OPTIMAL FOREIGN RESERVES: THE CASE OF CROATIA

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Abstract

This paper develops a simple model of precautionary foreign reserves in a dollarized economy subject to a sudden stop shock that occurs concurrently 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 the strong accumulation of foreign reserves over the last ten years. Whether this trend has been too strong or whether the actual reserves are lower than the optimal reserves depends on the possible reaction of the parent banks during a crisis. We show that for plausible values of parameters, the Croatian National Bank has enough reserves to fight a possible crisis of the magnitude of the 1998/1999 sudden stop with a banking crisis episode. This result holds regardless of the parent banks' reaction. We also show how use of the two standard indicators of "optimal" reserves, the Greenspan-Guidotti and the 3-months-of-imports rules, might lead to an unrealistic assessment of foreign reserves optimality in the case of Croatia.

Keywords: sudden stop, banking crisis, dollarized economy, optimal reserves

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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 behavior. It has been argued that part of the motivation for the accumulation of reserves stems from the mercantilist desire of some governments to maintain undervalued exchange rates and bolster the domestic economy. Apart from these exchange rate objectives, which have resulted in rapid reserve accumulations 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 played an important role in explaining the rise in 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 the 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 likely to result in a large withdrawal of foreign currency deposits (an internal drain risk). Therefore, in a dollarized economy reserves are not only an insurance against the negative effects of a sudden stop but also a key tool for managing domestic financial instability.

The strong accumulation of foreign reserves has also been apparent in Croatia. Since 1998 gross foreign reserves of the Croatian National Bank (CNB henceforth) have quadrupled. We explore the reasons for the strong accumulation of CNB reserves. One might say that a strong inflow of foreign capital in a dirty float of the exchange rate was behind the buildup of foreign reserves. However, the question of foreign reserves adequacy is still relevant regardless of the exchange rate regime. Providing that the double drain risk is present in Croatian economy we analyze whether CNB reserves are sufficient to mitigate negative effects of a potential sudden stop of capital inflows and a 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 self-insurance against a sudden stop and a banking crisis in a dollarized economy. By including specific features of the Croatian economy[1] in our model we extend the framework of Goncalves (2007), which develops a model of optimal reserves for Uruguay. In the model economy there are two main opposite forces driving optimal accumulation of reserves. 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 for lower yielding foreign assets. 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 accompanied by a banking crisis.

[1] In the same period, the short-term foreign debt of the Croatian economy has almost quintupled, while 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 has been too strong. In other words, the upsurge of reserves observed in Croatia over the past decade seems in excess of what would be implied by an insurance motive against a sudden stop and a banking crisis. This result crucially depends on the assumed behavior of parent banks during a sudden stop. In working with the data, we assume two possible reactions of parent banks during the crisis. Parent 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 the benchmark calibration we study optimal reserves in an economy that is hit by a sudden stop with a banking crisis on the scale of the 1998/1999 crisis. 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 parent banks. Finally, we compare our formula of optimal reserves with two standard indicators of "optimal" reserves for the Croatian economy, the Greenspan-Guidotti and the 3-months-of-imports rules. We present advantages of our optimal reserves formula over the two standard indicators in assessing adequacy of reserves.

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 the buffer stock model had the capacity to explain the behavior of foreign reserves in the 1980s, the greater flexibility of the exchange rates exhibited in recent decades should have reduced reserve hoarding according to the buffer stock model (Aizenman and Lee (2005)). Recent welfare-based models of optimal reserves as a form of self-insurance had more success in explaining the 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 payment imbalances in the event of a sudden stop and to 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 the importance of the double drain risk for the Croatian economy and describe the episode of banking

[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.

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

crisis combined with sudden stop that took place in 1998/1999. In section 3 we present a model of optimal reserves together with a 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 a financial account shortfall that reduces 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 the 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 combined with a banking crisis. Because of the double drain risk, the protective role of reserves is more important in dollarized economies. Foreign reserves serve not only as a domestic absorption stabilizer but 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 a credit crunch by providing liquidity in the event of foreign deposit withdrawal.

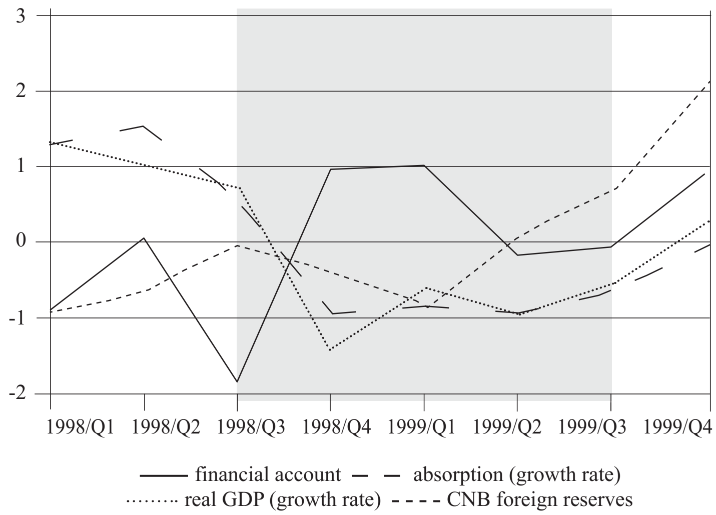
We place emphasis on a double drain risk, given that foreign lenders stopped providing credits to the Croatian economy in the 1998/1999 banking crisis (see Jankov 2000 for details). Internal drain risk seems to be more important in explaining the slowdown of domestic absorption than the financial account 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 Dubrova ka banka and unfolded in parallel with the sudden stop in the third quarter of 1998. The financial account reversal was relatively mild and lasted for one quarter only. The negative effects of the sudden stop were lessened by the release of a part of the foreign reserves.

However, output and domestic absorption continued to fall (until the third quarter of 1999 – the shaded area in Figure 1). 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. Bank activity peaked in the third quarter of 1998 (at the same time when the sudden stop occurred) after it reached a trough in the second

[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.

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

Figure 1 Components of domestic absorption (series are standardized)



Source: HNB

quarter of 1999 (shaded area in Figure 2) followed by the end of the real activity slowdown in the next quarter.

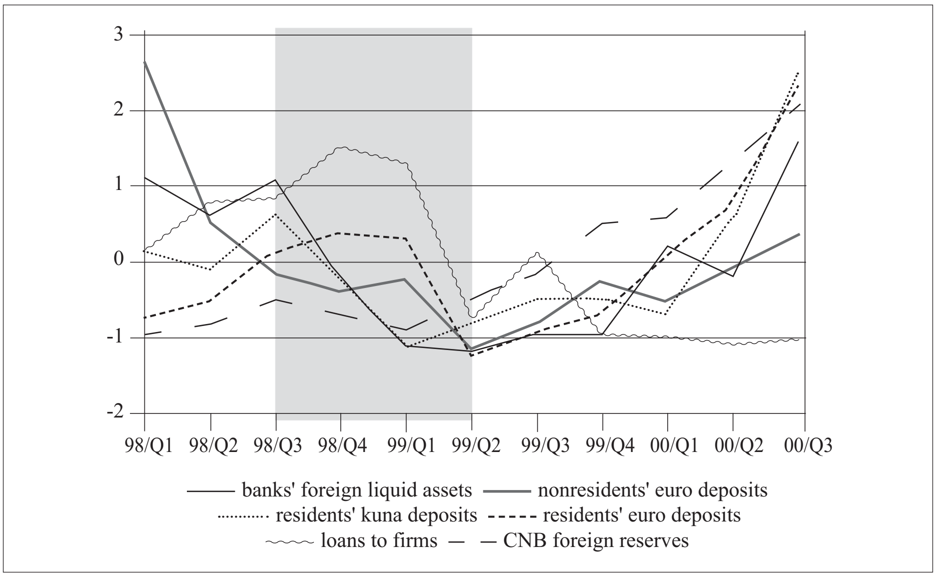
Besides the central bank's foreign reserves, the commercial banks' foreign reserves were also important in absorbing the fall in the euro deposits as a result of withdrawals in the period from August 1998 until May 1999 (Figure 3). Yet, the bankruptcy of a number of banks accentuated the credit crunch,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

Euro deposits[8] and short-term external debt[9] provide the background for a double drain risk in Croatia. The volatility in these two variables during a crisis could lead to a large foreign liquidity requirement (as they did during the 1998/1999 crisis). Hence, foreign reserves serve the twofold role of stabilizing both output and domestic absorption in a dollarized economy faced with a double drain risk. Nowadays, as in 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 covered 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

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

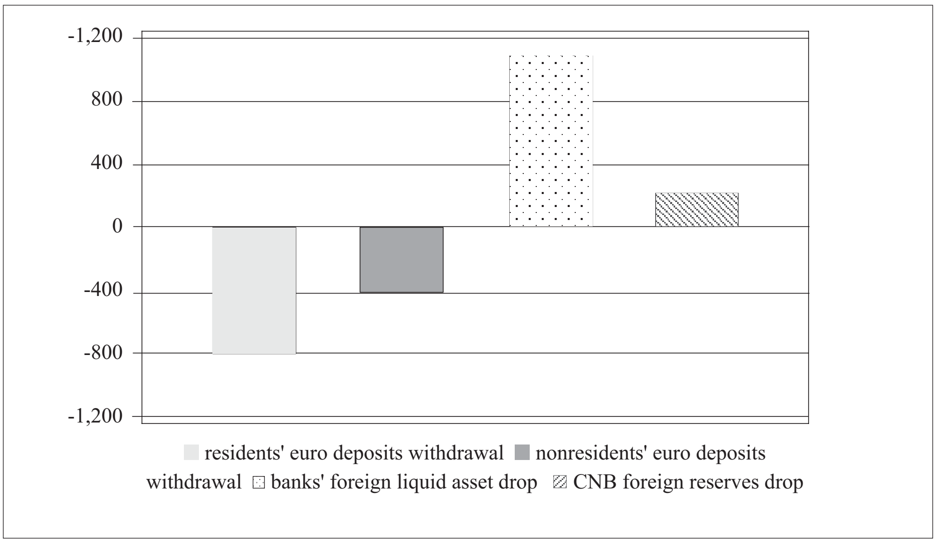
[9] We treat installments on long term debt that are due in period (year) *t* as short-term debt issued in the previous year. It will not be possible to roll over this principal repayment if a sudden stop shock hits the economy. We have been unable to present data on short term debt during the sudden stop with a banking crisis since data on short-term debt are available only since the end of 1998.

Figure 2 Banking sector activity during the sudden stop combined with banking crisis (series are standardized)



Source: CNB

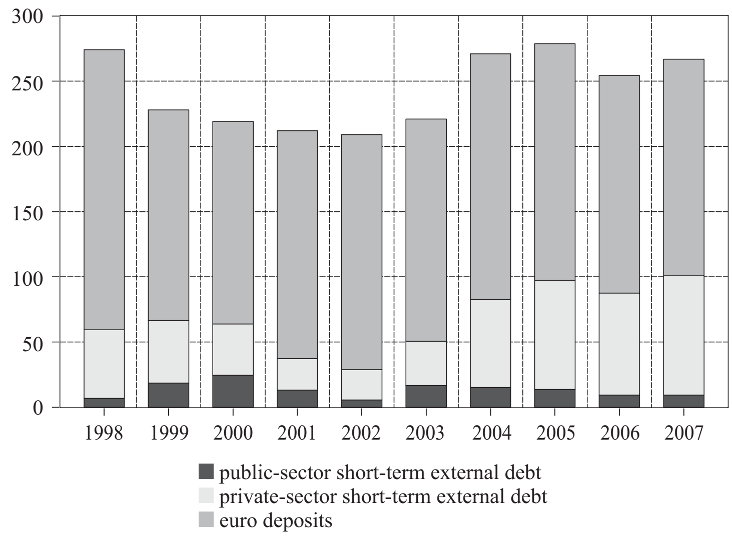
Figure 3 Euro deposits withdrawal and foreign buffers drop (mil. EUR) during the sudden stop with banking crisis



Source: CNB

high external drain risk since on average the foreign reserves covered a little over 100% of the short-term external debt during the same period.

Figure 4 Short term foreign currency debt and euro deposits in % of foreign reserves in the period 1998-2007



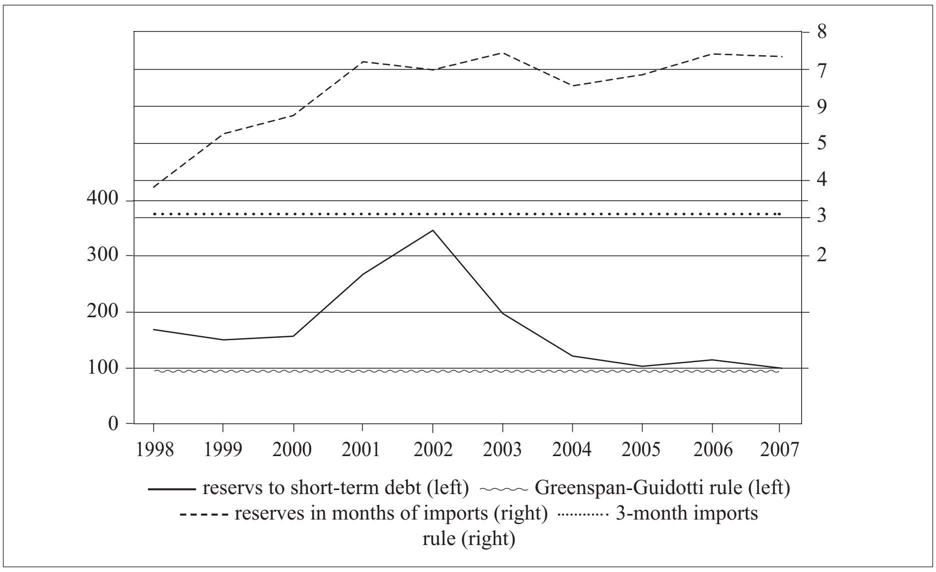
Source: CNB

In practice foreign reserve 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[10]. According to Šonje (2007) Croatia is on safe grounds as far as the second indicator of adequacy of foreign reserves is concerned. Even if one considers a situation of an extreme shock hitting our economy, Šonje shows, 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 (even though short-term external debt is almost equal to foreign reserves in recent years). Moreover, Croatia's (gross) foreign reserves cover more than 100%[11] 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.

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

[11] Notice that we are using an extended definition of short-term external debt that is usually not used in the literature that discusses the foreign reserves adequacy. Therefore the reader should be careful in interpreting the threshold of 100% as an alarming signal for the crisis since the threshold in our case should be smaller that 100%.

Figure 5 Reserves to short-term external debt ratio (%) and Reserves in months of imports



Source: authors' calculation, CNB

Moreover, use of 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 of whether central banks have enough foreign reserves to mitigate the negative effects of a possible sudden stop combined with a 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 – they neither consider the opportunity costs of holding reserves nor take into account the expected precautionary benefit of holding reserves.

In a previous article Šonje (2005) had conjectured correctly that the two standard indicators of reserve adequacy might no longer be valid in the new financial environment. He called 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 rightly calls for the missing optimality criterion in determining the desirable level of private foreign liquidity, Šonje's argument is based on historical thresholds that are by no means founded on an optimality norm.

[12] He used the short term debt/foreign reserves and the M4/foreign reserves ratios as crisis indicators.

By contast, 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 household and corporate 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 a sudden stop combined with banking crisis events.

The only uncertainty in the model comes from the probability of a sudden stop. There are three sectors in our model economy: households (which also incorporate corporate behavior), banks, and the government, which 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:

- no short-term foreign loans are rolled over in any sector,
- real GDP falls by some fraction,
- kuna/euro exchange rate depreciates,
- some kuna deposits (both household and corporate) are exchanged for euro deposits,
- a bank run occurs – a fraction of the overall deposits of the non-financial sector is withdrawn from banks,
- the 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 it and the model in Goncalves (2007). These differences stem from differences between the Croatian and Uruguayan economy. A bank run in our model occurs as a result of a loss of household confidence (in comparison to nonresident deposit withdrawal in Goncalves (2007)). Some of the deposits pulled out of the banking system are used as a buffer against lost access to the foreign loans market. Furthermore, during the bank run, households exchange some of their kuna deposits for euro deposits because of the loss of confidence in the 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 a 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 with respect to 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 price of consumption good is P_t. This good is financed by a deterministic exogenous endowment y_t, which grows 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 the 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, which 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 the financial sector they receive all their profits, Π_t (if any). For simplicity, we assume that all interest rates, r, are the same and constant.[13]

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[14]: 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.

The timing of the actions within the period when the sudden stop occurs is as follows. At the beginning of the period households invest their funds in kuna and euro deposits. Then a sudden stop occurs. The kuna depreciates (against the euro) by an absolute change of ΔS. Access of households to the foreign loans market is canceled. Households convert a fraction, η, of kuna deposits into euro deposits. At the end of the period households withdraw a fraction of overall deposits, ϕ, (which also include the newly converted 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 withdrawn from the banking system will not be used as a buffer against sudden stop effects. In our model wi-

[13] Differentiating between interest rates on deposits and loans would not change our formula of optimal reserves.
[14] This assumption circumvents modeling households and firms behavior separately.

thdrawing 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 money into a term deposit that does not fall due during the period of a sudden stop.

Tables 1 and 2 present the balance sheets of households in the period before the sudden stop and in the period when the sudden stop occurs. These tables summarize actions of households during those two periods.

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:

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

- during a sudden stop:

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

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

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	

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. The bank's assets consist of kuna credit, l_t^k, euro credit, l_t^f, reserve requirement that the monetary authority imposes on bank's sources of funds, RB_t, and private banks' foreign liquid assets, FRB_t^b. The reserve requirement is imposed on both domestic and foreign sources of finance (RB_t^k, RB_t^f respectively). However, half of the reserve requirement imposed on foreign liabilities is paid in kuna. The 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 the 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, r.

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 (which 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

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

with

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

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

- profits during a sudden stop

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

with

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

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

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. Government expenditures consist of international reserves, R_t, transfers to households[15], 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

$$R_t = PN_t.$$

By selling this security, the government pays term premium, δ, which 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[16]. 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 the expected present discounted value of its payoffs next period (equal to 1) and the expected price of the bond next period:

$$\begin{aligned} P &= \frac{1}{1+(r+\delta)} + \frac{E_t(P_{t+1})}{1+(r+\delta)} \\ &= \frac{1+(0\cdot\pi+(1-\pi)\cdot P)}{1+(r+\delta)} \end{aligned} \tag{10}$$

$$P = \frac{1}{r+\delta+\pi} \tag{11}$$

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 , PN_t, reserve requirement, RB_t and the international reserves that are due in period t. During a sudden stop, government cannot issue short-debt. 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 the actions of government, are given in Tables 5 and 6.

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

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

$$T_t + S_t R_t + S_t(1+r)FG_{t-1} + S_t N_{t-1} + S_t PN_{t-1} + RB^k_{t-1} + S_t RB^f_{t-1} =$$
$$S_t(1+r)R_{t-1} + S_t FG_t + S_t PN_t + RB^k_t + S_t RB^f_t \tag{12}$$

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 follows:

$$T_t + (S_t + \Delta S)R_t + (S_t + \Delta S)(1+r)FG_{t-1} + (S_t + \Delta S)N_{t-1} + RB^k_{t-1} + (S_t + \Delta S)RB^f_{t-1} =$$
$$(S_t + \Delta S)(1+r)R_{t-1} + (S_t + \Delta S)PN_t + RB^k_t + (S_t + \Delta S)RB^f_t \tag{13}$$

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

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

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 $\{r, P, S_t, P_t\}$ and a government policy $\{R_t, T_t, FG_t, RB_t^k, RB_t^f, N_t\}$ such that

- given prices and government policy, the allocation solves both household and bank problems
- given allocation and prices, government policy satisfies the government budget constraint.

There are many competitive equilibria since there are many government policies satisfying the government budget constraint. Hence the government is in a position to choose the best equilibrium by its choice of policy. In the Ramsey problem the government chooses a competitive equilibrium that maximizes household welfare (given by he household 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[17] 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

$$P_t c_t^b + S_t(1+r)b_{t-1} + S_t FRB_t^h = P_t y_t + S_t b_t + S_t(1+r)FRB_{t-1}^h + S_t FB_t + S_t(1+r)FRB_{t-1}^b - S_t(1+r)FB_{t-1} - S_t FRB_t^b - S_t(1+r)FG_{t-1} + S_t FG_t - S_t(\delta+\pi)R_{t-1} \tag{14}$$

• during a sudden stop

$$P_t c_t^d + (S_t+\Delta S)(1+r)b_{t-1} = (1-\gamma)P_t y_t + (S_t+\Delta S)(1+r)FRB_{t-1}^h + (S_t+\Delta S)(1+r)FRB_{t-1}^b - (S_t+\Delta S)\phi\left(d_t^{fh} + \frac{\eta}{S_t+\Delta S}d_t^{kh}\right) - (S_t+\Delta S)(1+r)FB_{t-1} - (S_t+\Delta S)(1+r)FG_{t-1} + (S_t+\Delta S)(1-\delta-\pi)R_{t-1} \tag{15}$$

In the Appendix we show that the consolidated budget constraint actually corresponds 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. The welfare maximization principle determines which consumption point the government will actually choose.

Furthermore, the 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 stemming from the possibility of replacing short-term by long-term debt during the sudden stop.

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

It is clear that holding foreign reserves is beneficial. Foreign reserves allow consumption smoothing of the 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 financed by issuing long-term debt at a term premium. In other words, the 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, which 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

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

subject to consolidated budget constraint (14) and (15). Substituting for consumption before a sudden stop, c_{t+1}^b, and consumption during a sudden stop, c_{t+1}^d, from consolidated budget constraint before and during a sudden stop 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

$$S_{t+1}(1-\pi)(\delta+\pi)u'(c_{t+1}^b) = (S_{t+1} + \Delta S)\pi(1-\delta-\pi)u'(c_{t+1}^d) \tag{16}$$

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 the sudden stop (left hand side).

From (16) we have a level of optimal reserves that reads as follows[18]

$$R_t = \frac{1}{q_{t+1}}\left\{(1+g)(1-\varepsilon_{t+1}^{\gamma})y_t + \left[\lambda_{t+1}^{*} - \frac{S_{t+1}^r}{P_{t+1}^r}(1+r)(1-\varepsilon_{t+1}^s)\lambda_t^{*}\right] - \left[\lambda_{t+1}^{A} - \frac{S_{t+1}^r}{P_{t+1}^r}(1+r)(1-\varepsilon_{t+1}^s)\lambda_t^{A}\right] + \phi\varepsilon_{t+1}^s\lambda_{t+1}^D\right\} \tag{17}$$

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

with

$$z_{t+1} = \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)\,(1+\frac{\Delta S}{S_{t+1}})}, \; \varepsilon_{t+1}^{\gamma} = z_{t+1}^{\frac{1}{\sigma}}(1-\gamma), \; \varepsilon_{t+1}^{s} = z_{t+1}^{\frac{1}{\sigma}}(1+\frac{\Delta S}{S_{t+1}})$$

$$y_{t+1} = (1+g)y_t, \; S_{t+1}^{r} = \frac{S_{t+1}}{S_t}, \; P_{t+1}^{r} = \frac{P_{t+1}}{P_t}$$

$$q_{t+1} = \frac{S_{t+1}}{P_{t+1}}\left[(\delta+\pi)(1-\varepsilon_{t+1}^{s}) + \varepsilon_{t+1}^{s}\right]$$

$$\lambda_t^{*} = \frac{S_t}{P_t}(b_t + FB_t + FG_t), \; \lambda_t^{A} = \frac{S_t}{P_t}(FRB_t^{h} + FRB_t^{b}), \; \lambda_t^{D} = \frac{S_t}{P_t}(d_t^{fh} + \frac{\eta}{S_t+\Delta S}d_t^{kh}).$$

A formula for optimal reserves provides the level of reserves that a central bank needs to hold today if it wants to prevent the expected negative effects of a sudden stop with banking crisis that might happen tomorrow. At the same time, by holding optimal reserves, a central bank is smoothing consumption, which yields maximum possible welfare. Optimal reserves increase with overall expected short-term external debt, λ_{t+1}^{*}, possible foreign deposit withdrawal, $\phi\lambda_{t+1}^{D}$, output loss, γ, probability of a sudden stop, π and exchange rate depreciation, ΔS. The first two variables pertain to a double drain risk. The 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 materialises (if 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 the central bank to hold more reserves. The first two variables pertain to a double drain risk. The 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 materialises (if 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 the central bank to hold more reserves, δ, increase and if the alternative buffer in terms of expected foreign liquid assets of private sector, λ_{t+1}^{A} increases.

Our formula for optimal reserves differs from that in Goncalves (2007) in that it preserves dynamics[19]. 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 a 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 hap-

[19] Goncalves (2007) makes all model variables in period t+1 equal to the value of the corresponding model variable in period t .

pened 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 that in Goncalves (2007)). 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 that are hit during the crisis fall (for example, short-term external debt falls since it is not rolled over and foreign deposits fall because of the bank run). Hence, optimal reserves in 2001 would be lower than those one would calculate using a static formula (which would not use 2002 data). Therefore, a dynamic formula would underestimate optimal reserves before the crisis. However, a 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 the holding of fewer reserves[20].

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 dynamic formula implies a level of reserves today such as to prevent a 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 tomake it equal to the Greenspan-Guidotti rule:

$$R_t = \lambda_{t+1}^* \tag{18}$$

This would hold if there were no alternative buffer to protect the economy from a 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 adequacy of reserves, it is clear that the restricted formula does not even reflect the stylized facts of sudden stops combined with banking crises since it excludes the main elements of all episodes of a sudden stop combined with abanking crisis.

3.6 Calibration

To go from the general formula for optimal reserves to quantitative statements about the issues of holding the optimal amount of international reserves we have to calibrate the model. In other words, the model's ability to say something about optimal reserves depends on the 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, which 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,

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

we will adapt its value from the existing studies and run a 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 a banking crisis episode during 1998/1999. In other words, benchmark calibration involves setting parameter values to reflect the 1998/1999 sudden stop with banking crisis episode. 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 the sudden stop happened somewhere in the middle of a year (third quarter of 1998). Furthermore, by the end of the next year the most severe effects of that sudden stop combined with banking crisis had 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 combined with banking crisis.

There is no official date when the 1998/1999 sudden stop combined with a banking crisis started. It should be the date when issuing new external debt was no longer possible and when a bank run occurred. Hence, we should be able to discern the beginning of the sudden stop with a banking crisis in the data for external debt and banking activity. Unfortunately, data on external debt are available from December 1998 only. However, we do have longer time series on non-residential deposits, which also count as external debt. Moreover, we have longer time series of financial accounts 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 combined with a banking crisis period, respectively. Therefore, the sudden stop with banking crisis began in March 1998 (that correspond to the date of Dubrovačka banka failure) and its consequences were still felt until end-May 1999. These dates approximately correspond to the 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 combined with a 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 real GDP over the period 1998 – 2007 which is equal to 3.9%. Potential GDP was estimated using the Hoddrick-Prescott filter. Output loss during the sudden stop with a banking crisis, γ, was calibrated as the difference between the average growth rate of potential GDP and the largest (negative) actual GDP growth rate during the sudden stop with a banking crisis period (which happened just after the sudden stop with a banking crisis had started – in the fourth quarter of 1998 when real GDP changed by -4,8%). Hence, the output loss during the sudden stop with banking crisis period is set to 8,7% of nominal GDP.

To account for a 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 the kuna reserve requirement relief during a sudden stop

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

where s_0 is the parameter of the kuna deposit that would be exchanged for euros in any event (even if the central bank did not respond to a sudden stop) and s_α measures the elasticity of deposit withdrawal to a central bank move to decrease the reserve requirement (" Tequila effect"). During the sudden stop with a bank run episode in Mexico, the Central Bank of Mexico tried to fight the credit crunch by lowering the 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 had a chance to exchange the full amount of their peso savings, and put an even higher burden on the banking system. Since the Croatian National Bank did not react to the sudden stop with a banking crisis by lowering the 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 according to 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 deposit withdrawal happened). We assume that those kuna deposits were exchanged for euros[21]. Notice that releasing the reserve requirement on banks' foreign liabilities does not have any effect on optimal reserves since we work with gross foreign reserves (partially financed by reserve requirement).

The parameter value that characterizes the deposit withdrawal rate during a sudden stop with a banking crisis period, ϕ, is set to the value that matches the drop of euro deposits[22] during the 1998/1999 episode. Data show that the peak level of 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 the 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 the probit estimation of a sudden stop probability on panel data for 34 middle income countries in Ranciere and Jeanne (2006).

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

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

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 (δ = 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 set at the six month Euribor rate (3.3%).

Table 7 summarizes the values of the calibrated parameters.

Table 7 Benchmark calibration

Symbol	Parameter	Benchmark (98/99) Value
π	probability of sudden stop (%)	10.0
g	growth rate of potential GDP (%)	3.9
r	interest rate (%)	3.3
δ	term premium (pp)	1.3
σ	relative risk aversion	2.0
ω^k	kuna reserve requirement ratio (%)	17.0
ω^f	euro reserve requirement ratio (%)	17.0
α^k	kuna reserve requirement relief during sudden stop (pp)	0.0
γ	output loss during sudden stop (%)	8.7
ΔS	exchange rate depreciation rate (%)	8.0
ϕ	fraction of deposit withdrawn (%)	17.0
s_0	fraction of kuna deposits exchanged for euro deposits (constant) (%)	19.0
s_α	fraction of kuna deposits exchanged for euro deposits (elasticity)	0.0

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 parent banks) of all maturities as short-term external debt of the 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 the reserve requirement we have to use the gross measure of the CNB's foreign reserves.

The presence of foreign banks in the Croatian banking system complicates the story. 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 subsidiaries by converting their short-term funding into long-term funding or they would simply, ”take the money and run". Current literature on parent bank behavior provides evidence that parent banks’ presence adds significantly to the stability of the financial sector as the parent banks tend to provide liquidity and capital support during banking crises. Gardo 2008 conjectures that parent banks might sustain business activities in Central and Eastern Europe to benefit from the opportunities arising from the region's catching-up potential in terms of the scale and scope of banking activities. Hence parent banks might protect their subsidiaries in the event of the crisis. Using panel data on the intra-group ownership structure and the balance sheets of 45 of the largest banking groups in the world, Haas (2006) finds that parent banks tend to support weak subsidiaries by providing additional capital when the latter are confronted with adverse financial conditions. Using annual financial statements of individual banks operating in 11 countries in East Asia and Latin America Brei 2007 finds that foreign banks significantly attenuate the adverse effects of sudden stops on domestic lending volume, playing an important stabilizing role.

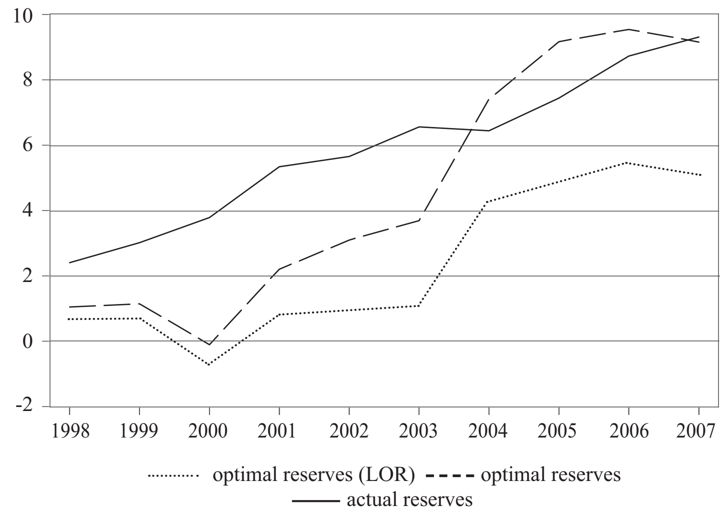
Moreover, in the case of the unexpected loss of Riječka banka in 2002, which provoked a run on its deposits, the parent bank (Bayerische Landesbank) ran as soon as it heard the bad news (by selling Riječka banka to the government for 1 euro). However, it did not claim its money back in terms of deposit withdrawal or cancellation of credit lines probably because the cost of loss of reputation would have been too large. To account for two possibilities of parent bank behavior we use two definitions of banks' foreign borrowing. When we treat parent 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 the data into the formula for optimal reserves, our benchmark calibration implies that the level of optimal reserves depends mainly on the reaction of parent banks during a potential sudden stop combined with a banking crisis (Figure 6).

If we assume that during the crisis all parent 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 almost twice as big as the optimal re-

Figure 6 Benchmark calibration – actual reserves, optimal reserves where parent banks act as the lenders of last resort, optimal reserves where parent banks participate in a crisis (bill. EUR)



Source: authors' calculation; CNB

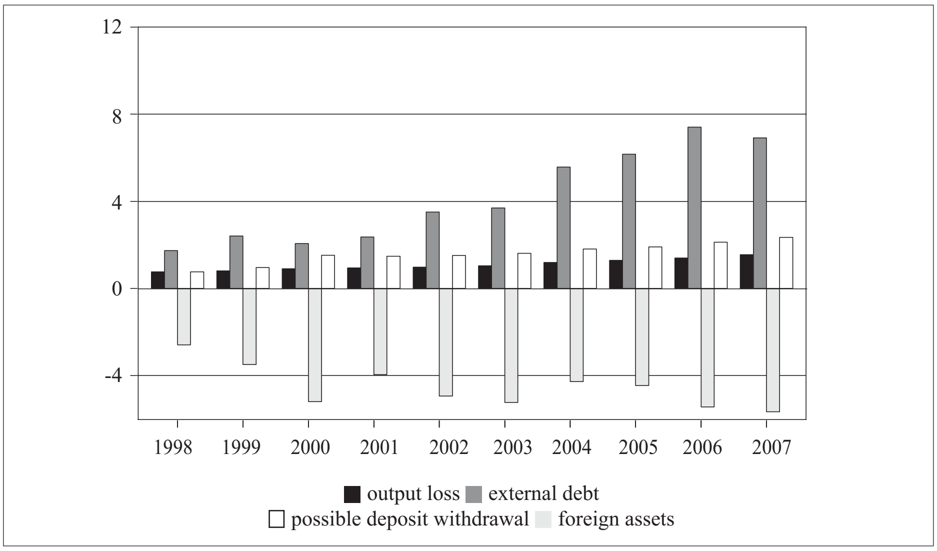
serves. However, the picture is quite different if we assume that parent banks will turn their back on Croatian banks in the event of a sudden stop combined with a banking crisis. Under this assumption, the need for foreign reserves has increased since 2003 from well below to near the actual level at the end of 2007 as domestic lending was fueled by foreign borrowing from parent 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 parent banks' reaction, the CNB has just enough reserves to prevent a financial account reversal and a bank run causing consumption loss.

Figures 7 and 8 explain the pattern of the optimal reserves. We decompose the optimal reserves into their four main components of optimal reserves formula (17). Optimal reserves are defined as the weighted difference between contributions of 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[23].

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 2001, due to the German mark-to-euro conversion at the end 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

[23] Note that these components do not perfectly correspond to the data since they are given weights that come from the Ramsey problem. Components correspond to the four elements of the optimal reserves formula (17).

Figure 7 Decomposition of optimal reserves (billion euros) where parent banks act as the lenders of last resort



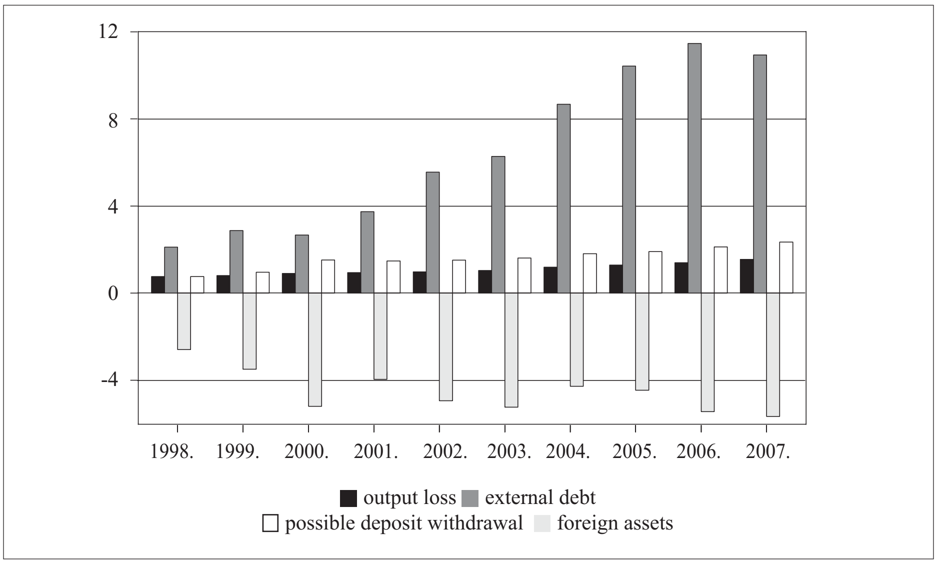
Source: authors' calculation

large enough to cope with a possible sudden stop with banking crisis during 2001[24]. The 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 parent banks' behavior. The large difference between the optimal reserve levels calculated in the two cases indicates that the major part of the external borrowing pertains to parent-subsidiary bank credit/deposit lines. The optimal reserves slowdown at the end of 2007 can for the most part be explained by a smaller increase in banks' foreign debt due to the CNB's credit growth ceiling.

Next, we 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 assuming that a *Tequila effect* would emerge. Note that if a *Tequila effect* does not exist releasing the reserve requirement on foreign liabilities will not have any impact on optimal reserves as it willreduce actual reserves and at the same time increase the buffer of banking sector. For the benchmark calibration with *Tequila effect* (i.e. with α^k = 17 pp, s_α = 1) where the parent banks acting as the lenders of last resort, 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. Figure 9 shows how the optimal reserves level in 2007 depends on the kuna reserve requirement reduction in this hypothetical scenario with the parent banks acting as the lenders of last resort (the perpendicular line indicates

[24] This result would not hold if the probability of sudden stop were a function of optimal reserves.

Figure 8 Decomposition of optimal reserves (bill. EUR) where parent banks participate in a sudden stop



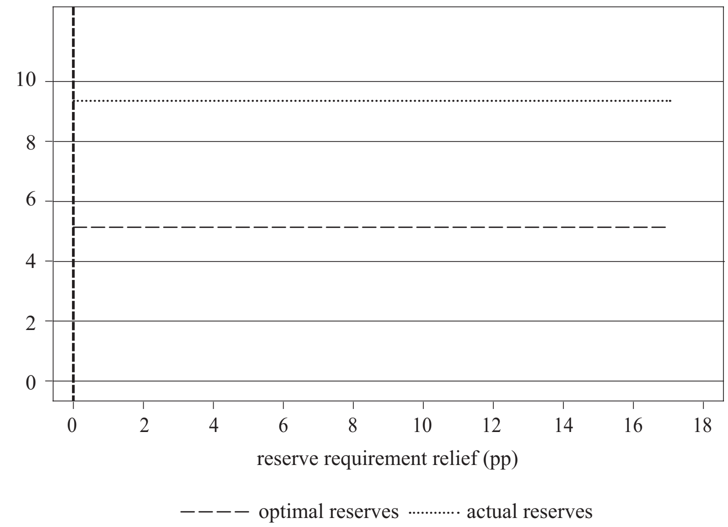
Source: authors' calculation

the zero benchmark value of kuna reserve requirement relief). 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. However, Figure 9 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 if a *Tequila effect* appears.

Finally, we investigate how our measure of optimal reserves (for a benchmark calibration and the parent 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 10). 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 combined with banking crisis, the short-term external debt and the 3-months-of-imports criteria do not take into account these features. Figures 11 and 12 show the optimal reserves level when output loss and the fraction of deposits withdrawn

Figure 9 Optimal reserves (bill. EUR) and kuna reserve requirenment relief

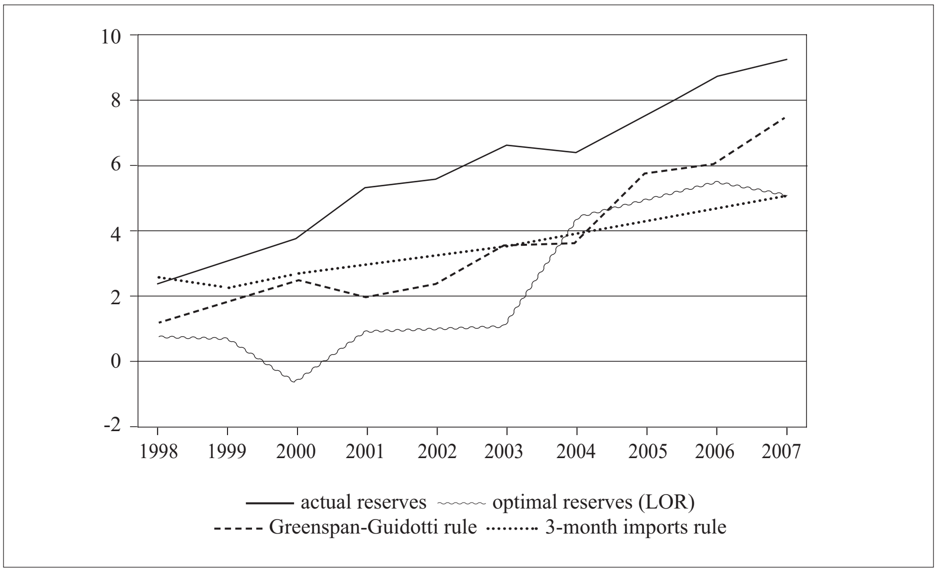


Source: authors' calculation, CNB

are different from the benchmark calibration (perpendicular lines indicates benchmark values of the two parameters).

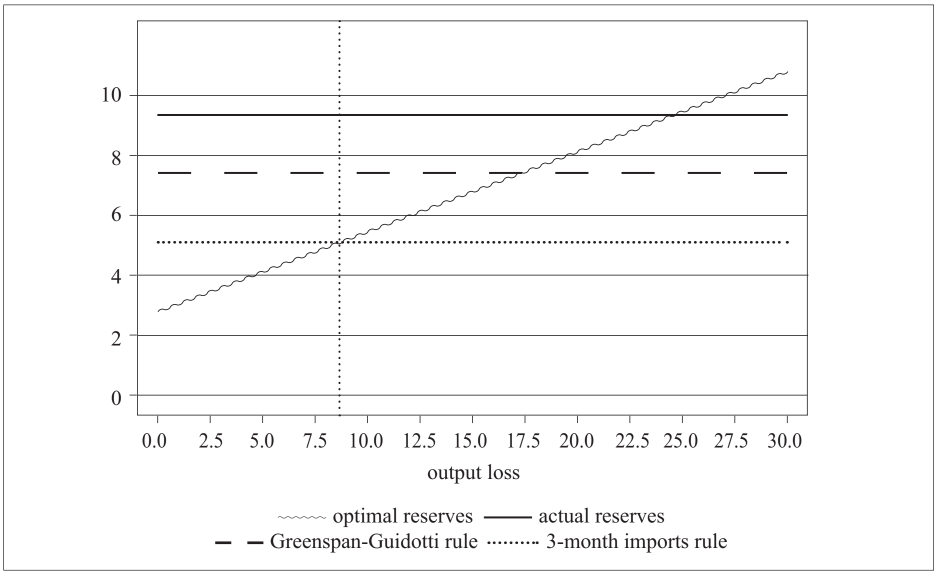
The error that one would make by using only the two standard measures of reserves adequacy in assessing the optimality of those reserves might be quite large. For example, if the Croatian economy were hit by a sudden stop with a banking crisis of the 1998/99 magnitude, then the Greenspan-Guidotti rule implies an "optimal" reserves level more than 2 billion euros higher than that implied by our measure (the perpendicular 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 17.5% (instead of 8.7%) of output loss or about 33% 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 11 and 12 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 twice as big as that during 1998/1999 then the Greenspan-Guidotti rule would be closer to our measure of optimal reserves than the 3-months-of-import rule.

Figure 10 Actual and optimal reserves with Greenspan-Guidotti and 3-months-of-imports rules (bill. EUR)



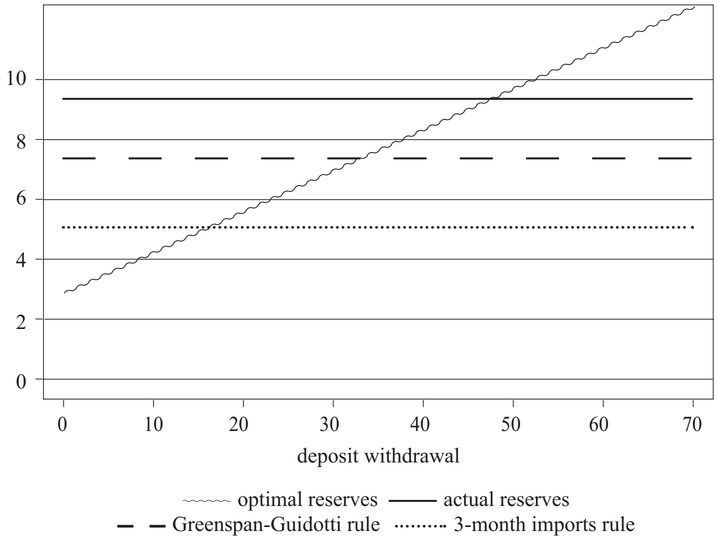
Source: authors' calculation, CNB

Figure 11 Optimal reserves, Greenspan-Guidotti rule and 3-months-of-imports rule (bill. EUR) with different values of output loss (%)



Source: authors' calculation, CNB

Figure 12 Optimal reserves, Greenspan-Guidotti rule and 3-months-of-imports rule (billion euros) with different values of fraction of deposit withdrawal (%).



Source: authors' calculation; CNB

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 13 we indicate the benchmark value of the corresponding parameter (using the perpendicular line). In our sensitivity analysis we assume that the parent banks act as the lenders of last resort in the event of a sudden stop combined with a bank run.[25]

Figure 13 shows that 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 a sudden stop, exchange rate depreciation, output loss, the term premium and the fraction of deposit that will be withdrawn during the banking crisis.[26] The

[25] We also run sensitivity analysis when parent 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.

[26] Note that this is in strike contrast with the Greenspan-Guidotti and 3-months-of imports rules, which do not depend on these 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 (%)	10.0	2 – 30
ΔS	exchange rate depreciation rate (%)	8.0	0 – 30
g	growth rate of potential GDP (%)	3.9	0 – 10
γ	output loss during sudden stop (%)	8.7	0 – 30
r	interest rate (%)	3.3	3 – 7
δ	term premium (pp)	1.3	0 – 5
ϕ	fraction of deposit withdrawn (%)	17.0	0 – 70
s_0	fraction of kuna deposits exchanged for euro deposits (constant) (%)	19.0	0 – 70

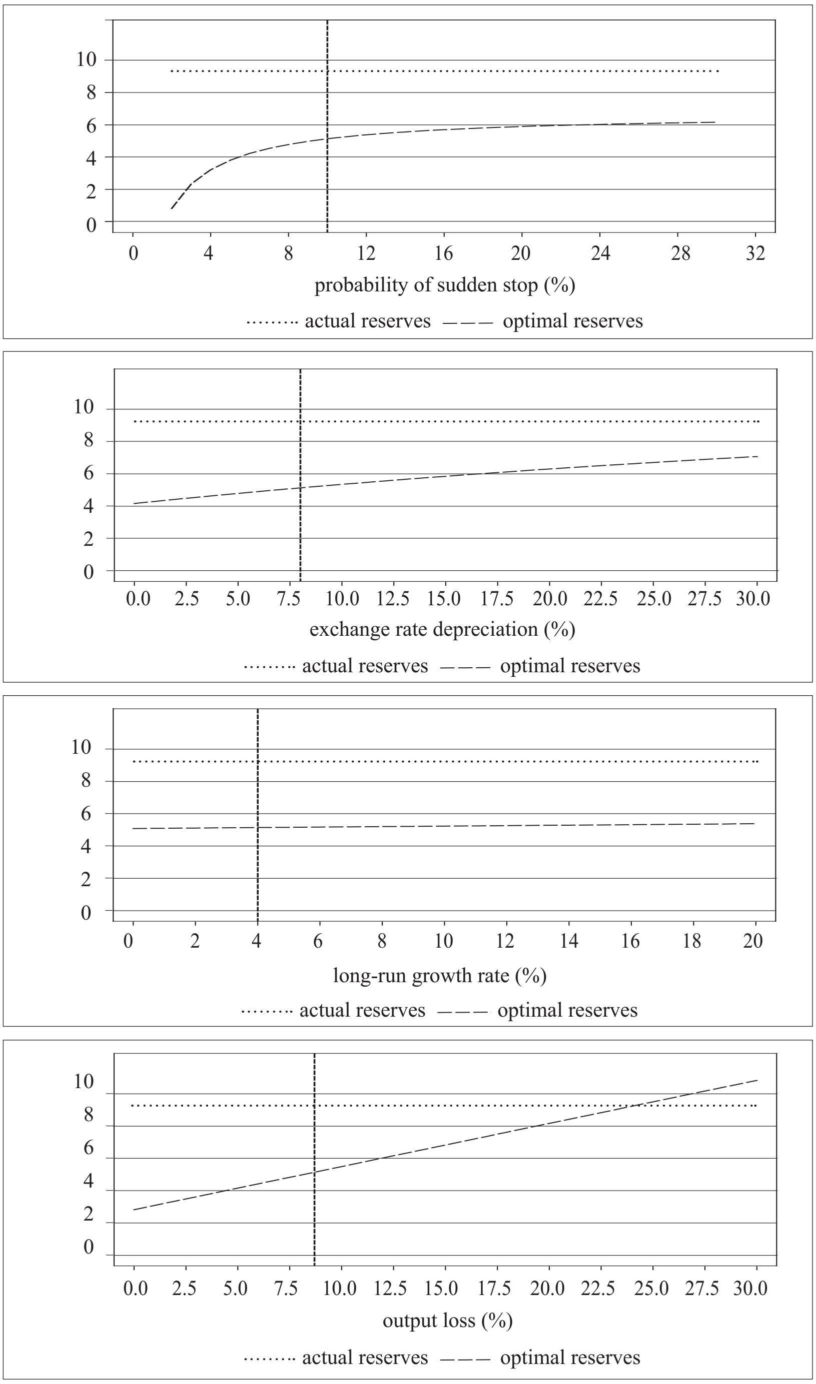
relation between the probability of a sudden stop and the optimal reserves level is nonlinear and positive. Hence, the actual probability of a sudden stop is relevant for the optimal reserves level only for small probability values. In the benchmark case, even if one doubles the probability (from 10% to 20%) the optimal reserves level would increase by only 15%. Increasing the exchange rate depreciation from 8% (in the benchmark case) to 20% increases the optimal reserve level by 23%. Doubling the output loss (from 8.7% to 17.4%) has an even larger impact (45%). Increasing the assumed deposit withdrawal rate from 17% to 30% increases the optimal reserves level from 5.130 million euros to 6.924 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[27]. 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 22%. Figure 13 also shows that, assuming that the parent banks act as the lenders of last resort, the actual reserves are still above 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 to fight off the crisis with the probability of its occurrence larger than 30%. Alternatively, even if the kuna depreciates during the crisis by more than 30%, the CNB holds reserves to overcome the higher burden of potential foreign liabilities. Finally, actual foreign reserves can be thought of as an insurance against a maximum 25% output loss or 50% deposit withdrawal as long as the scale of other effects of the crisis is at the benchmark level.

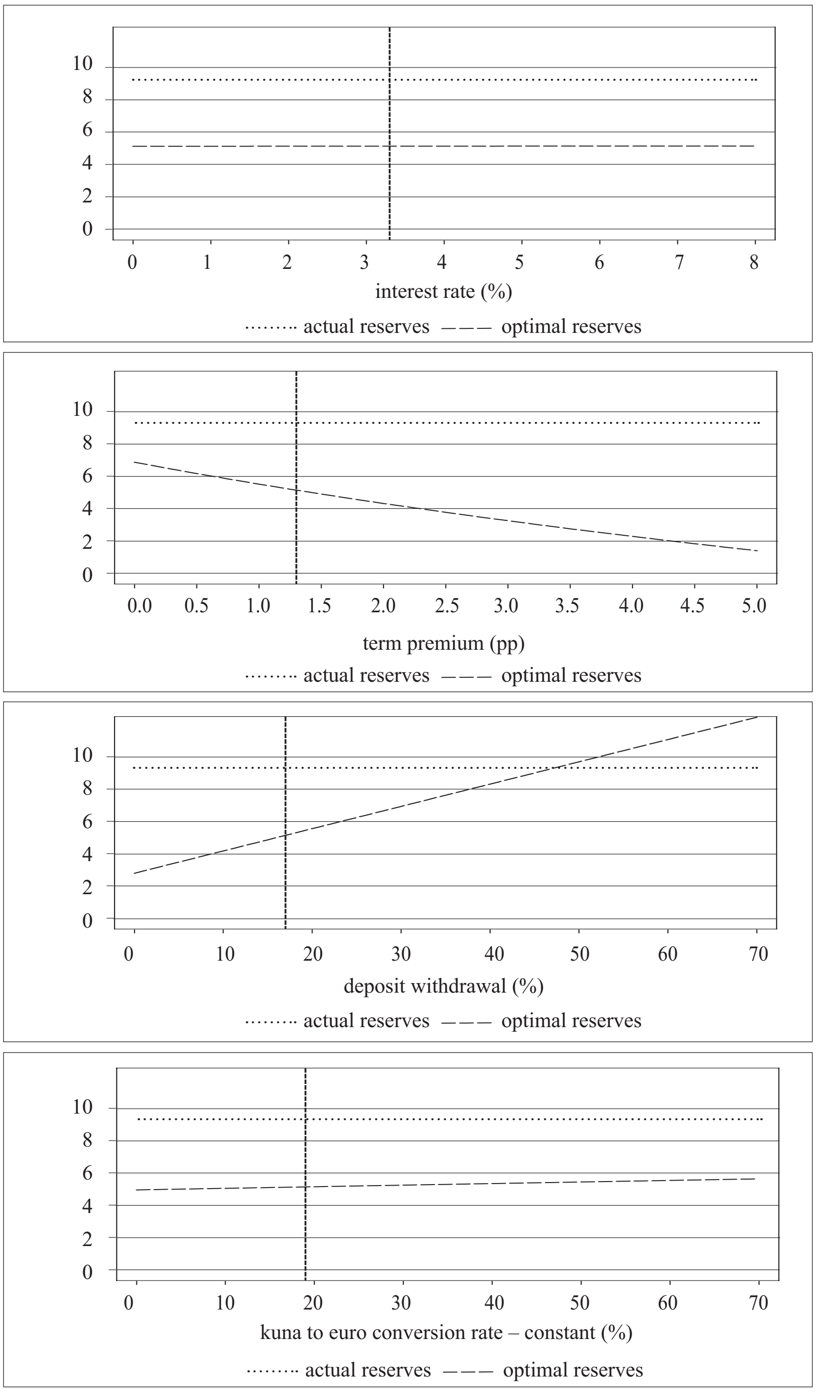
4 Conclusion

This paper has explored the main issues related to the trend of strong foreign reserves accumulation in Croatia during the last decade within the context of a simple analyti-

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

Figure 13 Sensitivity analysis of optimal reserves (mil. EUR)





Source: authors' calculation; CNB

cal 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 the expected reaction of the parent banks during the crisis. Our study reveals that for plausible values of parameters, related to the 1998/1999 sudden stop/banking crisis, the CNB holds enough foreign reserves to fight a possible crisis in the near future. This result holds regardless of the parent banks' reaction. Moreover, we show that the CNB reserves present an insurance asset against a crisis of a 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 parent banks act as the lenders of last resort. We also show that 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) and 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. An interesting issue to tackle would be to analyze the relation between profits of parent banks, their behavior during a crisis and the probability of a crisis. These extensions would endogenize 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 yielding the optimal reserves level below their actual level would be considered costly. All those extensions constitute a task for future research.

5 Appendix

In the first part of Appendix we show how to derive the consolidated budget constraint (14) and (15). In the second part of Appendix, we show how to derive the formula for the optimal reserves (17). 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.

5.1 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:

$$\begin{gathered} P_t c_t + S_t(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + S_t(1+r)b_{t-1} + S_t(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + \\ S_t FRB^h_t = P_t y_t + S_t l^f_t + l^k_t + S_t b_t + S_t(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) + (1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) + \\ S_t(1+r)FRB^h_{t-1} + S_t(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + S_t(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + \\ S_t FB_t + RB^k_{t-1} + S_t RB^f_{t-1} + S_t(1+r)FRB^b_{t-1} - \\ S_t(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) - (1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) - S_t l^f_t - l^k_t - \\ S_t(1+r)FB_{t-1} - RB^k_t - S_t RB^f_t - S_t FRB^b_t + \\ S_t R_t - S_t(1+r)FG_{t-1} - S_t N_{t-1} - S_t PN_{t-1} - RB^k_{t-1} - S_t RB^f_{t-1} + \\ S_t(1+r)R_{t-1} + S_t FG_t + S_t PN_t + RB^k_t + S_t RB^f_t \end{gathered} \tag{19}$$

where

$$RB^k_t = \omega^k [d^{kh}_t + d^{kc}_t + 0.5 S_t (d^{fh}_t + d^{fc}_t + FB_t)] \tag{20}$$

$$S_t RB^f_t = 0.5\omega^f S_t (d^{fh}_t + d^{fc}_t + FB_t) \tag{21}$$

$$R_t = PN_t \tag{22}$$

Canceling out most of the terms and substituting for the reserves equation (22) we get consolidated budget constraint given in (14).

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

$$\begin{gathered} P_t c_t + (S_t + \Delta S)(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + (S_t + \Delta S)(1+r \\ (S_t + \Delta S)(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) = \end{gathered}$$

$$(1-\gamma)P_t y_t + (S_t + \Delta S)l_t^f + l_t^k + (S_t + \Delta S)(1+r)(d_{t-1}^{fh} + d_{t-1}^{fc}) +$$

$$(1+r)(d_{t-1}^{kh} + d_{t-1}^{kc}) + (S_t + \Delta S)\phi(d_t^{fc} + \frac{\eta}{S_t + \Delta S} d_t^{kc}) + \phi(1-\eta)(d_t^{kh} + d_t^{kc}) +$$

$$(S_t + \Delta S)(1+r)FRB_{t-1}^h +$$

$$(S_t + \Delta S)(d_t^{fh} + d_t^{fc}) + (d_t^{kh} + d_t^{kc}) + (S_t + \Delta S)(1+r)l_{t-1}^f + (1+r)l_{t-1}^k +$$

$$RB_{t-1}^k + (S_t + \Delta S)RB_{t-1}^f + (S_t + \Delta S)(1+r)FRB_{t-1}^b -$$

$$S_t + \Delta S)(1+r)(d_{t-1}^{fh} + d_{t-1}^{fc}) - (S_t + \Delta S()\phi(d_t^{fh} + d_t^{fc}) + \frac{\eta}{S_t + \Delta S}(d_t^{kh} + d_t^{kc})] -$$

$$(1+r)(d_{t-1}^{kh} + d_{t-1}^{kc}) - \phi(1-\eta)(d_t^{kh} + d_t^{kc}) - (S_t + \Delta S)l_t^f - l_t^k -$$

$$(S_t + \Delta S)(1+r)FB_{t-1} - RB_t^k - (S_t + \Delta S)RB_t^f +$$

$$(S_t + \Delta S)R_t - (S_t + \Delta S)(1+r)FG_{t-1} - (S_t + \Delta S)N_{t-1} - RB_{t-1}^k -$$

$$(S_t + \Delta S)RB_{t-1}^f + (S_t + \Delta S)(1+r)R_{t-1} + (S_t + \Delta S)PN_t + RB_t^k +$$

$$(S_t + \Delta S)RB_t^f \tag{23}$$

where

$$RB_t^k = (\omega^k - \alpha^k)[d_t^{kh} + d_t^{kc} + 0.5S_t(d_t^{fh} + d_t^{fc})] \tag{24}$$

$$(S_t + \Delta S)RB_t^f = 0.5(\omega^f - \alpha^f)(S_t + \Delta S)(d_t^{fh} + d_t^{fc}) \tag{25}$$

$$R_t = PN_t \tag{26}$$

5.2 Optimal reserves

The optimal reserves formula is derived in the following way. First order condition (16) can be rewritten as

$$\frac{u'(c_{t+1}^d)}{u'(c_{t+1}^b)} = \left(\frac{c_{t+1}^b}{c_{t+1}^d}\right)^\sigma = \frac{S_{t+1}(1-\pi)(\delta+\pi)}{(S_{t+1}+\Delta S)\pi(1-\delta-\pi)} = \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)(1+\dfrac{\Delta S}{S_{t+1}})} = z_{t+1} \tag{27}$$

where (from consolidated budget constraints (14) and (15))

$$P_{t+1}c_{t+1}^{b} = P_{t+1}y_{t+1} + S_{t+1}\left[(b_{t+1} + FB_{t+1} + FG_{t+1}) - (1+r)(b_t + FB_t + FG_t)\right] -$$
$$S_{t+1}\left[(FRB_{t+1}^{h} + FRB_{t+1}^{b}) - (1+r)(FRB_t^{h} + FRB_t^{b})\right] -$$
$$S_{t+1}(\delta + \pi)R_t \tag{28}$$

$$P_{t+1}c_{t+1}^{d} = (1-\gamma)P_{t+1}y_{t+1} - (S_{t+1} + \Delta S)(1+r)(b_t + FB_t + FG_t) +$$
$$(S_{t+1} + \Delta S)(1+r)(FRB_t^{h} + FRB_t^{b}) -$$
$$(S_{t+1} + \Delta S)\phi(d_{t+1}^{fh} + \frac{\eta}{S_{t+1} + \Delta S}d_{t+1}^{kh}) + (S_{t+1} + \Delta S)(1-\delta-\pi)R_t \tag{29}$$

After substituting (28) and (29) into (27) and after some manipulation we get (17) with the optimal level of foreign reserves given in equation (17).

5.3 National accounts identity and consolidated budget constraint

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

$$\underbrace{S_t[(b_t - b_{t-1}) + (FB_t - FB_{t-1}) + (FG_t - FG_{t-1})] -}_{FA_t}$$
$$\underbrace{[(FRB_t^{h} - FRB_{t-1}^{h}) + (FRB_t^{b} - FRB_{t-1}^{b})] + (PN_t - PN_{t-1} - N_{t-1})}_{FA_t} + \underbrace{S_t(R_t - R_{t-1})}_{\Delta R_t} =$$
$$\underbrace{P_t(y_t - c_t^{b})}_{Y_t - A_t} + \underbrace{S_t r[(b_{t-1} + FG_{t-1} + FB_{t-1}) - (FRB_{t-1}^{h} + FRB_{t-1}^{b} + R_{t-1})]}_{IA_t} \tag{30}$$

The first term on the left hand side corresponds to the financial account since it involves foreign borrowing, the second term represents change in foreign reserves as an element of the 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:

$$\underbrace{S_t\{[(-b_{t-1}) + (-FB_{t-1}) + (-FG_{t-1})] - [(-FRB_{t-1}^{h}) + (-FRB_{t-1}^{b})]\} + (PN_t - N_{t-1})}_{FA_t} +$$

$$\underbrace{S_t(R_t - R_{t-1})}_{\Delta R_t} =$$

$$\underbrace{P_t(y_t - c_t^d)}_{Y_t - A_t} + \underbrace{S_t r[(b_{t-1} + FG_{t-1} + FB_{t-1}) - (FRB_{t-1}^h + FRB_{t-1}^b + R_{t-1})]}_{IA_t} \quad (31)$$

5.4 Data description and data sources

The table below matches model variables with their data counterpart (the source of data is given in parenthesis, where most of the data come from CNB bulletin's table).

Table 9 Model symbols, model variables and sources of data

Symbol	Model variable	Data counterpart
y_t	exogenous endowment	gross domestic product (constant prices, DZS)
S_t	nominal kuna/euro exchange rate	nominal kuna/euro exchange rate (H10)
P_t	price index	consumer price index (J1)
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) (-parent banks' euro deposits-parent 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)

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