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CROATIAN NATIONAL BANK

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Optimal International Reserves of the CNB with Endogenous Probability of Crisis[1]

Ana Maria Čeh and Ivo Krznar

Abstract

In this paper we expand the model of optimal reserves assuming an exogenous probability of crisis proposed in Čeh and Krznar (2008), in order to analyse not only holding reserves as an instrument for self-insurance against crisis, but also reserve accumulation for crisis prevention. The benefit of holding reserves as self-insurance in the model assuming an exogenous probability of crisis arises from the mitigation of the adverse effects of the crisis on the level of consumption, and, consequently on the welfare of the economy. On the other hand, the benefit of holding reserves for crisis prevention stems from reduced probability of a crisis breaking out, which depends on the reserve level. Given this two-sided cause-and-effect connection between reserves and the probability of crisis, the model of optimal reserves with endogenous probability of crisis has no analytical solution. Therefore, we applied the value function iteration method in order to work out a numerical solution of the model. For plausible parameter values, the model of optimal reserves with endogenous probability of crisis better explains reserve accumulation in the case of Croatia during the last ten-year period. The conclusion about whether Croatia has enough reserves to mitigate the adverse effects of a crisis, or even prevent a crisis similar to that in 1998/1999, depends on the parent banks' reaction to the crisis. Only in a "more favourable" scenario, in which parent banks assume the role of lenders of last resort, does the Croatian National Bank hold enough reserves for self-insurance and the prevention of a potential future crisis.

JEL: F31, F32, F37, F41

Keywords*:* sudden stop of foreign capital inflows, banking crisis, dollarised economy, optimal reserves, endogenous probability of crisis

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Contents

1 Introduction

Current literature on international reserves adequacy highlights at least two motives for strong reserve accumulation in developing economies over the last 15 years. Aizenman and Marion (2002) and Aizenman and Lee (2005) suggest that some countries have explicitly chosen to accumulate reserves for security reasons, i.e. as self-insurance against a potential sudden stop of foreign capital inflows. However, Bassat and Gottlieb (1992) and Garcia and Soto (2004) point to another benefit of holding reserves, which relates to crisis prevention, i.e. reducing the risk of a sudden stop of foreign capital inflows.

In order to answer the question of whether the Croatian National Bank (hereinafter: CNB) has enough reserves to mitigate the adverse effects of a potential sudden stop of foreign capital inflows and a banking crisis, we developed an optimal reserves model that only includes reasons for holding reserves as a self-insurance instrument (Čeh and Krznar, 2008). This model assumes two opposite forces influencing the movements of optimal international reserves. First, holding reserves is costly. The cost of holding reserves can be interpreted as the opportunity cost resulting from the substitution of relatively lower-yielding foreign assets for higher-yielding domestic assets. Second, reserves absorb fluctuations in foreign payment imbalances, ease crediting problems and make it possible to smooth consumption in case of a sudden stop of foreign capital inflows combined with a banking crisis.

In this paper we expand the model from Čeh and Krznar (2008) in order to analyse not only the holding of reserves as a self-insurance instrument but also reserve accumulation for crisis prevention. The benefit of holding reserves as self-insurance in the model assuming an exogenous probability of crisis arises from mitigating the adverse effects of the crisis on the level of consumption, and, consequently on the welfare of the economy. On the other hand, the benefit of holding reserves for crisis prevention can be included in the model if we assume that the probability of a crisis breaking out is the falling function of optimal reserves. Therefore, the motivation for the prevention of a crisis will be reflected in crisis probability movements, i.e. low reserves will enhance the probability of a crisis, which is why the central bank in the model will hold higher reserves to reduce the probability of a crisis. Given this two-sided cause-and-effect connection, the model of optimal reserves with endogenous probability of crisis has no analytical solution (in contrast to the model assuming an exogenous probability of crisis). Therefore, the new model has been solved numerically, by applying the value function iteration method.

Both models were calibrated using Croatian data derived from the circumstances related to the sudden stop of foreign capital inflows and the banking crisis in 1998/1999. Therefore, the calculation of optimal reserves in both models was based on the assumption that a potential future crisis will be similar to that of 1998/1999. The models were simulated in order to establish whether the dependence of the probability function on reserves affects the conclusion on the optimal level of international reserves. For plausible parameter values, the model of optimal

reserves with endogenous probability of crisis better explains reserve accumulation in the case of Croatia during the last ten-year period. Apart from the motives for self-insurance against crisis, this is the consequence of the motive to prevent a crisis that might break out as a result of all the factors facilitating a crisis breaking out that are not included in the model assuming an exogenous probability of crisis. This statement applies in particular to the first half of the reference period, in which the model of optimal reserves assuming an exogenous probability of crisis, presented in Čeh and Krznar (2008), recommends holding negative international reserves.

The two motivations for holding reserves are obviously connected. We can imagine a situation in which the central bank holds high reserves as a self-insurance instrument, while these high reserves also serve as a crisis prevention instrument. However, the different results of the two models for the first half of the reference period illustrate a situation in which there is a difference between the two motives for holding reserves, i.e. the negative optimal reserves as a self-insurance instrument in this period certainly do not serve as a crisis prevention instrument.

The conclusion about whether the CNB holds enough reserves to mitigate the adverse effects of a crisis and even to prevent the outbreak of a crisis similar to that in 1998/1999 depends on the parent banks' reactions during a crisis. Parent banks could act as lenders of last resort by refinancing short-term loans and providing additional liquidity. On the other hand, parent banks could withdraw their deposits and cut credit lines to subsidiaries in their ownership. Only in the former, "more favourable" scenario, does the CNB hold enough reserves as an instrument for self-insurance and the prevention of a potential future crisis.

The remainder of this paper consists of three sections. In Section 2, we present the two optimal reserves models, together with their calibration and quantitative implications. Section 3 provides an analysis of the dependence of our conclusions on changes in the probability function parameters. Section 4 sums up the conclusions.

2 The Model

In the following, we present and compare two optimal reserves models varying only in the form of the crisis probability function. First we will briefly describe the baseline model identical to the one in Čeh and Krznar (2008) assuming an exogenous probability of crisis. In the new model, having the same economic structure as the baseline model, the probability of crisis depends on the optimal level of international reserves, as in Jeanne and Ranciere (2008).

2.1 The Baseline Model of Optimal Reserves Assuming an Exogenous Probability of Crisis

The only uncertainty in the model comes from the parameter 'probability of a sudden stop of foreign capital inflows' π. The economy modelled consists of three

sectors: households (also including the corporate sector), banks and the government (also acting as the central bank). Households make decisions on the volume of consumption, domestic and foreign currency savings and net foreign loans by maximising the expected discounted utility function, subject to the budget constraint. Banks make decisions on demand for deposits, credit supply and net foreign loans by maximising profit. The government issues short-term and long-term external debt, allocates reserve requirements, invests in international reserves and provides the surplus of revenues over expenditures to households in the form of transfers. For details of the model structure, see Čeh and Krznar (2008).

A period of a sudden stop of foreign capital inflows is characterised by the following assumptions. When the economy is hit by a sudden stop of foreign capital inflows, no short-term foreign loans can be rolled over in any sector (b_t, FB_t and FG_t denote the short-term external debt of households, banks and the government respectively). Real GDP y_t falls by a certain value γ, whereas the kuna/euro exchange rate S_t depreciates by ΔS. A fraction (η) of kuna deposits (both household and corporate), d_t^{kh}, is exchanged for foreign currency (euro) deposits, d_t^{fh}, which is followed by withdrawing a fraction (ϕ) of deposits from the banking system (a fraction of total non-financial sector deposits is withdrawn from banks). Household kuna deposits, together with kuna and foreign currency deposits of enterprises will serve as a buffer against the effects of a sudden stop of foreign capital inflows. However, the foreign currency deposits of households withdrawn from banks are not used as a buffer against the effects of a sudden stop of foreign capital inflows, but are rather "put under the mattress", thus posing a potential risk for the international reserve level. The government stops repaying its long-term due liabilities (issued at a term premium δ above the interest rate r), whereas banks and households withdraw their foreign assets (FRB_t^b and FRB_t^h respectively) in order to use them as a buffer against a sudden stop of foreign capital inflows.

Under such circumstances, the government will, by choosing an international reserve level, R_t, maximise the expected discounted welfare of the entire economy, subject to budget constraint on the total economy. The welfare of the economy is measured by the welfare, i.e. utility function $u(\cdot)$ of households,[2] which depends on their consumption c_t. The budget constraint of the total economy is obtained by consolidating the budget constraints of households, banks and the government.

The government's problem is represented by the following:

$$\max_{\{c_t, R_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t) \right\} = \max_{\{c_t, R_t\}_{t=0}^{\infty}} \left\{ \sum_{t=0}^{\infty} \beta^t \left((1-\pi) u\left(c_t^b\right) + \pi u\left(c_t^d\right) \right) \right\}$$

subject to consolidated budget constraints if there is no sudden stop in foreign capital inflows combined with a banking crisis:

2 Households are owners of all the sectors.

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

or, if a crisis breaks out:

$$P_t c_t^d + (S_t + \Delta S)(1+r)(b_{t-1} + FB_{t-1} + FG_{t-1}) + (S_t + \Delta S)\phi\left(d_t^{fh} + \frac{\eta}{S_t + \Delta S} d_t^{kh}\right) =$$
$$= (1-\gamma)P_t y_t + (S_t + \Delta S)(1+r)(FRB_{t-1}^h + FRB_{t-1}^b) + (S_t + \Delta S)(1-\delta-\pi)R_{t-1} \quad (2)$$

where β is the discount factor, $u(c_t) = \frac{c_t^{1-\sigma} - 1}{1-\sigma}$ is the utility function of a constant relative risk aversion form, σ is the relative risk aversion parameter, and c_t^i, $i=b,d$ is the level of consumption in the presence vs. absence of a crisis.

A consolidated budget constraint indicates the sources and funds of financing of the entire economy. In good times, the sources of financing include an exogenous endowment in the form of the nominal GDP (P_t represents the price index), the newly issued short-term debt of the economy and the matured foreign assets of the economy invested in the previous period. Note that the reserves acting as government transfers to households are negative. This is due to the fact that the government actually imposes taxes on households in order to cover the cost of holding reserves which is proportional to the term premium and the probability of crisis. On the other hand, the sources of financing are spent on the purchase of goods, debt repayment of all the sectors and new investments in short-term foreign assets.

In bad times, the economy uses foreign assets to make up for its inability to refinance matured debt. Moreover, a run on household deposits involves costs to the economy. These costs, together with the purchase of goods and matured debt repayment, are financed by a portion of γ an exogenous endowment (a portion of disappeared due to the crisis), matured foreign assets and government transfers. In times of crisis, the government transfer in the form of reserves is positive, and is aimed at maintaining a certain level of consumption due to adverse effects of the crisis on the welfare of the economy.

In other words, the benefit of holding international reserves results from consumption smoothing during the crisis by a change of transfers to the non-financial sector. Note that this benefit actually stems from the possibility of replacing a short-term debt by a long-term debt in the time of a sudden stop of foreign capital inflows. However, just because holding reserves is equal to the repayment of a short-term debt by the issue of a (more expensive) long-term debt, such holding of reserves will be expensive.

In practice, the cost of holding reserves results from replacing higher-yielding domestic assets by lower-yielding foreign assets. In our model, we do not approximate this cost as a difference between the marginal productivity of domestic capital and the return on international reserves, but we model them in the same way as in Ranciere and Jeanne (2006) – international reserves involve an opportunity cost, because they are financed by issuing long-term debt at a term premium. In other

words, the opportunity cost of reserves is defined as a spread between the interest rate paid by the government on its own liabilities and a lower return on reserves, or as a spread between the interest rate on government liabilities ($r+\delta$) and a lower return on reserves (r).

Choosing between consumption if there is no sudden stop of foreign capital inflows, c_t^b, and consumption during a sudden stop of foreign capital inflows, c_t^d and deciding on the level of reserves, R_t, which maximises the total welfare of the economy, the first order condition of the government's problem is given as:

$$S_{t+1}(1-\pi)(\delta+\pi)u'(c^b_{t+1}) = (S_{t+1}+\Delta S)\pi(1-\delta-\pi)u'(c^d_{t+1}) \tag{3}$$

This optimality condition strikes a balance between the costs and benefits of holding reserves - the expected marginal benefit of holding reserves if a crisis breaks out (the right side) must be equal to the expected marginal cost of holding reserves if there is no crisis (the left side).

From (3) it follows that the optimal reserve level is given as:[3]

$$R_t = \frac{1}{q_{t+1}}\left\{\left(1-\varepsilon^{\gamma}_{t+1}\right)\frac{y_{t+1}P_{t+1}}{S_{t+1}} + \left[\lambda^{*}_{t+1} - (1+r)\left(1-\varepsilon^{s}_{t+1}\right)\lambda^{*}_{t}\right] - \right.$$
$$\left. - \left[\lambda^{A}_{t+1} - (1+r)\left(1-\varepsilon^{s}_{t+1}\right)\lambda^{A}_{t}\right] + \phi\varepsilon^{s}_{t+1}\lambda^{D}_{t+1}\right\} \tag{4}$$

where the net short-term debt of the economy is:

$$\lambda^{*}_t - \lambda^{A}_t = (b_t + FB_t + FG_t) - (FRB^{h}_t + FRB^{b}_t)$$

the potential cost of deposit withdrawal from the banking system

$$\lambda^{D}_t = \left(d^{fh}_t + \frac{\eta}{S_t + \Delta S} d^{kh}_t\right),$$

the real GDP growth

$$y_{t+1} = (1+g)y_t$$

and the model parameter-dependent variables are given by:

$$z_{t+1} = \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)\left(1+\frac{\Delta S}{S_{t+1}}\right)}, \varepsilon^{\gamma}_{t+1} = z^{\frac{1}{\sigma}}_{t+1}(1-\gamma), \varepsilon^{s}_{t+1} = z^{\frac{1}{\sigma}}_{t+1}\left(1+\frac{\Delta S}{S_{t+1}}\right)$$

$$q_{t+1} = (\delta+\pi)(1-\varepsilon^{s}_{t+1}) + \varepsilon^{s}_{t+1}$$

3 For formula derivation, see Čeh and Krznar (2008).

In order to provide for a comparison with optimal reserves given endogenous probability of crisis (see below), we will express optimal reserves as a share in GDP, ρ_t. If optimal reserves in (4) are divided by GDP in foreign currency $\frac{y_{t+1}P_{t+1}}{S_{t+1}}$, we get the following optimal reserves-to-GDP ratio, ρ_t:

$$\rho_t = \frac{1}{q_{t+1}}\left[\left(1-\varepsilon^{\gamma}_{t+1}\right)+\left(H_{t+1}+B_{t+1}+G_{t+1}\right)-\right.$$
$$\left.-\frac{1+g^{s}_{t}}{1+g^{y}_{t}}(1+r)\left(1-\varepsilon^{s}_{t+1}\right)\left(H_t+B_t+G_t\right)+\phi\varepsilon^{s}_{t+1}D_{t+1}\right] \qquad (5)$$

where the share of the net debt of households, banks and the government respectively, in GDP, is

$$H_t = S_t\frac{b_t - FRB^{h}_{t}}{P_t y_t}, B_t = S_t\frac{FB_t - FRB^{b}_{t}}{P_t y_t}, G_t = S_t\frac{FG_t}{P_t y_t}$$

the share of potential cost of deposit outflow in GDP

$$D_t = S_t\frac{d^{fh}_{t}+\frac{\eta}{S_t+\Delta S}d^{kh}_{t}}{P_t y_t}$$

and the growth rates of the nominal GDP and exchange rate are

$$g^{y}_{t} = \frac{P_t y_t}{P_{t-1}y_{t-1}}-1 = \frac{P_t(1+g)y_{t-1}}{P_{t-1}y_{t-1}}-1$$
$$g^{s}_{t} = \frac{S_t}{S_{t-1}}-1,\ g^{\Delta s}_{t} = \frac{S_t+\Delta S}{S_{t-1}}-1 = g^{s}_{t}\left(1+\frac{\Delta S}{S_t}\right)-1.$$

The optimal reserves formula gives us the level of reserves to be held by the central bank today in order to mitigate the anticipated adverse effects of a sudden stop of foreign capital inflows and a banking crisis that might occur tomorrow. Moreover, by maintaining the optimal reserve level, the central bank smoothes consumption, which maximises the welfare of the economy.

Optimal reserves grow in parallel with the total anticipated short-term external debt, λ^{*}_{t+1}, the potential foreign currency deposit withdrawal, $\phi\lambda^{D}_{t+1}$, output loss, γ, probability of a sudden stop of foreign capital inflows, π, and exchange rate depreciation, ΔS. Therefore, the central bank holds reserves in order to intervene in the event of the materialisation of an external risk (the short-term external debt dropping to zero), or of the occurrence of an internal risk (deposit outflow from banks). The output loss, exchange rate depreciation and probability of a sudden stop of foreign capital inflows are the model parameters to be calibrated.

The output loss affects the optimal reserve level by reducing domestic absorption. The exchange rate depreciation increases the burden of potential external liabilities and motivates the central bank to hold higher reserves. By contrast, the central bank's reserves will be lower if the cost of these reserves, δ, goes up, and if

their alternative buffer in terms of the expected private sector's foreign assets λ^{A}_{t+1}, strengthens.

2.2 The Model of Optimal Reserves Assuming an Endogenous Probability of Crisis

The benefit of holding reserves in the model assuming an exogenous probability of crisis consists in mitigating the adverse effects of the crisis on the level of consumption, and, consequently on the welfare of the economy. However, Bassat and Gottlieb (1992) and Garcia and Soto (2004) emphasize another benefit of holding reserves, which consist of a reduction of the risk of a crisis outbreak. This benefit can be included in the model if we assume the probability of a crisis outbreak to be the falling function of optimal reserves. In developing the crisis probability function $\pi(\cdot)$ (and its calibration later on) we use the form of the probability function from Jeanne and Ranciere (2008), where the crisis probability is negatively correlated with the level of reserves:

$$\pi_t = \pi(R_t), \pi' < 0$$

The model of optimal reserves assuming an endogenous probability of crisis will indirectly include all the elements for the holding of reserves by the central bank that do not relate to those optimal reserves components which are involved in the model of exogenous probability of crisis. For example, the model assuming an exogenous probability of crisis does not take into account the fact that, owing to low optimal reserves, the economy would be exposed to a higher risk of attack on domestic currency, which would end up in a crisis. Thus Čeh and Krznar (2008) suggest that optimal reserves should have been negative in 2001. However, in a situation where the central bank had no "ammunition" to fight the crisis, an attack on the domestic currency, a run on deposits and, finally, a sudden stop of foreign capital inflows would be very likely. In the case of endogenous probability of crisis, there will be no negative optimal reserves, because reducing the reserves increases the probability of crisis, which will in turn be a signal to the central bank to increase reserves in order to prevent the outbreak of a crisis.

Similarly, note that the endogenous probability of crisis contributes to the persistent behaviour of optimal reserves, because each change in their level leads to a change in the probability of crisis, which will have a feedback effect on the optimal reserve level. Moreover, by assuming that the crisis probability depends on the level of reserves, we indirectly model the central bank's aptitude to maintain exchange rate stability, as is the case with the CNB: by holding high reserves the central bank signals to the market that it has enough funds to keep the exchange rate stable. By acting so, the central bank tries to reduce the probability of a crisis which would break out due to domestic currency depreciation and the resulting banking crisis, as well as due to a possible interruption of foreign capital inflows.

In the new model, in which the level of reserves has not only the role of

mitigating the effects of a crisis, but also of preventing any crisis, the government's problem is the same as in the model assuming an exogenous probability of crisis, except that the crisis probability depends on the reserve level. Thus, the government chooses the level of consumption and that of reserves in order to maximise the expected, discounted sum of utilities:

$$\max_{\{c_t, R_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t) \right\} = \max_{\{c_t, R_t\}_{t=0}^{\infty}} \left\{ \sum_{t=0}^{\infty} \beta^t \left((1-\pi(R_t)) u(c_t^b) + \pi(R_t) u(c_t^d) \right) \right\}$$

subject to consolidated budget constraints (1) and (2). This problem has no analytical solution, owing to the two-sided cause-and-effect connection between optimal reserves and the probability of crisis. The circularity between the two variables can be explained in the following manner. Let us assume that the government chooses a level of international reserves which maximises the above problem. The optimal reserves level depends on the probability of crisis. However, by choosing a certain level of optimal reserves the government also influences it. This is exactly the reason why, in the case of the endogenous probability of crisis when the crisis probability is assumed to be the falling function of optimal reserves, an analytical solution to the new model does not exist.

In the following, we describe the method of numerical solution of the model in order to calculate optimal reserves in a situation of endogenous probability of crisis. For a numerical solution of the model we used the value function ($V(R_t)$) iteration algorithm. This algorithm requires that the government's problem be presented in the form of a value function. The government's value function is the following:

$$V(R_t) = \max_{R_t} (1 - \pi(R_t)) u^b(R_t) + \pi(R_t) u^s(R_t)$$

subject to (1) and (2), where the welfare of the economy if no crisis occurs is given as

$$u^b(R_t) = u(c_t^b) + \frac{1}{1+r} V(R_t^*) \tag{6}$$

or, if a crisis occurs

$$u^s(R_t) = u(c_t^d) + \frac{1}{1+r} u^b(R_t^*) \tag{7}$$

where we used $\beta = \frac{1}{1+r}$ arising from the first order condition of the problem of households in a steady state, and where R_t^* stands for an optimal reserve level.

The interpretation of the value function of the equation is intuitive. The central bank chooses the level of international reserves in order to maximise the expected welfare of the economy. Given the possibility of two "states of the world", the expected welfare of the economy can be expressed as a weighted sum of welfares in the two states, i.e. if a crisis occurs and if no crisis occurs, where the weights

are determined by the probability of crisis depending on the optimal reserve level, $\pi(R_t)$.

The welfare of the economy if no crisis occurs, $u^b(R_t)$, depends on the utility the economy obtains from the level of consumption if no crisis occurs, $u(c_t^b)$, and on the discounted sum of utilities in the future (which takes into account the possibility of a crisis in the future) which is summarised by the value function, $V(R_t^*)$.

The welfare of the economy if a crisis occurs, $u^s(R_t)$, also depends on the level of consumption during the crisis, $u(c_t^d)$, and the discounted value of utility in the period immediately after the crisis, $u^b(R_t^*)$ – we assume the crisis to last for a period of time, followed by a period of stability similar to that before the crisis.

The welfare in the post-crisis period of stability also depends on the discounted sum of future utilities which again takes into account the possibility of a future crisis.

At this point, it should be emphasized that all the above mentioned actually takes place within a single period of time and that the term "future" is used in the context of the value function convergence towards a fixed point in order to deal with the circularity problem.

To make the problem stationary, the model has been normalised by dividing by $y_t^{1-\sigma}$, where the value function and the probability of crisis now depend on optimal reserves as a share in GDP.

$$\widetilde{V}(\rho_t) = \max_{\rho_t} \left(1-\pi(\rho_t)\right)\widetilde{u}^b(\rho_t) + \pi(\rho_t)\widetilde{u}^s(\rho_t)$$

where

$$\widetilde{V}(\rho_t) = \frac{V(R_t)}{y_t^{1-\sigma}},\ \rho_t = \frac{S_{t+1}R_t}{P_{t+1}y_{t+1}}$$

$$\widetilde{u}^b(\rho_t) = u\left(\frac{c_t^b}{y_t}\right) + \frac{(1+g)^{1-\sigma}}{1+r}\widetilde{V}(\rho_t^*) \tag{8}$$

$$\widetilde{u}^s(\rho_t) = u\left(\frac{c_t^d}{y_t}\right) + \frac{(1+g)^{1-\sigma}}{1+r}\widetilde{u}^b(\rho_t^*) \tag{9}$$

where $\frac{u(c_t^i)}{y_t^{1-\sigma}} = u\left(\frac{c_t^i}{y_t}\right)$, $i=b,d$ due to the homogeneity of the utility function, $u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}$. Moreover, based on (1) and (2), consumption can be expressed as a share in GDP if no crisis occurs

$$\begin{aligned}\frac{c_t^b}{y_t} &= 1 + H_t - \frac{1+g_t^s}{1+g_t^y}(1+r)H_{t-1} + \\ &+ B_t - \frac{1+g_t^s}{1+g_t^y}(1+r)B_{t-1} + \\ &+ G_t - \frac{1+g_t^s}{1+g_t^y}(1+r)G_{t-1} - (\delta+\pi)\rho_{t-1}\end{aligned} \tag{10}$$

or, if a crisis occurs

$$\frac{c_t^d}{y_t} = (1-\gamma) - \frac{1+g_t^{\Delta s}}{1+g_t^y}(1+r)H_{t-1} +$$
$$-\frac{1+g_t^{\Delta s}}{1+g_t^y}(1+r)B_{t-1} +$$
$$-\frac{1+g_t^{\Delta s}}{1+g_t^y}(1+r)G_{t-1} +$$
$$-\left(1+\frac{\Delta s}{S_t}\right)\phi D_t +$$
$$+\left(1+\frac{\Delta s}{S_t}\right)(1-\delta+\pi)\rho_{t-1} \qquad (11)$$

If the function mapping operator $T(V)$ updating the value function V is defined by using the above shown value function (see Stokey, Lucas and Prescott (1989)), we could show that T is a contraction (with a modulus $\beta \in (0,1)$), where T has a unique fixed point V^* ($T(V)=V^*$) towards which T^j converges for any initial function V^0 ($V^*=\lim_{j\to\infty} T^j(V^0)$) when the number of value function updates on the basis of a value function equation goes to infinity. The algorithm of the value function iteration uses these two features to asymptotically calculate the solution of the fixed point problem in the form of a value function. After the value function calculation (starting with the arbitrary value of the initial value function, $V^0=0$), we can calculate optimal reserves as an argument maximising the value function

$$\rho_t^{j*} = \text{argmax} V^j(\rho_t) \qquad (12)$$

Optimal reserves are used in consecutive value function iterations in the utility functions (8) and (9) until reaching a fixed point V^*. The final optimal reserves ρ^* represent the argument maximising the final value function at the fixed point

$$\rho_t^* = \text{argmax} V^*(\rho_t) \qquad (13)$$

2.3 Model Calibration

The model calibration consists in assigning numerical values to all the parameters of the model describing preferences and the technology in order to bring the model into consistency with empirical facts about the structure of the Croatian economy. The model parameters are calibrated in the same manner as in Čeh and Krznar (2008), except for three parameters describing the crisis probability function. Thus, the model parameter values reflect the sudden stop of foreign capital inflows combined with the banking crisis in 1998/1999, during which the kuna depreciated by 8%, the real GDP rate dropped below the potential rate (3.9%) by 8.7 percentage points, 19% of kuna deposits were converted into euro deposits

and 17% of household euro deposits were withdrawn from the banking system. The calculation of optimal reserves depends on the parameter values describing the crisis magnitude. Therefore, the optimal reserves analysis indirectly assumes the outbreak of a crisis with the consequences of the 1998/1999 crisis.

The risk aversion parameter, σ, was assigned a standard value taken from the literature on business cycles ($\sigma=2$). The term premium, δ, was calculated as an average difference between the yield on a ten-year German government bond and ECB benchmark rate $\delta=1{,}3$ percentage points). We assumed the interest rate in the model, r, to be the return on reserves (among other things) and to be equal to an average foreign risk-free interest rate (in the Croatian case: the six-month Euribor, $r=3{,}3\%$).

In the calibration of the model assuming an exogenous probability of crisis, the probability of crisis parameter was set in such a manner that it implied one crisis on average each ten years ($\pi=0{,}1$). Moreover, this value corresponds to the probability estimate of a sudden stop of foreign capital outflows combined with a banking crisis based on a probit model presented on the panel of 34 medium-developed countries from Ranciere and Jeanne (2006).

Table 1 shows the values of all calibrated model parameters, where the first nine parameters relate to the model of optimal reserves assuming an exogenous probability of crisis. In the model of optimal reserves with endogenous probability of crisis, given the same values of the above mentioned nine parameters, we must additionally calibrate three probability function parameters. We assume that the probability of crisis is the probit function of reserves:

$$\pi_t = F\left(b - a\rho_t + c\frac{1}{\rho_t}\right) \tag{14}$$

where $F(\cdot)$ is the cumulative distribution function of a standard normally distributed random variable, where b,a,c are the parameters to be calibrated. Parameter a has a negative sign suggesting a negative correlation between the probability of crisis and the share of reserves in GDP.

Our probability function is very similar to that in Jeanne and Ranciere (2008). The difference consists in the fact that in our crisis probability function, c is different from zero. Parameter b was calculated in such a manner that

$$b=F^{-1}(0{,}1)$$

so that the value of this parameter reflects the exogenous probability of crisis (set at 0.1). The probability does not depend on reserves if parameter a equals zero. Consequently, the model of optimal reserves assuming an endogenous probability of crisis in which $a=0$, $b=F^{-1}(0{,}1)=-1{,}3$ and $c=0$ corresponds to the model of optimal reserves with exogenous probability of crisis. If $c=0$, our probability function corresponds to that in Jeanne and Ranciere (2008)

$$\pi_t=F(b-a\rho_t) \tag{15}$$

Why do we introduce an additional parameter $c>0$ into the function? Note that we obtain exogenous probability in the model of endogenous probability of crisis, demonstrated in (15), if we set $a=0$, so that the probability does not depend on reserves. However, this can also be achieved if reserves are equal to zero, $\rho_t=0$ and $a\neq0$! In this case, the probability of crisis will be 0.1, and one of the reasons for introducing the dependence of the probability of crisis on the level of reserves is to avoid such a situation. In order to avoid a situation where the central bank has no reserves, with probability returning to a (low) level of exogenous probability, we introduce a new parameter that will be close to zero in the case of "normal" levels of reserves, and thus not significantly contributing to a change in the probability of crisis. However, for reserves-to-GDP ratios close to zero (i.e. in a situation where, in the absence of parameter c, the probability would be about 0.1), c takes the value of 0.05. As parameter c is divided by the reserves-to-GDP radio, reducing the reserves towards zero considerably enhances the probability of crisis.

The parameter value was taken from Jeanne and Ranciere (2008) ($a=0{,}15$). This value of the "elasticity" of the probability of crisis with respect to the level of reserves is obtained as a result of estimating the probit function of the probability of crisis in many developing countries (see Garcia and Soto (2004) or Jeanne (2007)). The sensitivity analysis will show how changes in parameters a and b influence changes in optimal reserves. Table 1 shows the values of all calibrated parameters of the model.

Table 1 Benchmark Calibration

Symbol	Parameter	Benchmark (98/99) value
π	Probability of a sudden stop in foreign capital inflows (%)	10
g	Potential GDP growth rate (%)	3.9
r	Interest rate (%)	3.3
δ	Term premium (perc. points)	1.3
σ	Relative risk aversion	2
γ	Output loss during a suden stop of foreign capital inflows (%)	8.7
ΔS	Exchange rate depreciation (%)	8
ϕ	Fraction of deposits withdrawn (%)	17
η	Fraction of kuna deposits exchanged for foreign currency deposits (%)	19
a	"Elasticity" of the probability of crisis with respect to the level of reserves	0.15
b	F(b) – exogenous probability of crisis	–1.3
c	See formula (14)	0.0000001/0.05

2.4 Findings

As in Čeh and Krznar (2008), we analyse two optimal reserves scenarios. The first one implies that in case of a crisis, parent banks assume the role of lenders of last resort with regard to their subsidiaries in Croatia, helping them refinance their short-term liabilities and providing them with additional foreign currency liquidity. Under the second scenario, parent banks simply "take the money and run ", i.e.

they do not help their subsidiaries in coping with the crisis. Current literature on parent banks' behaviour in crisis situations shows that parent banks contribute significantly to financial sector stability, because they provide the necessary liquidity and capital in times of crisis (for details, see Čeh and Krznar (2008)).

As concerns data, several things have to be emphasized. First, each sector's short-term external debt has been increased by the repayments of the long-term debt principal due, as they represent short-term liabilities and are not conditional on a sudden stop of foreign capital inflows. Due to differences in the potential behaviour of parent banks, we use two definitions of banks' external debt. When we assume that parent banks will act as lenders of last resort, their foreign currency deposits and short-term loans are excluded from the above definition of extended short-term external debt.

Second, the bulk of deposits, even including term deposits, can simply be untied at any time. Therefore, non-resident deposits (mainly the deposits of parent banks) are treated as the banking sector's short-term debt. The non-banking sector's foreign assets consist of cash and deposits invested abroad which can simply be withdrawn. The banking sector's foreign assets include foreign currency reserve requirement which can be used as a buffer against deposit outflow. Finally, given that the model implies the financing of a portion of international reserves by the foreign currency reserve requirement, we use the gross international reserves of the CNB.[4]

Optimal reserves of the model assuming an exogenous probability of crisis have been calculated on the basis of an analytical solution for optimal reserves (5), the data on the variables influencing optimal reserves[5] and calibrated parameters. By simulating a model with endogenous probability of crisis, it is possible numerically to calculate optimal reserves on the basis of the same data and parameters used in the benchmark calibration.

2.4.1 Scenario Implying Parent Banks as Lenders of Last Resort

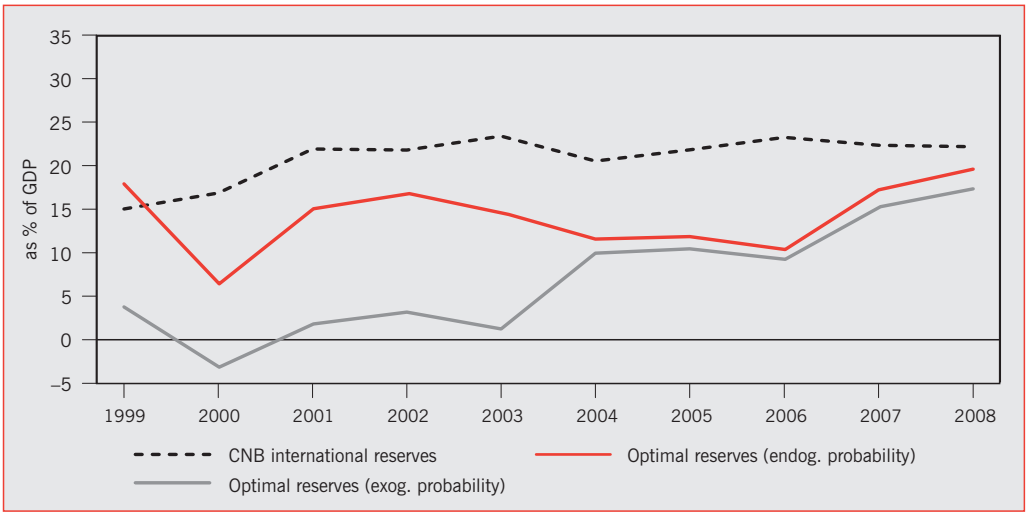
Figure 1 shows optimal reserves in the two models together with the CNB's international reserves in a case where parent banks assume the role of lenders of last resort during a crisis. It is obvious that during the entire reference period, except in 1999, the CNB held enough reserves to mitigate or prevent a potential crisis similar to that in 1998/1999. In the first half of the reference period, the CNB's motives for holding reserves were more like crisis prevention motives than self-insurance motives. This is a logical conclusion, given that a crisis really broke out at the beginning of the reference period. The small difference between the two optimal reserves measures in the second half of the reference period suggests that the optimal reserve level as a self-insurance instrument against crisis is also sufficient for crisis prevention.

4 Gross international reserves comprise special drawing rights, the reserve positions in the IMF, foreign currency and deposits with foreign banks, as well as bonds and notes. For details, see the CNB Bulletin, Table H7 and the Monetary Authorities Accounts (CNB Bulletin, Table C1).

5 For more details on data sources, see Appendix 2.

The sharp difference between the CNB's actual international reserves and both measures of optimal reserves can be interpreted in two ways. First, both models suggest that, over the entire period, the CNB held more reserves than were required for self-insurance and crisis prevention. Second, the CNB held more reserves than suggested by the models for the same motives in the expectation of a more violent crisis than in 1998/1999. If a deeper crisis is expected, then such a high level of reserves could not be considered as oversized. Anyway, should Croatia in 2009 be hit by a sudden stop of foreign capital inflows combined with a banking crisis of a magnitude similar to that in 1998/1999, and should parent banks provide foreign currency liquidity resort, the CNB would have enough reserves to soften the fall in consumption caused by a reversal in the financial account and deposit withdrawal from banks.

Figure 1 Actual Reserves, Optimal Reserves Assuming an Exogenous Probability of Crisis, Optimal Reserves Assuming an Endogenous Probability of Crisis (as % of GDP); The Scenario with Parent Banks Acting as Lenders of Last Resort

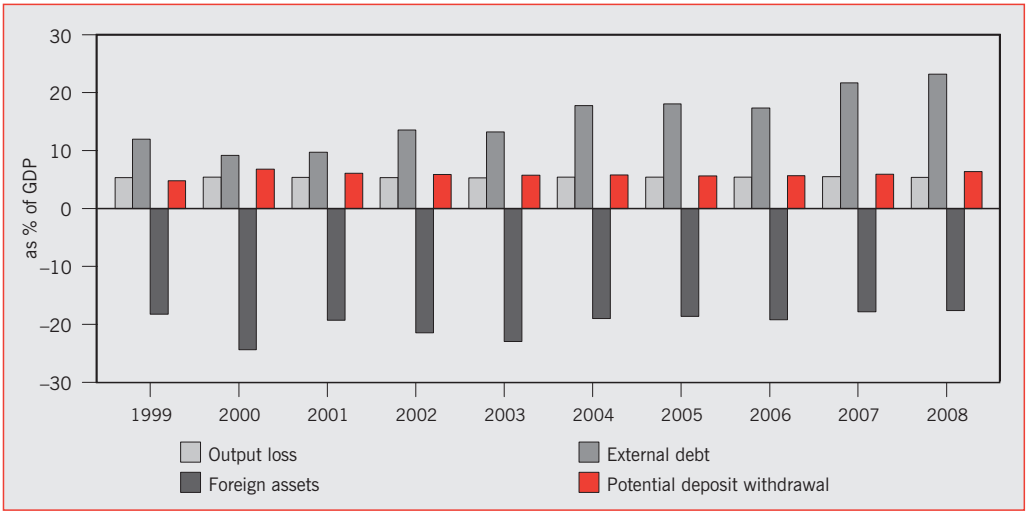


The movement of optimal reserves assuming an exogenous probability of crisis depends exclusively on the four components of optimal reserves reflecting the motives for holding reserves as self-insurance against crisis. Thus, external debt, output loss and deposit outflow components increase optimal reserves, whereas the foreign assets of enterprises and banks reduces them (Figure 2).[6] The negative optimal reserves level in 2000 was due to the strong growth of the private sector's foreign assets in 2001 as a result of the German mark-to-euro conversion in late 2001. In such a case, the model suggests that the CNB was not supposed to hold reserves at end-2000, because the private sector's buffer was strong enough to

6 Optimal reserves consist of the four main components arising from equation (4). Accordingly, optimal reserves are defined as a weighted difference between the contribution of the loss of output, change in the short-term external debt and deposit withdrawal on the one side, and the contribution of the change in foreign assets of enterprises and banks on the other side.

cope with a potential sudden stop of foreign capital inflows and a banking crisis during 2001. The optimal reserves growth since 2004 has mainly been fuelled by strong foreign borrowing of banks and enterprises over a given period.

Figure 2 Decomposition of Optimal Reserves (as % of GDP) in the Model Assuming an Exogenous Probability of Crisis Where Parent Banks Act as Lenders of Last Resort



The same components also influence the optimal reserves movements in the model assuming an endogenous probability of crisis. However, the role of optimal reserves assuming an endogenous probability of crisis is not only to insure against crisis but also to prevent a crisis that might break out due to factors outside the model assuming an exogenous probability of crisis. Given the interdependence between the probability and reserves in such a case, the probability of crisis changes from year to year. This is the only cause of the different movements of optimal reserves between the model assuming exogenous and that assuming endogenous probability of crisis.

The difference between the two optimal reserves measures could tentatively be interpreted as a level of reserves for crisis prevention above the level of reserves that the central bank should hold to mitigate the crisis effects. As shown in Figure 1, this difference was the sharpest during the first half of the reference period (1999-2003). The optimal reserves assuming an exogenous probability of crisis during this period indicate that the level of reserves held by the CNB should have been lower than 5% of GDP. For 2000, the model "recommends" holding negative international reserves. Low optimal reserves during the first half of the reference period are exclusively due to a small difference between the three components increasing optimal reserves (primarily, the impact of external debt is relatively limited compared with that in the second half of the reference period) and the private sector's foreign assets. During 2000, foreign assets covered all potential liabilities that would have been realized if the crisis had broken out in 2001. In other words, for the period 1999-2003, the model of optimal reserves assuming an exogenous probability of crisis suggests the holding of relatively low optimal reserves, because the private sector's reserves were almost sufficient to mitigate the negative effects

of a potential crisis. Such a low optimal reserve level serves exclusively as a self-insurance instrument against crisis.

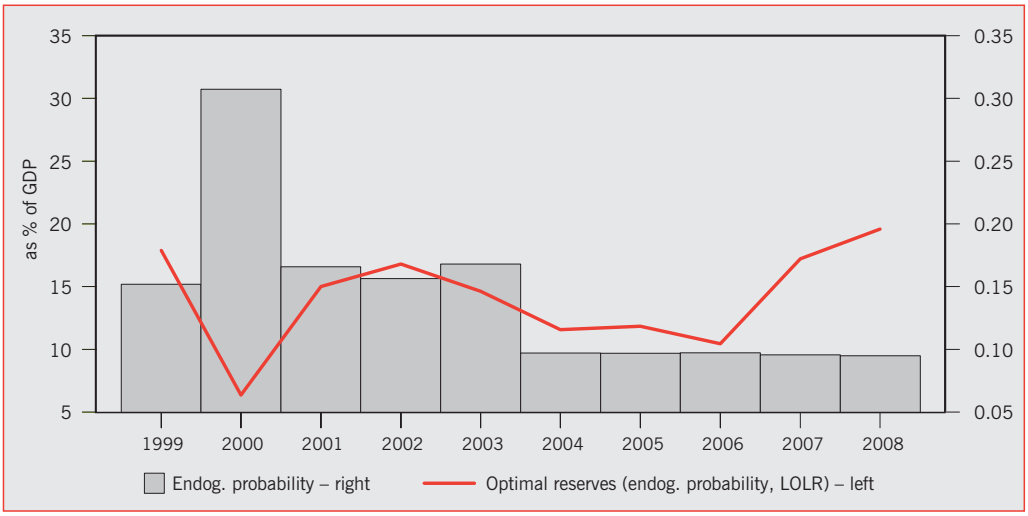
By contrast, the model of optimal reserves with endogenous probability of crisis shows that, in the same period, the level of optimal reserves assuming an exogenous probability of crisis was too low. The new model also emphasizes the holding of reserves for crisis prevention. In other words, the new model includes the central bank signalling that it has enough reserves to prevent a crisis that might occur due to some other factors outside the model assuming an exogenous probability of crisis. Thus, for the first half of the reference period, the model with endogenous probability of crisis "recommends" holding triple the amount of reserves, in order to prevent a crisis that would otherwise break out in the absence of a crisis prevention instrument. For example, given low reserves, a crisis might break out due to an attack on the domestic currency. This particularly relates to 2000, when a crisis would definitely have broken out had the central bank not held any reserves whatsoever. Since the new model also includes risk prevention motives, negative reserves are not possible.

Parallel movements of the two measures of optimal reserves in the second half of the reference period (2004-2008), i.e. there was only a small difference between them, suggest that the level of optimal reserves to mitigate the adverse consequences of a potential crisis, would also be quite sufficient to prevent a crisis that would break out for reasons not included in the model assuming an exogenous probability of crisis. In other words, the level of optimal reserves as a self-insurance instrument against crisis in the second half of the reference period also has a preventive role, signalling that the central bank has enough reserves to respond not only to a sudden stop of foreign capital inflows and deposit outflow (similar in magnitude to the 1998/1999 crisis), but also to a potential attack on domestic currency.

The probability of crisis shows the way in which the motive for crisis prevention influences the movements of optimal reserves. Owing to the numerical solution of optimal reserves in the new model, it is impossible to break optimal reserves down into components, in the way that was possible in the model assuming an exogenous probability of crisis. However, Figure 3 can be helpful in explaining the movements of optimal reserves in an environment of endogenous probability of crisis.

The first period is marked by a sharp difference between the two optimal reserves measures, where optimal reserves assuming an endogenous probability of crisis are much higher than in the case of an exogenous probability of crisis. This difference is due to the reserve accumulation for the prevention of a crisis reflected in a huge enhancement of crisis probability above the exogenous crisis probability. This particularly applies to 2000, when the crisis probability jumped to 0.3, as a consequence of low optimal reserves in the case of exogenous probability of crisis. Therefore, in the new model, the central bank decides to hold positive optimal reserves. A small difference between the two optimal reserves measures, observed in the second half of the reference period, arose from the small difference between the endogenous and the exogenous probabilities, given that the level of reserves as a self-insurance instrument also suffices for crisis prevention.

Figure 3 Optimal Reserves in the Model with Endogenous Probability of Crisis (left, as % of GDP) and Endogenous Probability of Crisis (right); The Scenario Implying Central Banks as Lenders of Last Resort

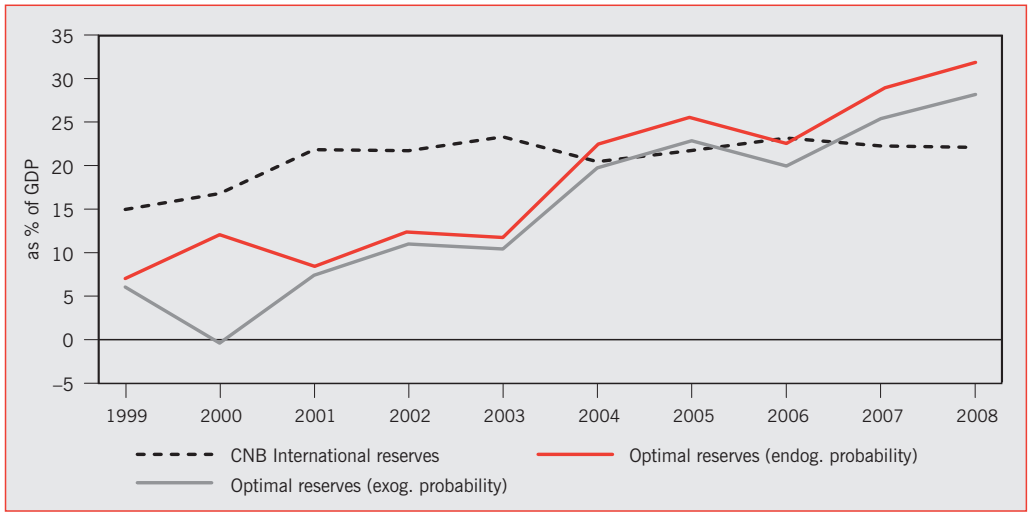


2.4.2 Scenario Implying the Parent Banks' Participation in the Crisis

The above conclusions depend on the parent banks' reactions during a crisis (Figure 4). In the following, we analyse the optimal reserves under the two models, when parent banks either refuse or are not in a position to provide foreign currency liquidity support. On this assumption, the needs for foreign currency reserves came close to and even exceeded the actual reserve level from 2004 to end-2008. This was largely due to domestic banks' borrowing from the parent banks (mainly in the form of foreign currency deposits) to finance strong domestic credit activity. At the start of the strong domestic bank borrowing from the parent banks, the CNB reserves did not grow significantly. However, the CNB introduced some instruments that forced the banking system to increase its foreign currency reserves. This actually prevented an even stronger increase in optimal reserves. Thus, a minimum required amount of foreign currency claims was introduced in 2003, requiring domestic banks to maintain a certain share of their liabilities in liquid foreign assets. This instrument enables the CNB to control optimal reserves without an international reserve accumulation. This instrument proved to be efficient in the current situation, when reducing the percentage of minimum liquid foreign currency claims improves banking system liquidity.

The finding that optimal reserves exceeded the actual reserves in the second half of the reference period applies regardless of whether the probability is exogenous or endogenous. Therefore, our model suggests that, if in 2009 Croatia were struck by a sudden stop of foreign capital inflows combined with a banking crisis of the same magnitude as that in 1998/1999, and if parent banks did not "help" their subsidiaries, the CNB reserves would not be sufficient to mitigate or prevent the consequences of such a crisis.

Figure 4 Actual Reserves, Optimal Reserves Assuming an Exogenous Probability of Crisis, Optimal Reserves with Endogenous Probability of Crisis (as % of GDP); The Scenario Not Implying Central Banks as Lenders of Last Resort



Concerning the movements of optimal reserves in the case of the parent banks' participation in the crisis, some interesting aspects should be pointed out, emphasizing the similarities and differences between the two motives for holding reserves. First, there is only a slight difference between optimal reserves with exogenous and those with endogenous probability of crisis. This finding emphasizes the connection between the two motives for holding reserves: given their high level, optimal reserves as a self-insurance instrument also serve as a crisis prevention instrument. In other words, the parallel movements of these two optimal reserves measures in a scenario in which parent banks are not willing or able to support their subsidiaries in a time of crisis are due to higher optimal reserves on account of parent banks participation in the crisis, which are sufficient to assume an additional role of crisis prevention. The exception to this being the year 2000, showing a difference in the motives for holding reserves: the negative optimal reserves as a self-insurance instrument in 2000 definitely did not serve as a crisis prevention instrument (Figure 5). Therefore, the model assuming an endogenous probability of crisis suggests the holding of a positive level of reserves as a crisis prevention instrument.

Figure 5 Optimal Reserves in the Model Assuming the Endogenous Probability of Crisis (left, as % of GDP), and Endogenous Probability of Crisis (right); a Scenario Not Implying Parent Banks as Lenders of Last Resort

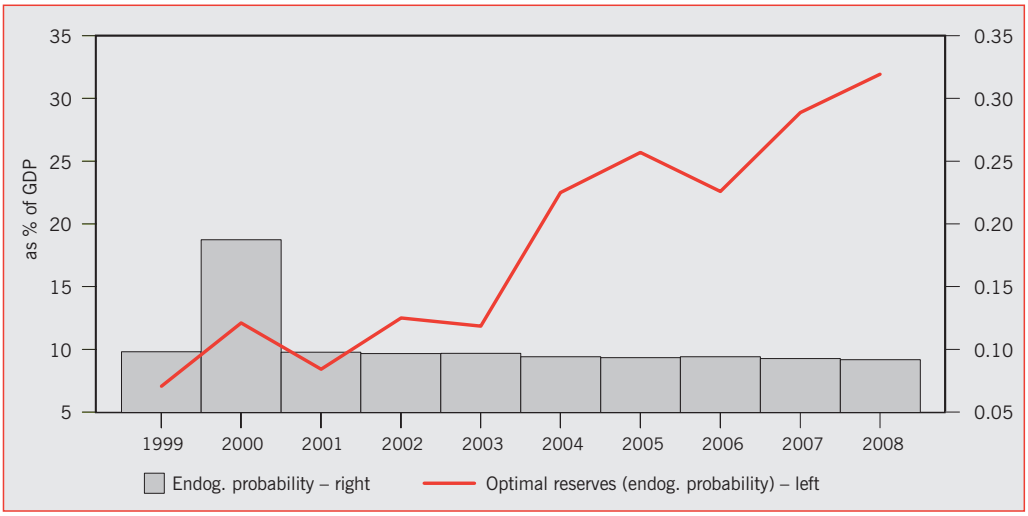
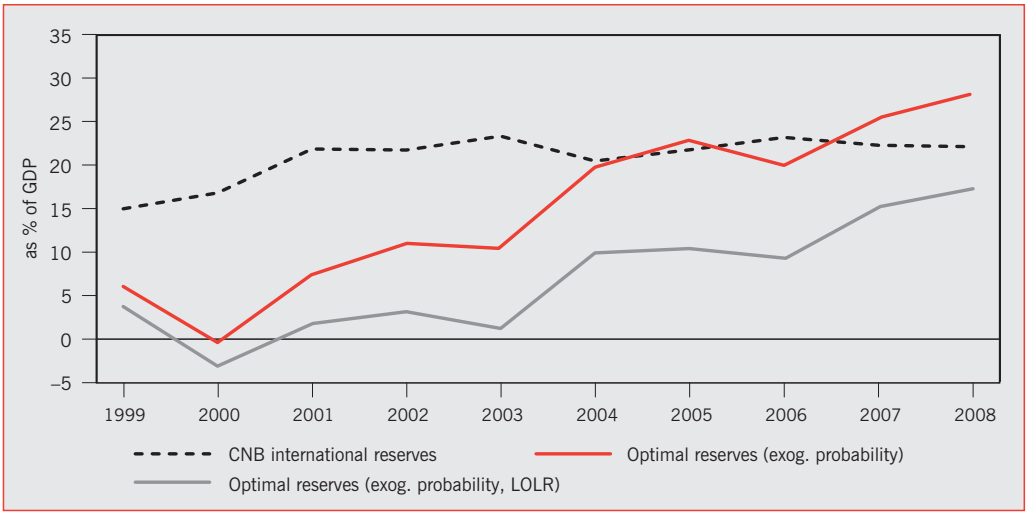
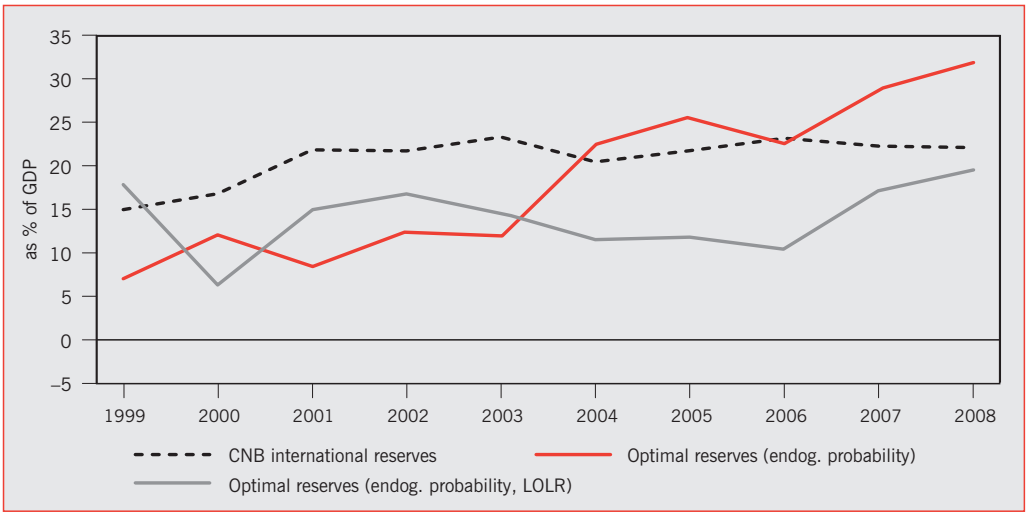


Figure 6 Actual Reserves, Optimal Reserves with Parent Banks Acting as Lenders of Last Resort (LOLR), Optimal Reserves with Parent Banks Participating in the Crisis (as % of GDP) and Exogenous Probability of Crisis



Second, in the case of an exogenous probability of crisis, the difference in optimal reserves between the two types of parent bank behaviour (Figure 6) is exclusively due to self-insurance, or the potential "cost" of the parent banks' escape (measured by the inability to refinance due debt and by deposit withdrawal from the subsidiaries; for more details, see Čeh and Krznar (2008). Therefore, the central bank tends to hold higher reserves in case the parent banks are unwilling or unable to support their subsidiaries in a time of crisis.

Figure 7 Actual Reserves, Optimal Reserves with Parent Banks Acting as LOLR, Optimal Reserves with Parent Banks Participating in the Crisis (as % of GDP) with Endogenous Probability of Crisis



However, the above conclusion does not apply if the probability depends on the level of reserves. Figure 7 shows that, in the first half of the reference period (excluding 2000), optimal reserves in the case of parent banks supporting their subsidiaries are higher than in the case when the parent banks cannot or will not provide support. How is it possible that, regardless of the parent banks helping their subsidiaries, the model suggests that the central bank should hold more reserves than in the case of the parent bank run? If subsidiaries are helped by their parent banks, the central bank can generally afford lower reserves, because there is no potential cost of a run on the banks. However, by holding lower reserves, it exposes itself to all other elements potentially causing a crisis that are not included in the model (e.g. an attack on the currency). Therefore, the central bank chooses to hold a higher level of reserves, even in the case when the parent banks act as lenders of last resort. The risk of holding lower reserves is also reflected in the higher probability of crisis when the parent banks provide support to their subsidiaries (Figure 3 vs. Figure 5).

3 Sensitivity Analysis

The conclusions and results from the previous section depend on the assumed model parameter values. In this section, we test the robustness of our results to changes in the model parameter values, but only for the probability function parameters.[7] Table 2 shows the model parameter value intervals and the corresponding values from the benchmark calibration. We solve the model for each discrete

7 For a sensitivity analysis of all other model parameters, see Čeh and Krznar (2008). That paper also presents a discussion of the CNB optimal reserves with respect to the magnitude of a potential crisis described by the crisis probability parameters and parameters related to the banking crisis.

point in a chosen interval and for each observed parameter (other parameters assume the values from the benchmark calibration), and we compare the obtained optimal value of reserves with actual reserves at the end of 2008. Figure 8 additionally highlights the value of a corresponding parameter from the benchmark calibration (perpendicular line). In our sensitivity analysis, we assume that parent banks will act as lenders of last resort in the event of a sudden stop of foreign capital inflows combined with a banking crisis.

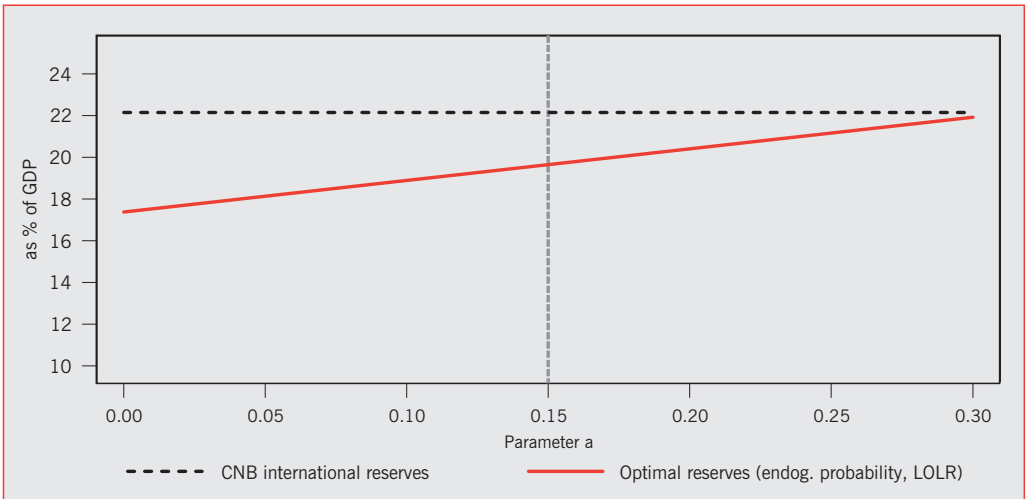
Table 2 Benchmark Calibration and Intervals for a Sensitivity Analysis

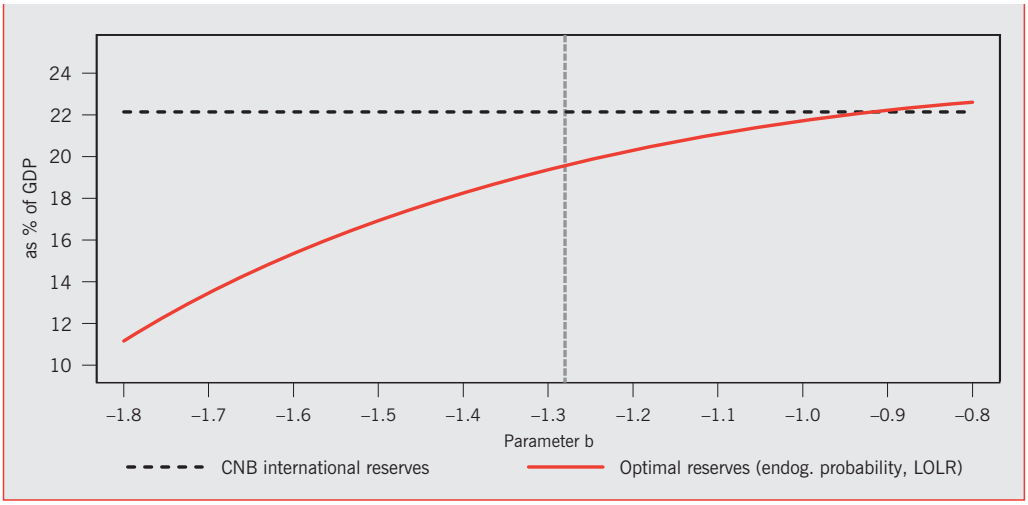
Symbol	Parameter	Benchmark calibration	Sensitivity analysis interval
a	"Elasticity" of the probability of crisis with respect to the level of reserves	0.15	0.00 – 0.30
b	F(b) – exogenous probability of crisis	–1.3	(–1.8) – (–0.8)

Figure 8 shows the quantitative effects of a change in the two probability function parameters from Table 2 on the level of optimal reserves. The level of optimal reserves is particularly sensitive to the value of the parameter defining the exogenous probability of crisis, *b*. Figure 8 also shows that, if a country is "by definition" more sensitive to a crisis, then its central bank is supposed to hold higher reserves. By increasing the "exogenous" sensitivity to crisis from the lower interval limit to the higher interval limit, the probability of crisis increases from 0.03 to 0.20, and optimal reserves from 11% to 23% of GDP.

The level of optimal reserves is relatively stable with respect to parameter *a*. A double increase in the "elasticity" of the probability of crisis with respect to the level of reserves (from 0.15 to 0.30) reduces the probability of crisis from 0.094 to 0.089, and increases the optimal reserves from 0.20 to 0.22.

Figure 8 Sensitivity Analysis of Optimal Reserves (as % of GDP)





4 Conclusion

This paper explores in what measure the motives for holding the CNB international reserves relating to self-insurance and crisis prevention determine the strong upward trend in international reserves in Croatia over the last decade. We demonstrate that the model of optimal reserves with endogenous probability of crisis better explains the upward trend in the CNB reserves over the last ten years. This argument is particularly true for the first half of the reference period. Whether this upward trend was too strong, or whether the actual reserves were below the optimum level depends greatly on the parent banks' reactions during a crisis. Given plausible parameter values relating to the data in the case of the sudden stop of foreign capital inflows and the banking crisis in 1998/1999, our model shows that the CNB reserves are only sufficient under the scenario in which parent banks assume the role of lenders of last resort.

5 Appendix

In the first part of the Appendix, we derive the consolidated budget constraint (1) and (2). At the end, we present a detailed table with the sources of data for the relevant model variables.

5.1 Consolidated Budget Constraint

If no crisis occurs

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

If a crisis occurs

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

5.2 Data Description and Data Sources

In the table below, model variables are matched with their data counterparts (the data sources are quoted in parentheses with most of the data coming from the CNB Bulletin tables).

Symbol	Model variable	Data counterpart
y_t	Exogenous endowment	Gross domestic product (at constant prices, CBS)
S_t	Nominal kuna/euro exchange rate	Nominal kuna/euro exchange rate (H10)
P_t	Price index	GDP deflator (CBS)
d_t^{fh}	Household foreign currency deposits	Household foreign currency deposits (D8)
d_t^{kh}	Household kuna deposits	Household kuna deposits (D6 and D7)
b_t	Non-banking sector's external debt	Short-term debt of other domestic sectors (incl. direct investments, H12) + principal payment of long-term debt by other domestic sectors (H14)

FB_t	Banks' external debt	Short-term debt of banks (excluding deposits, H12) + non-resident deposits (D10) + principal payment by banks of long-term debt (H14) (– parent banks' foreign currency deposits – parent banks' short-term loans)
FG_t	Government's external debt	Short-term debt of the government and CNB (H12) + principal payment of long-term debt by the government and CNB) (H14)
FRB_t^h	Non-banking sector's foreign assets	Currency and deposits of households and other domestic sectors with foreign banks (H19)
FRB_t^b	Banks' foreign assets	Banks' foreign currency reserves (H7)
R_t	International reserves	Gross international reserves of the CNB (H7)

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