country is normalised to one.

This three-country-model may represent the current constellation with the US at the centre and two periphery regions, namely the emerging markets as the reserve-accumulating countries (Home) and industrialised countries (Foreign), which maintain stable levels of reserves. In this interpretation, the reserve-accumulating emerging markets impose a negative externality on the industrialised countries because their behaviour increase the probability of a global crisis.

The credit ceiling, the budget constraints (consumption equations), expected utility and the first order condition correspond to the respective equations of the benchmark case (section 4.1) where \( p^L \) is replaced by \( p^{LG} \). For simplicity, it is assumed that \( \alpha_H = \alpha_F = \alpha \). The cost of a global crisis is equal to the cost of a local crisis, namely \( (\delta + \epsilon) \). After computing the partial derivatives and substituting them into the first order condition, one obtains the expression for the optimal amount of reserves:

\[
A = D + \frac{(\delta + \epsilon)}{(\rho - r_f)}\left[ (\theta - 1)\beta R_H [R_H(1 + r_f)^2 + 2\alpha \theta (\rho + \epsilon)] - 2\alpha \beta \theta R_H (1 + \rho \theta)(\rho + \epsilon) \\
- \beta \theta (R_H)^2 (1 + \rho)(1 + r_f) - \alpha \beta \theta R_F (\delta + \epsilon)^2 [1 - \theta](1 + r_f) + \theta (1 + \rho)\right] 
\]

(18)

where R is replaced by \( R_H \) in A and D. The terms after D on the right-hand side are called E. This quadratic expression in \( R_H \) might be solved for \( R_H \). However, since we focus on qualitative effects, we compare this expression with equation (16) of the benchmark model. It turns out that the optimal amount of reserves is clearly lower when the probability of a global crisis is taken into account. It is the lower, (1) the larger the effect of reserve accumulation on the probability of a global crisis (large \( \beta \)) and (2) the stronger the mitigating effect of reserves on the probability of a local crisis (large \( \alpha \)).

High costs of a crisis increase the reduction in the level of reserves. Finally, the more reserves the foreign country has accumulated (high \( R_F \), which is taken as exogenous), the lower the optimal level of reserves in the home country. This is contradictory to empirical evidence, where competitive hoarding induces countries to increase their reserves if neighbours do so (see Cheung and Qian, 2009). Hence, from a perspective of systemic risk, countries’ reserve policy is far from optimal.

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\(^{23}\)This result can be explained as follows: The larger \( \alpha \) is, the stronger is the positive effect of higher reserves on the crisis probability in the center country. This effect overcompensates the negative impact of reserves on the probability of a domestic crisis.
3.4 Global social planner

The analysis so far has focused on an individual country choosing the utility-maximizing level of reserves. If it accumulates reserves, it increases the probability of a global financial crisis. In contrast to the benchmark model, the monetary authority takes the negative effects of a global crisis on domestic income into account. However, it disregards that a global crisis also lowers income in other countries. In other words, when choosing its reserve level, a country neglects the negative externality its reserve accumulation imposes on other countries.

This behaviour is more probable if the number of reserve-accumulating countries is large. If there are only some large players they have an incentive to recognise the negative externality.

This section analyzes the solution of a global social planner that internalises the negative externality.\textsuperscript{24} Assume that the social planner maximizes the joint utility of both countries. Joint second period income is given by

\[
Y_{HF,2} = \begin{cases} 
2(1 + \delta) & \text{with probability } 1 - p^{LG} \\
2(1 - \epsilon) & \text{with probability } p^{LG}
\end{cases}
\]

(19)

where the index $HF$ (home - foreign) indicates that the sum of a variable over both countries is considered. Furthermore, $B_{HF} = 2B$. As a consequence, the joint credit ceiling of the two countries is given as $\bar{B}_{HF} = 2\bar{B}$ where $\bar{B}$ is defined by equation (12). As before, one obtains the expression for the optimal level of reserves after computing the partial derivatives and substituting them into the first order condition:

\[
A = D + E + \frac{(\delta + \epsilon)}{(\rho - r^f)}\beta R_H \left[ (\theta - 1)(R_H(1 + r^f)^2 + 2\alpha(1 + r^f)(\delta + \epsilon)) \\
-(1 + \rho)(\theta R_H(1 + r^f) + \alpha \theta^2(\delta + \epsilon)) \right]
\]

(20)

The term $E$ quantifies the reduction in the level of reserves when an individual country’s maximization problem accounts for the risks of a global crisis. In comparison to equation (18), the additional terms on the RHS measure how maximization by a social planner affects the optimal amount of reserves. Because all additional terms are negative, the amount of reserves, which a social planner chooses for each individual country, is clearly lower than what a domestic authority would accumulate. This reduction is positively affected by the

\textsuperscript{24}The social planner coordinates the policies of both countries but does not take into account that alternative arrangements like reserve-pooling, mutual credit lines and swap lines might provide more efficient forms of insurance.
costs of a crisis \((\delta + \epsilon)\) and by the risk-free interest rate \((r^f)\). The larger the effect of reserve accumulation on the probability of a global crisis (large \(\beta\)) and the stronger the mitigating effect of reserves on the probability of a local crisis (large \(\alpha\)), the stronger are the reserve reductions implemented by a social planner.

### 3.5 Implementation of socially optimal level of reserves

As shown above, the socially optimal level of reserves is in general lower than the level of reserves individual countries hoard in the decentralized equilibrium. Welfare could be improved by taxing the hoarding of reserves. Since the private domestic costs of reserves do not cover their social global costs, a tax might charge the difference. This Pigouvian tax induces individual countries to internalize the negative externality of their reserve accumulation. It corrects individual country behaviour and leads to a globally efficient level of reserves.

We assume that a social planner - a global financial institution or the reserve currency country itself - taxes both the level of reserves and their interest earnings at a rate \(t\). This policy modifies the budget constraint of period 2: In (13) the last term \((1+r^f)R\) is multiplied by \((1-t)\) for each state of the nature. The optimization of (14) under the modified set of budget constraints provides the first order condition for the optimal level of reserves:

\[
A = \frac{\rho - r^f}{\rho - r^f - t - tr} [D + E] \quad (18')
\]

This expression corresponds to (18) where \(t\) and \(tr\) are additionally subtracted in the denominator on the right-hand side. For \(t > 0\), the level of reserves chosen by an optimizing country is lower than without taxation. Since \(t\) has to be chosen such that the first order condition of an individual country equals the first order condition of a social planner ((20)=(18')), the optimal tax rate is given by

\[
t = - \frac{(\delta + \epsilon)\beta R_H (\theta - 1)(R_H (1 + r^f)^2 + 2\alpha (1 + r^f)(\delta + \epsilon)) - (1 + \rho) (\theta R_H (1 + r^f) + \alpha \theta^2 (\delta + \epsilon))}{[(1 + r^f)R_H + \alpha \theta (\delta + \epsilon)]^2 (1 + r^f)} \quad (21)
\]

As long as the assumptions of our model are satisfied - all parameters are positive - the optimal tax rate is larger than zero. The optimal allocation can be implemented with an appropriate tax on reserves, with tax revenue rebated as a lump sum transfer across countries or transferred to an international institution and used to grant liquidity to crisis-hit countries. The optimal tax rate is the higher, the stronger the relationship between reserve hoarding and the probability of a global crisis is (large \(\beta\)). Moreover, the optimal tax increases in the level of reserves \(R_H\). Our model also shows that the tax base should
be rather the absolute level of reserves than reserves scaled by some domestic variable. In particular, it is irrelevant for the stability of the reserve currency country whether reserves are accumulated by a small or large country. The effect of accumulated reserves on the crisis probability, however, depends on the level of reserves hold by the centre (see equation (6)).

How could the Pigouvian tax be implemented? The reserve currency country might tax government bonds in the hands of foreign monetary authorities. Since the reserve currency country is negatively affected by the global crisis, it might have an incentive to restrict the supply of reserve currency. In this case, however, the rest of the world would not be endowed with the reserves it demands. Since the demand for reserves is inelastic with respect to its price, the demand-supply mechanism might not work properly. Alternatively, the accumulation of reserves might be taxed by an international financial institution. In this vein, Eichengreen (2009) proposes to levy a tax if reserves had been accumulated over the last three years and if the increase exceeded 3% of GDP.

Whereas our results indicate that the accumulation of reserves should be taxed, Aizenman (2011) comes to an opposing conclusion: It is socially desirable to subsidize reserve hoardings. His argumentation is based on an overborrowing externality. Although the results seem to be contradictory, they can be easily conciliated: Aizenman optimizes the level of foreign borrowing and reserve hoardings for a representative commercial bank. A central bank, however, is likely to internalize the overborrowing externality caused by individual borrowers. Therefore, the tax-cum-subsidy scheme is primarily a mechanism to guarantee that those who increase the need for reserves - namely domestic borrowers who benefit from lower interest rates abroad - also pay the costs their borrowing imposes on society as a whole.

Thus, from the perspective of an individual country, the level of reserves may well be optimal without subsidization. The tax-cum-subsidy scheme may be combined with our policy of taxing reserve hoardings: At the national level, the overborrowing externality may be internalised by a monetary transfer from those who borrow internationally to the central bank. A global social planner, however, imposes a tax on central banks’ reserve hoardings.

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25 Alternative scaling variables might be the fiscal capacity or the GDP of the center country.
26 Equation (6) shows that the global demand for reserves increases the crisis probability in the center country.
27 If (1) price-taking borrowers ignore their impact on the cost of a crisis and (2) the risk of liquidation of investment projects rises with the ratio of external borrowing to reserves, external borrowing imposes a negative externality. This externality implies that the marginal social benefit of borrowing is lower than the private benefit, whereas the marginal social benefit of hoarding reserves exceeds the private one. As a consequence, the optimal policy mix combines a tax on external borrowing with a subsidy on reserve hoardings.
28 Within our model, this assumption implies that the central bank correctly estimates the costs of a crisis ($\delta + \epsilon$) and the effects of borrowing and reserves on the probability of a local crisis ($\alpha_i$ in equation (1)).
4 Discussion of policy implications

The analysis of the previous section has shown two effects: First, if countries take into account that their accumulation of reserves increases the probability of a global financial crisis, their optimal demand for reserves will be lower. Second, if a supranational authority determines the optimal level of reserves for each country, it internalizes the negative externality and further reduces its demand for reserves. Both effects have not been analysed in a model of the optimal demand for reserves so far.

Besides taxing the accumulation of reserves, there exist several alternative options how the probability of global crises emanating from countries desire for reserves might be reduced. A first approach could aim at lowering the demand for reserves. This option comes closest to the solution a social planner would implement in our model. Second, since the instabilities stem from the fact that a national currency serves as reserve currency, the introduction of a supra-national reserve asset alleviates the problem. Finally, cooperation between central banks reduces the demand for reserves. We discuss these options in the following sections.

Lower the demand for reserves

Besides lowering the demand for reserves by raising their costs (taxation), one might prefer to rely on market-based instruments: The provision of substitutes for reserves should reduce their demand.

Credible mechanism of crisis management might be a substitute. To this end, the IMF has adjusted its lending facilities with the goal of creating a global financial safety net: It redefined its Flexible Credit Line (FCL) making it more generous and introduced the Precautionary Credit Line (PCL) aiming to provide crisis prevention for countries that do not meet the high standards of sound policies as required for the FCL. Despite increased transparency and access, those safety nets are only imperfect substitutes for reserves since there will always be selectivity and conditionality in the access to international liquidity.

Alternatively, one might encourage the diversification of reserves into various competing reserve currencies. If world reserves are no longer concentrated in the currency of a single country, the negative effects on the reserve currency country are spread between several countries. However, a multicurrency reserve currency system also creates instabilities: Substitution among reserve currencies increases the volatility of exchange rates.

Further mechanisms how the demand for reserves could be lowered and the potential role for international institutions are discussed in a series of recent papers (i.e. Mateos y Lago et al., 2009).
**Provision of a supranational reserve asset**

Systematic problems might be mitigated by international financial institutions that are endowed to create outside liquidity in a crisis. This idea was put forward recently by the governor of the People’s Bank of China, Zhou Xiaochuan. He proposed to create a reserve currency that is disconnected from individual countries’ policies and currencies. A similar idea was already proposed by Keynes. He suggested to create an International Clearing Union based on an international currency. However, any lender of last resort creates moral hazard problems if support is expected. The IMF might be endowed with additional financial resources to be able to credibly assist countries during crises. This might be accomplished by the creation of new SDRs. To separate the creation of SDRs from political pressures, their increase could be automatized with SDRs increasing with worldwide real output growth. However, the use of SDRs as reserve assets also contains pitfalls: SDRs are only backed by the the credibility and liquidity of the IMF. A national currency, however, is at least backed by the GDP of the issuing country.

**Central bank cooperation in reserve policies**

Might independent central banks be willing to cooperate in order to stabilize the international financial system? Important lessons might be drawn from two historical episodes, when major central banks agreed to coordinate their reserve policies in order to preserve the stability of the monetary system.

One example is the Gold Pool, which was established in 1961 by the United States and 7 European countries under the gold-dollar standard of the Bretton Woods system. The arrangement aimed at stabilizing the price of gold in terms of dollars in order to prevent a depletion of US gold reserves. Analogously to the current issue of reserve accumulation, it is an example where individual and collective interests of central banks differ. Arbitrage transactions by individual central banks were individually rationale, but collectively undesirable: They reduced US gold reserves and questioned the US commitment to exchange gold for dollars at the fixed price. However, when the market price for gold rose, individual central banks left the pool or engaged in offsetting transactions - they bought gold when the pool sold gold.²⁹

A second example of central bank coordination in reserve policies is the Central Bank Gold Agreement. A number of central banks - especially in industrial countries - aim for getting rid of their large reserve holdings in the form of gold. Knowing that a simultaneous sale of gold decreases its price, they agreed to coordinate their sales of gold.³⁰ Although the


³⁰ The first Central Bank Gold Agreement was signed in 1999 by 14 European central banks for the
accumulation of foreign exchange has similar price effects - it lowers the interest rate in the reserve currency country - central banks do not coordinate their reserve policy when they accumulate reserves.\textsuperscript{31}

Cooperation might be intensified in the future. The extension of swap lines between central banks, pioneered during the financial crisis of 2008-10, might become a standardized instrument to tackle future global crises. The pooling of reserves provides a means of lowering the worldwide demand for reserves. Besides economies of scales, regional reserve pools prevent inefficient competitive hoarding games.

5 Conclusions

This paper has put central banks accumulation of international reserves in new context: The policy of reserve accumulation as a form of self-insurance, which has gained popularity since the East Asian financial crisis, might rather cause than prevent financial crises. The empirical evidence suggests that the global financial crisis of 2008-10 is an example of a global crisis that is a by-product of central banks appetite for reserves. However, as we have shown, this correlation is not coincidental. On the contrary, if the reserve currency fulfills the double role of global store of value and national medium of exchange, the accumulation of reserves increases the vulnerability of the reserve currency country. There exist externalities that suggest that it might be optimal to tax the accumulation of reserves in a second-best world.

These considerations are integrated in a model of the optimal demand for reserves. The resulting demand for reserves is lower than in the benchmark case, which disregards the relationship between reserve accumulation and global crises. First, if countries take into account that their accumulation of reserves increases the probability of a global financial crisis, their optimal demand for reserves will be lower. Second, if a supranational authority determines the optimal level of reserves for each country, it internalizes the negative externality and accumulates fewer reserves. It is shown that a macroprudential tax might induce the socially optimal level of reserves in a decentralized world. The negative externality reinforces the case for supranational reserve pooling since the internalisation of the social externality is purpose of limiting the amount of gold to be sold in the following 5 years. The signatories roughly make up 50\% of the worldwide official gold holdings. This agreement was renewed in 2004 and 2009.

\textsuperscript{31}There exists, however, an 'automatic stabilizer effect': Since the massive accumulation of reserves reduces the interest rate paid on reserves, it increases reserves' opportunity costs defined as the difference between domestic cost of capital and the return on reserves. As a consequence, theory predicts that this slows down the accumulation of reserves. Empirical studies, however, often conclude that opportunity costs do not significantly affect the level of reserves.
more probable for larger players.\footnote{In other words, social relative to private costs decrease in the share of one reserve pool in global reserves.}

This re-opens the discussion on the adequate level of international reserves. Arguments in favour of lower reserves point usually to the fiscal opportunity costs of reserves. They disregard that as long as a national currency serves as fiduciary reserves central banks buy a product that - besides being expensive - may not hold its promise. The question whether the medicine is worse than the disease is warranted. As a consequence, the global financial crisis of 2008-10 might be used as an opportunity to rethink the architecture of the international financial system.

The discussion of policies that lower the demand for reserves has shown that, while desirable, their implementation in a decentralized world is a delicate endeavour. Individual countries are autonomous in their reserve policies and due to political economy considerations might prefer to continue their policy of reserve hoarding in a second-best world. We have justified the taxation of reserve hoardings by the presence of policy distortions and market failures. An alternative might be to address the distortions that cause excessive borrowing and excessive lending directly along the lines described in Aizenman and Turnovsky (2002). It might be easier to resolve these externalities at the domestic level than those arising at the global level. This might lower the demand for reserves and hence mitigate the negative externality of reserve accumulation.


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Figure 1: US current account deficit and global dollar reserve accumulation

Notes: A positive number corresponds to a current account deficit, whereas a negative number is defined as a surplus. Data source: World Bank (2010) and own calculations based on the COFER database.

Figure 2: Cost-benefit analysis of reserve accumulation: a global view