

# A MATHEMATICAL MODEL AND DECISION SUPPORT SYSTEM FOR DETERMINATION OF THE VALUES OF THE MARGINAL RESERVE REQUIREMENT AS INSTRUMENT OF MONETARY POLICY

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## *Abstract*

*This paper studies the problem of interdependence between central bank and commercial bank goals. The basic central bank task is to achieve and to maintain price stability. Croatian external debt has been increasing for years and so the activities of the Croatian National Bank are designed to correct this situation. In order to stop the further increase of the external debt, the Croatian National Bank uses several monetary policy instruments, among which is the marginal reserve requirement. On the other hand, the goal of commercial banks is to maximise profits. Banks take loans from abroad at a lower interest rate and invest this money in Croatia at a higher interest rate, thus fulfilling their goal. In order to obtain the desired effects of the marginal reserve requirement, its optimal percentage value should be determined. This problem is modelled as a bi-level mixed 0-1 programming problem. The objective of the leader (Croatian National Bank) is to minimize the increase in household loans by setting different percentages of the reserve requirements for loans extended to households and for those granted to enterprises. The objective of the followers (banks) is to maximize profits. In order to solve this NP-hard problem a heuristic is proposed. In order to verify the model, the paper ends with simulations and the presentation of computational results.*

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## **1 Introduction**

Because the foreign debt of the commercial banks accounts for a large proportion of the overall foreign indebtedness of the Republic of Croatia, the Croatian National Bank (CNB) makes use of measures to affect bank behaviour. One such measure, on which the accent is placed in this paper, is the marginal reserve requirement (MRR below). One of the problems is to determine the MRR in percentage terms, in order to induce the commercial banks to restrict the growth of their foreign borrowings.

For the purpose of determining this percentage, this paper formulates a mathematical model of the interdependence of central bank and commercial bank activity. The model belongs to the class of bi-level mixed 0-1 programming models. At the upper level there is central bank decision making, and according to the framework of this paper, its objective is to minimise the growth in loans extended to households by the commercial banks. On the lower or following level is the decision making of commercial banks, the goal of which is to maximise profit. The profit of commercial banks is defined as the difference in the interest that they charge on loans extended in the domestic market and the interest they have to pay for foreign borrowings. Other revenues of commercial banks are in this paper ignored and considered only as a means to cover operational costs. The model has been developed with given premises that simplify the real situation, but on the assumption of professional implementation it could without any essential inroads into the basic idea be developed with other elements of the relation between the central bank and the commercial banks. Two models are observed. The first and basic model, apart from the reserve requirement (RR), an ongoing measure, covers the MRR and the special reserve requirement (SRR). The second model is an extension of the first model for the subscription of compulsory central bank bills (CCBB). The SRR is included in the first model only at the level of definition, while in the case of numerical simulations the issue of bonds by the commercial banks is ignored. This assumption does not distort the applicability of the model since on the one hand it does not affect the numerical results and on the other hand immediately after its introduction the commercial banks halted their borrowings via the issue of bonds.

In general, models of bi-level programming belong to the class of NP-hard problems. In addition, the models developed in this paper are large-scale problems for large numbers of real and integer number variables and constraints. On the other hand the parameters such as the interest rates of commercial banks according to which loans are made on the domestic market are subject to business confidentiality. For this sake, while numerical simulations were performed, numbers of relaxations were introduced.

In the procedure of solving the model, heuristics based on tabu searching were developed and a decision support system for the use of the application CPLEX9 was made. This decision support system enabled a number of analyses of the impacts of different values of MRR on the loans made by commercial banks.

After that, a number of numerical simulations were performed for the sake of verifying the models set up. A change in the parameters, the addition of other assumptions, ob-

servation of SRR, change in the objectives of the central bank and commercial banks, and involvement of additional measures of monetary policy do not represent significant incursions into the basic idea of the model created or of the manner in which it is solved.

The numerical results show the essential differences depending on whether an effective or a nominal interest rate is used. The numerical results obtained can be used for other ex-ante analyses of the effects of monetary policies as well.

The paper consists of seven chapters and an appendix. In the second chapter the interdependence in the operations of central and commercial banks is described. The main reference is to the working of the central bank directed towards the growth in the foreign debts of the commercial banks. This problem is stressed because of the high level of the foreign debt of the Republic of Croatia, which has passed the 80% of GDP level, which according to economic theory, is considered the ceiling for foreign indebtedness, after which there is a danger of a so-called debt-crisis breaking out.

In Chapter 3 mathematical models are created for the purpose of determining the optimal values of MRR. The first model describes the condition of central bank measures prescribed for slowing down the growth of the foreign indebtedness of banks and the excessive growth of loans, which held true up to January 2007. The second model, apart from the measures that are covered by the first model, covers the new methods for subscribing to CCBBs, in force since January 2007. Since, as earlier stated, the problems of bi-level programming belong to the class of NP-hard problems, heuristics have been developed for solving them. The heuristics developed for the purposes of this paper, and the basic methods used for the making of these heuristics and the relaxations, are described in the fourth chapter.

In the fifth chapter the results of numerical simulations obtained by solving with the help of the heuristics described in the preceding chapter are given. Analyses are made with the use of nominal and effective interest rates. At the end, in the sixth and seventh chapters, conclusions are given and suggestions are made for further research for the purpose of developing the model.

In brief, the objective of this research is the creation of a mathematical model of the current condition and the relations between the central bank and the commercial banks in the segment concerning the foreign borrowings of the commercial banks. The current condition of this part of the banking system is described, and by the performance of numerical simulations concomitantly with certain assumptions that simplify the real situation the relationship between central bank measures and the profit made by the commercial banks is established.

## **2 The interdependence of the operations of central bank and commercial banks**

The Croatian National Bank, within the framework of its monetary policy, carries out various measures to maintain price stability, that is, to maintain the maximum amount of economic growth concurrently with a low rate of inflation, and thus fulfils its statutorily defined role. History tells us that periods of high inflation on the whole lead to economic collapse, since the attention of enterprises shifts from the production of goods to the preservation of the assets that they own and/or manage.

Modern economic systems show that inflation is nevertheless in a sense necessary for economic growth to be achieved. On the other hand, it is practically impossible to make

a connection between the actual rate of inflation and economic growth, which makes the central bank's operations additionally difficult. It has on the one hand to maintain price stability, and on the other to allow a certain rise in prices in order to achieve as great economic growth as possible.

In an economy like that of Croatia, which makes more than half of its GDP in trade with the rest of the world, there is an additional danger from the import of inflation, and price stability also means stability of the exchange rate with the currency to which most credit operations are indexed, as well as the price of fixed assets (in the case of Croatia this is the euro). Similarly, because of the exceptional degree of openness of the market, there is a large chance that inflation can be transferred from abroad (for example, a large rise in the price of fuels on the world market will have a direct impact on the rise in domestic prices). For these reasons the total foreign debt of Croatia is important, since if an influx of money occurs it will have a powerful impact on the stability of domestic prices, producing a major deterioration in the balance of trade, which could lead to long-term problems in the development of the economy.

Since the foreign debt of the commercial banks constitutes a large portion of the total foreign debt of the Republic of Croatia, the CNB makes use of measures to affect the behaviour of the banks. One of them, which is particularly considered in this paper, is the marginal reserves requirement.<sup>1</sup> This is the obligatory foreign currency deposit placed for an indefinite period of time in a foreign currency account at the central bank. The amount of the deposit is defined in terms of a percentage of a base that is made up of the cumulative rise of foreign liabilities of the bank as against the base period. It is a considerable problem to determine the value of this percentage in order to achieve the desired effects on the banking system.

Apart from the marginal reserve requirement, two other measures are used, and these are the special reserve requirement and compulsory central bank bills. The special reserve requirement is similar to the marginal reserve requirement, but differs from it in the commercial bank debt sources that it covers. It is calculated on bonds issued, irrespective of whether the bonds have been issued on the domestic or foreign market.

Compulsory CNB bills are securities to which commercial banks must subscribe at the central bank when they exceed the allowed growth of loans made. The subscription is regulated by special central bank regulations<sup>2</sup>, and the maturity period is 360 days. A particular feature of these securities is that they cannot be traded on the secondary market.

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<sup>1</sup> In 2004 the application of MRR started, at a rate of 24%; in February 2005 this was increased to 30% and calculated according to the same base period. In May that year the rate was increased once again and came to 40% with respect to the initial calculation period. In November 2005 the decision was made in such a way that non-working days were included in the calculation, and the day of the calculation was shifted to the second Wednesday in the month. In December 2005 with a new change in the decision, a second calculation period was introduced, and for a growth in a debt with respect to this new calculation period an additional 15% of the growth in foreign borrowing had to be set aside. In the last change in the decision, June 2006, the base for MRR was extended to guarantees and other investments that are kept off-balance sheet, and the MRR rate for such loans is 55%.

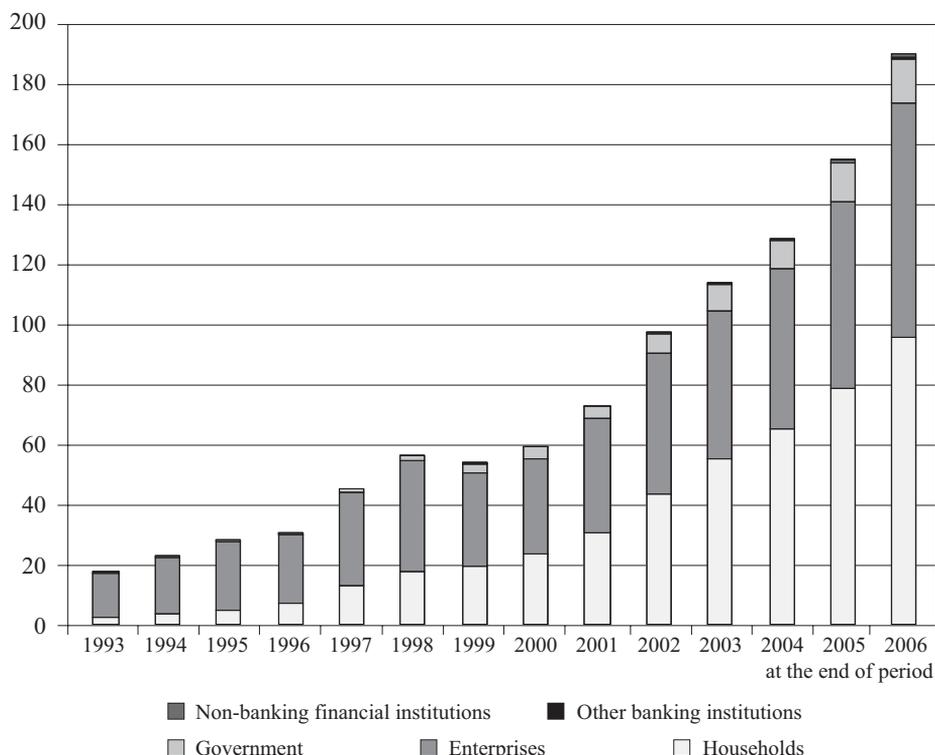
<sup>2</sup> Compulsory CNB bills were brought into force the first time in 2003, and then the allowed growth of loans was 16% per annum, or 4% per quarter, and their subscription took place at the same tempo. The measure was in force again from January 2007, the initial allowed growth of loans being 1% per month. But during the year this measure has been changed several times. Unlike 2003, when the measure lasted only a year, it is expected that this measure will now last some considerable time.

The reserve requirement, that is, the policy of liquidity reserves<sup>3</sup>, is the last central bank measure, referred to in this paper. It is one of the oldest instruments used by the central bank. In highly developed financial markets, the importance of this instrument has essentially declined and been compensated for by other monetary policy measures, particularly open market operations.

The importance of such a measure, particularly for undeveloped financial markets, inheres in its facilitating the simple control of monetary and credit multiplications. On the other hand, banks and saving banks are the only institutions that are subject to central bank influence that are subject to this measure, while other participants in the financial market are not. Since in highly developed financial markets the share of the non-banking sector is over 50%, it is clear why the effect of this instrument on them has declined.

On the other hand, the commercial banks look for various ways in which to circumvent the measures prescribed by the CNB and to protect the interests of their owners, which inhere in making as much long-term profit as possible.

*Figure 1 Allocation of bank loans per institutional sectors (in billion of kuna)*



<sup>3</sup> The reserve requirement is the prescribed minimum amount of collected deposits that the commercial banks must set aside into special accounts at the central bank or keep in their own accounts in the form of liquid financial resources.

In the operations of the Croatian banks, on the liability side, a major part is constituted by short-term deposits, while another important source of funds consists of mid-term and long-term loans taken out on the world financial market. On the asset side, on the other hand, mid-term and long-term loans made to households and enterprises prevail. There is an increasingly important share of short-term loans to the household sector via overdraft facilities and credit cards. Since the banks have been lending to the household sector to a larger extent in recent years, with households taking on debt to a much greater extent for final consumption, mainly of imported goods, the CNB measures are an endeavour to persuade the banks to reduce loans made to the household sector for the sake of final consumption. In this manner the CNB endeavours to affect the whole of the economy, since the behaviour of banks and households, had there been no central bank reaction, would certainly have led to an economic breakdown.

The most important objective of commercial banks is making a profit.<sup>4</sup> However their role in the financial system of a country is much more important and complex than simply making an operating profit. With their activity, banks have an effect on other economic agents, and hence on the whole of the economy of the country. A central bank does not accomplish its goals via direct contact with other agents in the financial system, with the household and corporate sectors, but works indirectly, via its influence on the commercial banks.

The owners of Croatian banks on the whole are located in the EU and are not able there to make so much profit from loans made, since the market conditions are such that the interest rates on loans made are considerably lower than they are in Croatia. In order to meet the wishes of their owners and to circumvent the measures prescribed them by the CNB, the commercial banks have transferred a good deal of their operations to associated enterprises. For this reason, in the second half of 2006., there was a slight fall in the foreign debt of the commercial banks, while the share of enterprises' foreign debt rose.<sup>5</sup> And so the CNB, in order to halt this behaviour of the banks, extended its instruments as far as it was allowed by its statutory authorities, to the associated enterprises, for its measures to cover all business entities that it is capable of affecting directly or indirectly to as great an extent as possible.

### **3 Mathematical models**

Within this work, only a small part from a wide spectrum of various kinds of mathematical programming used to develop models of relations between the CNB and the commercial banks will be described. Since the paper poses the mathematical model as a bi-level programming problem, we shall set out in brief the basic concepts necessary to understand this.

The essential characteristic of all bi-level programming problems is that the decision maker at the upper level (the leader) should affect the lower level decision makers (the follower), the follower's possible choice and the benefit that derives from this choice.

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<sup>4</sup> In Galac and Dukić (2005) the view is stated that some banks privilege immediate profits over market share and the consequent long-term profit.

<sup>5</sup> The enterprise sector includes leasing firms that on the whole are related in terms of equity with the banks.

The first formulation of the problem of bi-level programming was stated in the market economy book *Marktform und Gleichgewicht* by H. von Stackelberg in 1934. Economic game theory studies a special type of bi-level programming problem known as the Stackelberg game. The general formulation of the problem that includes several levels was described for the first time by Bialas and Karwan in 1982.

The problem of bi-level programming is a special case of the multi-level programming problem. This group of mathematical programming problems is characterised by the following features:

- there are two decision making levels, the upper and the lower, or leader and follower, which have a hierarchical relationships and affect each other,
- the decision is first of all made by the leader (in game theory, the first move),
- after that, the follower reacts, creating and carrying out its own strategy, as response to the leader's move,
- both levels have their own goal or benefit, independently of other units of the system,
- the interaction of the decision makers are displayed as objective functions, and as a set of decisions that either one of them can make.

Here we are looking at a large hierarchical system and the process of interaction that goes on in time, where the leader is the central bank and the follower is the set of all the commercial banks. Each commercial bank acts independently of the other commercial banks, in line with its own business strategy.

From a mathematical point of view, the problem of bi-level programming is an NP-hard problem, which means that there are no algorithms finding an optimal solution in polynomial time. Such complex problems and the solution of them arouse enormous interest because they can be found in many areas of application. In the last 30 years varying authors have proposed some score of algorithms for solving these problems. However, these algorithms are either exceptionally ineffective or markedly impractical in application. Hence in practice heuristics are created, which is the method used in this paper.

Two models have been defined that describe the contemporary situation in the working of the central bank vis-à-vis the commercial banks. The first model, apart from the reserve requirement, which is a permanent instrument, covers MRR and SRR. The second model, which describes the current state of affairs, is an extension of the first model by the subscription of compulsory CNB bills.

The reason for division into the two models lies in the fact that the subscription of compulsory CNB bills is a measure that has been in force since January 1, 2007. An additional reason for the split into two models is the fact that this is a measure that is considered a short-lasting instrument, which will be in force for only a limited period of time.<sup>6</sup> Resources that are bound by investment in compulsory CNB bills are repaid into the system when the bill matures.<sup>7</sup> On the other hand, in the reserve requirement large resources

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<sup>6</sup> When this measure was previously in force it lasted for a year only, that is, during 2003, the calculation and setting aside started at the end of the first quarter of 2003, and ended at the end of the first quarter in 2004.

<sup>7</sup> The current decision prescribes a maturity period of 360 days.

with no maturity date are accumulated, which cannot at any given time be put back into the system without consequences being incurred.

In the models it is assumed that the central bank objective is a reduction in the growth of commercial bank loans to the household sector. The decision the central bank has to make is what the percentage of the MRR is. The maximisation of profit is assumed to be the objective of the commercial banks.

### **3.1 A mathematical model that covers the marginal reserve requirement and the special reserve requirement**

For the sake of formulating the said mathematical model, we make the following definitions:

#### *Indices*

- $i$  – type of borrowing ( $i = 1$  loans taken from abroad,  $i = 2$  bonds)
- $j$  – commercial bank,  $j = 1, \dots, J$
- $l$  – type of loans of borrowed resources ( $l = 1$  housing loans,  $l = 2$  other loans to households,  $l = 3$  loans to enterprises)
- $p$  – prescribed percentage of marginal / special reserve requirement
- $t$  – time for which debt is taken on (macro period),  $t = 1, \dots, T$
- $\tau$  – time for which loans are made (micro period)  $\tau \in S_p$ ,  $t = 1, \dots, T$

#### *Parameters*

- $op^8$  – percentage of reserve requirement
- $kb$  – commercial bank credit multiplier
- $x_{jil0}$  – stock of debt of bank  $j$  from source of resources  $i$ , that it has loaned in loans  $l$  at the beginning of the period under observation
- $W_{jl0}$  – stock of loans  $l$  of bank  $j$  at the beginning of the period under observation
- $o_l$  – number of instalments for repayment of the loan  $l$
- $b_i$  – number of payments for the return of the borrowed sum  $i$
- $k_{it}$  – interest rate at which money is borrowed from source  $i$  in period  $t$
- $m_{jlt}$  – interest rate at which bank  $j$  loans resources  $l$  in period  $t$
- $d_{lt}$  – minimum demand that has to be met for loans  $l$  in period  $t$
- $g_{lt}$  – maximum supply of loans  $l$  in period  $t$

#### *Notations*

- $y_{jilpt}$  – amount of resources that bank  $j$  has repaid via annuity payments for sources of resources  $i$ , at interest rate  $k_{it}$  with depositing marginal reserve requirement at the rate of  $p$  in period  $t$ , which it has loaned in loan  $l$

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<sup>8</sup>  $op = 17\%$ .

$W_{jlt}$  – total amount of resources that bank  $j$  has loaned in loan  $l$  in the macro period  $t$  at the interest rate of  $m_{jlt}$

$U_{jlt}$  – total amount of resources that bank  $j$  has received in annuities from loan  $l$  at an interest rate of  $m_{jlt}$  in the macro period  $t$

$Q_{jip}$  – stock of debt of bank  $j$  from source  $i$  borrowed at an interest rate of  $k_{it}$ , along with depositing marginal reserve requirement at a rate of  $p$  at the end of the period  $t$

$R_{jlt}$  – stock of loan of bank  $j$  in loan  $l$  loaned at an interest rate of  $m_{jlt}$  at the end of period  $t$

*Decision variables*

$x_{jilpt}$  – amount of resources that bank  $j$  borrowed in period  $t$  from source  $i$ , at interest rate  $k_{it}$  in conjunction with depositing for marginal reserve requirement at a rate of  $p$ , in order to lend them in loan  $l$

$w_{jlt}$  – amount of resources that bank  $j$  lent in loan  $l$  in micro period  $\tau$  at an interest rate of  $m_{jlt}$

$$z_{ilpt} = \begin{cases} 1, & \text{if the percentage of prescribed marginal (i = 1) / special (i = 2) reserve} \\ & \text{requirement on resources borrowed for loan } l \text{ in period } t \text{ is equal to } p \\ 0, & \text{otherwise } l = 1, 2 \text{ (loans to households), } l = 3 \text{ (loans to enterprises)} \end{cases}$$

$$v_{jilpt} = \begin{cases} 1, & \text{if } \sum_{i,p,t} (x_{jilpt} - y_{jilpt}) > 0 \\ 0, & \text{otherwise } x_{jilpt}, w_{jlt} \geq 0; z_{ilpt}, v_{jilpt} \in \{0, 1\} \end{cases}$$

The following expressions hold for the notations

$$y_{jilpt} = \frac{1}{b_i} (x_{jil0} + \sum_{\alpha=\max(t-b_i,1)}^{t-1} z_{ilp\alpha} x_{jilp\alpha}), \quad \forall j, i, l, p, t \quad (a)$$

$$W_{jlt} = \sum_{\tau \in S_t} w_{jl\tau}, \quad \forall j, l, t \quad (b)$$

$$U_{jlt} = \frac{1}{o_l} (W_{jl0} + \sum_{\alpha=\max(t-o_l,1)}^{t-1} W_{jl\alpha}), \quad \forall j, l, t \quad (c)$$

$$Q_{jip} = \sum_{l=1}^3 (x_{jil0} + \sum_{\alpha=1}^t (x_{jilp\alpha} - y_{jilp\alpha})), \quad \forall j, i, p, t \quad (d)$$

$$R_{jlt} = W_{jl0} + \sum_{\alpha=1}^t (W_{jl\alpha} - U_{jl\alpha}), \quad \forall j, l, t \quad (e)$$

Expression (a) shows how much resources bank  $j$  has to return in each period on the basis of the loans it has taken out abroad or on the basis of bonds it has issued.<sup>9</sup> Expression (b) shows the total loans of bank  $j$  in macro period  $t$ ,<sup>10</sup> and expression (c) shows the total receipts of the same bank on the basis of repayment of the part of the loans made in the previous periods.<sup>11</sup> Expression (d) shows the total stock of indebtedness of bank  $j$  at the end of period  $t$ ,<sup>12</sup> while expression (e) tells of the stock of the loans of bank  $j$  and the end of period  $t$ .<sup>13</sup>

The model:

$$\min_z \sum_{\substack{l=1,2 \\ j,t}} (W_{jlt} - U_{jlt}) \quad (I)$$

Subject to the constraints:

$$\sum_p z_{ilpt} = 1, \quad \forall j, l, t \quad (1)$$

$$\max_t \sum \left( \sum_l m_{jlt} R_{jlt} - \sum_{i,p} k_{it} Q_{jip} \right) \quad \forall j \quad (II)$$

Subject to the constraints:

$$W_{jlt} \leq \left( kb \left( \frac{100 - op}{100} \right) \right) \left( \sum_i x_{jil0} + \sum_{i,p,\alpha=1}^t v_{jilpt} \frac{100 - p}{100} z_{ilp\alpha} (x_{jilp\alpha} - y_{jilp\alpha}) \right. \\ \left. + \sum_{i,p,\alpha=1}^t (1 - v_{jilpt}) (x_{jilp\alpha} - y_{jilp\alpha}) \right) + \sum_{\alpha=1}^t U_{j\alpha} - \sum_{\alpha=1}^{t-1} W_{j\alpha} - W_{j0}, \quad \forall j, l, t \quad (2)$$

$$x_{jilpt} \leq Mz_{ilpt}, \quad \forall j, l, p, t \quad (3)$$

$$\sum_{\alpha=1}^t (x_{jilp\alpha} - y_{jilp\alpha}) \leq Mv_{jilpt}, \quad \forall j, l, p, t \quad (4)$$

<sup>9</sup> It is assumed that resources are repaid in equal monthly instalments. In reality this is not the case, but as a rule the banks repay their borrowings in quarterly, semi-annual or annual instalments, while they usually pay out bonds on maturity, with the interest (the coupon) being paid semi-annual or annual, while there are also variants, such as the whole amount (principal and interest) being paid out only at maturity.

<sup>10</sup> The amount of intercalary interest that the bank collects for the payment of loans before the date of maturity is negligible compared with all the other revenues of the commercial banks.

<sup>11</sup> Today banks grant loans with flexible maturity dates (they can be any day in the month). Earlier the maturity dates were fixed for all clients and as a rule the maturity of a loan would be the first or last day in the month, irrespective of the day the loan was granted.

<sup>12</sup> Bank liabilities.

<sup>13</sup> Bank assets.

$$\sum_{\alpha=1}^t (y_{jilp\alpha} - x_{jilp\alpha}) \leq M(1 - v_{jilpt}), \quad \forall j, l, p, t \quad (5)$$

$$W_{jt} \geq d_{jt}, \quad \forall j, t, l = 1, 2 \quad (6)$$

$$W_{jt} \leq g_{jt}, \quad \forall j, l, t \quad (7)$$

$$x_{jilpt}, w_{jl\tau} \geq 0, z_{jilpt}, v_{jilpt} \in \{0, 1\}, \quad \forall j, i, l, p, t \quad (8)$$

In expressions (a) and (c) the amounts are equal to the repayment quotas (instalments), while revenue made from interest collected is used to cover interest expenses and for operational profit made.

For the credit multiplier of the commercial bank ( $kb$ ) the expression  $kb = \frac{1}{1 - sz \times (1 - op)}$ , holds, where  $op$  is the prescribed percentage of the reserve requirement, and  $sz$  is the percentage of the borrowing retained in the bank in the form of the loan it makes. With an assumed rate of retention  $sz = 60\%$ , then:

$$kb = \frac{100}{100 - 0,6 \times (100 - op)} = \frac{100}{40 + 0,6op} \quad (9)$$

By introducing expression (9) into (2) we obtain the expression:

$$W_{jt} \leq \left( \left( \frac{100 - op}{40 + 0,6op} \right) \left( \sum_i x_{jil0} + \sum_{i,p,\alpha=1}^t v_{jilpt} \frac{100 - p}{100} z_{ilp\alpha} (x_{jilp\alpha} - y_{jilp\alpha}) \right) + \sum_{i,p,\alpha=1}^t (1 - v_{jilpt}) (x_{jilp\alpha} - y_{jilp\alpha}) \right) + \sum_{\alpha=1}^t U_{jl\alpha} - \sum_{\alpha=1}^{t-1} W_{jl\alpha} - W_{jl0}, \quad \forall j, l, t \quad (10)$$

In model (I)-(10) the central bank minimises the growth of loans to households, while the commercial banks, within the framework of the constraints that are forced on them by the upper level (the leader), maximise their profits. The micro and macro periods are included into the model because the central bank (leader) makes its decision about changes in the rates of the marginal or special reserve requirements once a month, while the followers (the commercial banks) can make their decisions daily.

Constraint (1) says that the percentages of marginal and special reserve requirement can take exactly one value for every kind of source of resources and for each kind of loan by the banks. They are the same for all the banks and are independent of the interest rates at which the bank obtains the resources. Apart from that, these percentages are always integer values.

Constraint (10) shows that the resources that bank  $j$  can extend in instrument  $l$  cannot be greater than the resources available. The available resources of bank  $j$  consist of the initial stock of the borrowed resources to which the remaining resources borrowed from sources covered by the marginal or special reserve requirement are added, minus the resources repaid for previous borrowings, minus the percentage of the reserve if the bank's borrowing rises, or only diminished by this amount if the borrowing of the bank from the sources of resources covered falls. These resources are multiplied by the credit multiplier in the period under observation. Collected repayments of loans made earlier diminished by resources extended in previous periods also form part of the available resources.

Constraint (3) describes the fact that banks can borrow abroad only at one rate of the prescribed marginal ( $i=1$ ) / special ( $i=2$ ) reserve requirement on resources borrowed for loan  $l$  in period  $t$  where  $M$  is a large real number.

Constraints (4) and (5) are essential for the determination of the status of the binary variable  $v$  that says whether in some period there are overall more borrowed or repaid resources,<sup>14</sup> which is essential for the sake of setting aside the marginal or special reserve requirements.

Constraint (6) is the lower bound for every type of loan of every bank in every period. The lower bound is the level of planned market share or the threshold of profitability.

Constraint (7) shows that the maximum demand for resources is known<sup>15</sup> in the case of every bank in every period that can be met, that is, the upper bound to the level of loans made.

And at the end, constraint (8) is the constraint of non-negativity and binarity of the variables.

### 3.2 The mathematical model extended to cover the subscription of compulsory CNB bills

This model differs from the preceding model only in the constraint (10), which has been replaced by the following constraint:

$$\begin{aligned}
 W_{jlt} \leq & \left( \left( \frac{100 - op}{40 + 0,6op} \right) \left( \sum_i x_{jil0} + \sum_{i,p,\alpha=1}^t v_{jilpt} \frac{100 - p}{100} z_{ilp\alpha} (x_{jilp\alpha} - y_{jilp\alpha}) \right. \right. \\
 & \left. \left. + \sum_{i,p,\alpha=1}^t (1 - v_{jilpt}) (x_{jilp\alpha} - y_{jilp\alpha}) \right) \right) + \sum_{\alpha=1}^t U_{j\alpha} - \sum_{\alpha=1}^{t-1} W_{j\alpha} - W_{j0} \\
 & - 0.5 \sum_{\alpha=2}^t \max \left\{ \left[ \left( \frac{\sum_{\beta=1}^{\alpha-1} W_{j\beta}}{W_{j0}} - \frac{\alpha - 1}{100} \right), 0 \right] \cdot W_{j0} \right\}, \quad \forall j, l, t \quad (11)
 \end{aligned}$$

<sup>14</sup> Depending on whether the total foreign borrowing is rising or falling.

<sup>15</sup> In reality this means that the bank has set a maximum amount of loans in each period with which it will satisfy the shown demand for loan resources.

This constraint shows the maximum available resources that bank  $j$  can invest in instrument  $l$ . The available resources of bank  $j$  consist of the initial stock of the borrowed funds to which are added remaining resources borrowed from sources covered by the marginal or special reserve requirements diminished by repaid resources from earlier borrowing, and diminished by the percentage of this reserve if bank borrowing should increase, or diminished only by this amount if the borrowing of the bank in terms of sources of resources covered should fall. These resources are multiplied by the credit multiplier in the observed period. Also counted in available resources are collected repayments of loans made earlier diminished by loans made in the previous periods. Should a commercial bank exceed the allowed growth of loans, the available resources will be diminished by the amount that the bank has to use to subscribe compulsory CNB bills.

#### **4 Relaxation of the model and heuristics for problem solving**

The problem described, and all bi-level programming problems belong to the class of NP-hard problems. For the solution of these problems, heuristics have been developed based on a combination of search methods and tabu search methods. The heuristics are conducted according to this procedure:

1 For the given bank, the rate of the marginal/special reserve requirements is changed, and it is checked whether making loans is profitable at this level, according to existing interest rates, for each kind of loan.

2 The lowest and highest rates of reserve at which operations cease to be valuable for each kind of loan separately are memorized.

3 If the solution for each kind of loan is found, then the search procedure is stopped.

4 A check is made to see if all the banks have been considered. If they have not, the next bank is chosen, and step 1 is repeated; if they have, then we pass to step 5.

5 A calculation is made of the average marginal/special reserve requirements for the whole system in terms of each kind of loan separately.

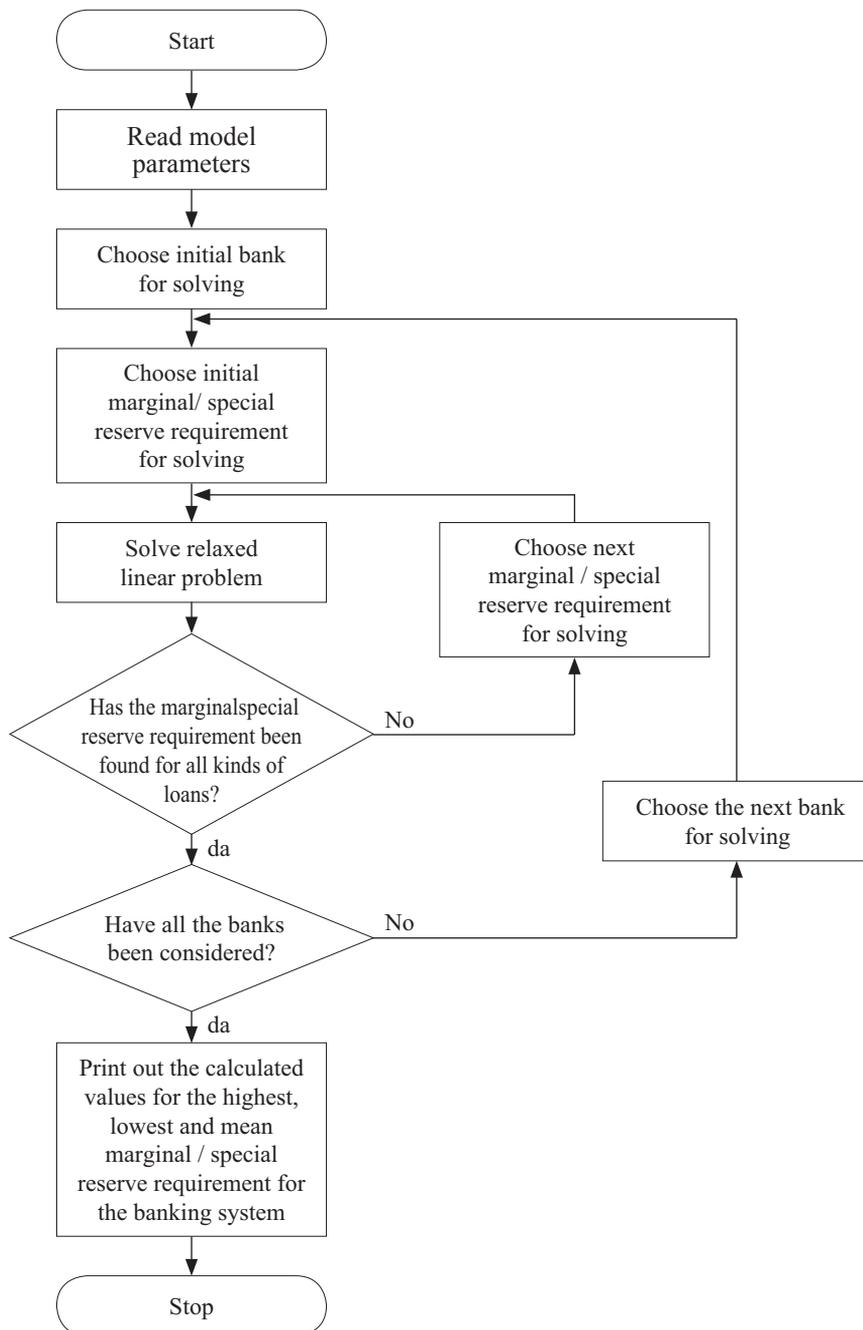
6 Stop of the calculation process.

The flow diagram for the constructed heuristics is shown in Fig. 2. In both models constructed within the context of this paper, the same heuristic is used, but with a differently relaxed model.

In the numerical part, certain relaxations have been carried out to simplify the model, or for the sake of confidentiality, so as not to let the data of the bank used be identified as coming from that bank.

The first assumption is that the interest rate on foreign borrowings is the same for all banks and comes to EURIBOR + 1.5 percentage points for borrowing and EURIBOR + 2 percentage points for bonds. The average value of EURIBOR for borrowings for one year used in the numerical calculation is 4.06%.

Figure 2 Heuristics flow chart



The interest rate at which the banks extend their funds ranges from 4.02% to 8.21% for housing loans. In other loans to the household sector the interest rates range from 7.30% to 11.92%. Interest rates for loans to the corporate sector range from 5.20% to 11.75%.<sup>16</sup> The data about interest rates used for the calculation are given in Table 7 and Table 8. Interest rates are the same in all periods of observation for each bank because we took the average interest rate. In this manner we, to some extent, took into account the variability of interest rates. Apart from that, an additional analysis was made in which, instead of the nominal interest rate that commercial banks employ, their effective interest rate was used (Table 9).

As stated in the description of the model, the rate of marginal and special reserve requirements is always an integer value. The analysis was carried out in a range from 10% to 80%, for in this case, together with the reserve requirement (which according to the official decision on setting aside the reserve requirement comes to 17%), it means that the maximum to be set aside for reserves is 97% of the amount of the increase of borrowed sources of funds, which are the subject of the research. A further assumption is that the rates of the marginal and special reserve requirements are equal ( $z_{1|pt} = z_{2|pt}$ ) and that the percentage of marginal/special reserve requirement on all kinds of loans made is equal ( $z_{i1|pt} = z_{i2|pt} = z_{i3|pt}$ ).

Only macro periods are observed in the model, since the sum of all events in the micro periods within a single macro period can be seen as a single event during this macro period.

Since the lower (market share of the bank) and the upper (maximum demand) bounds are defined in the model for every kind of loan, we observed the following circumstances from the numerical calculations. For each bank and each kind of loan, in the case of low rates of marginal reserve requirement, the funds lent out are on the upper bound. As the rates of marginal reserve requirement gradually increase, certain loans fall from the upper bound to the lower bound (that is, from the amount sufficient to satisfy the maximum demand they decline to an amount sufficient to achieve the planned market share). For each bank and each kind of loan there is one rate of marginal reserve requirement at which the funds extended drop from the upper to the lower bound. Such rates are then calculated for each bank and each kind of loan separately. Then, for each kind of loan made, the average value of MRR as the arithmetical mean of all MRRs is calculated, and not just the minimum and maximum. The average value is calculated as the arithmetical mean because we assumed that market shares are identical. It should be said that this relaxation was done so that the banks in the analysis should not be identifiable from the market share and interest rates data. The decision support system created allows for various market shares without any problems or efforts. In addition, if it is taken into account that most of the interest rates are the same for a given kind of loan and a given bank, market share does not actually play a great part during the calculation of the average value of MRR.

In the framework of this heuristic the value of the binary variable  $v_{ij|pt}$  was also set at 1<sup>17</sup> in all points of observation. In other words, it is assumed that there is a constant rise in

<sup>16</sup> Data obtained from CNB and used in this paper. Certain categories constitute averages of several different types of loans (kuna loans, foreign currency loans...)

<sup>17</sup>  $v_{ij|pt} = 1, \forall j, i, l, p, t$

bank borrowing, since this corresponds to the real life situation in the banking system. It is possible to replace borrowing from loans via bonds and vice versa. And that is why in the numerical calculations, without losing generality, we calculated only MRR.

The amount of the marginal/special reserve requirements is observed, at which amount of a given kind of loan moves from the upper to the lower bound of lending. The leader (the central bank) prescribes the rate of marginal/special reserve requirements ( $p$ ), while the commercial banks then decide about the amount they will borrow under the conditions set (they cannot affect the upper level or the world capital market).

At the beginning, an equal market share is assumed for all banks, and in the calculations of the average values of the rates of marginal/special reserve requirements it is enough to use the ordinary arithmetical mean. The initial level of loans from which the calculation starts for each individual bank is done in such a way that the calculation is carried out with a rate of marginal reserve requirement of 55%, and then the aggregate of all loans extended is distributed according to the proportions of given loans in total loans made by the banking sector. There are two types of commercial banks, distinguished by whether they do or do not give housing loans. The shares of the loans made depending on the type of bank are given in the table below.

*Table 1 Shares of loans in the total loans of a commercial bank (in %)*

Type of loan	Housing loans	Other loans to households	Loans to enterprises
Banks that do give housing loans	31.87	32.45	35.68
Banks that do not give housing loans	0.00	47.63	52.37

*Source: CNB*

In linear programmes that helped in the calculation, the expressions for the notations were removed. The values that are given by the notations from the first model are calculated later in the computer programme. The only notations used are those for the returns of loans made earlier ( $y_{jilpt}$ ).

## **5 Numerical results and analyses**

Banks in the Croatian banking system are observed. The basic difference among the different banks is the difference in the interest rate policy. The values of interest rates are obtained from the CNB. The average annual values of each individual bank are taken. The interest rates that are employed in the analysis are given in the tables in the Appendix (Table 7, 8 and 9).

The amount of profit in conjunction with varied rates of marginal reserve requirement is observed, that is, the rate of marginal reserve requirement at which given loans fall from the upper to the lower bound.

*Table 2 Shares of loans in the banking system (in %)*

Type of loan	Housing loans	Other loans to households	Loans to enterprises
Proportions of loans	24.37	36.02	39.61

*Source: CNB*

With the help of data concerning the proportions of each kind of loans inside the banking system and the calculated average values for the marginal reserve requirement within each individual model, the rate of marginal reserve requirement that has a major effect on system behaviour was calculated.

The analysis was made with the use of a nominal interest rate. This interest rate in some sense nevertheless conceals the real state of affairs inside the banking system.

We note that the level of loans made is limited, which means that there is an upper and a lower bound. For a small MRR, each bank, in each period, for each type of loan, makes its loans maximally, and if the MRR is large, then minimally. The threshold at which the change described in the behaviour of a commercial bank occurs varies according to the individual commercial bank.

Tables 3 – 6 give the minimum and maximum values of MRR at which in terms of each kind of loans and individual banks there is a change in behaviour, i.e., a fall from the upper to the lower bound of loans made (the threshold of profitability is reached or the planned market share for this kind of loan in this bank has been achieved). Then a calculation is made of the average value of the threshold of MRR as arithmetical mean of all MRR thresholds.

In this way in the case of the model that covers MRR and SRR, Table 3 is obtained:

*Table 3 Results of the basic model of the current state of affairs (in %)*

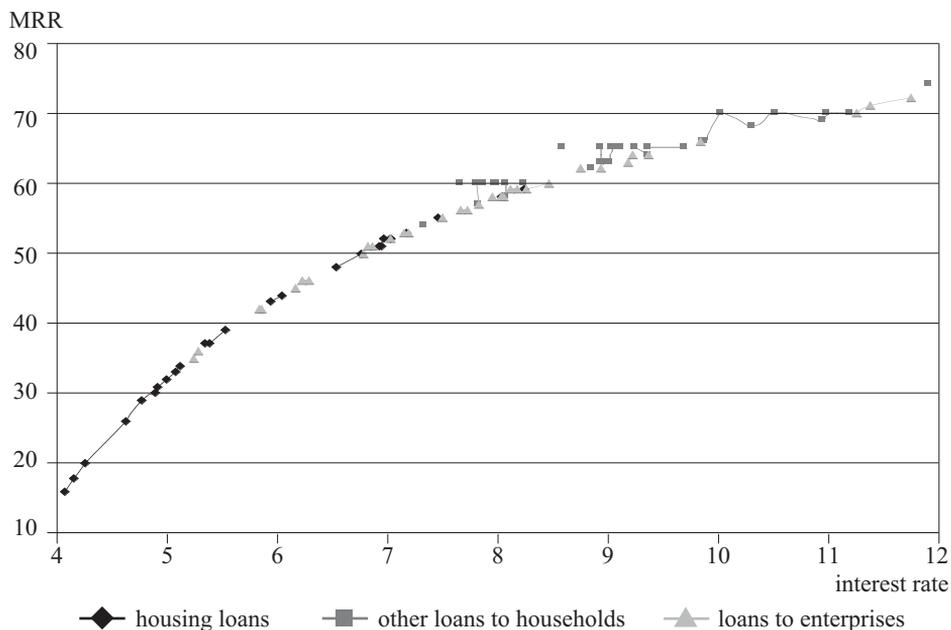
Type of loan	Marginal Reserve Requirement		
	Minimum MRR	Maximum MRR	Average MRR
Housing loans	16	59	40.38
Other loans to households	54	74	64.03
Loans to enterprises	35	72	55.56

*Source: authors' calculations*

Using data about the portions of the each kind of loans from Table 2 and the data about the average MRR from Table 3<sup>18</sup> the value of 54.91% is obtained as the rate of the MRR that will affect the system.

<sup>18</sup>  $0.2437 * 40.38 + 0.3602 * 64.03 + 0.3961 * 55.56 = 54.91$

*Figure 3 The impact of change in MRR on profitability of loans depending on the nominal interest rate – basic mathematical model (in %)*



*Source: authors' calculations*

The second research was carried out on the model extended to the subscription of compulsory central bank bills.

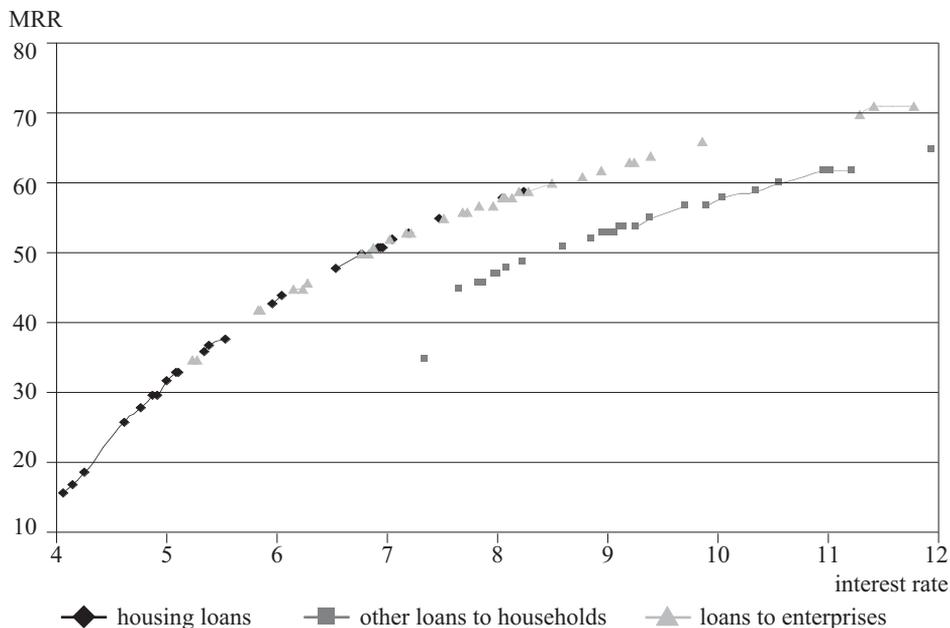
*Table 4 Results of the model extended to the subscription of compulsory central bank bills (%)*

Type of loan	Marginal Reserve Requirement		
	Minimum MRR	Maximum MRR	Average MRR
Housing loans	16	59	40.08
Other loans to households	35	65	53.03
Loans to enterprises	35	71	55.32

*Source: authors' calculations*

By a calculation on data concerning average MRR from this model, the rate of 50.78% was obtained as the rate at which MRR will have an effect on the system. As expected, it is lower than the rate from the previous model.

*Figure 4 The impact of change in MRR on profitability of loans depending on the nominal interest rate – the mathematical model has been extended to the subscription of compulsory CNB bills (in %)*



Source: authors' calculations

As the nominal interest rate is not a realistic price of loans made by commercial banks an analysis was also carried out with the use of the effective interest rate. Not even an analysis using this rate is completely reliable, because some bank loans, at exceptionally high effective interest rates, are hidden from statistical monitoring by the central bank (a number of data that are not included in the regular central bank report are implied here).

The second part of the analysis too was started with the use of the basic model of the current state of affairs that covers the MRR and the SRR, and the only change in the calculations, as already mentioned, was the use of the effective interest rate on commercial banks' loans.

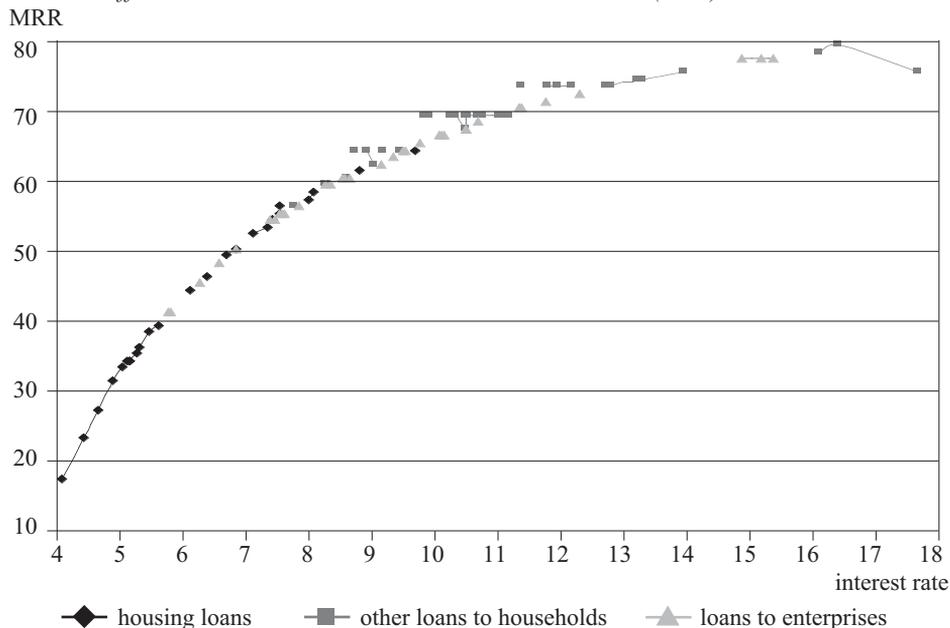
*Table 5 Results of the basic model of the current state of affairs (in %)*

Type of loan	Marginal Reserve Requirement		
	Minimum MRR	Maximum MRR	Average MRR
Housing loans	18	65	44.62
Other loans to households	57	80	67.71
Loans to enterprises	42	78	62.29

Source: authors' calculations

By calculating from data concerning the average rate of MRR impact, the rate of 59.94% was obtained as the MRR that had an impact on the system. In the same model, but with the use of the nominal interest rate, the figure of 54.91% was obtained as the rate of MRR that had an impact on the system, and the rate using the effective interest rate was 9.16% greater than the rate using the nominal interest rate, which is not a negligible consideration.

*Figure 5 The impact of change in MRR on the profitability of loans depending on the effective interest rate – basic mathematical model (in %)*



*Source: authors' calculations*

After that, an analysis was carried out of the model extended to the subscription of compulsory CNB bills with the use of the effective interest rate, and the following results were obtained for this:

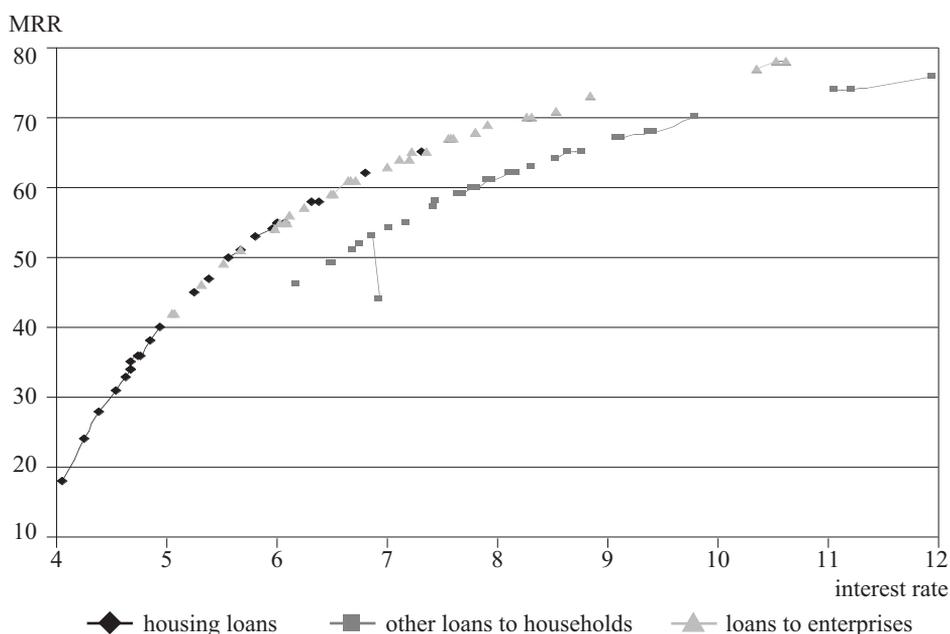
*Table 6 Results of the model extended to the subscription of compulsory CNB bills (in %)*

Type of loan	Marginal Reserve Requirement		
	Minimum MRR	Maximum MRR	Average MRR
Housing loans	18	65	44.23
Other loans to households	44	76	60.65
Loans to enterprises	42	78	61.97

*Source: authors' calculations*

For this model, given the use of the effective interest rate, the rate of 57.17% was calculated as the rate at which the MRR had an impact on the system. According to expectations, it was lower than the rate from the previous model as described in 5.3. In the same model, but with the use of a nominal interest rate (5.2) the rate of the MRR that had an impact on the system was 50.78%, and the rate with the use of the effective interest rate was thus 12.58% greater than the rate using the nominal interest rate, which once again is not a negligible factor.

*Figure 6 The impact of a change of MRR on the profitability of loans depending on the effective interest rate – the mathematical model extended to the subscription of compulsory CNB bills (in %)*



*Source: authors' calculations*

From all these calculations it can be seen that the behaviour of the banks is similar, independent of whether the nominal or the effective interest rate is used, the difference lying only in the rate of MRR, which affects the behaviour of the banks. This rate is higher in the case of calculations that are carried out when effective interest rates are used.

Apart from that, graphs about the impact of a change in MRR on operational profitability depending on the interest rate show an interesting feature, which is the divergence of the line of impact on other loans to households from the main line of MRR impact, in the case of the model extended to the subscription of compulsory central bank bills (Figure 4 and Figure 6).

An interesting fact that we can see from the table of the results (Tables 4 and 6) is that in the model that covers the subscription of compulsory CNB bills, the average rate of the impact of MRR on other loans to households is lower than the average rate of impact on loans to enterprises. From the graph it can also be seen that the instrument of subscription of compulsory CNB bills has almost no effect on housing loans, or on loans to enterprises. One explanation of this might be that these loans of the banks are already at a sensibly lower level of profitability than the other loans to households, and thus the impact of the fall in profitability is sensibly lower. Apart from that, the models allowed a certain kind of loan to stay at the initial level, and this has an impact on the results of the analyses carried out with the use of the mathematical models created.

If the statistical data of the central bank covered loans of central banks that are hidden from statistical monitoring and made at high effective interest rates, it is highly probable that the rates of MRR impact calculated would be still higher.

## **6 Conclusion**

Commercial banks, via various charges, are capable of putting up the nominal interest rate quite considerably. For this reason, an analysis of data using the nominal interest rate can lead to erroneous conclusions, and this paper recommends using the effective interest rate.

The graphs show us that within the framework of all the models that even when the MRR rate is changed, the MRR has an equal effect on housing loans and loans to enterprises, a change in impact existing only in the case of other loans to households.

Commercial banks run the kind of business (interest rate) policy such that the rate of MRR prescribed by the central bank does not have negative effect on the level of loans, but only on their profitability. If, for example, housing loans are advanced at a low interest rate, this will be made up for by the high interest rate on loans to enterprises or other loans to households. Some other banks will advance all loans according to a unified interest rate. Because of market conditions, the commercial banks do not put up interest rates on current banking products very significantly, so as not to lose market share; rather, they endeavour to bring in new products that include various charges and fees, and in this way practically raise the effective interest rate, without any change in or even a reduction in the nominal interest rate.

The Republic of Croatia has a relatively high foreign debt, exceeding 80% of GDP. This is a level of debt that is considered a potential trigger of a debt crisis. The growth of the debt is considerably influenced by commercial banks, borrowing abroad, because of the insufficiency of domestic capital accumulation, in order to lend these funds via various kinds of loan to households and corporations.

The objective of the CNB is defined by law, and this is, primarily, price stability, in other words, the stability of the whole of the economic system of the Republic of Croatia. The central bank, through its measures, can affect only the banking system, and endeavours through these measures to hold back the growth in bank foreign debts. It turns out that the growth of the foreign debt of the commercial banks is slowing down, and that the debt of the government is even falling, but the other domestic sectors' foreign debt is

rising considerably. Leasing companies, to which the banks associated with them have transferred a considerable part of their operations, are responsible for a large part of this debt of other domestic sectors.<sup>19</sup>

The mathematical models of bi-level programming developed in this paper describe only the relations between central bank and commercial banks oriented to the foreign borrowings of the commercial banks. The main goal of the central bank is to reduce the growth of loans from banks to the household sector, since enterprise entities can, with relative ease, take on debt abroad directly, which the central bank can not affect. The results of the analysis of these models show that the use of the decision support system created, would be useful in an ex-ante analysis of the effects of monetary policy. Although the analysis uses assumptions that simplify the model, the results are still a good signpost of the way the central bank might proceed while making decisions about the level of the MRR. Every additional fact related to the Croatian monetary system, and real data, can very easily be included into the decision support system, which would thus have an important role in the regulation of monetary trends.

In the forthcoming period it would be important to improve the central bank statistics monitoring the loans of commercial banks. Data obtained in this way could give a much better picture of the banking sector of the Republic of Croatia. With the help of data so processed, the central bank would be able to adopt more precisely targeted measures with respect to a certain kind of commercial bank behaviour.

## **7 Guidelines for future research**

In forthcoming research changes might be made in the existing model of calculating the rate of impact of the marginal/special reserve requirements by having this rate calculated for each bank separately according to the distribution of its loans. A rate calculated for each individual commercial bank, along with the rate of the impact of the marginal/special reserve requirements of the system, would be added according to the bank's market share. This would naturally affect the relaxation of the model in which we assumed that borrowing abroad increases all the time (i.e., that all the binary variables were fixed at  $v_{jilpt} = 1$ , and in further research it would be necessary to hypothesize a possible fall in borrowing).

It would be necessary to carry out an analysis of the sensitivity of the optimal solution to a change in parameters, i.e., for various commercial bank strategies expressed in the changing interest rate or in the accomplishment of the planned market share to observe the impact on the marginal reserves. It would be interesting to carry out econometric analysis of the dependence of MRR on the interest rate, and on the market share of the commercial bank.

Certain other functions of the objectives of the central bank and the commercial banks can also be observed. It is possible to observe certain sub-problems as being multi-criterion, where the objectives would be profit and accomplishment of market share.

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<sup>19</sup> For example, loans for the purchase of passenger cars have been shifted from classic bank loans to purchases via leasing.

One direction for new research might be other measures that the central bank might prescribe which in the current conditions might halt further growth of the foreign debt of the banking sector of the Republic of Croatia.

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## Appendix

*Table 7 Interest rates on loans from commercial banks used in the analysis  
of heuristics for calculation of the initial state (in%)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	9.31	9.61
02	–	10.58	11.37
03	–	12.19	10.58
04	–	10.77	9.29
05	–	9.54	5.12
06	–	10.76	11.96
07	–	9.24	9.70
08	–	10.38	8.91
09	6.89	11.63	11.75
10	8.21	9.77	7.29
11	4.84	9.51	8.32
12	4.90	9.72	6.43
13	4.00	9.47	6.66
14	4.19	8.03	6.76
15	6.91	10.20	8.15
16	5.91	8.25	6.87
17	6.00	12.54	7.84
18	5.63	7.70	7.90
19	7.44	10.49	7.87
20	7.00	7.54	8.39
21	5.04	9.12	5.81
22	7.84	7.17	8.62
23	4.91	8.83	6.25
24	8.00	9.40	9.55
25	7.52	11.34	8.85
26	5.45	9.33	6.30
27	5.20	9.00	7.27
28	7.00	11.51	8.16
29	7.15	11.47	10.51
30	4.87	8.36	7.05
31	4.77	9.48	5.56
32	8.00	8.71	8.34
33	3.86	8.42	6.34
34	5.36	9.62	5.74

Source: CNB

*Table 8 Nominal interest rates on loans from commercial banks used in analysis of heuristics for calculations (in %)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	9.35	9.16
02	–	9.87	9.35
03	–	11.20	11.39
04	–	9.86	9.21
05	–	8.93	7.92
06	–	10.31	11.26
07	–	9.01	8.24
08	–	8.05	8.03
09	6.89	10.99	11.75
10	8.21	8.56	8.15
11	4.84	8.99	9.82
12	4.96	9.36	6.99
13	4.11	9.02	6.84
14	4.21	7.63	7.17
15	6.91	10.02	8.45
16	5.91	7.97	6.80
17	5.49	11.92	5.81
18	6.01	9.04	8.02
19	7.44	9.23	8.10
20	7.00	7.80	7.80
21	5.31	9.07	6.74
22	6.93	7.30	8.02
23	5.07	8.06	6.12
24	8.00	8.83	8.91
25	6.73	10.52	8.73
26	5.35	9.23	5.80
27	4.87	8.21	6.25
28	7.00	9.68	7.64
29	7.15	10.94	7.48
30	4.72	7.84	7.13
31	4.57	8.92	5.20
32	6.50	7.95	7.70
33	4.02	7.79	6.19
34	5.04	9.11	5.24

*Source: CNB*

*Table 9 Effective interest rates on loans of commercial banks used in the analysis of  
the heuristics for the calculations (in %)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	17.60	15.15
02	–	13.21	12.27
03	–	16.06	14.85
04	–	11.03	10.49
05	–	16.35	11.32
06	–	12.77	15.33
07	–	12.69	9.75
08	–	9.05	10.16
09	7.12	13.27	11.75
10	9.68	11.12	9.48
11	4.93	10.48	10.08
12	5.30	10.77	7.86
13	4.12	9.85	7.62
14	4.46	8.31	7.58
15	7.43	12.16	10.69
16	6.39	9.46	7.49
17	8.09	11.93	5.81
18	6.14	11.77	9.53
19	8.80	11.16	10.12
20	7.56	8.63	9.15
21	5.63	10.24	7.39
22	7.36	7.76	9.34
23	5.19	8.28	6.27
24	7.43	10.47	11.36
25	6.86	12.70	10.49
26	5.49	10.53	6.61
27	5.08	9.17	6.87
28	7.56	11.37	8.64
29	7.99	13.93	8.58
30	5.16	8.74	8.29
31	5.17	10.33	8.54
32	6.70	8.92	8.33
33	4.69	9.92	7.56
34	5.33	10.68	5.84

Source: CNB

*Table 10 Marginal reserve requirement at which certain loans of a certain bank move into the area of non-profitability at the nominal interest rate – the basic model (in %)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	64	63
02	–	66	64
03	–	70	71
04	–	66	64
05	–	63	58
06	–	68	70
07	–	63	59
08	–	58	58
09	51	70	72
10	59	65	59
11	30	63	66
12	32	65	52
13	18	65	51
14	20	60	53
15	51	70	60
16	43	60	51
17	39	74	42
18	44	65	58
19	55	65	59
20	52	57	57
21	37	65	50
22	52	54	58
23	34	60	45
24	58	62	62
25	50	70	62
26	37	65	42
27	31	60	46
28	52	65	56
29	53	69	55
30	29	60	53
31	26	65	35
32	48	60	56
33	16	60	46
34	33	65	36

*Source: authors' calculations*

*Table 11 Marginal reserve requirement at which certain loans of a certain bank move into the area of non-profitability at the nominal interest rate – the basic model extended to the subscription of CCBB (in %)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	55	63
02	–	57	64
03	–	62	71
04	–	57	63
05	–	53	57
06	–	59	70
07	–	53	59
08	–	48	58
09	51	62	71
10	59	51	59
11	30	53	66
12	32	55	52
13	17	53	51
14	19	45	53
15	51	58	60
16	43	47	50
17	38	65	42
18	44	53	58
19	55	54	58
20	52	46	57
21	36	54	50
22	51	35	58
23	33	48	45
24	58	52	62
25	50	60	61
26	37	54	42
27	30	49	46
28	52	57	56
29	53	62	55
30	28	46	53
31	26	53	35
32	48	47	56
33	16	46	45
34	33	54	35

*Source: authors' calculations*

*Table 12 Marginal reserve requirement at which certain loans of a certain bank move into the area of non-profitability at the effective interest rate – the basic model (in %)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	80	78
02	–	75	73
03	–	79	78
04	–	70	68
05	–	80	71
06	–	74	78
07	–	74	66
08	–	63	67
09	53	75	72
10	65	70	65
11	32	70	67
12	36	70	57
13	18	70	56
14	24	60	56
15	55	74	69
16	47	65	55
17	59	74	42
18	45	74	65
19	62	70	67
20	57	61	63
21	40	70	55
22	54	57	64
23	35	60	46
24	55	68	71
25	51	74	68
26	39	70	49
27	34	65	51
28	56	74	61
29	58	76	61
30	35	65	60
31	35	70	61
32	50	65	60
33	28	70	56
34	37	70	42

*Source: authors' calculations*

*Table 13 Marginal reserve requirement at which certain loans of a certain bank move into the area of non-profitability at the effective interest rate – the basic model extended to the subscription of CCBB (in %)*

Bank	Housing loans	Loans to households	Loans to enterprises
01	–	76	78
02	–	68	73
03	–	74	77
04	–	62	68
05	–	74	70
06	–	67	78
07	–	67	65
08	–	44	67
09	53	68	71
10	65	62	64
11	31	60	67
12	36	61	57
13	18	57	56
14	24	49	55
15	55	65	69
16	47	55	55
17	58	65	42
18	45	64	65
19	62	62	67
20	55	51	63
21	40	59	54
22	54	46	64
23	35	49	46
24	55	60	70
25	51	67	68
26	38	60	49
27	33	54	51
28	55	63	61
29	58	70	61
30	34	52	59
31	34	59	61
32	50	53	59
33	28	58	55
34	36	61	42

*Source: authors' calculations*