YOUNG ECONOMISTS' SEMINAR to
14th Dubrovnik Economic Conference

Organised by

Ana Maria Čeh and Ivo Krznar

Optimal Foreign Reserves: The Case of Croatia

Hotel "Grand Villa Argentina",
Dubrovnik
June 25, 2008

Draft version

Please do not quote

Optimal Foreign Reserves: The Case of Croatia*

Ana Maria Čeh, Ivo Krznar
Croatian National Bank

June 5, 2008

Abstract

This paper develops a simple model of precautionary foreign reserves in a dollarized economy suspect to a sudden stop shock that occurs in hand with a bank run. By including specific features of the Croatian economy in our model we extend the framework of Goncalves (2007). An analytical expression of optimal reserves is derived and calibrated for Croatia in order to evaluate the adequacy of the Croatian National Bank foreign reserves. We show that the precautionary demand for reserves is consistent with the trend of strong accumulation of foreign reserves over the last 10 years. Whether this trend was too strong or whether the actual reserves were lower than the optimal reserves depends on two factors: on the possible reaction of the mother banks during a crisis and on the calibration of the model. We show that for plausible values of parameters, the Croatian National Bank has enough reserves to fight a possible crisis of magnitude of the 1998/1999 sudden stop with banking crisis episode. This result holds regardless of the mother banks' reaction. Furthermore, we show that the foreign reserves of the Croatian National Bank present insurance against a crisis of the scale larger than that in 1998/1999 provided that not all shocks assume their extreme values. This is true only if the mother banks do not participate in the sudden stop. However, in the event of a severe sudden stop that would significantly erode confidence in the banking system, the foreign reserves of the Croatian National Bank would not be sufficient to mitigate the fall in consumption that would result from the ensuing credit crunch and financial account reversal. We also show how using the two standard indicators of "optimal" reserves, the Greenspan-Guidotti and the 3-months-of-imports rules, might lead to an unrealistic assessment of the foreign reserves optimality in the case of Croatia.

Keywords: Sudden stop, Banking crisis, Dollarized economy, Optimal reserves
JEL classification: F31, F32, F37, F41

*We are grateful to Žarko Miljenović for all the discusions and usefull comments. We are especially indebted to Tomislav Galac for his extensive and detailed review of the paper. All remaining errors are ours. The views expressed in this paper are solely those of the authors and do not necessarily reflect official positions of the Croatian National Bank.

1 Introduction

Foreign reserves accumulation is a widespread phenomenon, particularly among emerging economies. Since 1990 emerging markets' foreign reserves have increased by more than five times, from 4 percent to over 20 percent of GDP (Obstfeld, Shambaugh, and Taylor (2008)). This practice has raised interesting questions in the literature regarding the reasons for such a behavior. It has been argued that part of the motivation for the reserve accumulation stems from an incarnated mercantilist desire by some governments to maintain undervalued exchange rates and bolster domestic economy. Apart from these exchange rate objectives which have resulted in rapid reserve accumulation as a side effect, some countries have chosen explicitly to build up reserves for precautionary motives or self-insurance against exposure to future sudden stops. Aizenman and Marion (2002) and Aizenman and Lee (2005) suggest that precautionary demand for reserves plays an important role in explaining rising foreign reserves in East Asia following the Asian crisis, which was to a large extent unexpected. The need for reserves, acting as a protection against a sudden stop, is even more pronounced in dollarized economies, like Croatian, where the central bank is exposed to a double drain risk (Obstfeld, Shambaugh, and Taylor (2008)). This twofold risk exists given that financial account reversals (an external drain risk) may be accompanied by a loss of confidence in the banking system that would result in a large withdrawal of foreign currency deposits (an internal drain risk). Therefore, in dollarized economy reserves are not only an insurance against negative effects of a sudden stop but also a key tool for managing domestic financial instability.

Strong accumulation of foreign reserves was also apparent in Croatia. Since 1998 foreign reserves of the Croatian National Bank (CNB henceforth) have quadrupled. We explore the reasons behind the strong accumulation of CNB reserves. Providing that the double drain risk is present in Croatian economy[1] we analyze whether CNB reserves are sufficient to mitigate negative effects of potential sudden stop of capital inflows and banking crisis. To tackle this issue we study precautionary demand for foreign reserves in a stochastic dynamic general equilibrium model, similar to Goncalves (2007), where central bank holds reserves as a self-insurance against a sudden stop and a banking crisis in a dollarized economy. By including specific features of Croatian economy in our model we extend the framework of Goncalves (2007) that develops a model of optimal reserves for Uruguay. In the model economy there are two main opposite forces driving optimal reserves accumulation. On one hand, reserves are expensive to hold. The cost of holding reserves might be interpreted as the opportunity cost that comes from substituting high yielding domestic assets for lower yielding foreign ones. On the other hand, reserves absorb fluctuations in external payment imbalances, ease the credit crunch and allow a country to smooth consumption in the event of a sudden stop with banking crisis.

[1] In the same period, the short-term foreign debt of the Croatian economy has almost quintupled, while the foreign deposits have more than doubled.

The model is calibrated using Croatian data and simulated to see whether the CNB holds more reserves than the model suggests are necessary. We find that for plausible values of the parameters the model accounts for the recent buildup of foreign reserves in Croatia. However, quantitative implications of the model imply that the accumulation of reserves was too strong. In other words, recent upsurge of reserves observed in Croatia over the past decade seems in excess of what would be implied by an insurance motive against sudden stop and banking crises. This result crucially depends on the calibration of the model and the assumed behavior of mother banks during a sudden stop. In working with data, we assume two possible reactions of mother banks during the crisis. Mother banks might withdraw deposits and cut credit lines to banks in their ownership. On the other hand, they might act as a lender of last resort by prolonging short-term loans and providing extra liquidity. In calibrating the model, we consider two different magnitudes of the crisis. In the benchmark calibration we study optimal reserves in the economy that is hit by the sudden stop with banking crisis of the 1998/1999 crisis scale. Alternative calibration of the model considers a severe sudden stop with banking crisis whose consequences would have much larger negative effects than the crisis 10 years ago. We find that the CNB is holding enough reserves to mitigate negative effects of a possible crisis similar to the one that took place during 1998/1999 even if we take into account an adverse reaction of mother banks. We also show that foreign reserves of the CNB present insurance against a crisis of the scale larger than that in 1998/1999 provided that not all shocks assume their extreme values. This result holds only if mother banks do not participate in sudden stop. However, CNB reserves are not sufficient to fight large scale crisis where all negative consequences take place at the same time even if we assume favorable reaction of mother banks. Finally, we compare our formula of optimal reserves with two standard indicators of "optimal" reserves for Croatian economy, namely Greenspan-Guidotti and 3-months-of-imports rules. We present advantages of our optimal reserves formula over the two standard indicators in assessing reserves adequacy.

Our framework builds on analytical models trying to characterize and quantify the optimal level of reserves from a prudential perspective[2] rather than from the cost-benefit perspective of reserve accumulation, pioneered by Heller (1966)[3]. The earlier cost-benefit literature focused on using international reserves as a buffer stock, part of the management of different exchange-rate regimes. In those models optimal reserves balance the macroeconomic adjustment costs that would be incurred in the absence of reserves with the opportunity cost of holding reserves[4]. Although buffer stock model had the capacity

[2] See Goncalves (2007), Ranciere and Jeanne (2006), Jeanne and Ranciere (2008), Aizenman and Marion (2002), Aizenman and Lee (2005), Caballero and Panageas (2004), Jeanne (2007).

[3] See Flood and Marion (2002) for a recent review on the cost-benefit literature.

[4] The buffer stock model predicts that optimal reserves depend negatively on adjustment costs, the opportunity cost of reserves, and exchange rate flexibility; and positively on GDP and on reserve volatility, driven frequently by the underlying volatility of international trade. See Frenkel and Jovanovic (1981) for details.

to explain behavior of foreign reserves in the 1980s, the greater flexibility of the exchange rates exhibited in recent decades should have reduced reserves hoarding according to the buffer stock model (Aizenman and Lee (2005)). Recent welfare-based models of optimal reserves as a self-insurance had more success in explaining recent hoarding of foreign reserves[5]. In our welfare-based model, precautionary motives for accumulating reserves pertain to the crisis management ability of the government to finance underlying foreign payments imbalances in the event of a sudden stop and provide foreign exchange liquidity in the face of a bank run. At the same time the government is trying to maximize the welfare of the economy.

The rest of the paper is organized as follows. In section 2 we discuss how important is the double drain risk for Croatian economy and describe the episode of banking crisis and sudden stop that took place in 1998/1999. In section 3 we present a model of optimal reserves together with calibration of the model, discussion of data, quantitative implications of the model and sensitivity analysis. Section 4 concludes.

2 Double drain risk and the Croatian economy

We first present a basic national account identity which shows, in a simple manner, the mechanism of self-insurance against a sudden stop provided by foreign reserves. Note that domestic absorption (of domestic goods), A_t can be decomposed into the sum of the domestic output, Y_t, the financial account, FA_t, the net factor income from abroad, IT_t, and the change in foreign reserves, ΔR_t:

$$A_t = Y_t + FA_t + IT_t - \Delta R_t \tag{1}$$

When a sudden stop hits the economy, short-term foreign loans become unavailable. Hence, a sudden stop brings about financial account shortfall that reduces the domestic absorption. If we assume that a bank run (internal drain) also occurs when a sudden stop (external drain) takes place, the negative effect will be magnified by a fall in the domestic output through the reduction of domestic savings[6] and resulting credit crunch. However, by providing enough foreign liquidity to the economy, the central bank can smooth the domestic absorption and diminish the negative effects of a sudden stop and a banking crisis. Because of the double drain risk, the protection role of reserves is more important in dollarized economies. Foreign reserves serve not only as a domestic absorption stabilizer but they also mitigate negative effects on output - they provide insurance against the risk of external loans not being rolled-over during a sudden stop and help lessen credit crunch

[5] See Durdu, Mendoza, and Terrones (2007) Caballero and Panageas (2004), Ranciere and Jeanne (2006), Jeanne and Ranciere (2008).

[6] To see this, remember that $Y_t = C_t + I_t + G_t + X_t - M_t = C_t + S_t + T_t - FA_t - IT_t + \Delta R_t$ where $C_t, I_t, G_t, X_t, M_t, S_t, T_t$ denote consumption, investment, government spending, export, imports, savings and taxes, respectively.

by providing liquidity in the event of foreign deposit withdrawal.

We put emphasis on a double drain risk given that foreign lenders stopped providing credits to Croatian economy in the midst of 1998/1999 banking crisis (see Jankov (2000) for details). Internal drain risk seems to be more important in explaining slowdown of domestic absorption than the financial account reversal during that crisis. Figure 1 shows how components of domestic absorption behaved during the banking crisis in Croatia[7]. The crisis began with the failure of Dubrovačka banka and unfolded in parallel with the sudden stop in the third quarter of 1998. Financial account reversal was relatively mild[8] and lasted for one quarter only. The negative effects of the sudden stop were lessened by releasing a part of the foreign reserves.

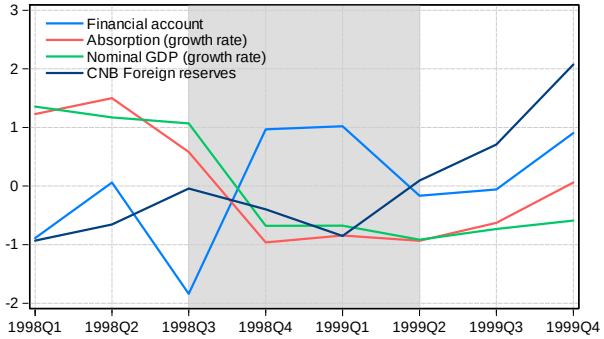

Figure 1: Components of domestic absorption (normalized).

However, output and domestic absorption continued to fall (until the second quarter of 1999). Hence, it seems that the banking crisis, the deposit run, and the credit crunch had a dominant role in shaping output and domestic absorption behavior during the 1998/1999 episode. Banks activity peaked in the third quarter of 1998 (at the same time when sudden stop occurred) after it reached its trough corresponding to the end of the real activity slowdown in the second quarter of 1999 (Figure 2).

Besides the foreign reserves, it seems that banks' foreign reserves were also important in absorbing the fall in the euro deposits' withdrawal in the period from August 1998 until May 1999 (Figure 3). Yet, the bankruptcy of a number of banks accentuated credit crunch, that could not be mitigated by any foreign liquidity buffer. While this resulted in a recession, the use of foreign assets (both CNBs' and private banks') helped offset a potentially larger fall in economic activity.

Euro deposits[9] and short-term external debt[10] give rise to a double drain risk in Croa-

[7] The series in Figure 1 are normalized. Hence, Figure 1 does not show the actual decomposition of domestic absorption as a sum of its components but provides direction of components behavior.

[8] The cost of financial account reversal was less than 5% of GDP.

[9] Euro deposits include euro deposits of households and non-residents of all maturities.

[10] We treat installments on long term debt that are due in period (year) t as short-term debt issued in the previous year. It will not be possible to roll over this principal repayment if sudden stop shock hits

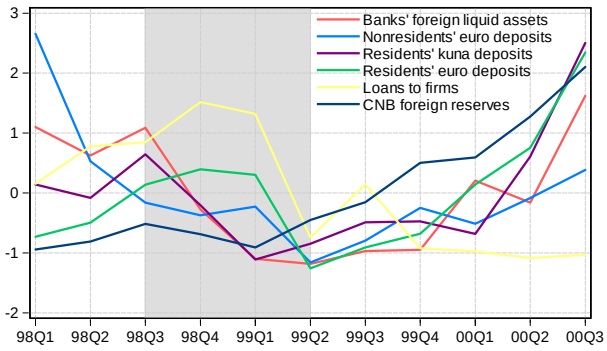

Figure 2: Banking sector activity during the sudden stop with banking crisis (series are normalized).

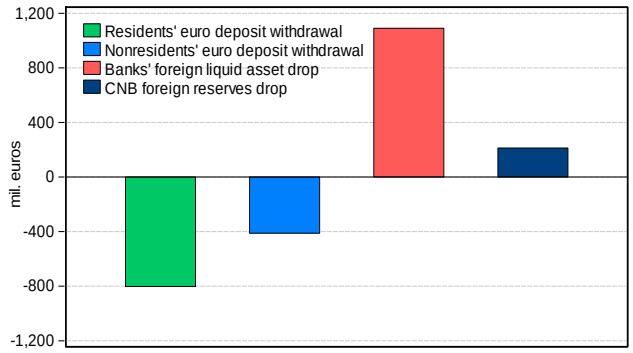

Figure 3: Euro deposits withdrawal and foreign buffers drop during the sudden stop with banking crisis

tia. The volatility in these two variables during a crisis could potentially lead to a large foreign liquidity requirement (as they had during the 1998/1999 crisis). Hence, foreign reserves serve the twofold role of stabilizing both the output and the domestic absorption in a dollarized economy faced with a double drain risk. Nowadays, just like during the 1998/1999 episode, euro deposits still represent the main vulnerability for the Croatian economy (Figure 4 shows that an internal drain risk might persistently be significant given that on average the foreign reserves were covering only half of the euro deposits during the observed period). On the other hand, short-term external debt does not seem to imply a persistently high external drain risk since on average the foreign reserves were covering little over 100% of the short-term external debt during the same period.

In practice foreign reserves adequacy has often been assessed using simple rules of thumb, such as maintaining reserves equivalent to three months of imports, or the Greenspan-Guidotti rule of full coverage of short-term external debt[11]. According to Šonje (2007)

the economy. We could not present data on short term debt during the sudden stop with banking crisis since data on short-term debt are available only since the end of 1998.

[11] These two indicators are used given that empirical research show that they appear to be a potent predictors of currency crises and sudden stops.

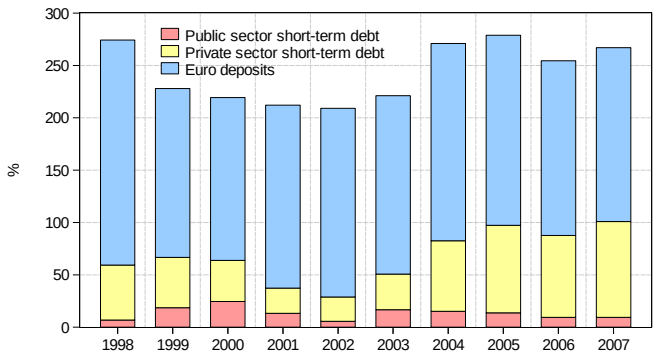

Figure 4: Short term debt and euro deposits in the period 1998-2007

Croatia is on safe grounds as far as the second indicator of foreign reserves adequacy is concerned. Even if one considers a situation of extreme shock hitting our economy Šonje shows that foreign reserves are twice as high as our short-term external debt. Although we use a broader definition of short-term external debt (Figure 5 shows the behavior of the two standard indicators), Šonje's result still holds. Moreover, Croatia's foreign reserves cover more than 100% of its short term external debt and more than 5 months of its imports. Thus, one might conclude that Croatia's foreign reserves are adequate. However, these two indicators do not take into account a high degree of deposit dollarization which represents a main vulnerability for the Croatian economy (as Figure 4 shows), raising doubts about their appropriateness.

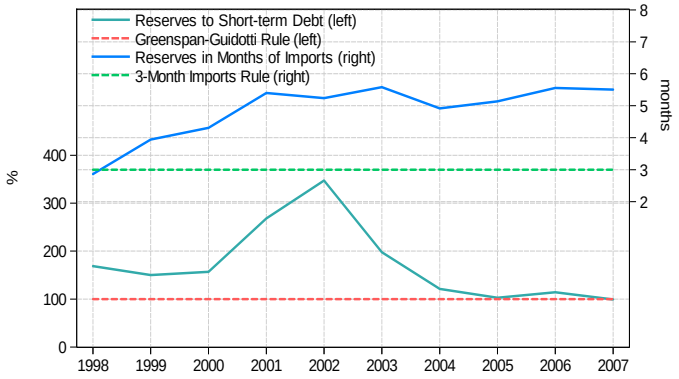

Figure 5: Reserves to short-term debt ratio and Reserves in months of imports

Moreover, using these indicators is not useful in general in assessing whether actual reserves are too high or too low, because they are not based on any optimality criterion. The national accounting equation (1) shows that by releasing foreign reserves it is possible to increase domestic absorption. Hence, holding foreign reserves comes at a cost - reserves

could be used to repay foreign loans or to invest in assets with higher returns. As much as we are interested in answering the question whether central banks have enough foreign reserves to mitigate negative effects of a possible sudden stop with banking crisis we also have to examine whether we have too much of a good thing. Standard indicators can not help in tackling this issue- neither do they consider the opportunity costs of holding reserves nor do they take into account expected precautionary benefit of holding reserves.

In his previous article Šonje (2005) conjectures correctly that the two standard indicators of reserve adequacy might no longer be valid in the new financial environment. He is calling for a new formula for optimal reserves, arguing against regulation that limits foreign-related risks by maintaining banks' foreign liquid assets, as an additional buffer, at a level that keeps crisis indicators[12] below certain thresholds. However, although he is rightly calling for the missing optimality criterion in determining the desirable level of private foreign liquidity, Šonje makes his argument based on historical thresholds that are by no means founded on an optimality norm. On the other hand, our model offers a formula of optimal reserves that is based on a micro-founded rule of maximizing the welfare of the economy. This norm balances between costs and benefits of holding foreign reserves and thus offers an appropriate benchmark for assessing the foreign reserves adequacy. Using optimal reserves in the cost-benefit analysis of regulation related to foreign risks might be therefore more appropriate than employing crisis indicators and their arbitrary thresholds.

3 The model

We construct a simple, discrete time model of self-insurance offered by foreign reserves. Our model follows the structure of the model in Goncalves (2007) and Ranciere and Jeanne (2006). Foreign reserves help mitigate negative domestic consumption effects of a sudden stop that comes in tandem with a bank run in a dollarized economy. Our model is simple in two aspects. First, we do not differentiate between households' and firms' behavior. Second, instead of modeling some elements explicitly, we make many assumptions about actions of the agents during a sudden stop period based on stylized facts of sudden stop with banking crisis events[13].

The only uncertainty in the model comes from the probability of a sudden stop. There are three sectors in our model economy: households (that also incorporate behavior of firms), banks, and the government that also plays the role of the central bank.

A sudden stop is characterized by the following assumptions. Once the economy is hit by a sudden stop:

- short-term foreign loans of every sector are not rolled over,

[12] He is using the short term debt/foreign reserves and the M4/foreign reserves ratios as crisis indicators
[13] It is possible to model all this actions, but at a high expense of technical complexity of the model.

- GDP falls by some fraction,
- kuna/euro exchange rate depreciates,
- a part of kuna deposits (both household and corporate) is exchanged for euro deposits,
- a bank run occurs - a fraction of overall deposits of non-financial sector is withdrawn from banks,
- a central bank (government) lowers kuna and euro reserve requirements by a fraction of α^k and α^f respectively,
- government stops repaying long-term liabilities that become due,
- banks and households withdraw their foreign liquid assets from abroad to use them as a buffer against a sudden stop.

Except for the richer structure of our model there are couple of important differences between our model and the model in Goncalves (2007). These difference stem from differences between Croatian and Uruguayan economy. A bank run in our model occurs as a result of the loss of households' confidence (in comparison to nonresident deposit withdrawal in Goncalves (2007)). A part of deposits that were pulled out of the banking system are used as a buffer against a lost access to foreign loans market. Furthermore, during the bank run, households exchange part of kuna deposits into euro deposits because of the lost confidence in domestic currency. This feature is not present in Goncalves (2007). Finally, removing dynamics in the formula for optimal reserves (as in Goncalves (2007)) might lead to problematic interpretation of reserves optimality (at least ex-ante). Therefore, our formula preserves the dynamics.

In the next several sections, we first present our model, then we calibrate the model and derive the formula for optimal reserves, and finally, we show and interpret our results and their robustness.

3.1 Non-financial sector - Households

There is a continuum of infinitely lived households of measure one. All households have identical preferences over consumption c_t of the single good. Preferences are represented by the Von Neumann-Morgenstern expected utility function that has a constant relative risk aversion form. The consumption of this good is financed by a deterministic exogenous endowment y_t that is growing over time at the rate of g. In addition to this endowment, the sources of households' funds include: domestic loans, foreign loans, transfer from the government, profits of financial sector, deposits and foreign liquid assets that become due. All loans and deposits of households are assumed to be short-term. Households can borrow

from domestic banks or from abroad. If they go for a loan to domestic banks they can choose between euro denominated (or indexed to kuna/euro exchange rate, S_t), l_t^f or kuna denominated loan, l_t^k. Loans from abroad, b_t, are only in euros. In the event of a sudden stop, that comes with probability π, households cannot roll over this foreign loan. A transfer from the government, T_t, is distributed in a lump sum manner. Since households are assumed to be owners of financial sector they receive all their profits, Π_t (if any). For simplicity, we assume that all interest rates are the same and constant[14].

From the overall sources of funds households buy goods, repay their domestic and foreign loans at given interest rates and decide about the structure of funds they will invest as domestic versus foreign bank deposit. They can choose between foreign denominated, d_t^f, and kuna denominated deposits, d_t^k, that are due next period. Moreover, there are also two types of deposits[15]: household deposits, d_t^{kh} and d_t^{fh}, and corporate deposits, d_t^{kc} and d_t^{fc}. Foreign bank deposits (foreign liquid assets) are denoted by FRB_t^h.

Tables 1 and 2 present balance sheets of households in the period before the sudden stop and in the period when sudden stop occurs. These tables summarize actions of households during those two periods. During the sudden stop access of households to foreign loans market is canceled. Moreover, bank run occurs during which households exchange part of kuna deposits for euro deposits. In the end a fraction of overall deposits are withdrawn. We also assume that during a sudden stop kuna depreciates (against euro) by an absolute change of ΔS.

Table 1 Balance sheet of households before the sudden stop

Assets	**Liabilities**
Kuna deposits, $d_t^k (= d_t^{kh} + d_t^{kc})$	Short-term Kuna loans, l_t^k
Euro deposits, $S_t\, d_t^f = S_t\ (d_t^{fh} + d_t^{fc})$	Short-term Euro loans, $S_t\, l_t^f$
Foreign liquid assets, $S_t\, FRB_t^h$	Short-term foreign borrowing, $S_t\, b_t$
Profits, Π_t	
Transfer from the government, T_t	

Table 2 Balance sheet of households in the period when the sudden stop occurs

Assets	**Liabilities**
Kuna household deposits, $d_t^{kh} - \phi(1-\eta)d_t^{kh}$	Short-term Kuna loans, l_t^k
Euro household deposits, $(S_t + \Delta S)d_t^{fh}$	Short-term Euro loans, $(S_t + \Delta S)\, l_t^f$
Kuna corporate deposits, $d_t^{kc} - \phi(1-\eta)d_t^{kc}$	Short-term foreign borrowing, $(S_t + \Delta S)\, b_t = 0$
Euro corporate deposits, $(S_t + \Delta S)d_t^{fc} - (S_t + \Delta S)\phi(d_t^{fc} + \frac{\eta}{S+\Delta S} d_t^{kc})$	
Foreign liquid assets, $S_t\, FRB_t^h = 0$	
Profits, Π_t	
Transfer from the government, T_t	

[14] Differentiating between interest rates on deposits and loans would not change our formula of optimal reserves.

[15] This assumption circumvents modeling households and firms behavior separately.

The timing of the actions within the period when sudden stop occurs is the following. At the beginning of the period households invest their funds into kuna and euro deposits. Then a sudden stop occurs. Households exchange a fraction, η of kuna deposits into euro deposits. At the end of the period households withdraw a fraction of overall deposits, ϕ (that also include newly exchanged deposits from kuna to euro). A fraction of euro household deposits withdrawn will not be used as a substitute for foreign loans that are no longer available. On the other hand, kuna household deposits together with kuna and euro corporate deposits will act as a buffer against sudden stop effects. In other words, only euro household deposits that are withdrawn from banking system will not be used as a buffer against sudden stop effects. In our model withdrawing euro deposits does not have any impact on the budget constraint of households during a sudden stop- households cannot use these funds to buy goods (since these funds are in euros) and they do not yield any interest rate (since these funds are outside financial sector). This is why they do not appear in the budget constraint- in the model putting euro deposits under the mattress is equal to putting them on fire (at least during the period of a sudden stop).

To make optimal decisions on how much to consume, how much to save and how much to borrow, households maximize the expected discounted value of utility i.e. solve the following problem:

$$\max_{\left\{c_t,l_t^f,l_t^k,b_t,d_t^{fh},d_t^{fc},d_t^{kh},d_t^{kc},FRB_t^h\right\}_{t=0}^{\infty}} E_0\left\{\sum_{t=0}^{\infty}\beta^t u(c_t)\right\}$$

subject to budget constraints

before a sudden stop:

$$\begin{aligned}
&c_t + S_t(1+r)l_{t-1}^f + (1+r)l_{t-1}^k + S_t(1+r)b_{t-1} + S_t(d_t^{fh}+d_t^{fc}) + (d_t^{kh}+d_t^{kc}) + \\
&S_t\,FRB_t^h = y_t + S_t\,l_t^f + l_t^k + S_t\,b_t + S_t(1+r)(d_{t-1}^{fh}+d_{t-1}^{fc}) + (1+r)(d_{t-1}^{kh}+d_{t-1}^{kc}) + \\
&+S_t(1+r)FRB_{t-1}^h + \Pi_t + T_t \qquad (2)
\end{aligned}$$

during a sudden stop:

$$\begin{aligned}
&c_t + (S_t+\Delta S)(1+r)l_{t-1}^f + (1+r)l_{t-1}^k + (S_t+\Delta S)(1+r)b_{t-1} + \\
&+(S_t+\Delta S)(d_t^{fh}+d_t^{fc}) + (d_t^{kh}+d_t^{kc}) = \\
&(1-\gamma)y_t + (S_t+\Delta S)l_t^f + l_t^k + (S_t+\Delta S)(1+r)(d_{t-1}^{fh}+d_{t-1}^{fc}) + \\
&+(1+r)(d_{t-1}^{kh}+d_{t-1}^{kc}) + (S_t+\Delta S)\phi(d_t^{fc}+\frac{\eta}{S_t+\Delta S}d_t^{kc}) + \phi(1-\eta)(d_t^{kh}+d_t^{kc}) \\
&+(S_t+\Delta S)(1+r)FRB_{t-1}^h + \Pi_t + T_t \qquad (3)
\end{aligned}$$

where $u(c) = \frac{c^{1-\sigma}-1}{1-\sigma}$ with σ the relative risk aversion parameter and γ the output cost of a sudden stop with banking crisis.

3.2 Financial sector - Banks

We consider a simple version of the banking sector where the only role of banks is to take deposits from households, take out loans from abroad and extend loans to households. We are assuming perfect competition in the banking sector so that the whole sector can be represented by a representative bank. Bank's assets consist of kuna credit, l_t^k, euro credit, l_t^f, reserve requirement that monetary authority imposes on bank's sources of funds, RB_t, and private banks' foreign liquid assets, FRB_t^b. Reserve requirement is imposed on both domestic and foreign source of finance (RB_t^k, RB_t^f respectively). However, half of the reserves requirement imposed on foreign liabilities is paid in kunas. Monetary authority pays no interest on these reserves. The source of finance consists of kuna deposits, d_t^k (as a sum of household and corporate kuna deposits), euro deposits, d_t^f (as a sum of household and corporate euro deposits), and short-term foreign borrowings, FB_t.

The bank earns profits by extending kuna and euro denominated loans after they become due. The amount of deposits that the bank has to return to households represents its costs (augmented by nominal deposit interest rate). Furthermore, if the bank takes the loan from abroad ($FB_t > 0$) it will have to return it in the next period with the cost of exogenous nominal interest rate.

Tables 3 and 4 present the balance sheet of the banking sector before and during sudden stop. During the sudden stop banks access to foreign loans market is stopped. Furthermore, a bank run on deposits occurs. To mitigate the effects on loans, banks liquidate their foreign assets and use them to cover a part of deposit claims. Notice that euro household deposits that are withdrawn from banking system and put under the mattress are visible here in the balance sheet of the banking sector.

Table 3 Balance sheet of banking sector before the sudden stop

Assets	**Liabilities**
Short-term kuna loans, l_t^k	Kuna deposits, $d_t^k (= d_t^{kh} + d_t^{kc})$
Short-term euro loans, $S_t\, l_t^f$	Euro deposits, $S_t\, d_t^f = S_t\, (d_t^{fh} + d_t^{fc})$
Reserve requirement, $RB_t^k + S_t\, RB_t^f$	Short-term foreign borrowing, $S_t\, FB_t$
Foreign liquid assets, $S_t\, FRB_t^b$	

Table 4 Balance sheet of banking sector during the sudden stop

Assets	**Liabilities**
Short-term kuna loans, l_t^k	Kuna household deposits, $d_t^{kh} - \phi(1-\eta)d_t^{kh}$
Short-term euro loans, $(S_t + \Delta S)\, l_t^f$	Euro household deposits, $(S_t + \Delta S)d_t^{fh} - (S_t + \Delta S)\phi(d_t^{fh} + \frac{\eta}{S_t + \Delta S} d_t^{kh})$
Reserve requirement, $RB_t^k + (S_t + \Delta S)\ RB_t^f$	Kuna corporate deposits, $d_t^{kc} - \phi(1-\eta)d_t^{kc}$
Foreign liquid assets,$(S_t + \Delta S)\, FRB_t^b = 0$	Euro corporate deposits, $(S_t + \Delta S)d_t^{fc} - (S_t + \Delta S)\phi(d_t^{fc} + \frac{\eta}{S_t + \Delta S} d_t^{kc})$
	Short-term foreign borrowing, $(S_t + \Delta S)\, FB_t = 0$

The representative bank is choosing domestic deposit demand, domestic loan supply and international net borrowings optimally i.e. so as to maximize its profit (that is returned to households) taking interest rates and the exchange rate as given:

$$\max_{\left\{d_t^{fh},d_t^{fc},d_t^{kh},d_t^{kc},l_t^f,l_t^k,FB_t,RB_t^k,RB_t^f,FRB_t^b\right\}_{t=0}^{\infty}} E_0\left\{\sum_{t=0}^{\infty} Q_{t,0}\,\Pi_t\right\}$$

subject to

profits before a sudden stop:

$$\begin{aligned}\Pi_t &= S_t(d_t^{fh}+d_t^{fc})+(d_t^{kh}+d_t^{kc})+S_t(1+r)l_{t-1}^f+(1+r)l_{t-1}^k+\\ &+ S_t\,FB_t+RB_{t-1}^k+S_t\,RB_{t-1}^f+S_t(1+r)FRB_{t-1}^b-\\ &- S_t(1+r)(d_{t-1}^{fh}+d_{t-1}^{fc})-(1+r)(d_{t-1}^{kh}+d_{t-1}^{kc})-S_t\,l_t^f-l_t^k-\\ &- S_t(1+r)FB_{t-1}-RB_t^k-S_t\,RB_t^f-S_t\,FRB_t^b \qquad (4)\end{aligned}$$

with

$$RB_t^k = \omega^k[d_t^{kh}+d_t^{kc}+0.5\,S_t(d_t^{fh}+d_t^{fc}+FB_t)] \qquad (5)$$

$$S_t\,RB_t^f = 0.5\,\omega^f S_t(d_t^{fh}+d_t^{fc}+FB_t) \qquad (6)$$

profits during a sudden stop:

$$\begin{aligned}\Pi_t &= (S_t+\Delta S)(d_t^{fh}+d_t^{fc})+(d_t^{kh}+d_t^{kc})+(S_t+\Delta S)(1+r)l_{t-1}^f+(1+r)l_{t-1}^k+\\ &+ RB_{t-1}^k+(S_t+\Delta S)RB_{t-1}^f+(S_t+\Delta S)(1+r)FRB_{t-1}^b-\\ &- (S_t+\Delta S)(1+r)(d_{t-1}^{fh}+d_{t-1}^{fc})-(S_t+\Delta S)\phi[(d_t^{fh}+d_t^{fc})+\frac{\eta}{S_t+\Delta S}(d_t^{kh}+d_t^{kc})]-\\ &- (1+r)(d_{t-1}^{kh}+d_{t-1}^{kc})-\phi(1-\eta)(d_t^{kh}+d_t^{kc})-(S_t+\Delta S)\,l_t^f-l_t^k-\\ &- (S_t+\Delta S)(1+r)FB_{t-1}-RB_t^k-(S_t+\Delta S)RB_t^f \qquad (7)\end{aligned}$$

with

$$RB_t^k = (\omega^k-\alpha^k)[d_t^{kh}+d_t^{kc}+0.5\,S_t(d_t^{fh}+d_t^{fc})] \qquad (8)$$

$$(S_t+\Delta S)\,RB_t^f = 0.5\,(\omega^f-\alpha^f)(S_t+\Delta S)(d_t^{fh}+d_t^{fc}) \qquad (9)$$

where $Q_{t,0}=\left(\frac{\beta^t u'(c_t)}{u'(c_0)}\right)$ is bank's stochastic discount factor (the marginal rate of substitution of consumption in the time period t for consumption in the time period 0 of the bank's owner). Reserve requirement ratio on domestic and foreign liabilities are denoted by ω^k and ω^f, respectively. Parameters α^k and α^f represent central bank relief in terms of releasing part of reserve requirement to mitigate a bank run.

3.3 Government - Central bank

The role of the government is simple. The government expenditures consist of international reserves, R_t, transfers to households[16], T_t, repayment of short-term foreign debt, FG_{t-1}, reserve requirement that is due, RB_{t-1} (as a sum of reserve requirement on kuna liabilities, RB^k_{t-1},and foreign reserve requirement, RB^f_{t-1}), and a long-term debt matured at time t, $P\ N_{t-1}$. The government is assumed to be the only sector that can issue long-term security to finance a stock of international reserves

$$R_t = P\ N_t$$

By selling this security, the government pays term premium, δ that captures the cost of issuing long-term debt instead of short-term debt. This long-term external debt (long-term security) yields one unit of good in every period until a sudden stop occurs. Hence, in period t the government has to pay one unit of a good for every unit bond issued (N_t denotes a stock of bonds issued by the time period t). For simplicity, the price of long-term debt, P is not explicitly modeled[17]. We assume that before a sudden stop the price of long-term security is constant and falls to zero when a sudden stop hits the economy. Hence, before the sudden stop the price of long-term security is equal to expected present discounted value of its payoffs next period (equal to 1 for sure) and the expected price of the bond next period:

$$\begin{aligned} P &= \frac{1}{1+(r+\delta)} + \frac{E_t(P_{t+1})}{1+(r+\delta)} \\ &= \frac{1+(0\cdot\pi+(1-\pi)\cdot P)}{1+(r+\delta)} \\ &= \frac{1}{r+\delta+\pi} \end{aligned}$$

where $r+\delta$ is the interest rate on the long-term security.

The government expenditures are financed by short-term foreign credits, FG_t, long-term borrowing $P\ N_t$, reserve requirement, RB_t and international reserves that are due in period t. During a sudden stop government cannot issue short-debt any more. It also releases part of the reserve requirement (by a fraction of α^k and α^f). Balance sheets of the government before and during a sudden stop, summarizing action of government, are given in Tables 5 and 6.

[16] The government returns to households any seigniorage revenues in form of a lump sum transfer.

[17] Modeling a price of a bond would require modeling behavior of agents selling bonds i.e. modeling behavior of foreigners. Nevertheless, the price of any bond comes down to a simple formula (e.g. from the Lucas tree model).

Table 5 Balance sheet of the government before a sudden stop

Assets	**Liabilities**
International reserves, $S_t\, R_t$	Short-term foreign borrowing, $S_t\, FG_t$
	Long-term foreign borrowing, $S_t\, PN_t - S_t\, PN_{t-1}$
	Reserve requirement, $RB_t^k + S_t\, RB_t^f$
	Transfer from the government, T_t

Table 6 Balance sheet of the government during a sudden stop

Assets	**Liabilities**
International reserves, $(S_t + \Delta S)R_t$	Short-term foreign borrowing, $(S_t + \Delta S)FG_t = 0$
	Long-term foreign borrowing, $(S_t + \Delta S)PN_t$
	Reserve requirement, $RB_t^k + (S_t + \Delta S)RB_t^f$
	Transfer from the government, T_t

Overall, before a sudden stop the government budget constraint is given by:

$$T_t + S_t\, R_t + S_t(1+r)FG_{t-1} + S_t\, N_{t-1} + S_t\, PN_{t-1} + RB_{t-1}^k + S_t\, RB_{t-1}^f = S_t(1+r)R_{t-1} + S_t\, FG_t + S_t\, PN_t + RB_t^k + S_t\, RB_t^f \tag{10}$$

where RB_t^k and RB_t^f are given as in (5) and (6) respectively.

During a sudden stop the government budget constraint reads as:

$$T_t + (S_t + \Delta S)\, R_t + (S_t + \Delta S)(1+r)FG_{t-1} + (S_t + \Delta S)N_{t-1} + RB_{t-1}^k + (S_t + \Delta S)RB_{t-1}^f = (S_t + \Delta S)(1+r)R_{t-1} + (S_t + \Delta S)PN_t + RB_t^k + (S_t + \Delta S)RB_t^f \tag{11}$$

where RB_t^k and RB_t^f are given as in (8) and (9) respectively.

3.4 Equilibrium and The Ramsey problem

A competitive equilibrium is an allocation $\{c_t, l_t^f, l_t^k, b_t, d_t^{fh}, d_t^{fc}, d_t^{kh}, d_t^{kc}, FRB_t^h\}$,$\{d_t^{fh}, d_t^{fc}, d_t^{kh}, d_t^{kc}, l_t^f, l_t^k, FB_t, RB_t^k, RB_t^f, FRB_t^b\}$, prices $\{r, P, S_t\}$ and a government policy $\{R_t, T_t, FG_t, RB_t^k, RB_t^f, N_t\}$ such that

- given interest rates and government policy, the allocation solves both household's and bank's problem
- given allocation and interest rates, government policy satisfies government budget constraint.

There are many competitive equilibria since there are many government policies satisfying government budget constraint. Hence the government is in position to choose the best equilibrium by the choice of its policy. In Ramsey problem the government chooses a competitive equilibrium that maximizes household's welfare (given by household's utility

function). In our case, the government will choose a competitive equilibrium indexed by international reserves that maximizes the welfare of households. In other words, the government imposes its policy to make households as happy as possible taking into account the overall (consolidated) budget constraint[18] of the economy:

$$\max_{\left\{c_t,R_t,FG_t,N_t,RB_t^k,RB_t^f,T_t\right\}_{t=0}^{\infty}} E_0\left\{\sum_{t=0}^{\infty}\beta^t u(c_t)\right\}$$

subject to consolidated budget constraint

before a sudden stop

$$\begin{aligned} &c_t^b + S_t(1+r)b_{t-1} + S_t\, FRB_t^h = y_t + S_t\, b_t + S_t(1+r)FRB_{t-1}^h + S_t\, FB_t + \\ &+S_t(1+r)FRB_{t-1}^b - S_t(1+r)FB_{t-1} - S_t FRB_t^b - S_t(1+r)FG_{t-1} + S_t\, FG_t - \\ &-S_t\ (\delta+\pi)R_{t-1} \end{aligned} \tag{12}$$

during a sudden stop

$$\begin{aligned} &c_t^d + (S_t+\Delta S)(1+r)b_{t-1} = (1-\gamma)y_t + (S_t+\Delta S)(1+r)FRB_{t-1}^h + \\ &+(S_t+\Delta S)(1+r)FRB_{t-1}^b - (S_t+\Delta S)\phi(d_t^{fh} + \frac{\eta}{S_t+\Delta S}d_t^{kh}) - \\ &-(S_t+\Delta S)(1+r)FB_{t-1} - (S_t+\Delta S)(1+r)FG_{t-1} + \\ &+(S_t+\Delta S)(1-\delta-\pi)R_{t-1} \end{aligned} \tag{13}$$

In Appendix we show that the consolidated budget constraint actually correspond to the national accounts identity (1). Hence, the budget constraint of the economy represents all maximum possible combinations of consumption which are consistent with national accounts. Welfare maximization principle determines which consumption point the government will actually choose.

Furthermore, consolidated budget constraint shows that holding reserves is equivalent to repaying short-term external debt by issuing more expensive long-term debt. Even though this is costly, there is a benefit which stems from possibility of substitution of short-term with long-term debt during the sudden stop.

It is clear that holding foreign reserves is beneficial. Foreign reserves allow consumption smoothing of non-financial sector by changing transfers to this sector. Counterbalancing these precautionary motives for holding reserves are their opportunity costs which in practice arise from substituting high yielding domestic assets for lower yielding foreign ones. We do not proxy these costs as the difference between the domestic marginal product of capital and the returns obtained on the reserve assets. Instead, we model these costs as in Ranciere and Jeanne (2006)- foreign reserves have opportunity costs since they are

[18] Derivation of consolidated budget constraint is provided in Appendix.

financed by issuing long-term debt at a term premium. In other words, opportunity cost of reserves is defined as the difference between the interest rate paid on the country's liabilities $(r+\delta)$ and the lower return received on the reserves (r).

3.5 Optimal reserves

Since we are interested in the optimal path of international reserves we present the optimality condition of the government's problem that pertains to international reserves, R_t, only. Choosing international reserves affects consumption in the next period. Therefore, we can simplify government's problem when choosing international reserves as

$$\max_{c_t,R_t} \beta E_t(c_{t+1}) = \max_{c_t,R_t} \beta \left[(1-\pi)\, u(c^b_{t+1}) + \pi u(c^d_{t+1})\right]$$

Substituting for consumption before a sudden stop, c^b_{t+1}, and consumption during a sudden stop, c^d_{t+1}, from consolidated budget constraint before and during a sudden stop (equations (12) and (13) respectively) and deciding about the level of reserves that maximizes the welfare of the economy, the first order condition with respect to R_t is given as

$$S_{t+1}(1-\pi)(\delta+\pi)u'(c^b_{t+1}) = (S_{t+1}+\Delta S)\pi(1-\delta-\pi)u'(c^d_{t+1}) \tag{14}$$

This optimality condition balances benefits and costs of holding reserves - expected marginal benefit of holding reserves during the crisis (right-hand side) has to be equal to expected marginal cost of holding reserves before sudden stop (left hand side).

From (14) we have that level of optimal reserves reads as[19]

$$\begin{aligned} R_t &= \frac{1}{q_{t+1}} \Big\{(1+g)(1-\varepsilon^{\gamma}_{t+1})y_t + \left[\lambda^*_{t+1} - (1+r)(1-\varepsilon^s_{t+1})S^r_{t+1}\lambda^*_t\right] - \\ &\quad - \left[\lambda^A_{t+1} - (1+r)(1-\varepsilon^s_{t+1})S^r_{t+1}\lambda^A_t\right] + z^{\frac{1}{\sigma}}_{t+1}\phi\lambda^D_{t+1}\Big\} \end{aligned} \tag{15}$$

with

$$\begin{aligned} z_{t+1} &= \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)(1+\frac{\Delta S}{S_{t+1}})},\ \varepsilon^{\gamma}_{t+1} = z^{\frac{1}{\sigma}}_{t+1}(1-\gamma), \varepsilon^s_{t+1} = z^{\frac{1}{\sigma}}_{t+1}(1+\frac{\Delta S}{S_{t+1}}) \\ y_{t+1} &= (1+g)y_t,\ S^r_{t+1} = \frac{S_{t+1}}{S_t} \\ q_{t+1} &= S_{t+1}\left[\varepsilon^s_{t+1} + (1-\varepsilon^s_{t+1})(\delta+\pi)\right] \\ \lambda^*_t &= S_t(b_t + FB_t + FG_t),\ \lambda^A_t = S_t(FRB^h_t + FRB^b_t),\ \lambda^D_t = (S_t+\Delta S)(d^{fh}_t + \frac{\eta}{S_t+\Delta S}d^{kh}_t) \end{aligned}$$

A formula for optimal reserves provides the level of reserves that a central bank needs to hold today if it wants to prevent expected negative effects of a sudden stop with banking crisis that might happen tomorrow. At the same time, by holding optimal reserves, central

[19] Derivation of the optimal reserves formula is provided in Appendix.

bank is smoothing consumption that yields maximum possible welfare.

Optimal reserves increase with overall expected short-term external debt, λ^*_{t+1}, possible foreign deposits withdrawal, $\phi\lambda^D_{t+1}$, output loss, γ, probability of sudden stop, π and exchange rate depreciation, ΔS. First two variables pertain to a double drain risk. Central bank is holding reserves so as to step in if an external drain risk is realized (short-term external debt falls to zero) or if an internal drain risk takes in (a bank run occurs). Output loss, exchange rate depreciation and probability of a sudden stop are parameters in our model that have to be calibrated. Output loss affects the optimal level of reserves in that it reduces domestic absorption. Exchange rate depreciation increases the burden of potential foreign liabilities and forces central bank to hold more reserves.

On the other hand, central bank will hold less reserves if their costs, δ, increase and if its alternative buffer in terms of expected foreign liquid assets of private sector, λ^A_{t+1} increases.

Our formula for optimal reserves differs from the one in Goncalves (2007) and Ranciere and Jeanne (2006) in that it preserves dynamics[20]. Excluding dynamics from the formula comes at the cost of losing one of the main implications of the model- the model implies that central bank needs to be ready for the potential crisis - to prevent the crisis a central bank needs to hold optimal reserves in the period before the crisis as a precautionary measure.

Ruling out dynamics does not pose a big problem in ex-post interpretation of optimal reserves. To see why, imagine, for example, that one is interpreting a crisis that happened in 2002 (as it did in Uruguay) from todays' perspective. A dynamic formula (like ours) would result in lower optimal reserves in comparison to optimal reserves implied by a static formula (like in Goncalves (2007) or Ranciere and Jeanne (2006)). The reason for this is that when calculating optimal reserves ex-post, one is using the past (realized) data and not the expected data. Hence when the crisis is realized the values of the variables fall (for example, the short-term external debt falls since it is not rolled over and the foreign deposits fall because of the bank run). Hence, optimal reserves in 2001 would be lower than the ones one would calculate using a static formula (that would not use 2002 data). Therefore, dynamic formula would underestimate optimal reserves before the crisis. However, static formula would overestimate optimal reserves during the crisis period since it does not take into account the recovery period that comes after the crisis and that implies holding less reserves[21].

Moreover, a static formula might lead to a problematic interpretation of optimal reserves ex-ante. A static formula is not a forward-looking formula. On the other hand, a

[20] Goncalves (2007) and Ranciere and Jeanne (2006) make all model variables in period $t+1$ to be equal to the value of corresponding model variable in period t.

[21] On average, static formula in Goncalves (2007) yields different results than dynamic one by 4% of GDP whereas the biggest difference comes in the crisis period. The comparison of results of static and dynamic formula in Goncalves (2007) are available upon request.

dynamic formula implies the level of reserves today so as to prevent crisis tomorrow. A forward looking analysis of current reserves using a static formula does not have anything to say about this issue.

Regarding the comparison of standard indicators of reserves adequacy and optimal reserves, notice that we can restrict a formula of optimal reserves to be equal to the Greenspan-Guidotti rule:

$$R_t = \lambda^*_{t+1} \tag{16}$$

This would hold if there is no alternative buffer to protect the economy from potential crisis, no output costs of the crisis, no effects from the bank run, and no depreciation during the crisis. Even though many analysts use this indicator in assessing reserves adequacy, it is clear that the restricted formula does not even reflect the stylized facts of sudden stops with banking crises since it excludes main elements of all sudden stop with banking crisis episodes.

3.6 Calibration

To go from the general formula for optimal reserves to quantitative statements about the issues of holding optimal amount of international reserves we have to calibrate the model. In other words, model's ability to say something about optimal reserves depends on model's parameters. Calibrating the model involves finding numerical values for parameters using the model as the basis for restricting the model economy and mapping that economy onto the data. Hence, in calibrating the model we assign numerical values to all the model's parameters, that characterize preferences and technology, so as to make it roughly consistent with some of the empirical regularities that reflect the structure of the Croatian economy. If the parameter value cannot be pinned down from the data, we adapt its value from the existing studies and run some sensitivity analysis to see how optimal reserves change if we change a specific parameter.

We managed to calibrate most of the parameter values based on the sudden stop with banking crisis episode during 1998/1999. Even though we use end-of-period annual data when calculating the optimal reserves (in the next section), in calibrating the model we use quarterly and monthly data so as to determine the date of the crisis and its consequences more precisely. This is because sudden stop happened somewhere in the middle of a year (third quarter 1998). Furthermore, by the end of the next year the most severe effects of that sudden stop with banking crisis disappeared as external credit lines reopened again and the banking crisis culminated somewhere in the middle of 1999. Hence, by using annual data we would probably underestimate the consequences of this sudden stop with banking crisis.

There is no official date when this sudden stop with banking crisis started. It should be the date when issuing new external debt was no longer possible and when bank run

occurred. Hence, we would see the beginning of the sudden stop with banking crisis in the data for external debt and banking activity. Unfortunately, data on external debt are available from December 1998 only. However, we have longer time series on non-residential deposits that also count as external debt. Moreover, we have longer time series of financial account that reflects the behavior of external debt. We take the peak and the trough of non-residential deposits as the start and the end of the sudden stop with banking crisis period, respectively. Therefore, the sudden stop with banking crisis began in March (that correspond to the date of Dubrovačka banka failure) and its consequences were still felt until end-May . These dates correspond to banking and real sector slowdown (and recovery) and financial account reversal discussed in Section 2.

We set the parameter value for exchange rate depreciation rate, ΔS, to match the exchange rate increase during the sudden stop with banking crisis period when it went up by 8%.

The growth rate of GDP, g, was calibrated as the average annual growth rate of potential nominal GDP over the period $1998 - 2007$ which is equal to 7.9%. Potential GDP was estimated using Hoddrick-Prescott filter. Output loss during the sudden stop with banking crisis, γ, was calibrated as the difference between the average growth rate of potential GDP and the largest actual GDP growth rate during the sudden stop with banking crisis period (which happened to be at the end of the sudden stop with banking crisis - in the second quarter when nominal GDP increased by 2.2%). Hence, the output loss during the sudden stop with banking crisis period is set to 5.7% of nominal GDP.

To account for possible "Tequila effect" we define a parameter that characterizes a fraction of kuna deposits exchanged for euro deposits, $\eta(\alpha^k)$, to be a function of kuna reserve requirement relief during a sudden stop

$$\eta(\alpha^k) = s_0 + s_\alpha \alpha^k$$

where s_0 is a parameter of kuna deposit that would be exchanged for euros in any event (even if the central bank would not respond to a sudden stop) and s_α measures the elasticity of deposit withdrawal to a central bank move to decrease reserve requirement ("Tequila effect"). Namely, during a sudden stop with bank run episode in Mexico the Central Bank of Mexico tried to fight credit crunch by lowering reserve requirement. This reaction by the central bank seemed to be a positive move towards stopping the bank run. However, it induced people to exchange even more pesos for dollars when they realized they have a chance to exchange the full amount of their peso savings and put even higher burden at a banking system. Since the Croatian National Bank was not reacting to the sudden stop with banking crisis by lowering reserve requirement in 1998/1999 we set $s_\alpha = 0$ in the benchmark case. This parameter will be relevant in the alternative calibration where we study what amount of optimal international reserve should be held as a precautionary

insurance against possible future "Tequila effects". Parameter s_0 was calibrated based on the fact that 19% of kuna deposits were withdrawn from the banking system (starting in August 1998 and ending just one month after the euro deposits withdrawal happened) and were exchanged for euros[22]. Notice that releasing reserve requirement on banks' foreign liabilities does not have any effect on optimal reserves since we work with gross foreign reserves (that are partially financed by reserve requirement).

A parameter value that characterizes the deposit withdrawal rate during a sudden stop with banking crisis period, ϕ, is set to the value that matches the drop of euro deposits[23] during the 1998/1999 episode. Data show that the peak level of the euro deposits was recorded in February 1999, followed by a 17% drop in the period of three months.

Parameter values that describe reserve requirement ratios on kuna and euro denoted liabilities, ω^k and ω^f, respectively, were set to their actual values at the end of 2007. Parameter ω^k was set to the ratio of kuna reserve requirement and bank's domestic liabilities (deposit money, kuna deposits, government deposits, CNB credits) in December 2007 that is equal to 17%. Parameter ω^f was set to the ratio of the euro reserve requirement and the banks' foreign liabilities (euro deposits, euro liabilities and the difference between foreign assets and banks' international reserves to account for the numerator of the CNB prescribed minimum foreign currency liquidity ratio for banks) equal to 17% in December 2007.

Since we experienced only one sudden stop in the last ten years, we cannot use standard probit estimation techniques to estimate a probability of a sudden stop. In the benchmark calibration we set the probability of crisis that implies on average one crisis in every ten years ($\pi = 0.1$). This value corresponds to probit estimation of a sudden stop probability on panel data for 34 middle income countries in Ranciere and Jeanne (2006).

We adapt the standard value for the risk aversion parameter, σ, from the real business cycle literature (equal to 2).

The term premium, δ, was calculated as an average difference between the yield on 10-year German government bond and ECB main refinancing repo rate ($\delta = 1.3$ percentage points).

We assume that the interest rate in the model, r, is the return on reserves (among other things) and is equal to an average foreign risk-free rate, in the Croatian case appropriately set at the six month Euribor rate (3.3%).

Table 7 summarizes the values of the calibrated parameters together with an alternative calibration of Scenario 1. While benchmark calibration involves setting parameter values to reflect the 1998/1999 sudden stop with banking crisis episode, in Scenario 1 we explore if current reserves are prone to an extreme sudden stop with bank run event. In this

[22] This might be a reason why euro deposits did not decline before February 1999 and were actually rising.

[23] In calibration of ϕ we were not considering kuna deposits since euro deposits account for the largest part of overall deposits.

extreme scenario exchange rate depreciates by 20%, output costs go up to 12%, fraction of kuna deposits exchanged for euros is equal to 30% (with additional 17 percentage point of kunas exchanged to euros as a result of Tequila effect), and a fraction of euro deposits withdrawal is equal to 40%. Furthermore, in Scenario 1 we study effects of releasing reserve requirement in the event of a sudden stop with banking crisis.

Table 7. Benchmark calibration and calibration of Scenario 1

Symbol	**Parameter**	**Benchmark (98/99) Value**	**Scenario 1**
π	probability of sudden stop	10%	10%
g	growth rate of potential GDP	7.9%	7.9%
r	interest rate	3.3%	3.3%
δ	term premium	1.3 pp	1.3 pp
σ	relative risk aversion	2	2
ω^k	kuna reserve requirement ratio	17%	17%
ω^f	euro reserve requirement ratio	17%	17%
α^k	kuna reserve requirement relief during sudden stop	0 pp	17 pp
γ	output loss during sudden stop	5.7%	12%
ΔS	exchange rate depreciation rate	8%	20%
ϕ	fraction of deposit withdrawn	17%	30%
s_0	fraction of kuna deposits exchanged for euro deposits (constant)	19%	40%
s_α	fraction of kuna deposits exchanged for euro deposits (elasticity)	0	1

3.7 Data

In addition to the parameter values, we need the data to plug into our formula of optimal reserves in order to explore the quantitative implications of the model. There are a couple of things worth mentioning regarding data. First, we augment the short-term external debt of every sector by the principal payments of its long-term debt that are due. These principal payments represent a short-term liability and do not depend on the occurrence of a sudden stop. Second, most deposits, even deposits with long maturities, can be easily withdrawn at any point in time. Therefore, we treat non-residents deposits (mainly deposits of mother banks) of every maturity as short-term external debt of banking sector. Foreign liquid assets of the non-banking sector consist of cash and deposits invested abroad that can be easily withdrawn. Foreign liquid assets of the banking sector comprise mandatory foreign currency reserves that can be used as a buffer against a bank run. Finally, since the model implies that reserves are partly financed with reserve requirement we have to use gross measure of the CNB's foreign reserves.

The presence of foreign banks in the Croatian banking system complicates the story. Namely, foreign banks are at the same time owners and largest lenders to the Croatian

banking sector. Therefore, their role in a sudden stop might be different from the role of "ordinary" foreign lenders. During the 1998/1999 episode foreign banks were mostly not present in Croatia. Hence, we do not know how they might behave during a sudden stop, that is, whether they could be expected to act as the lenders of last resort for their Croatian daughters by converting their short-term funding into long-term funding or they would simply „take the money and run“. To account for these two possibilities we use two definitions of banks' foreign borrowing. When we treat mother banks as lenders of last resort their euro deposits and their short-term loans are excluded from the above definition of augmented short-term external debt.

3.8 Findings

Plugging in the data into the formula for optimal reserves, our benchmark calibration implies that the level of optimal reserves depends mainly on the reaction of mother banks during a potential sudden stop with banking crisis (Figure 6).

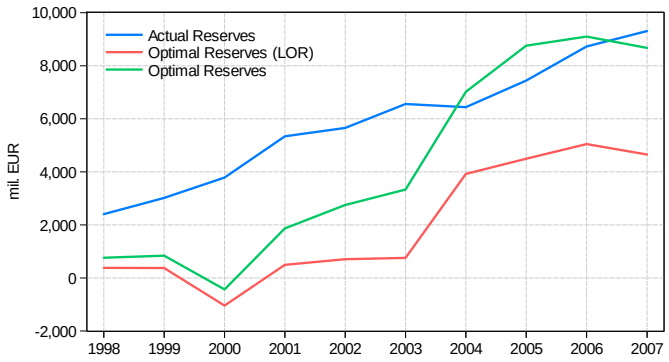

Figure 6: Benchmark calibration- Actual reserves, optimal reserves where mother banks act as the lenders of last resort (LOR), optimal reserves where mother banks participate in a crisis

If we assume that during the crisis all mother banks play their lender of last resort roles, then the level of the actual reserves was on average three times the optimal level in the period 1998-2007. The large difference between the actual and the optimal levels of the foreign reserves is a consequence of the low calculated level of the optimal reserves (even negative in 2000) and the strong accumulation of the actual reserves until 2003. After 2003, the difference between the actual and the optimal reserve levels falls mainly as a consequence of a big increase in the calculated level of the optimal reserves. At the end of 2007, the foreign reserves of the CNB were twice as big as the optimal reserves. However, the picture is quite different if we assume that mother banks will turn their back on Croatian banks in the event of a sudden stop with banking crisis. Under this assumption, the need for foreign reserves has increased since 2003 from well below to near the actual level at the end of 2007 as domestic lending was fueled by foreign borrowing from mother

banks (mostly in the form of foreign deposits). Still, if during 2008 Croatia experiences a sudden stop with banking crisis of the 1998/1999 magnitude, then regardless of the mother banks' reaction, the CNB has enough reserves to prevent the simulated financial account reversal and bank run from causing consumption loss.

Figures 7 and 8 explain the pattern of the optimal reserves. We decompose the optimal reserves into their four main components. Optimal reserves are defined as the weighted difference between contributions of the output loss, the short-term external debt change, and the deposit withdrawal on one hand, and the contribution of the change in the foreign liquid assets of firms and banks on the other[24].

The negative calculated optimal reserve level for 2000 is primarily a consequence of the high growth of foreign liquid assets of the private sector during that year, due to the German mark-to-Euro conversion in the beginning of 2001. The model suggests that at the end of 2000 the CNB did not have to hold any reserves since the private sector's buffers were large enough to cope with a possible sudden stop with banking crisis during 2001. A high growth of the calculated optimal reserve level by 2004 is largely the end result of high borrowing of banks and firms from abroad in the interim period. These trends in the calculated level of the optimal reserves are observed for both scenarios of the mother banks' behavior. The large difference between the optimal reserve levels calculated in the two cases indicates that the major part of the external borrowing used mother-daughter bank credit/deposit lines. The optimal reserves slowdown at the end of 2007 can be for the most part explained by a smaller increase in banks' foreign debt due to the CNB's credit growth ceiling.

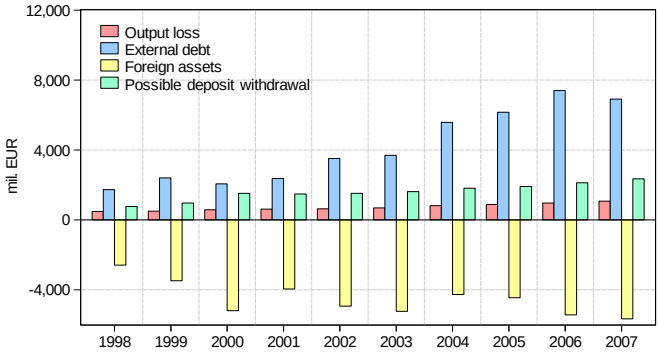

Figure 7: Decomposition of optimal reserves where mother banks act as the lenders of last resort

To examine if actual reserves are prone to larger negative shocks associated with a sudden stop with banking crisis we simulate the formula in the event of an "extreme" crisis as summarized by the parameters of Scenario 1 (Table 7). In a this context, we

[24] Note that these components do not perfectly correspond to data since they are given weights that come from the Ramsey problem. Components correspond to the four elements of the optimal reserves formula (15).

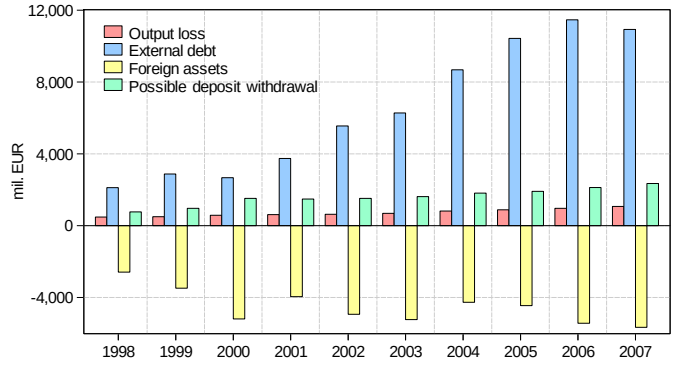

Figure 8: Decomposition of optimal reserves where mother banks participate in sudden stop

also study if it is wise to release a part of the banks' reserves (by lowering the reserve requirement) to help the banking sector cope with the deposit run.

Again, the assessment of the reserve adequacy depends on the two possible reactions of the mother banks (Figure 9). In both cases, the calculated optimal reserves are significantly higher than the actual reserves since 2004. Figure 9 shows that in the severe

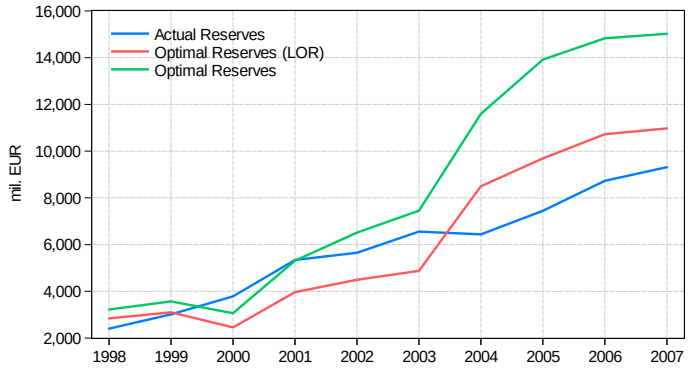

Figure 9: Scenario 1 calibration- Actual reserves, optimal reserves where mother banks act as the lenders of last resort (LOR), optimal reserves where mother banks participate in a sudden stop

crisis scenario for 2008 the foreign reserves amount to 87% of the calculated optimal reserves if the mother banks act like the lenders of last resort and 63% otherwise. The high calculated optimal reserves level is primarily a consequences of a large output loss and a massive bank run under this scenario. Nevertheless, in the next section we show that given its actual reserves the CNB would be able to cope with any shock (output loss, deposit withdrawal, exchange rate depreciation, kuna-to-euro conversion rate) for as long as they do not all occur at the same time. However, if the Croatian economy is hit by a harsh sudden stop that would cause a major loss of confidence in the domestic banking sector (in other words, if all extreme shocks occur at the same time), the CNB would barely find

enough reserves to mitigate the consumption fall.

In the extreme scenario, the central bank would fail to help the banking system to overcome the deposit run even if it released a part of the kuna reserve requirement[25]. This is a consequence of Tequila effect. Figure 10 shows how the optimal reserves level in 2007 depends on the kuna reserve requirement reduction in this hypothetical scenario with the mother banks acting as the lenders of last resort (black line indicates the full Scenario 1 kuna reserve relief amount). The upshot is that due to the Tequila effect, the central bank would actually have to hold more (!) reserves to help tackle the deposit run. By removing the reserve requirement the central bank would actually be adding oil to the fire. Figure 10 shows that in our model the level of the optimal reserves is not sensitive to a change in the reserve requirement. Nevertheless, the model suggests that it would not be wise to reduce the reserve requirement when a crisis occurs.

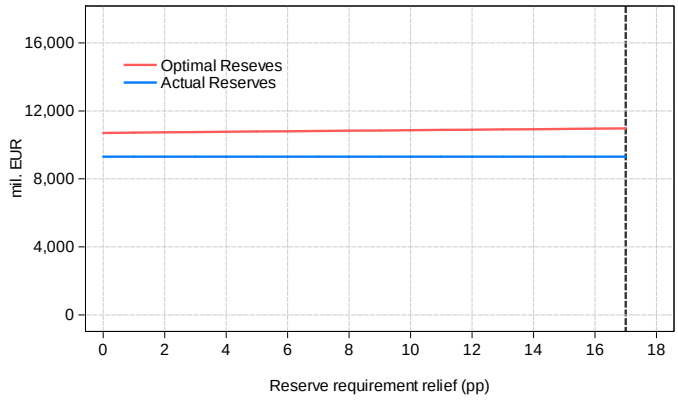

Figure 10: Optimal reserves and kuna reserve requirenment relief (Scenario 1)

Finally, we investigate how our measure of optimal reserves (for a benchmark calibration and the mother banks acting as the lenders of last resort) corresponds to the rule-of-thumb measures of reserves adequacy. All three measures of reserves adequacy suggest that the CNB had enough reserves as an insurance against a potential crisis during the last ten years (Figure 11). However, it is important to notice that the two standard measures of reserves adequacy behave differently from our optimal reserves measure. For example, in 2000 the optimal reserve level was shown to be negative, but since the two standard measures of reserves adequacy do not take into account the private sector's liquid foreign assets' buffer they suggest that the optimal reserves should have been positive.

While the optimal reserves level depends on many parameters reflecting common features of sudden stops with banking crisis, the short-term external debt and the 3-months-of-imports measures do not take into account these features. Figures 12 and 13 show the

[25] Note that releasing reserve requirement on foreign liabilities does not have any impact on optimal reserves as it would reduce actual reserves and at the same time increase a buffer of banking sector.

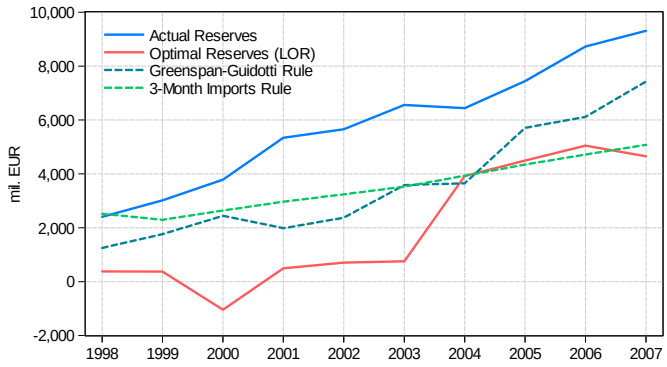

Figure 11: Actual and optimal reserves with Greenspan-Guidotti and 3-months-of-imports rules

optimal reserves level when the output loss and the fraction of deposits withdrawn are different from the benchmark calibration. The error that one would make by using only

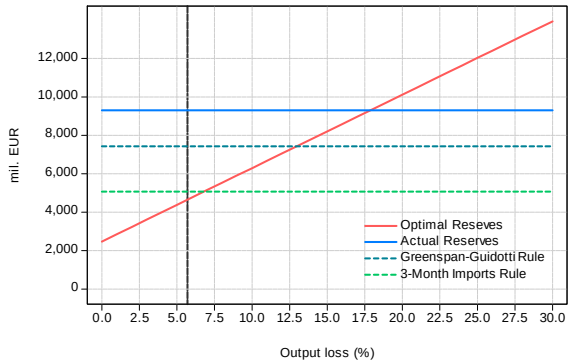

Figure 12: Optimal reserves, Greenspan-Guidotti rule and 3-months-of-imports rule with different values of output loss

the two standard measures of reserves adequacy in assessing the optimality of those reserves might be quite large. For example, if the Croatian economy is hit by a sudden stop with banking crisis of the 1998/99 magnitude, then the Greenspan-Guidotti rule implies the "optimal" reserves level higher than that implied by our measure by more than 2 billion euros (black line denoting the benchmark calibration of the output loss parameter). Actually, for the Greenspan-Guidotti rule and our optimal reserves measure to be equal we should be expecting either about 13% (instead of 5,7%) of output loss or about 40% deposit withdrawal (instead of 19%) during the hypothetical 2008 crisis. The 3-months-of-import rule does a good job in terms of assessing reserves optimality in 2007 in the baseline scenario. However, even though the two measures are almost equal from 2004 onward, Figures 12 and 13 show that they might yield very different results for the optimal reserves level, depending on the assumed output loss and deposit withdrawal parameters.

For example, if one expects a crisis of the size as in Scenario 1 than the Greenspan-Guidotti rule would be closer to our measure of optimal reserves than the 3-months-of-import rule.

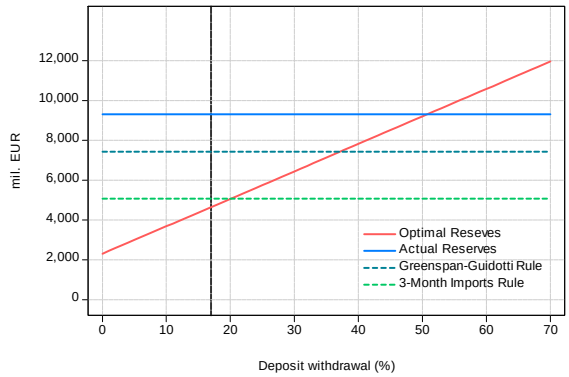

Figure 13: Optimal reserves, Greenspan-Guidotti rule and 3-months-of-imports rule with different values of fraction of deposit withdrawal

3.9 Sensitivity analysis

The results discussed in the previous section are conditional on parameter values. In this section we check if our results are robust to changes in those parameter values. Table 8 shows the examined intervals of parameter values and their benchmark calibration. We solve for the optimal reserves level for every discrete point in the interval, for each individual parameter, and compare this level with the actual reserves level at the end of 2007. Furthermore, in Figure 14 we indicate the benchmark value of the corresponding parameter (using the green line). In our sensitivity analysis we assume that the mother banks act as the lenders of last resort in the event of a sudden stop with bank run[26].

[26] We also run sensitivity analysis when mother banks participate in sudden stop (available upon request). Overall, sensitivity analysis results did not change by much. We do not provide sensitivity analysis for kuna reserve requirement relief during a sudden stop and a fraction of kuna deposits exchanged for euro deposits (elasticity) since in the benchmark calibration we assume they are both zero. Sensitivity analysis of the model calibrated in Scenario 1 (available upon request) shows that optimal reserves are very robust to the change of those two parameters.

Table 8. Benchmark calibration and intervals for the sensitivity analysis

Symbol	Parameter	Benchmark (98/99) Value	Sensitivity analysis interval
π	probability of sudden stop	10%	2% – 30%
ΔS	exchange rate depreciation rate	8%	0% – 30%
g	growth rate of potential GDP	7.9%	0% – 10%
γ	output loss during sudden stop	5.7%	0% – 30%
r	interest rate	3.3%	3% – 7%
δ	term premium	1.3 pp	0 pp –5 pp
ϕ	fraction of deposit withdrawn	17%	0% – 70%
s_0	fraction of kuna deposits exchanged for euro deposits (constant)	19%	0% – 70%

Figure 14 shows how the optimal level of the reserves depends on the size of the eight parameters from Table 8. The optimal level of reserves is particularly sensitive to the probability of sudden stop, exchange rate depreciation, output loss, the term premium and the fraction of deposit that will be withdrawn during the banking crisis[27]. The relation between the probability of a sudden stop and the optimal reserves level is nonlinear and positive. Hence, the actual probability of a sudden stop is relevant for the optimal reserves level only for small probability values. In the benchmark case, even if one doubles the probability (from 10% to 20%) the optimal reserves level would increase by only 23%. Increasing the exchange rate depreciation from 8% (in the benchmark case) to 20% increases the optimal reserve level by 38%. Doubling the output loss (from 5.7% to 11.4%) has an even larger impact (47%). Increasing the assumed deposit withdrawal rate from 17% to 30% increases the optimal reserves level from 4.650 million euros to 6.445 million euros. It is interesting that increasing the term premium by just a little (say 1 percentage point) has a large impact on the cost of holding reserves[28]. Increasing the term premium from 1.3 percentage points (in the benchmark case) to 2.3 would decrease the optimal level of the foreign reserves by 36%.

Figure 14 also shows that, assuming that the mother banks act as the lenders of last resort, the actual reserves are at their optimal level under a range of shocks that do not assume their extreme values at the same time. For example, providing that the magnitude of other shocks is at the benchmark level, the CNB has enough reserves for fighting off the crisis with the probability of its occurrence larger than 30%. Alternatively, even if Kuna depreciates during the crisis by more than 30%, the CNB is holding reserves for overcoming the higher burden of potential foreign liabilities. Finally, actual foreign reserves can be though of as an insurance against maximum 17.5% output loss or 50% deposit withdrawal as long as scale of other effects of crisis is at the benchmark level. However, as shown in

[27] Note that this is in strike contrast with the Greenspan-Guidotti and 3-months-of imports rules, which do not depend on these parameters.

[28] This might be the biggest weakness of the model then.

the previous section, the current level of foreign reserves is inadequate if all the shocks assume their extreme values at the same time, or if the mother banks participate in the crisis.

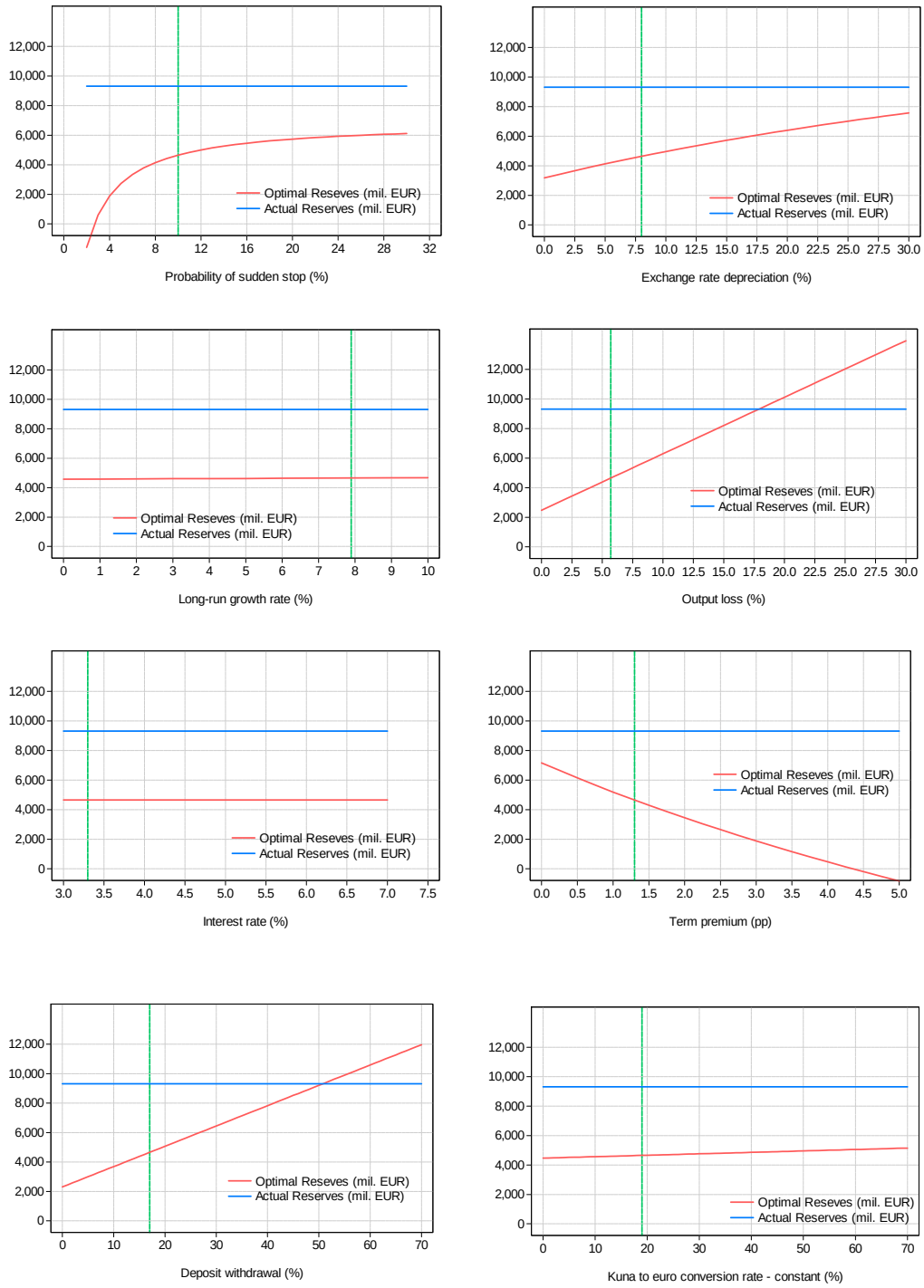

Figure 14: Sensitivity analysis

4 Conclusion

This paper has explored the main issues related to the trend of strong foreign reserves accumulation in Croatia during the last decade within a context of a simple analytical model. We show that this trend is consistent with the precautionary demand for foreign reserves. Whether this trend has been too strong or whether the actual reserves have been lower than optimal depends on two factors- on the expected reaction of the mother banks during the crisis and on the calibration of the model. Our study reveals that for plausible values of parameters, related to the 1998/1999 sudden stop/banking crisis, the CNB is holding enough foreign reserves to fight the possible crisis in the near future. This result holds regardless of the mother banks' reaction. Moreover, we show that the CNB reserves present an insurance asset against a crisis of the magnitude larger than that during the 1998/1999 episode, provided that not all shocks assume their extreme values at the same time and that the mother banks act as the lenders of last resort. However, in case of a severe sudden stop that would completely erode the confidence in the banking system, the CNB's foreign reserves would not be sufficient to mitigate the resulting consumption shortfall, even if supported by a favorable reaction of the mother banks. We also show how using the two standard indicators of foreign reserves adequacy might be misleading in assessing foreign reserves optimality. This result stems from the elements that determine optimal reserves and that Greenspan-Guidotti and 3-months-of-imports rules do not take into account.

Our model could be extended in many directions. In particular, it would be worth exploring the elements of the models by Ranciere and Jeanne (2006), Goncalves (2007), Jeanne and Ranciere (2008) like crisis prevention (where the probability of a crisis depends on the level of reserves) and endogenous agents' behavior during a sudden stop. These extensions would endogeneize some of the assumptions in our model. Other extensions of the model could include introducing parameters related to regulation: optimality of reserves models provide a natural setting for comparing the costs and the benefits of regulation, at least from the prudential perspective. For example, it would be possible to introduce a parameter representing the CNB's „minimum required liquid foreign assets" instrument and find its optimal value, in a sense that any value of this parameter that would yield the optimal reserves level below their actual level would be considered costly. All those extensions constitute a task for future research.

A Appendix

In the first part of Appendix we show how to derive the consolidated budget constraint (12) and (13). In the second part of Appendix, we show how to derive the formula for the optimal reserves (15). In the end we show how the consolidated budget constraint relates to the national accounts identity (1) and present a table with our data sources.

A.1 Consolidated budget constraint

Substituting for profits of banking sectors as well as transfers into the budget constraint of household before a sudden stop we have:

$$
\begin{aligned}
&c_t + S_t(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + S_t(1+r)b_{t-1} + S_t(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + \\
&+S_t\, FRB^h_t = y_t + S_t\, l^f_t + l^k_t + S_t\, b_t + S_t(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) + (1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) + \\
&+S_t(1+r)FRB^h_{t-1} + S_t(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + S_t(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + \\
&+S_t\, FB_t + RB^k_{t-1} + S_t\, RB^f_{t-1} + S_t(1+r)FRB^b_{t-1} - \\
&-S_t(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) - (1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) - S_t\, l^f_t - l^k_t - \\
&-S_t(1+r)FB_{t-1} - RB^k_t - S_t\, RB^f_t - S_t\, FRB^b_t + \\
&-S_t\, R_t - S_t(1+r)FG_{t-1} - S_t\, N_{t-1} - S_t\, PN_{t-1} - RB^k_{t-1} - S_t\, RB^f_{t-1} + \\
&+S_t(1+r)R_{t-1} + S_t\, FG_t + S_t\, PN_t + RB^k_t + S_t\, RB^f_t
\end{aligned} \tag{17}
$$

where

$$RB^k_t = \omega^k[d^{kh}_t + d^{kc}_t + 0.5\, S_t(d^{fh}_t + d^{fc}_t + FB_t)] \tag{18}$$

$$S_t\, RB^f_t = 0.5\, \omega^f\, S_t(d^{fh}_t + d^{fc}_t + FB_t) \tag{19}$$

$$R_t = PN_t \tag{20}$$

Canceling out most of the terms and substituting for reserves equation (20) we get consolidated budget constraint given in (12).

During a sudden stop the augmented households budget constraint reads as:

$$
\begin{aligned}
&c_t + (S_t + \Delta S)(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + (S_t + \Delta S)(1+r)b_{t-1} + \\
&+(S_t + \Delta S)(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) = \\
&(1-\gamma)y_t + (S_t + \Delta S)l^f_t + l^k_t + (S_t + \Delta S)(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) + \\
&+(1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) + (S_t + \Delta S)\phi(d^{fc}_t + \frac{\eta}{S_t + \Delta S}d^{kc}_t) + \phi(1-\eta)(d^{kh}_t + d^{kc}_t) \\
&+(S_t + \Delta S)(1+r)FRB^h_{t-1} + \\
&+(S_t + \Delta S)(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + (S_t + \Delta S)(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + \\
&+RB^k_{t-1} + (S_t + \Delta S)RB^f_{t-1} + (S_t + \Delta S)(1+r)FRB^b_{t-1} - \\
&-(S_t + \Delta S)(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) - (S_t + \Delta S)\phi[(d^{fh}_t + d^{fc}_t) + \frac{\eta}{S_t + \Delta S}(d^{kh}_t + d^{kc}_t)] - \\
&-(1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) - \phi(1-\eta)(d^{kh}_t + d^{kc}_t) - (S_t + \Delta S)\, l^f_t - l^k_t - \\
&-(S_t + \Delta S)(1+r)FB_{t-1} - RB^k_t - (S_t + \Delta S)RB^f_t + \\
&-(S_t + \Delta S)\, R_t - (S_t + \Delta S)(1+r)FG_{t-1} - (S_t + \Delta S)N_{t-1} - RB^k_{t-1} - \\
&-(S_t + \Delta S)RB^f_{t-1} + (S_t + \Delta S)(1+r)R_{t-1} + (S_t + \Delta S)PN_t + RB^k_t + \\
&+(S_t + \Delta S)RB^f_t
\end{aligned} \tag{21}
$$

where

$$RB^k_t = (\omega^k - \alpha^k)[d^{kh}_t + d^{kc}_t + 0.5\, S_t(d^{fh}_t + d^{fc}_t)] \tag{22}$$

$$(S_t + \Delta S)\, RB^f_t = 0.5\,(\omega^f - \alpha^f)(S_t + \Delta S)(d^{fh}_t + d^{fc}_t) \tag{23}$$

$$R_t = PN_t \tag{24}$$

A.2 Optimal reserves

Optimal reserves formula is derived in the following way. First order condition (14) can be rewritten as

$$\frac{u'(c^d_{t+1})}{u'(c^b_{t+1})} = \left(\frac{c^b_{t+1}}{c^d_{t+1}}\right)^{\sigma} = \frac{S_{t+1}(1-\pi)(\delta+\pi)}{(S_{t+1} + \Delta S)\pi(1-\delta-\pi)} = \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)(1+\frac{\Delta S}{S_{t+1}})} = z_{t+1} \tag{25}$$

where (from consolidated budget constraints (12) and (13))

$$
\begin{aligned}
c^b_{t+1} &= y_{t+1} + S_{t+1}\left[(b_{t+1} + FB_{t+1} + FG_{t+1}) - (1+r)(b_t + FB_t + FG_t)\right] - \\
&\quad -S_{t+1}\left[(FRB^h_{t+1} + FRB^b_{t+1}) - (1+r)(FRB^h_t + FRB^b_t)\right] - S_{t+1}(\delta+\pi)R_t
\end{aligned} \tag{26}
$$

$$
\begin{aligned}
c^d_{t+1} &= (1-\gamma)y_{t+1} - (S_{t+1} + \Delta S)(1+r)(b_t + FB_t + FG_t) + \\
&\quad +(S_{t+1} + \Delta S)(1+r)(FRB^h_t + FRB^b_t) - \\
&\quad -(S_{t+1} + \Delta S)\phi(d^{fh}_{t+1} + \frac{\eta}{S_{t+1} + \Delta S}d^{kh}_{t+1}) + (S_{t+1} + \Delta S)(1-\delta-\pi)R_t
\end{aligned} \tag{27}
$$

After substituting (26) and (27) into (25) and after some manipulation we get (15) with optimal level of foreign reserves given in equation (15).

A.3 National accounts identity and consolidated budget constraint

Here we show how consolidated budget constraint corresponds to national accounts identity. Before a sudden stop consolidated budget constraint reads as:

$$\begin{aligned} & \underbrace{S_t[(b_t - b_{t-1}) + (FB_t - FB_{t-1}) + (FG_t - FG_{t-1})]}_{FA_t} - \\ & - \underbrace{[(FRB_t^h - FRB_{t-1}^h) + (FRB_t^b - FRB_{t-1}^b)] + (PN_t - PN_{t-1} - N_{t-1})}_{FA_t} + \underbrace{S_t(R_t - R_{t-1})}_{\Delta R_t} \\ = \; & \underbrace{(y_t - c_t^b)}_{Y_t - A_t} + \underbrace{S_t r[(b_{t-1} + FG_{t-1} + FB_{t-1}) - (FRB_{t-1}^h + FRB_{t-1}^b + R_{t-1})]}_{IA_t} \end{aligned} \tag{28}$$

The first term on the left hand side corresponds to financial account since it involves foreign borrowing, the second term represents foreign reserves change as an element of financial account. On the right-hand side we have the difference between domestic output and domestic absorption (consumption in our model) and the elements of current account that are related to interest rate payments and are therefore stated in the income account.

During a sudden stop we have:

$$\begin{aligned} & \underbrace{S_t\{[(-b_{t-1}) + (-FB_{t-1}) + (-FG_{t-1})] - [(-FRB_{t-1}^h) + (-FRB_{t-1}^b)]\} + (PN_t - N_{t-1})}_{FA_t} + \\ & + \underbrace{S_t(R_t - R_{t-1})}_{\Delta R_t} \\ = \; & \underbrace{(y_t - c_t^d)}_{Y_t - A_t} + \underbrace{S_t r[(b_{t-1} + FG_{t-1} + FB_{t-1}) - (FRB_{t-1}^h + FRB_{t-1}^b + R_{t-1})]}_{IA_t} \end{aligned} \tag{29}$$

A.4 Data description and data sources

Symbol	Model variable	Data counterpart
y_t	Exogenous endowment	Gross domestic product (current prices, DZS)
S_t	Nominal kuna/euro exchange rate	Nominal kuna/euro exchange rate (H10)
d_t^{fh}	Household euro deposits	Household euro deposits (D8)
d_t^{kh}	Household kuna deposits	Household kuna deposits (D6 and D7)
b_t	Foreign borrowing by non-banking sector	Short term foreign debt by firms (including FDI debt, H12) + principal payment by firms of long-term debt (H14)
FB_t	Foreign borrowing by banks	Short term foreign debt by banks (excluding deposits, H12) + nonresident deposits (D10) + principal payment by banks of long-term debt (H14) (-mother banks' euro deposits- mother banks' short-term loans)
FG_t	Foreign borrowing by the government	Short term foreign debt by the government and CNB (H12) + principal payment by the government and CNB of long-term debt (H14)
FRB_t^h	Foreign liquid assets of non-banking sector	Cash and deposits in foreign banks of households and firms (H19)
FRB_t^b	Foreign liquid assets of banks	(Mandatory) banks' foreign currency reserves (H7)
RB_t^k	Kuna reserve requirement	Kuna reserve requirement (C1)
RB_t^f	Euro reserve requirement	Euro reserve requirement (C1)
R_t	International reserves	Gross international reserves of CNB (H7)

References

Aizenman, J., and J. Lee (2005): "International reserves: precautionary versus mercantilist views, theory and evidence," Proceedings, Federal Reserve Bank of San Francisco.

Aizenman, J., and N. Marion (2002): "The high demand for international reserves in the Far East: what's going on?," Discussion paper, Federal Reserve Bank of San Francisco.

Caballero, R. J., and S. Panageas (2004): "Contingent Reserves Management: An Applied Framework," NBER Working Papers 10786, National Bureau of Economic Research, Inc.

Durdu, C. B., E. G. Mendoza, and M. E. Terrones (2007): "Precautionary Demand for Foreign Assets in Sudden Stop Economies: An Assessment of the New Merchantilism," NBER Working Papers 13123, National Bureau of Economic Research, Inc.

Flood, R. P., and N. P. Marion (2002): "Holding International Reserves in an Era of High Capital Mobility," IMF Working Papers 02/62, International Monetary Fund.

Frenkel, J. A., and B. Jovanovic (1981): "Optimal International Reserves: A Stochastic Framework," *Economic Journal*, 91(362), 507–14.

Goncalves, F. M. (2007): "The Optimal Level of Foreign Reserves in Financially Dollarized Economies: The Case of Uruguay," IMF Working Papers 07/265, International Monetary Fund.

Heller, H. (1966): "Optimal International Reserves," *Economic Journal*, 76, 296–311.

Jankov, L. (2000): "Problemi banaka: uzroci, načini rješavanja i posljedice," CNB working paper P-2, Croatian National Bank.

Jeanne, O. (2007): "International Reserves in Emerging Market Countries: Too Much of a Good Thing?," *Brookings Papers on Economic Activity*, 38(2007-1), 1–80.

Jeanne, O., and R. Ranciere (2008): "The Optimal Level of International Reserves For Emerging Market Countries: A New Formula and Some Applications," CEPR Discussion Papers 6723, C.E.P.R. Discussion Papers.

Obstfeld, M., J. C. Shambaugh, and A. M. Taylor (2008): "Financial Stability, the Trilemma, and International Reserves," CEPR Discussion Papers 6693, C.E.P.R. Discussion Papers.

Ranciere, R., and O. Jeanne (2006): "The Optimal Level of International Reserves for Emerging Market Countries: Formulas and Applications," IMF Working Papers 06/229, International Monetary Fund.

Šonje, V. (2005): "Pokazatelji regulacijskog opterećenja banaka u šest zemalja srednje Europe i Hrvatskoj," Istraživanje za hrvatsku udrugu banaka, Arhivanalitika.

——— (2007): "VANJSKI DUG: Gdje prestaje oprez i počinje strah," Hub analize, Arhivanalitika.