Péter Lang

A model of bank behaviour for the assessment of the potential balance sheet impact of the NSFR liquidity requirement

MNB Working Papers 3

2017

Péter Lang

A model of bank behaviour for the assessment of the potential balance sheet impact of the NSFR liquidity requirement

MNB Working Papers 3

2017

The views expressed are those of the authors' and do not necessarily reflect the official view of the central bank of Hungary (Magyar Nemzeti Bank).

MNB Working Papers 3

A model of bank behaviour for the assessment of the potential balance sheet impact of the NSFR liquidity requirement*

(Banki viselkedési modell az NSFR likviditási követelmény lehetséges mérlegszerkezeti hatásainak vizsgálatára)

Written by Péter Lang

Budapest, March 2017

Published by the Magyar Nemzeti Bank

Publisher in charge: Eszter Hergár

Szabadság tér 9., H-1054 Budapest

www.mnb.hu

ISSN 1585-5600 (online)

*I would like to express my gratitude to Judit Temesváry, Ádám Banai, Gyöngyi Körmendi, Zsuzsanna Hosszú, György Csikós, Zénó Fülöp and Martin Stancsics, as well as all discussion participants at Magyar Nemzeti Bank and Národná banka Slovenska for their helpful comments.

Contents

Abstract

This paper provides a framework to examine the potential balance sheet adjustments of individual financial institutions for complying with the NSFR liquidity requirement. The suggested approach, which is also flexible enough to be applied in assessing the potential balance sheet impact of other regulatory proposals affecting the balance sheet of financial institutions, is an optimum model of bank behaviour, in which a bank statically rearranges its observed balance sheet by maximizing its profit with respect to constraints representing the balance sheet equality and various regulatory measures. According to our results, banks react to the introduction of the NSFR by strongly increasing their high-quality liquid assets, as well as fundamentally altering their short-term interbank funding to long-term. In addition, assuming no market frictions in the market for long-term funding from financial institutions, lending to the real economy decreases rather moderately as a consequence of the measure.

JEL: C33, C36, C61, G21, G28.

Keywords: NSFR, liquidity regulation, optimisation, Basel III.

Összefoglaló

Cikkünk egy keretrendszert mutat be az NSFR likviditási követelmény pénzügyi intézmények mérlegszerkezetére gyakorolt potenciális hatásának értékelésére. Javasolt megközelítésünk, amely kellően rugalmas más, a pénzügyi intézmények mérlegszerkezetét érintő szabályozói javaslatok lehetséges mérlegszerkezeti hatásainak vizsgálatához is, egy optimumfeladat a banki viselkedés modellezésére, amelyben a bank statikusan rendezi át megfigyelt mérlegszerkezetét, profitot maximalizálva a mérlegegyezőség, valamint különböző szabályozói követelmények által támasztott korlátok figyelembe vétele mellett. Eredményeink szerint a bankok az NSFR bevezetésére magas minőségű likvid eszközeik állományának jelentős növelésével, továbbá rövid lejáratú bankközi forrásaik hosszú lejáratúra való cserélésével reagálnak majd. Emellett, ha a hosszú lejáratú, pénzügyi intézményektől származó források piacán nem teszünk föl frikciókat, a reálgazdaság hitelezése az intézkedés hatására csak mérsékelten csökkenhet.

1 Introduction

Determining uniform liquidity requirements is one of the most fundamental developments of the Basel III regulatory proposals. A key element of these liquidity requirements is the *net stable funding ratio* (NSFR), which requires banks to maintain a stable funding structure in relation to their asset composition and off-balance sheet activities, in order to reduce the risk of future funding stress.

The NSFR is defined as the amount of *available stable funding* (ASF) relative to the amount of *required stable funding* (RSF), and financial institutions will be expected to maintain this ratio at or above a minimum of 100 per cent. Available stable funding consists of capital and liability items expected to be reliable over a one-year time horizon, whereas the amount of required stable funding depends on the liquidity characteristics and maturity structure of the institution's asset-side portfolio, as well as on its off-balance sheet exposures. (BCBS, 2014a)

The calculation of the ASF measure consists of first determining the carrying value of the bank's funding sources, and then multiplying them by their respective ASF factors, which are stipulated in legislation and are based on the relative stability of an institution's funding sources. Finally, the ASF measure is obtained as the sum of these products. Similarly, the measurement methodology of the RSF is also based on assigning weights to the carrying value of assets and off-balance sheet exposures of the bank according to their liquidity risk characteristics and summing up the product of each exposure and its respective weight. The exact categories and their assigned weights are detailed in BCBS (2014a), that is in the final standard. (BCBS, 2014a)

The first version of the NSFR was proposed in the 2010 Basel III agreement (BCBS, 2010b); however, after a consultation period (during which both the BCBS and various other organisations tried to assess the potential impacts of regulatory proposals on the financial markets and the economy), a revised consultative document with a recalibrated NSFR was published (BCBS, 2014b). Finally, in October 2014 the final version of the standard was put forward (BCBS, 2014a), imposing minor changes in the calculation of the RSF, as well as accounting for interdependencies among certain assets and liabilities. According to the official implementation timeline, the requirement is scheduled to come into effect on 1 January 2018. (BCBS, 2014a)

This paper contributes to the preparation for the newly-introduced liquidity requirement by providing a framework for examining the potential balance sheet adjustments of individual financial institutions to comply with the requirement. The method presented below thus provides an approach for estimating changes in the credit supply of individual institutions as well as the change in aggregate credit supply resulting from the new regulation. In addition, the flexible methodology presented in the paper can also be utilised to assess the potential balance sheet impact of other regulatory proposals affecting the balance sheet of financial institutions. For example, by slightly modifying the assumed balance sheet structure in the model, the impacts of measures such as changing the level of the Foreign Exchange Funding Adequacy Ratio (FFAR)[1] can also be evaluated.

Furthermore, from the impact of the NSFR on credit supply determined by this framework, and additionally using the results estimated by various papers examining the relationship between credit supply and economic growth (e.g. Moinescu and Codirlasu (2013), or for Hungarian corporate loans, Tamási and Világi (2011)), a preliminary estimate may be provided regarding the GDP impact of the new liquidity regulation.[2]

The suggested approach is an optimum model of bank behaviour, in which a bank, setting off from observed balance sheet data, statically rearranges its balance sheet[3] by maximizing its profit with respect to constraints representing the balance sheet

[1] The Foreign Exchange Funding Adequacy Ratio was introduced by the MNB in July 2012 to alleviate the systemic refinancing and liquidity risks the extensive currency mismatch in banks' balance sheets, especially the extensive reliance on short-term foreign currency liabilities carries.

[2] Although there are differences in the related literature regarding the exact variables representing lending (change in estimated credit supply, credit growth or change in the credit-to-GDP ratio) and its GDP impact (change in GDP or change in GDP per capita), the articles arrive at roughly the same conclusion: a 10 per cent increase in lending results in 1-2 per cent growth in the real economy. Thus, based on this result and on our estimated impact of the NSFR on credit supply, a rough, preliminary estimate of the GDP impact of the new liquidity regulation may be obtained by simple multiplication.

[3] That is, the optimum problem in which the bank decides the level of its balance sheet categories is not dynamic: banks are myopic in the sense that they only focus on complying with the requirements in the given period.

equality and various regulatory measures. Then, the impact of the introduction of the NSFR can be assessed, based on the difference between the optimal adjustments in the model's decision variables in the two cases of taking and not taking the NSFR constraint into account. We also assume rigidity in changing the current level of items in the bank's balance sheet, and, complementing the applied methodology of Giordana and Schumacher (2011), estimate the non-financial cost of adjusting balance sheet items[4] using a simultaneous equations approach.

In our analysis, we focus on the balance sheet adjustments needed for the eight largest individual financial institutions operating in Hungary to comply with the requirement. According to our results, banks react to the introduction of the NSFR requirement by strongly increasing their high-quality liquid assets (along with a considerable decrease in their long-term interbank lending), as well as fundamentally changing their short-term interbank funding to long-term interbank funding. However, there is only a moderate increase in deposits of households and non-financial corporates; in addition, in the baseline model (in which we assume the smooth functioning of the market for long-term funding from financial institutions), loans to non-financial corporates and to households decrease rather modestly.

As a robustness test, we also examine how the resulting balance sheet adjustments change when market frictions are taken into account. We implement the market friction which appears to be the most important for banks' balance sheet adjustments induced by the NSFR: a limited supply of long-term funding from financial institutions (i.e. both from the interbank market and from abroad). According to the balance sheet adjustments obtained in this manner, financial institutions decrease their loans to households and non-financial corporates with a much higher magnitude. Therefore, the introduction of the NSFR could only threaten banks' credit supply in the case of serious difficulties in raising long-term funds both from the interbank market and from abroad.

The structure of the paper is the following. We provide a review of the relevant literature in section 2, and outline the considerations behind the choice of our framework. Section 3 details the applied methodology, and in section 4 we present the results. Finally, section 5 concludes the paper.

[4] For deposit categories, for instance, these costs could contain costs related to additional staff, branches, marketing, etc...

2 Literature Review

There has been vigorous debate about the impact of liquidity regulation on banks and on the real economy. However, due to the scarcity of stringent liquidity regulation before the financial crisis, there are few historical episodes to evaluate the response of banks to tighter liquidity regulation. This is particularly true in the case of measures such as the NSFR, i.e. measures aimed at reducing funding risk over a longer time horizon.[5] Hence, an ex ante estimation of the impact of implementing the NSFR is only possible, by assuming the most probable behaviour of financial institutions instead of by observing their actual reactions. Despite the difficulty in providing an ex ante assessment, numerous articles have experimented with evaluating the regulation, because of the high relevance of the question in view of both financial stability and GDP growth. In these articles, four different approaches can be identified: performing qualitative analyses, employing statistical-econometric methods, applying macroeconomic models and using micro-level optimisation methods.

2.1 QUALITATIVE ANALYSES

Before building up a quantitative framework, it is essential to identify the intuitive theoretical reactions we expect banks to follow in order to comply with the newly-introduced requirement, as well as the effects of these reactions on the financial markets and the economy as a whole, i.e. to perform a qualitative analysis. This approach is detailed in various papers, also in ones providing a quantitative examination, too. Among these, Scalia et al. (2013) provide a thorough collection of the theoretical predictions appearing in the literature. According to their analysis, the new liquidity requirement will motivate banks to make changes in their balance sheets and maybe even in their business models, and these changes will have significant consequences on financial markets and central bank operations (Scalia et al., 2013). In the next few paragraphs, we outline their most important predictions.

As a first effect, banks will increase lending spreads (and probably also decrease credit supply by rationing credit) as a response to the increased cost of lending to retail and SME customers, which will need to be backed by a higher ratio of stable funding, even at shorter maturities. In addition, as a result of the marked difference in their RSF factors, financial institutions will now favour low-yielding, high-quality securities over higher-yielding ones, which will increase the difference between the volatility and liquidity of the markets of securities included and not included in the category of *high-quality liquid assets* (HQLA). (Scalia et al., 2013)

Turning to the liability side, stronger competition is expected to appear for retail and SME deposits, which are considered more stable by the standard than wholesale deposits and are thus rewarded by relatively high ASF factors. As a consequence of the stronger competition, however, these deposits will probably become less stable and more expensive. Since there is limited potential in increasing banks' funding ratio from retail and SME deposits, banks will still need to resort in part to wholesale funding. However, instead of building upon short-term financing from the interbank market, banks will be incentivised to either raise longer-term interbank funds or issue bonds, especially covered bonds. This will both lengthen the maturities in the interbank market and reduce the depth and relevance of the interbank market as a whole, also increasing the volatility of interbank rates. (Scalia et al., 2013)

All of the balance sheet adjustments listed above point to a substantial negative impact on the profits of banks complying with the regulation. Although, thanks to the requirement, banks will also be considered as a safer investment, and thus the ROEs expected by their investors will probably decrease, the reduced profitability will almost surely motivate banks to exploit their market power on the loan and deposit markets and increase their interest margin, as well as to change their business models. (Scalia et al., 2013)

[5] To our knowledge, the only exceptional article which analyses the effects of a newly-introduced liquidity regulation which is conceptually similar to the NSFR is Shi and Tribe (2012), who examine the core funding ratio implemented in New Zealand in 2010. The article uses aggregated data for the banking sector in New Zealand collected through the Standard Statistical Return Survey, and employs Mann-Whitney tests to draw conclusions about the significance of changes in key variables resulting from the introduction of the new liquidity regulation. The New Zealand experience shows that banks increased the average maturity of their liabilities and achieved some shift from wholesale to retail funding. (Shi and Tribe, 2012)

2.2 APPLICATION OF ECONOMETRIC METHODS

Among the articles which have employed statistical-econometric methods to assess the impact of liquidity requirements or even specifically the NSFR, two distinct groups can be defined. Papers in the first group (Banerjee and Mio (2014); Bonner (2012)) try to draw conclusions on the impact of liquidity requirements by observing an existing regulatory framework in a certain country and building econometric models on the observed data. By contrast, the papers in the second group (Dietrich et al. (2014); Bologna (2015); Hong et al. (2014)) apply the not-yet-introduced NSFR measure as an explanatory variable for examining certain questions.

Banerjee and Mio (2014) use the heterogeneous implementation of the new liquidity regulation called the *Individual Liquidity Guidance* (ILG) introduced by the UK Financial Services Authority in 2010 to identify impacts of the regulation on banks, and find that banks both increased the share of HQLA to total assets and moved their funding to sources considered more stable according to the regulation, such as non-financial deposits. However, they do not find evidence that the ILG regulation (which is similar in structure to the *liquidity coverage ratio* (LCR)) had a negative impact on lending to the non-financial sector. Similarly, Bonner (2012) examines the impact of the Dutch Liquidity Ratio, which is similar to the LCR, on banks' funding costs and corporate lending rates, based on a dataset of 26 Dutch banks from January 2008 to December 2011. According to his findings based on panel regressions with fixed effects, banks just below their liquidity requirement do not charge higher corporate lending rates, because banks do not have pricing power in the corporate loan market. Sadly, the methods followed by these articles are only applicable in an ex post analysis; thus, when trying to provide an ex ante assessment of the impact of the NSFR regulation, a different approach is required. (Banerjee and Mio, 2014; Bonner, 2012)

As papers from the second group, Hong et al. (2014) and Bologna (2015) examine the performance of the NSFR in explaining bank failures. Using a discrete-time hazard model that links bank failures to insolvency and both systemic and idiosyncratic liquidity risk measures on data obtained from the Call Reports data of U.S. banks, Hong et al. (2014) finds a consistent and statistically significant negative relationship between bank failures and the NSFR. Bologna (2015) uses a logit model on commercial bank defaults which occurred in the U.S. between 2007 and 2009 and concludes that the structural funding position has a significant explanatory power in explaining the probability of bank defaults, which corresponds to the earlier conclusion of Hong et al. (2014) on the impact of the NSFR. (Bologna, 2015; Hong et al., 2014)

In order to evaluate the potential effects of the NSFR in the future, Dietrich et al. (2014) analyse on a sample of 921 Western European banks over the period from 1996 to 2010 what factors have driven the level of the NSFR. With the help of regression analysis, they also examine whether and how NSFR has affected bank performance in the sense of both profitability and macroeconomic outcomes: first, they review how various factors may have determined the level of the NSFR and then they analyse the impact of all of the above factors jointly with the NSFR as an additional explanatory variable on bank performance. According to their results, no evidence is found for a statistically significant influence of the NSFR on bank profitability measured by any of the common profitability measures. However, in our opinion this result cannot be interpreted in a way that the introduction of the NSFR will not have any impact on banks' profitability since in the past, a certain profitability level could be reached by markedly different business models, and thus balance sheet structures. However, banks operating with a funding structure which is not stable enough are now required to change their balance sheet structure, which is a costly challenge. Hence, in general, in our opinion it is very difficult to draw conclusions from data obtained from the period in which the NSFR has not yet been implemented about the potential impacts the new regulation will have in the future, and thus we refrain from similar analyses.

2.3 ASSESSMENT USING MACROECONOMIC MODELS

After the first proposal of the Basel III regulatory reform package in 2010, a stream of articles (Kopp et al. (2010); Elliott and Santos (2012); BCBS (2010a); MAG (2010); Slovik and Cournéde (2011)) tried to analyse the expected impacts of the package on economic output, using the macroeconomic models at the authors' disposal. However, "unless adjusted, traditional macro models which have been designed to simulate the effect of economic policy measures and to make macroeconomic projections are typically not able to capture the macroeconomic effects of regulatory measures directly, as most of these models have not been developed further to include (sophisticated) financial market frameworks." (Kopp et al., 2010, p. 89) Therefore, one approach could be to build a partial equilibrium model to determine the connection regulatory measures have directly with the loan market, i.e. to assess their impact on either lending spreads or credit supply. Then, in order to come up with the effect on economic output, one could use these estimated price or quantity impacts as exogenous shocks in the macro model.

Typically, articles estimating the impact of the Basel III regulatory proposals use three steps in the analysis (Kopp et al. (2010); Elliott and Santos (2012); BCBS (2010a); Slovik and Cournéde (2011)). First, they estimate the absolute cost of the respective measures the banking sector has to bear. Second, they assume that these increased costs are wholly absorbed by lending rates, i.e. the increased funding costs and reduced profitability is fully passed through in the loan market. The implicit assumption is that financial institutions only have pricing power in the loan market.[6] The mapping of costs to the increase in lending rates is performed using the loan pricing formula. And finally, they simulate the macroeconomic effects of rising lending spreads using a macroeconomic model.

The articles arrive at markedly different estimates. Besides using different models and sometimes also in part different assumptions, this may likely be, as Elliott and Santos (2012) point out, due to three reasons. First, market forces may account for some of the increases in safety margins. Second, banks are expected to absorb part of the higher costs by cutting expenses. And third, since banks become safer investments as a result of the regulatory measures, investors are expected to reduce their required rate of return. Whether and at which rate to incorporate these features into the articles' calculations can lead to significantly different results.

It is interesting to compare the approach presented in this paper and the approach of macroeconomic models commonly used in the literature. The introduction of the NSFR creates a shortfall at financial institutions not yet complying with the regulation. The shortfall has to be eliminated by adjusting the balance sheet structure of the institution. This results in some decrease in credit supply. The amount of this decrease is what the model presented in this paper tries to estimate. Then, with this estimation for credit supply, we can use articles such as Moinescu and Codirlasu (2013) or Tamási and Világi (2011) to map the estimated change in credit supply to economic growth. By contrast, the stream of papers attempting to identify the impacts of Basel III opt for another method. They first evaluate the costs entailed by the respective regulation using either external analyses, expert judgements or e.g. by imposing assumptions regarding the order in which banks make the necessary changes to their assets and liabilities. Hence, they do not try to explicitly estimate either the amount of adjustments banks are motivated to make for compliance or the costs thereof. Nevertheless, they translate their cost assessment into an increase in lending rates and enter these lending rates into their macro model. That is, the two approaches use two different variables, the lending rate and the credit supply, to examine the impact of the regulation on the real economy. However, neither of the models consider how these two variables affect each other. The macro model takes the impact of the increased lending rates on the supply of credit into account, but this does not necessarily show the required adjustments in the loan portfolio and definitely does not address other modifications in the balance sheet structure. The model presented here does not account for potential changes in lending rates as we consider the assessment of this connection rather uncertain without imposing assumptions for the market structure of the loan market.

Sadly, the construction of a comprehensive macro model which is able to precisely capture financial intermediation and is thus suitable for including all the above mentioned effects remains for further research. Nonetheless, we believe our framework is useful in providing a method to assess changes in the balance sheet structure resulting from regulatory measures affecting the balance sheet of financial institutions. Before introducing our method in detail, however, let us present the papers on which our methodology is based.

2.4 MODELS OF OPTIMAL ADJUSTMENTS

As stated above, since we are not yet able to observe financial institutions' balance sheet adjustments, we need to provide an ex ante assessment for which we would like to determine banks' most probable reactions to the new regulation. To do this, a simple but quite plausible approach may be to assume that banks adjust their portfolios rationally; thus, given their constraints, they choose the optimal one from the set of available portfolios, i.e. the one which maximises their profits. This thought is applied in Giordana and Schumacher (2011)[7], an article on which we fundamentally based our approach, as well as in Schmaltz et al. (2014) and Furfine (2000).

[6] However, the analysis of Bonner (2012) concluded that, based on his reasoning, banks in the Netherlands do not have that pricing power for corporate loans.

[7] Although the authors have already published their work in the International Review of Applied Economics (Giordana and Schumacher (2013)), throughout this paper we refer to their working paper as that is the version of their work in which they have given a detailed description of their optimisation framework.

Giordana and Schumacher (2011) aim to estimate the impact of liquidity regulations on the bank lending channel in Luxembourg. Therefore, they examine the effect of bank characteristics identified in the literature as important for monetary policy transmission in a regression model, and complement these with measures calculated from the LCR and NSFR. However, instead of only using historical data, they also simulate the optimal balance sheet adjustments needed to adhere to the regulations, by maximizing banks' profits subject to the balance sheet constraints and the requirements of the new regulations. They do so because, in their opinion, historical data would be relevant for their analysis only if the introduction of the new requirements does not induce modifications in the balance sheets of banks; however, this is hardly the case. Finally, they use these simulated data to examine how the transmission mechanism would have operated if the regulations had been put in place at the start of the time series. (Giordana and Schumacher, 2011)

Schmaltz et al. (2014) also build an optimisation programme since they noticed that regulators only publish the distance to Basel III compliance measures on a ratio-by-ratio basis, but this neither accounts for the interdependencies among the various measures nor has microeconomic foundations. Instead, they propose a distance-to-compliance portfolio, which, in their interpretation, is optimal for a bank which is satisfied with its current balance sheet structure and wants to achieve compliance in the cheapest manner, i.e. with the least effect on its balance sheet composition. In order to arrive at this portfolio, they apply an optimisation programme with differentiated adjustment costs on balance sheet exposures. (Schmaltz et al., 2014)

Trying to explain the shifts in banks' portfolios which occurred in the United States from 1989 to 1994, Furfine (2000) also develops an optimisation model: a structural, dynamic model of a profit-maximizing bank in which banks experience capital shocks, face uncertain loan demand and incur costs based on their proximity to minimum capital requirements. He then uses his model to evaluate how banks adjust their loan portfolios over time with and without capital regulation. An interesting part of his optimisation model is that while first order conditions are derived formally from the maximisation problem, they are also estimated from data on U.S. bank portfolios. (Furfine, 2000)

Due to the reasons detailed above, in this paper we employ an optimisation framework to assess the potential balance sheet adjustments needed to comply with the newly-introduced liquidity regulation, for the eight largest financial institutions in Hungary. Our model is fundamentally based on the work of Giordana and Schumacher (2011), and is presented in detail in the next section.

3 The model of optimal balance sheet adjustments

According to our considerations detailed in the previous section, in the model we examine banks' potential balance sheet reactions to the introduction of the NSFR liquidity measure, as well as its effects on credit supply. We take banks' actual balance sheet structure as a starting point, and employ a static optimisation problem. In order to determine the framework of the model, we pose five fundamental assumptions and assume optimal behaviour within the framework characterised by our assumptions. In line with Giordana and Schumacher (2011), these assumptions are the following:

1. Banks are myopic in the sense that they only focus on the given period (e.g. the given quarter) and they ignore any information regarding the future (Giordana and Schumacher, 2011). Since the model is static, the length of this period is not important, and thus we can easily ignore the market liquidity effects of banks' resulting balance sheet adjustments, which would occur in the short run. In addition, the gradual implementation of regulatory requirements also assumes a certain myopic behaviour by financial institutions.
2. Lending and deposit rates, as well as yields on securities and the required rate of return on equity are, when possible, bank-specific rates, and are by assumption exogenous, that is, when deciding about the levels of balance sheet items (decision variables), the bank does not take the price change resulting from its quantity decision into account. Should we lift this assumption, we would have to model the market structure explicitly. However, for that, a much more complicated and comprehensive model would be appropriate, and since here we only want to provide an estimate of the probable effects of the introduction of the NSFR, we try to keep the model as simple as possible. (Giordana and Schumacher, 2011)
3. Banks do not co-operate; each of them maximises its profit separately, without taking into consideration the effects its actions cause to the market (Giordana and Schumacher, 2011). Although often disputable in practice, this is the simplest and most typical assumption in the literature.
4. The bank's business model is partly fixed, i.e. the proportion of exogenous balance sheet items to endogenous items is fixed. The reason for this assumption is that we only want to represent the main parts of the balance sheet as decision variables; however, for the purpose of calculating the requirement constraints, occasionally a much more granular perspective is necessary. We handle this issue following Giordana and Schumacher (2011) by assuming that exogenous items in the balance sheet are tied to an endogenous variable (or to a combination of them), in the sense that the movement of this endogenous variable also means a (fixed) proportionate movement in the exogenous variable. The choice of the endogenous variables depends on what is economically more justifiable. (Giordana and Schumacher, 2011)
5. We assume rigidity in the bank's balance sheet, i.e. it is costly to change the current level of endogenous variables (Giordana and Schumacher, 2011). In line with Giordana and Schumacher (2011) and Schmaltz et al. (2014), we assume basic, intuitive relations among the adjustment cost parameters, e.g. the cost of the change of the level of capital should be higher than that of securities (Giordana and Schumacher, 2011). However, we test the breaking of these intuitive relations both explicitly in our robustness checks detailed in appendix C, and implicitly by checking the effect of imposing an upper bound on long-term interbank funding.

The decision variables in the model try to capture the main balance sheet categories:

- On the liability side:
  - *Cap*: regulatory capital,
  - *Debt*: borrowings and own-issued debt securities,
  - $D_{C+P,<1}$: deposits of non-financial corporates, institutions, sovereigns and abroad, maturing within a year[8],

[8] The distinction by remaining maturity for the decision variables representing loan and deposit categories is necessary for both better grasping the NSFR requirement and allowing for the intuitively expected changes in short-term and long-term assets and liabilities induced by the requirement.

- $D_{C+P,\geq 1}$: deposits of non-financial corporates, institutions, sovereigns and abroad, maturing beyond a year,
- $D_{R,<1}$: household deposits maturing within a year,
- $D_{R,\geq 1}$: household deposits maturing beyond a year,
- $D_{FI,<1}$: deposits of financial institutions maturing within a year,
- $D_{FI,\geq 1}$: deposits of financial institutions maturing beyond a year.

• On the asset side:
  - *Cash*: cash and central bank reserves irrespective of maturity,
  - *GovBond*: government bonds irrespective of maturity,
  - *S*: other securities,
  - $L_{FI,<1}$: loans to financial institutions maturing within a year,
  - $L_{FI,\geq 1}$: loans to financial institutions maturing beyond a year,
  - $L_{C+P,<1}$: loans to non-financial corporates, institutions, sovereigns and abroad, maturing within a year,
  - $L_{C+P,\geq 1}$: loans to non-financial corporates, institutions, sovereigns and abroad, maturing beyond a year,
  - $L_{R,<1}$: household loans maturing within a year,
  - $L_{R,\geq 1}$: household loans maturing beyond a year.

The objective function of the optimisation problem tries to describe the bank's profits: it consists of interest earnings net of interest expenses and the adjustment cost Ψ, which is the sum of squared adjustments in the decision variables (that is the square of the difference between the decision variable and its initial value, denoted by tilde), weighted by the so-called *adjustment cost parameters*. More specifically:[9]

$$\max \Pi = \sum_i r_{L_i}(L_i - d_i L_i) + r_{Cash}Cash + r_{GovBond}GovBond + r_S S - \sum_j r_{D_j} D_j - r_{Debt}Debt - r_{Cap}Cap - \Psi, \tag{1}$$

where

$$\begin{aligned}\Psi = \sum_i \lambda_{L_i}(L_i - \widetilde{L_i})^2 + \lambda_{Cash}(Cash - \widetilde{Cash})^2 + \lambda_{GovBond}(GovBond - \widetilde{GovBond})^2 + \lambda_S(S - \tilde{S})^2 + \\ + \sum_j \lambda_{D_j}(D_j - \widetilde{D_j})^2 + \lambda_{Cap}(Cap - \widetilde{Cap})^2 + \lambda_{Debt}(Debt - \widetilde{Debt})^2.\end{aligned} \tag{2}$$

The constraints (their detailed version is provided in appendix A) represent certain regulatory requirements the bank has to comply with, as well as the balance sheet equality. For this analysis, we only build in two requirements: the minimum capital requirement complemented with the Supervisory Review and Evaluation Process (SREP) factor (accounting for both the use of the standard and the IRB framework in calculating the capital adequacy), and the NSFR liquidity requirement. The balance sheet equality captures equal *changes* in assets and liabilities.

NSFR constraint:

$$NSFR = \frac{ASF}{RSF} \geq 1, \tag{3}$$

Constraint of the capital adequacy ratio:

$$CAR = \frac{Cap}{RWA} \geq srep, \tag{4}$$

Balance sheet equality:

$$\begin{aligned}&(Cap - \widetilde{Cap}) + (Debt - \widetilde{Debt}) + (D_{C+P,<1} - \widetilde{D_{C+P,<1}}) + (D_{C+P,\geq 1} - \widetilde{D_{C+P,\geq 1}}) + (D_{R,<1} - \widetilde{D_{R,<1}}) + \\ &+ (D_{R,\geq 1} - \widetilde{D_{R,\geq 1}}) + (D_{FI,<1} - \widetilde{D_{FI,<1}}) + (D_{FI,\geq 1} - \widetilde{D_{FI,\geq 1}}) = \\ &= (Cash - \widetilde{Cash}) + (GovBond - \widetilde{GovBond}) + (S - \tilde{S}) + (L_{C+P,<1} - \widetilde{L_{C+P,<1}}) + (L_{C+P,\geq 1} - \widetilde{L_{C+P,\geq 1}}) + \\ &+ (L_{R,<1} - \widetilde{L_{R,<1}}) + (L_{R,\geq 1} - \widetilde{L_{R,\geq 1}}) + (L_{FI,<1} - \widetilde{L_{FI,<1}}) + (L_{FI,\geq 1} - \widetilde{L_{FI,\geq 1}})\end{aligned} \tag{5}$$

where *ASF*, *RSF* and *RWA* are defined in appendix A in a detailed manner.

[9] In these formulas, indices *i* and *j* run through loan and deposit categories, respectively.

3.1 CALIBRATION OF THE ADJUSTMENT COSTS OF BALANCE SHEET ITEMS

After collecting the bank-level data on the initial balance sheet structure and lending and deposit rates using the databases of the MNB's supervisory reporting data, the only parameters which still need to be determined are the adjustment cost parameters. As Schmaltz et al. (2014) states, the adjustment costs captured by these parameters represent non-financial costs to change positions. Costs occur not only at position increases (e.g. additional staff, branches, marketing), but also at position decreases ("A bank might face contractual penalties to shut down branches, lay off staff, and exit infrastructure." (Schmaltz et al., 2014, p. 7)). Generally, these costs are not straightforward to compute, or even to determine whether increases or decreases in a particular position incur higher non-financial adjustment costs. Thus, we use a simple quadratic functional form for the calculation of the adjustment costs of changes in positions. That is, we do not make a distinction between the cost of increases or decreases in a particular decision variable: we apply one adjustment cost parameter for each variable and the same quadratic functional form for all decision variables.

For determining the adjustment cost parameters, Giordana and Schumacher (2011) apply the following method. In their opinion, the level of the adjustment cost parameters is of minor importance, and the model is rather robust to their modification. In contrast, the relation of the parameters is what really matters, and for this Giordana and Schumacher (2011) provide the following intuitively expected relations in their model:

$$\lambda_S < \lambda_L = \lambda_D < \lambda_{Cap}, \tag{6}$$

that is, according to their expectations, the adjustment cost parameter of securities should be lower than the adjustment cost parameters of loans and deposits, in addition, the adjustment cost parameter of capital should be even higher than these. We agree with these relations and expect their compliance in our case as well.

Since they consider their level of minor importance, Giordana and Schumacher (2011) do not try to calibrate their model to real data by estimating the adjustment cost parameters. By contrast, they assume the parameters to be unknown and try to ascertain the robustness of the model in terms of these parameters with a simple simulation. They simulated 5,000 realisations. For each realisation, they transform the generated, uniformly distributed random number into adjustment cost parameters using the following mapping (which takes the above given intuitive relations into account) (Giordana, 2014):

$$\lambda_L = \lambda_D = 0.01 + 0.03\omega$$

$$\lambda_{Cap} = 0.1(1 + \omega)$$

$$\lambda_S = 0.01\omega.$$[10]

Finally, they substitute the simulated adjustment cost parameters into the optimisation programme, which they then solve. In their article, they present the average effect of the 5,000 optimal solutions on the balance sheet items. (Giordana and Schumacher, 2011; Giordana, 2014)

If the results obtained from the model are robust enough to the modification of the parameters, their approach is justifiable. In our opinion, however, even in this case the level of these parameters has a fundamentally influential impact on the size of the optimal adjustment. Thus, we consider it inevitable to provide a benchmark level estimated from real data for each of our parameters, to which we can anchor the expected value of the robustness simulation. In order to estimate this benchmark level, we derive the Lagrange function of the constrained optimisation problem, and analyse it in its optimum (i.e. we analyse the system of equations given by the Lagrange function's first order conditions). As an illustration, we demonstrate a typical first order condition of a deposit category, e.g. household deposits maturing within a year:

$$\frac{\partial \mathcal{L}}{\partial D_{R,<1}} = -r_{D_{R,<1}} - 2\lambda_{D_{R,<1}}(D_{R,<1} - \widetilde{D_{R,<1}}) + \Lambda_1\gamma_1 + \Lambda_3 = 0.$$

We denote the dual variables (otherwise known as Lagrange-multipliers) by $\Lambda_i, i = 1, 2, 3$. As is well-known, their values mean the extent of change that would occur in the objective function should we relax the constraint represented by the dual variable by one unit. Their sign depends on the relation of the original constraint: in particular, there are no sign restrictions for a dual variable belonging to an equality constraint. In the first order condition presented above, Λ_1 represents the NSFR constraint,

[10] In these formulas, $\omega \sim U(0, 1)$.

whereas Λ_3 the balance sheet equality. Note that since the balance sheet equality is by definition always met with equality, its dual variable is, according to the Kuhn-Tucker theorem, never restricted by sign. Furthermore, the Lagrange-multiplier of the balance sheet equality appears in every first order condition, as all decision variables are included in the balance sheet constraint. In addition, in all the equations only the adjustment cost parameter of the variable used in derivation for that particular first order condition is represented.

Therefore, similar to Furfine (2000), we may reinterpret the first order conditions to calibrate the adjustment cost parameters to real data. Let us convert the above equation to the following form:

$$(D_{R,<1} - \widetilde{D_{R,<1}}) = -\frac{1}{2\lambda_{D_{R,<1}}} r_{D_{R,<1}} + \frac{\gamma_1}{2\lambda_{D_{R,<1}}} \Lambda_1 + \frac{1}{2\lambda_{D_{R,<1}}} \Lambda_3. \tag{7}$$

If we now replace the values of the optimal decision variables determined by the model with their observed level in the next period, and in addition we replace the latent dual variables with an intercept, observable control variables and – since Λ_3 appears in every equation, and it has no sign restriction – with an error term not restricted in sign, we transform the optimal behaviour mechanisms represented in the first order conditions into models estimable from real data. That is, instead of the model-based first order condition (equation 7), we consider the following equation:

$$\Delta D_{R,<1,it} = \alpha_0 + \alpha_1 r_{D_{R,<1},it} + \mathbf{Z_{it}} \boldsymbol{\alpha_2} + \varepsilon_{it},$$

where $\mathbf{Z}$ represents the vector of control variables.

Since the equations we want to estimate represent the connection between the “price” and the “traded quantity” in a market, if estimated in this form, the resulting coefficient would show a certain weighted average of demand and supply-side effects. However, according to the assumptions of our model, the opposite side of the bank’s markets (i.e. the demand side in loan markets and the supply side in deposit markets) is given exogenously, there is no simultaneous determination of price and quantity. For this reason, for the parameter we are interested in, the coefficient estimated this way would give a strongly biased estimate, which may even be counterintuitive in sign. Therefore, in order to provide more precise estimates, it is advisable to transform our single-equation models into models consisting of two simultaneous equations: a demand equation and a supply equation. An example could be the following simultaneous system of equations:

$$\Delta D_{R,<1,it} = \alpha_0 + \alpha_1 r_{D_{R,<1},it} + \mathbf{S_{it}} \boldsymbol{\alpha_2} + \varepsilon_{it} \tag{8}$$

$$\Delta D_{R,<1,it} = \beta_0 + \beta_1 r_{D_{R,<1},it} + \mathbf{T_{it}} \boldsymbol{\beta_2} + \eta_{it}. \tag{9}$$

Here, the change in the deposit stock and the deposit interest rate are variables determined in an endogenous, simultaneous manner. For the identification of the equations, that is for deciding which equation belongs to the demand curve and which to the supply curve, we need exogenous explanatory variables in each equation which do not appear in the other equation. Translating this to our topic, we need to find exogenous explanatory variables which justifiably only determine the demand *or* the supply of deposits (i.e. the vector of explanatory variables $\mathbf{S}$ has to have at least one explanatory variable not included in $\mathbf{T}$, and vice versa). An intuitive demand-side variable could be, for example, the change in the bank’s credit stock, and for the supply side, the change in households’ disposable income. After identifying our equations, they can be estimated separately by two-stage least squares (2SLS).

Generally, we utilise the coefficient of the interest rate in the equation representing the bank’s side of the market. Thus, in this particular case, we need the coefficient of the deposit rate from the equation representing the deposit demand. From this estimated coefficient, we derive the adjustment cost parameter by a simple algebraic transformation, using the model-based nexus between the coefficient of the interest rate and the adjustment cost parameter $\alpha_1 = -\frac{1}{2\lambda_{D_{R,<1}}}$.

4 Adjustments imposed by the NSFR requirement

Before demonstrating our main results, let us quickly summarise the most important considerations behind the calibration of the adjustment cost parameters. For the estimation, we employ simultaneous systems of equations according to the methodology presented in the previous section, on a quarterly panel dataset of the eight banks in question, from 2003 Q1 to 2014 Q3. We try to estimate the adjustment cost parameters of all decision variables where it is possible to assume an equilibrium determination. However, we do not experiment with estimating the adjustment cost parameters assumed to be very low, i.e. the parameters of the decision variables *Cash*, *GovBond*, *S*, $L_{FI,<1}$, $L_{FI,\geq 1}$, $D_{FI,<1}$ and $D_{FI,\geq 1}$. The reason for this is that the stocks and the markets of these exposures are usually governed by different incentives than equilibrium considerations such as longer-term supply and demand: liquidity creation, or merely passive adjustment to monetary policy actions.

We are also unable to provide reliable estimates for the adjustment cost parameters of capital and of borrowings and own-issued debt securities. We suspect that this is due to the fact that in the Hungarian market environment, it is rather difficult to assume an active market governed by equilibrium adjustment of prices according to the quantities demanded and supplied in the market for the aforementioned balance sheet items. Banks' demand for capital is basically determined by regulatory requirements, and for the majority of banks, in cases of scarcity it is usually the foreign owners of the banks which step in with a capital injection. In addition, only one of the examined banks is listed on the Hungarian stock exchange. Also, the bulk of long-term borrowings are from the Hungarian banks' foreign parent companies, and bond issuance is not considered a typical source of funding for Hungarian banks. However, it is important to note that it is only the specific properties of the Hungarian market which makes it difficult or even impossible to perform these estimations. Theoretically, and probably also practically in countries with more developed security markets, equilibrium models with simultaneous equations can be built for capital and bond markets as well.

The estimated systems of equations as well as all of the estimated coefficients are presented in detail in appendix B. The resulting adjustment cost parameters are summarised in Table 1. The adjustment cost parameters which are assumed to be large, i.e. the adjustment cost parameters of capital and borrowings and own-issued securities, are set to the ad-hoc level of 0.001.[11]

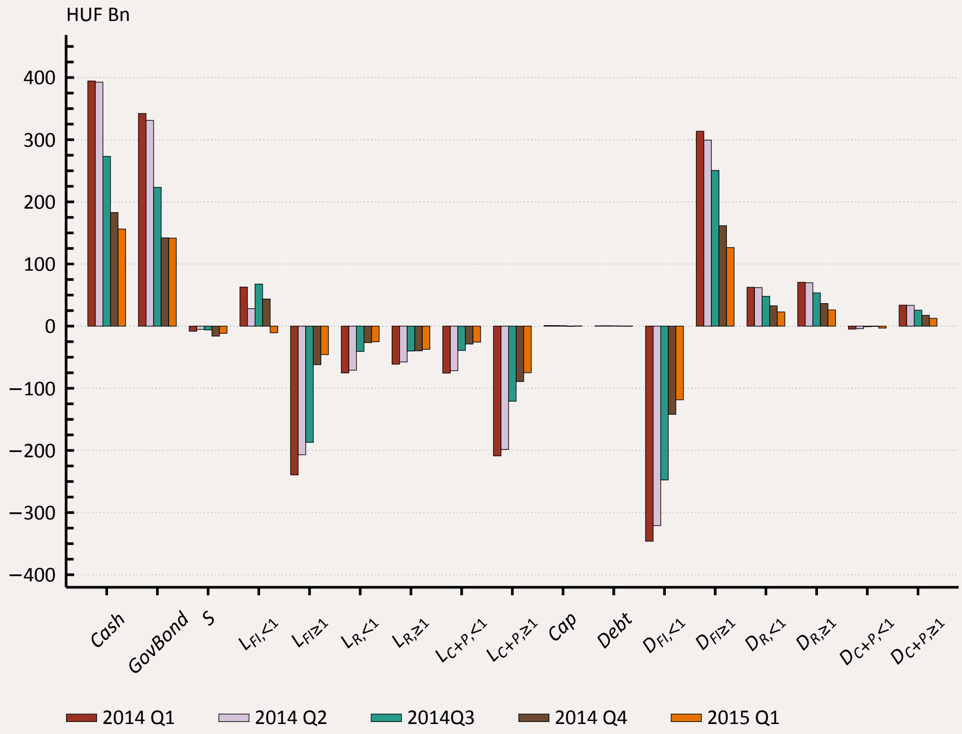
Table 1
Adjustment cost parameters calibrated by simultaneous systems of equations ($\times 10^{-6}$)

$\lambda_{L_{C+P,<1}}$	$\lambda_{L_{C+P,\geq 1}}$	$\lambda_{L_{R,<1}}$	$\lambda_{L_{R,\geq 1}}$	$\lambda_{D_{C+P,<1}}$	$\lambda_{D_{C+P,\geq 1}}$	$\lambda_{D_{R,<1}}$	$\lambda_{D_{R,\geq 1}}$
11.800	9.201	22.120	22.120	28.172	28.172	13.486	13.486

Since we only estimate these adjustment cost parameters to provide a benchmark for the level of the adjustment cost parameters from real data, and as it is not possible to estimate all of the adjustment cost parameters with econometric methods, it is of paramount importance to check whether our results are robust to the modification of these adjustment cost parameters. Therefore, we conduct a sequence of robustness tests, which are detailed in appendix C. The main conclusions from the robustness tests are that the adjustment cost parameters of capital, borrowings and own-issued debt securities, as well as deposits and loans of households and non-financial corporates behave robustly to their absolute and relative modifications, provided that we do not break the intuitive relations stipulated in equation 6. However, the results are very unstable to the modification of the small adjustment cost parameters, although the more of these values we are able to set reliably, the more stable results we will obtain. This instability is both observable when their parameters are changed relative to each other and in the case when the distance of their common level to other parameter categories is modified.

[11] As will be obvious from the following paragraphs and also from appendix C, the exact level of the adjustment cost parameters of these two variables is not important in the model, provided that they are considerably higher than all other adjustment cost parameters.

Figure 1
Aggregate optimal adjustments in the decision variables



Note: The figure depicts the additional effect the introduction of the NSFR requirement imposes in banks' balance sheets, i.e. the difference between the two optimal adjustments when the NSFR constraint is taken and not taken into account.

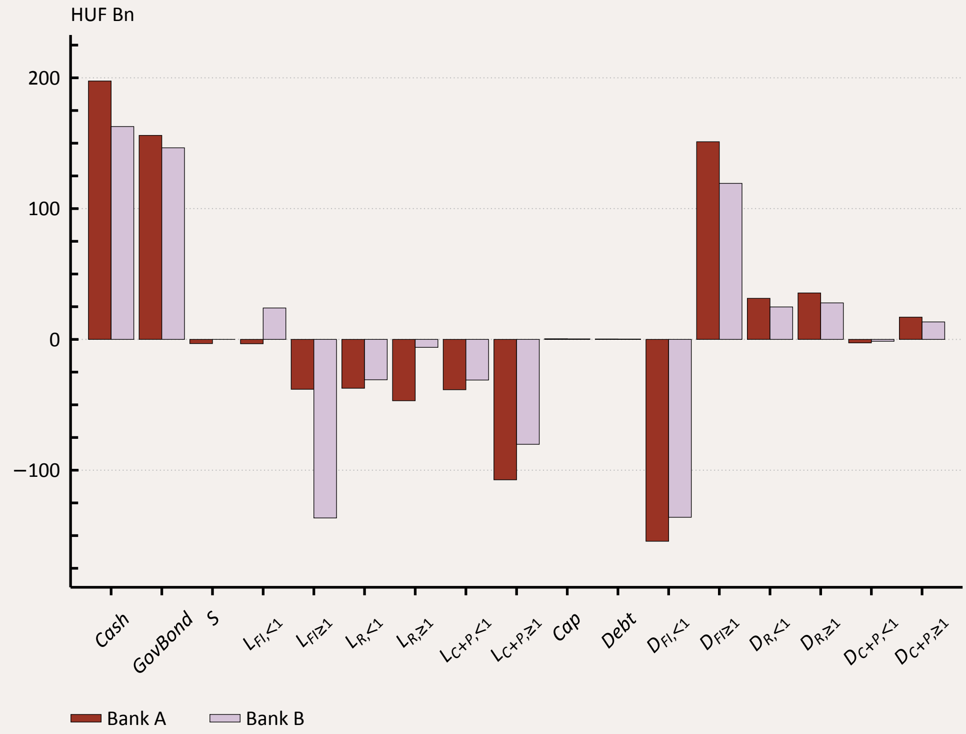
The instability of the model to changes in the small adjustment cost parameters seems intuitive, since it is rather obvious that in the model, the bank will try to comply with its constraints in the easiest, cheapest way possible, that is by changing the level of the exposures where the adjustment costs are lowest relative to the contribution of the given balance sheet item to achieving the NSFR. Thus, when these small parameters are altered relative to each other, huge changes can occur in the optimal solutions. Similarly large substitution effects are, however, highly unlikely in case of larger parameters, e.g. we could observe almost no variability in our results when altering the adjustment cost parameters of capital and debt. Therefore, when forming conclusions, we need to particularly take into consideration the sensitivity of the model to small adjustment cost parameters. By contrast, the level of adjustment cost parameters of capital and debt is of minor importance, hence an ad-hoc level of the adjustment cost parameter, which is, according to our intuition, much higher than all the other parameters, seems justifiable.

Because of the instability of the model to the small adjustment cost parameters, we calculate the optimal adjustments using 100 realisations[12] of simulated small adjustment cost parameters, varying in the interval $[0.5, 7] \cdot 10^{-6}$. The results shown in Figure 1 are the *mean* of the distribution of optimal adjustments resulting from this simulation. In the figure, we show the adjustments resulting from the introduction of the NSFR constraint in every decision variable.

In our opinion, the optimal balance sheet structure is very difficult to interpret. This is due to the fact that this model captures only a few reasons according to which a financial institution chooses a balance sheet structure which it considers to be optimal. Therefore, it is almost certain that the bank (with other motivations also in mind) will consider as optimal (and will actually choose) a balance sheet structure different from our results. By contrast, the *difference* between the optimal adjustments of the two cases when the NSFR constraint is accounted for and when it is not included in the model, is thought to be very informative, since – provided that the relative size of adjustment cost parameters are correctly captured – it represents the additional effect the introduction of the NSFR requirement imposes in the bank's balance sheet structure. Therefore, we depict this difference between the two optimal adjustments in the figures.

[12] We also performed calculations with higher number of realisations, but remained at a fairly low number as the mean of optimal adjustments has already proven itself to be stable at this number; moreover, increasing the number of realisations slowed down computation speed considerably.

Figure 2
An example of the heterogeneity of optimal adjustments in the decision variables



Note: The figure depicts the additional effect the introduction of the NSFR requirement imposes in banks' balance sheets, i.e. the difference between the two optimal adjustments when the NSFR constraint is taken and not taken into account.

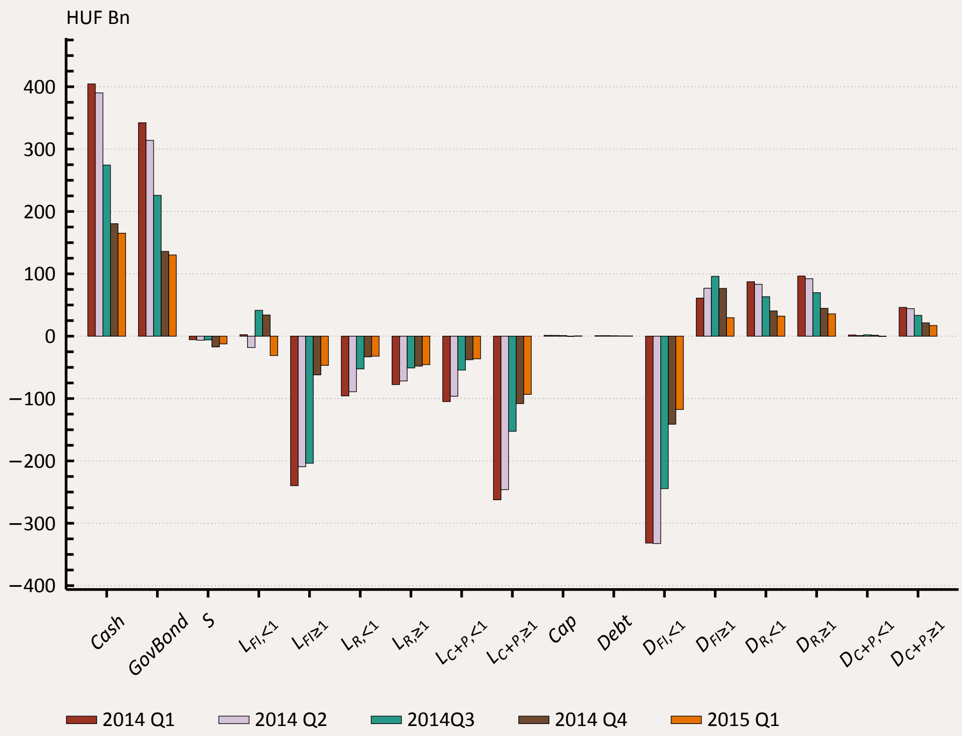
We demonstrate the *aggregate* adjustments of the eight largest banks in Hungary, which account for more than 77 per cent of the banking sector, based on the 2015 Q1 balance sheet total. We provide the adjustments *for the last five periods*[13] in our database, because we have individual NSFR values estimated approximately by MNB for these periods. These estimated values are useful for fitting the model-based NSFR values to real data. The reason for this fitting is that – although our NSFR calculated in the constraint captures the effect of the main balance sheet exposure categories on the NSFR as well as the time series dynamics of the requirement, which channels of impact are the truly relevant aspects of the NSFR constraint for the model – our model-based NSFR calculation is not as granular as the calculation stipulated in the standard, thus it cannot yield the real NSFR level. Therefore, in order to grasp the adjustment needs which are actually relevant for banks, we fit the level of our model-based NSFR to its real level. We also perform similar fitting in case of the capital adequacy ratio.

Figure 1 thus represents a bar plot for each period, and in a bar plot for a given period, we can observe the difference between the optimal adjustments of taking and not taking the NSFR requirement into account, for every decision variable. It is important to note that the magnitudes of adjustments are highly heterogeneous among institutions. For the institutions initially complying with both the CAR and the NSFR requirements, there are by definition no additional adjustments due to the introduction of the NSFR.[14] Hence, adjustments appear only for two to four institutions, depending on the period in question. In addition, the differences among institutions in the magnitudes of adjustments are not only due to differences in initial NSFR levels: there is also considerable heterogeneity among banks due to their initial balance sheet structures and bank-specific exogenous "price" parameters. To illustrate that, we choose a period when two similar-sized institutions had approximately the same initial NSFR figures (and both complied with the requirement of the capital adequacy ratio), and demonstrate their adjustments implied by

[13] As it is not our goal to analyse balance sheet adjustment needs in a time series dimension, but we are only interested in the most recent adjustment needs, we do not consider a problem that the potential balance sheet impact of complying with the NSFR requirement can only be examined in these periods.

[14] There are also only negligible adjustments at a level of maximum 4-5 million forints when moving to the optimum from the initial balance sheet structure. The reason for these is that changes to the optimum cannot be quite high because of the loss in profit caused by the increasing adjustment costs.

Figure 3
Aggregate optimal adjustments in the decision variables – with upper bound on long-term interbank funding



Note: The figure depicts the additional effect the introduction of the NSFR requirement imposes in banks' balance sheets, i.e. the difference between the two optimal adjustments when the NSFR constraint is taken and not taken into account.

the model in Figure 2. It is observable in the figure that, although the primary adjustment directions are the same and their magnitudes are highly similar, differences in the balance sheet structure (following our example, a significant disparity in the initial stock of long-term interbank loans) could easily yield somewhat different adjustments.

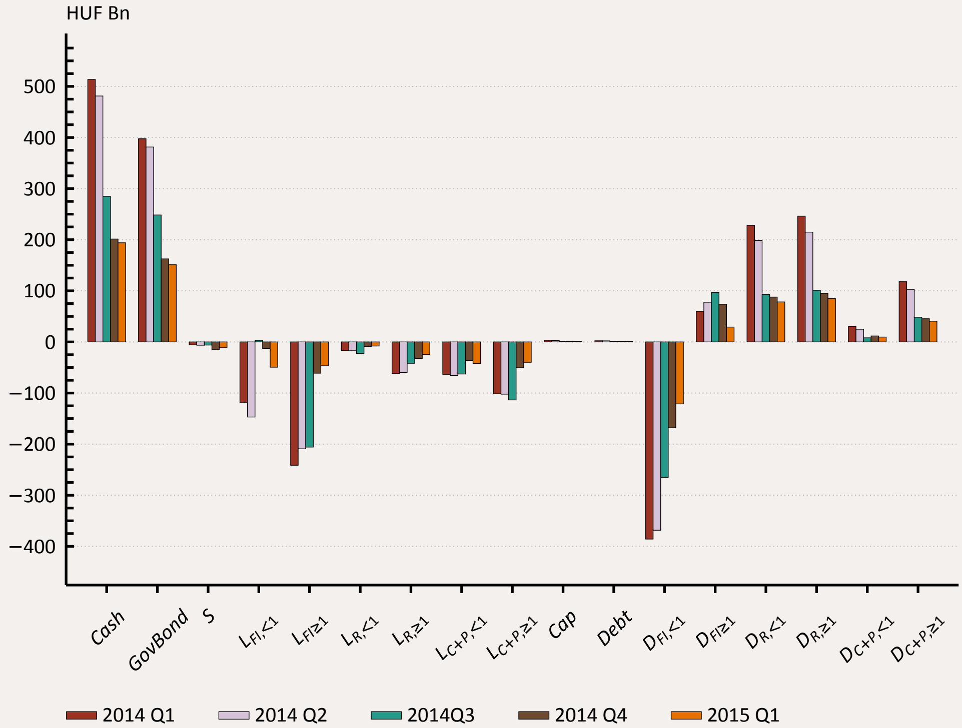
According to the aggregate adjustments shown in Figure 1, banks react to the introduction of the NSFR requirement by strongly increasing their high-quality liquid assets (*Cash* and *GovBond*), as well as fundamentally changing their short-term interbank funding into long-term funding. There is a somewhat significant decrease in long-term loans to financial institutions as well. Interestingly, however, we can only observe a moderate increase in deposits of households and non-financial corporates. Given that adjustments of this magnitude are possible in high-quality securities and interbank funding, loans to non-financial corporates and to households decrease rather modestly, with the only exception of long-term loans to non-financial corporates, for which category we estimated a relatively lower adjustment cost parameter (see Table 1).

4.1 ALTERNATIVE SPECIFICATIONS

There are some extensions, or slight modifications of the model which are interesting to consider. First, the balance sheet adjustments imposed by our baseline calculations are not definitely possible in all market situations: despite the fact that we have implicitly assumed a normal market environment, there may be frictions which could limit adjustments in some markets. It is thus highly important to test how our results change when we include such frictions in the model. Given the adjustments obtained from our baseline model, the freezing of the long-term interbank market entails the highest risk to our results. That is, banks might not be able to raise long-term interbank funding of this magnitude.[15] Therefore, we introduce an upper bound for the adjustment in the variable $D_{FI,\geq 1}$.

[15] Or – which is equivalent in effect – that the increased price of long-term interbank funding resulting from the rising net demand in the market makes it not worthy for certain market participants to raise funding this way.

Figure 4
Aggregate optimal adjustments in the decision variables – with upper bound on long-term interbank funding and lower bound on corporate and household lending

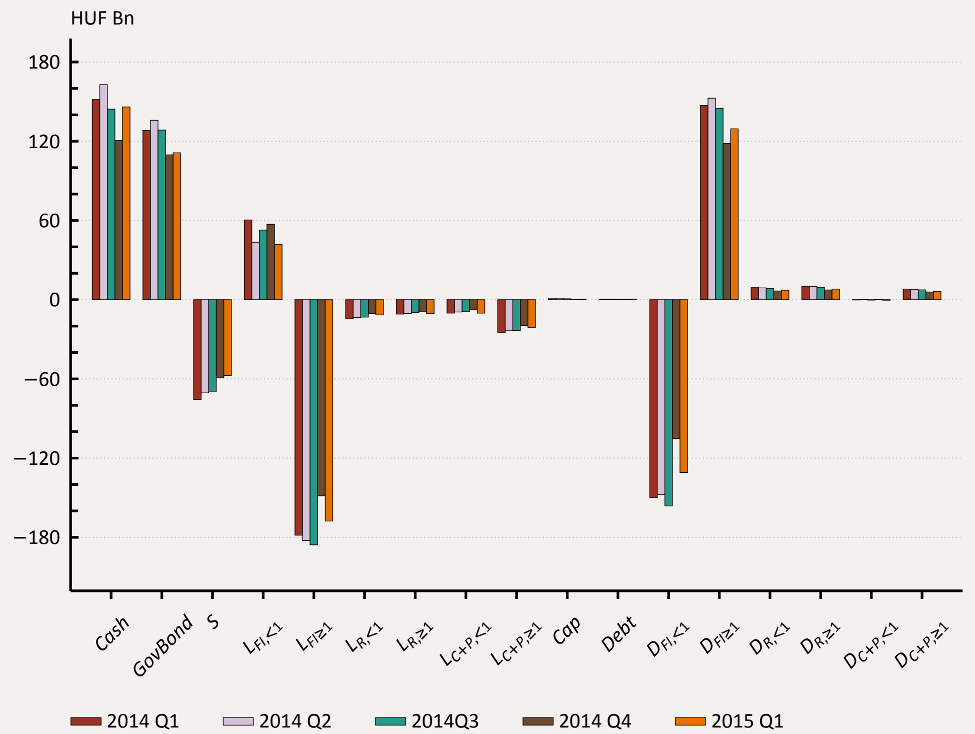


Note: The figure depicts the additional effect the introduction of the NSFR requirement imposes in banks' balance sheets, i.e. the difference between the two optimal adjustments when the NSFR constraint is taken and not taken into account.

We first set this upper bound at the reasonable level of the aggregate initial ASF reserve of banks whose NSFR is initially above the 100 per cent requirement; however, this upper bound does not bind our adjustments. Therefore, and also in order to abstract from the peculiarities of the Hungarian market and thus generalise our model, as well as to illustrate the fact that expert considerations can also be built into the model, we have introduced an ad-hoc upper bound for long-term interbank funding. According to this upper bound, positive adjustments in $D_{FI,\geq 1}$ cannot exceed 30 per cent of the variable's initial level. The resulting adjustments are depicted in Figure 3. It is visible in Figure 3 that with the upper bound imposed this way, financial institutions decrease their loans to households and non-financial corporates with a much higher magnitude. This can be argued considering that by imposing the upper bound, we strongly decrease the bank's ASF level. In order to comply with the NSFR requirement, with this decrease in ASF in mind, the bank also has to cut its RSF. And to do so, the most effective strategy seems to be to cut the amount of loans to households and to non-financial corporates, since the RSF weight of high-quality liquid assets is very low, and in addition the substitution of this missing long-term interbank funding to deposits is also disincentivised by their high adjustment cost. As a conclusion, introduction of the NSFR could only threaten banks' credit supply in the case of serious difficulties raising long-term funds both from the interbank market and from abroad.

How could a bank avoid the considerable reputational loss that would result from this marked decrease in lending to households and non-financial corporates? To additionally examine this in our framework, we limit banks' opportunity to reduce their lending to the real sector by adding lower bounds for the variables $L_{C+P,<1}$, $L_{C+P,\geq 1}$, $L_{R,<1}$ and $L_{R,\geq 1}$. These lower bounds ensure that negative adjustments of the loan stocks extended to households and non-financial corporates cannot be higher than e.g. 10 per cent of the stocks' initial level. The results shown in Figure 4 indicate that in this case banks need to resort to attracting higher amounts of deposits. This is due to the fact that by artificially limiting banks' adjustment opportunities in the variables representing lending to the real sector, the strong decrease in their ASF level caused by the upper bound on long-term interbank funding can be counteracted most efficiently by increasing deposit amounts. Although this cannot be analysed within the model, in practice in the longer run this can be easily accomplished by increasing deposit rates.

Figure 5
Aggregate optimal adjustments in the decision variables when every bank has to increase its current NSFR level by 5 percentage points



Note: The figure depicts the effect of requiring every bank to increase its current NSFR level by 5 percentage points, i.e. the difference between the two optimal adjustments when the NSFR constraint is set at 5 percentage points plus the current NSFR level of the institution, and when it is set at the bank's current level.

We can obtain another extension, a generalisation of the model if, instead of complying with the NSFR requirement stipulated in the legislation, we require every bank to increase its current NSFR level by e.g. 5 percentage points.[16] In this framework, we can also easily examine to what extent financial institutions would alter their balance sheet structures if the NSFR *requirement* was raised by 5 per cent, which is an interesting question for macroprudential policymaking. However, in this case we want to abstract from the particularities of the Hungarian market and to demonstrate the size of the adjustments a general need to increase banks' NSFR levels would necessitate, which answers the question of the costs which might be entailed by a move towards a more stable funding structure.[17]

The aggregate optimal adjustments, which are demonstrated in Figure 5, cover some heterogeneities. Although the magnitude of the adjustments is similar for all banks, there are some differences due to the institutions' different size and balance sheet structure. In addition, some variability may appear in the resulting adjustments across periods and institutions, due to the changing, exogenously given "prices" of balance sheet categories. Despite these heterogeneities, however, the resulting aggregate adjustments are considerably smaller than observed in the previous figures, i.e. when examining the aggregate effects of all banks complying with the 100 per cent NSFR requirement. This is because in this exercise, although the adjustment of all banks was expected, the amount of the adjustment need – 5 percentage points – is much lower in this case for banks not yet complying with the requirement. Nevertheless, the direction of the resulting adjustments coincides with our expectations, as well as with our baseline results.

[16] The results of this exercise can be calculated as the difference between the optimal adjustments when the NSFR constraint is set at 5 percentage points plus the current NSFR level of the institution, and when it is set at the bank's current level.

[17] Although the question is rather theoretical, such a move might actually occur, even without regulatory pressure as well, e.g. if banks want to rebuild their target NSFR level after a system-wide shock.

5 Conclusion

With this paper, we contribute to the preparation for the upcoming NSFR liquidity requirement by assessing the balance sheet adjustments needed for the eight largest financial institutions operating in Hungary to comply with the requirement. In order to perform this ex ante assessment, we employ an optimisation model of bank behaviour. In the optimisation problem, a bank maximises its profit (which consists of interest earnings net of interest expenses minus the non-financial costs of changing its balance sheet structure towards compliance with regulatory measures) with respect to the NSFR and the capital adequacy ratio as constraints, as well as the balance sheet equality. The model departs from observed balance sheet data and performs a static optimisation. For obtaining the parameters governing the non-financial cost of balance sheet adjustments from real data, where it is possible based on the particularities of the given market we estimate simultaneous equations models representing the markets of balance sheet items (e.g. long-term household loans or short-term corporate deposits). In addition, we also examine the robustness of our results due to changes in adjustment cost parameters, based on various simulations.

Our results depict the difference between optimal adjustments of the two cases when the NSFR constraint is accounted for and when it is not included in the model. According to our results, which mask significant heterogeneities among banks, banks react to the introduction of the NSFR requirement by strongly increasing their high-quality liquid assets, as well as fundamentally changing their short-term interbank funding into long-term funding. However, there is only a moderate increase in deposits of households and non-financial corporates, and, given that adjustments of this magnitude are possible in high-quality securities and interbank funding, loans to non-financial corporates and to households decrease rather modestly. By additionally imposing an upper bound on adjustments in long-term interbank funding, we also lift our baseline assumption of normal market circumstances and include possible market frictions in the model. In this manner, we were able to ascertain that banks would only be incentivised to drastically contract credit supply as a reaction to the introduction of the NSFR requirement in the case of serious difficulties raising long-term funds both from the interbank market and from abroad. However, in case they associate high reputational costs to a considerable reduction of credit supply, they could alternatively raise their deposit stocks for complying with the requirement. Additionally, we also examine the aggregate impact of requiring every bank in the system to increase its current NSFR level by 5 percentage points. This exercise emphasises that our results are not only relevant for Hungary, but could be of general importance to macroprudential policymakers.

This assessment could also be useful as a first step in providing a preliminary estimate regarding the GDP impact of the new liquidity regulation, as well as a general framework of assessing the potential balance sheet impact of regulatory proposals affecting the balance sheets of financial institutions. Providing more precise estimates of the adjustment cost parameters, or expanding the model to include further segmentation of balance sheet categories used as decision variables (adding different currencies, for example) remain for future research.

References

Banerjee, R. N. and H. Mio (2014), *The Impact of Liquidity Regulation on Banks*, BIS Working Paper No. 470, Bank for International Settlements.

BCBS (2010a), *An assessment of the long-term economic impact of stronger capital and liquidity requirements*, Report, Bank for International Settlements.

BCBS (2010b), *Basel III: International framework for liquidity risk measurement, standards and monitoring*, Standard, Bank for International Settlements.

BCBS (2014a), *Basel III: The Net Stable Funding Ratio*, Standard, Bank for International Settlements.

BCBS (2014b), *Basel III: The Net Stable Funding Ratio*, Consultative Document, Bank for International Settlements.

Bologna, P. (2015), 'Structural Funding and Bank Failures: Does Basel III Net Stable Funding Ratio Target the Right Problem?', *Journal of Financial Services Research*, vol. 47 no. 1, pp. 81–113

Bonner, C. (2012), *Liquidity Regulation, Funding Costs and Corporate Lending*, DNB Working Paper No. 361, De Nederlandsche Bank.

Dietrich, A., G. Wanzenried and K. Hess (2014), 'The good and bad news about the new liquidity rules of Basel III in Western European countries', *Journal of Banking & Finance*, vol. 44, pp. 13–25

Elliott, D. and A. O. Santos (2012), *Estimating the Costs of Financial Regulation*, IMF Staff Discussion Note SDN/12/11, International Monetary Fund.

Furfine, C. (2000), *Evidence on the Response of US Banks to Changes in Capital Requirements*, BIS Working Papers No. 88, Bank for International Settlements.

Giordana, G. A. (2014), Personal Communication.

Giordana, G. A. and I. Schumacher (2011), *The Impact of the Basel III Liquidity Regulations on the Bank Lending Channel: A Luxembourg case study*, Working Paper No. 61, Banque Centrale du Luxembourg.

Giordana, G. A. and I. Schumacher (2013), 'Bank Liquidity Risk and Monetary Policy: Empirical Evidence on the Impact of Basel III Liquidity Standards', *International Review of Applied Economics*, vol. 27, pp. 633–655

Hong, H., J.-Z. Huang and D. Wu (2014), 'The information content of Basel III liquidity risk measures', *Journal of Financial Stability*, vol. 15, pp. 91–111

Kopp, E., C. Ragacs and S. W. Schmitz (2010), 'The Economic Impact of Measures Aimed at Strengthening Bank Resilience – Estimates for Austria', in, *Financial Stability Report 20 – December 2010*, Oesterreichische Nationalbank.

MAG (2010), *Assessing the macroeconomic impact of the transition to stronger capital and liquidity requirements*, Final report, Bank for International Settlements.

Moinescu, B.-G. and A. Codirlasu (2013), *Lending, economic growth and nonperforming loans: empirical evidences from the new EU member states*, Working Paper, Project PN-II-ID-PCE-2011-3-1054 - Uncertainty, Complexity and Financial Stability.

Scalia, A., S. Longoni and T. Rosolin (2013), *The Net Stable Funding Ratio and banks' participation in monetary policy operations: some evidence for the euro area*, Occasional Paper No. 195, Banca d'Italia.

Schmaltz, C., T. Heidorn and I. Torchiani (2014), *Distance to Compliance Portfolios: An Integrated Shortfall Measure for Basel III*, Unpublished Working Paper.

Shi, J. and D. Tribe (2012), *The effects of changes in liquidity rules under Basel III: evidence from New Zealand*, Paper presented at the New Zealand Finance Colloquium, School of Economics and Finance, Massey University, 8-10 February 2012.

Slovik, P. and B. Cournéde (2011), *Macroeconomic Impact of Basel III*, Economics Department Working Paper No. 844, Organisation for Economic Co-operation and Development.

Sóvágó, S. (2011), *Identifying supply and demand in the Hungarian corporate loan market*, Occasional Paper OP 94, Magyar Nemzeti Bank.

Tamási, B. and B. Világi (2011), *Identification of credit supply shocks in a Bayesian SVAR model of the Hungarian economy*, Working Paper WP 2011/7, Magyar Nemzeti Bank.

Appendix A Detailed specification of the optimum problem

As stated in the main text, the boundary constraints of the bank's optimum problem are the balance sheet equality as well as two regulatory requirements: the NSFR liquidity requirement and the minimum capital requirement, supplemented with the SREP factor. In determining the constraints derived from the two regulatory requirements, we try to map the regulations as closely as possible, but also to retain the model's simplicity. Therefore, we introduce fixed proportionality factors with which we tie the changes in exogenous balance sheet items to our decision variables. That is, our regulatory constraints are the following.

1. NSFR constraint:

$$NSFR = \frac{ASF}{RSF} \geq 1,$$

where

$$ASF = Cap + D_{C+P,\geq 1} + D_{FI,\geq 1} + D_{R,\geq 1} + \delta Debt + \gamma_1 D_{R,<1} + \gamma_2 (D_{C+P,<1} + \beta D_{FI,<1} + \vartheta Debt),$$

$$\begin{aligned} RSF = {} & \gamma_3 Cash + \gamma_8 GovBond + \gamma_4 \left[\zeta(1-d_{FI,<1})L_{FI,<1} + f_1 S + f_2 S\right] + \gamma_5 \big[f_3 S + f_4 S + (1-\zeta)(1-d_{FI,<1})L_{FI,<1} + \\ & + \eta(1-f_1-f_2-f_3-f_4)S + (1-d_{R,<1})L_{R,<1} + (1-d_{C+P,<1})L_{C+P,<1}\big] + \gamma_6 f_5 L_{R,\geq 1} + \\ & + \gamma_7 \big[f_6 L_{R,\geq 1} + (1-d_{C+P,\geq 1})L_{C+P,\geq 1} + (1-\eta)(1-f_1-f_2-f_3-f_4)S\big] + (1-d_{FI,\geq 1})L_{FI,\geq 1} + \sum_i d_i L_i + \widetilde{RA}. \end{aligned}$$

2. CAR constraint:

$$CAR = \frac{Cap}{RWA} \geq srep,$$

where

$$\begin{aligned} RWA = {} & \Bigg[\alpha_1(Cash + GovBond) + \alpha_2 g_1 \left(\sum_i L_i + S + Cash + GovBond + \widetilde{RA}\right) + \\ & + \alpha_3\big[(1-d_{FI,<1})L_{FI,<1} + (1-d_{FI,\geq 1})L_{FI,\geq 1} + (1-d_{C+P,<1})L_{C+P,<1} + (1-d_{C+P,\geq 1})L_{C+P,\geq 1}\big] + \\ & + \alpha_4 g_2 (L_{R,<1} + L_{R,\geq 1}) + \alpha_5 f_7 (L_{R,<1} + L_{R,\geq 1}) + \alpha_6 f_8 (L_{R,<1} + L_{R,\geq 1}) + \\ & + (\alpha_7 g_3 + \alpha_8 g_4 + \alpha_9 g_5 + \alpha_{10} g_6 + \alpha_{11} g_7 + \alpha_{12} g_8)\left(\sum_i L_i + S + Cash + GovBond + \widetilde{RA}\right) + \sum_i d_i L_i\Bigg] + \\ & + \Bigg[h_1(Cash + GovBond) + h_2(L_{C+P,<1} + L_{C+P,\geq 1} + L_{R,<1} + L_{R,\geq 1}) + h_3(L_{R,<1} + L_{R,\geq 1}) + \\ & + h_4\left(\sum_i L_i + S + Cash + GovBond + \widetilde{RA}\right) + h_5(L_{C+P,<1} + L_{C+P,\geq 1} + L_{R,<1} + L_{R,\geq 1}) + \\ & + h_6\left(\sum_i L_i + S + Cash + GovBond + \widetilde{RA}\right)\Bigg]. \end{aligned}$$

The fixed proportionality factors are defined below. The factors denoted by $g_i, i = 1, \dots 8$ are used to calculate the amount of risk-weighted assets according to the Basel II standard approach, whereas the factors $h_j, j = 1, \dots 6$ are used for the calculation of risk-weighted assets in internal ratings-based (IRB) models.

- δ is the proportion of the part maturing beyond one year from borrowings and own-issued securities;
- β is the proportion of the part which matures later than six months from funding from financial institutions maturing within a year;

- ϑ is the proportion of the part maturing later than six months but within one year from borrowings and own-issued securities;
- ζ is the proportion of the part maturing within six months from credit granted to financial institutions maturing within a year;
- f_1 is the corporate bonds or covered bonds with a credit rating of at least AA- in proportion to the decision variable "other securities";
- f_2 is marketable government securities in proportion to other securities;
- f_3 is marketable securities representing a fraction of ownership, issued by non-financial institutions, proportional to other securities;
- f_4 is the proportion of marketable corporate bonds or covered bonds bearing higher risk (i.e. with a credit rating of A+ to BBB-) to other securities;
- η is the proportion of the part maturing within one year from securities not covered by the previous four security subcategories;
- f_5 is the performing residential mortgage loans with an LTV not higher than 80 per cent,[18] maturing beyond one year, in proportion to all loans to households maturing beyond one year;
- f_6 is the performing household loans maturing beyond one year not complying with the category for the risk weight of maximum 35 per cent, in proportion to all household loans maturing beyond one year;
- g_1 is the proportion of performing loans to public sector entities, regional governments and other institutions to the balance sheet total;
- g_2 is the performing household loans not secured by a mortgage to all loans to households;
- f_7 is the performing residential mortgage loans with an LTV not higher than 80 per cent[19], in proportion to all household loans (irrespective of maturity);
- f_8 is the performing household loans not complying with the category for the risk weight of maximum 35 per cent, in proportion to all household loans (irrespective of maturity);
- g_3 is the proportion of exposures bearing extremely high risk, proportional to the balance sheet total;
- g_4 is covered bonds proportional to the balance sheet total;
- g_5 is exposures to institutions and corporates with a short-term credit rating, to the balance sheet total;
- g_6 is exposures of collective investment forms, to the balance sheet total;
- g_7 is exposures possessing stock-like features, to the balance sheet total;
- g_8 is the proportion of assets not categorised in the calculation of risk-weighted assets, to the balance sheet total;
- h_1 is the risk-weighted exposures to central governments and central banks in proportion to the sum of the decision variables *Cash* and *GovBond*;
- h_2 is the risk-weighted exposures to institutions in proportion to loans to non-financial corporates, sovereigns, institutions and abroad;
- h_3 is residential risk-weighted exposures, proportional to all loans to households;
- h_4 is risk-weighted exposures possessing stock-like characteristics to the balance sheet total;
- h_5 is the proportion of risk-weighted corporate exposures to loans granted to financial institutions, non-financial corporates, sovereigns, institutions and abroad;

[18] This category corresponds to the risk weight of maximum 35 per cent in the Basel II standard approach to credit risk.
[19] See footnote 18.

- h_6 is the proportion of risk-weighted exposures of other assets representing other than credit-like commitments, to the balance sheet total;
- d_i (i running through decision variables of various loan categories) is the proportion of non-performing loans to all loans in that particular loan category.

Additionally, $\widetilde{RA}$ represents the observed initial value of residual assets, that is assets not captured by the NSFR regulation. We assume these residual assets to be unchanged in the optimisation. The parameters $\gamma_i, i = 1, \dots 7$ stand for the regulatory weights of the categories in the NSFR specification. Similarly, $\alpha_j, j = 1, \dots 12$ contain the risk weights used for the calculation of risk-weighted exposures in the Basel II standard approach. For the IRB approaches, since our fixed proportionality factors $h_k, k = 1, \dots 6$ include the consideration of risk weights, we have not imposed additional parameters.

Appendix B Detailed results of the calibrating equations

As stated in the main text, this section details the estimation results of the simultaneous systems of equations we employ to calibrate the model's adjustment cost parameters. We do not experiment with estimating the adjustment cost parameters assumed to be very low, i.e. the parameters of the decision variables *Cash*, *GovBond*, S, $L_{FI,<1}$, $L_{FI,\geq 1}$, $D_{FI,<1}$ and $D_{FI,\geq 1}$. The reason for this is that the stocks and the markets of these exposures are usually governed by different incentives than equilibrium considerations such as longer-term supply and demand: liquidity creation, or merely passive adjustment to monetary policy actions.

Also, we are unable to provide reliable estimates for the adjustment cost parameters of capital and of borrowings and own-issued debt securities. We suspect that this is due to the fact that in the Hungarian market environment, it is rather difficult to assume an active market governed by equilibrium adjustment of prices according to the quantities demanded and supplied in the market for the aforementioned balance sheet items. Banks' demand for capital is basically determined by regulatory requirements, and for the majority of banks, in cases of scarcity it is usually the foreign owners of the banks which step in with a capital injection. In addition, only one of the examined banks is listed on the Hungarian stock exchange. Also, the bulk of long-term borrowings are from the Hungarian banks' foreign parent companies, and bond issuance is not considered a typical source of funding for Hungarian banks. However, it is important to note that it is only the specific properties of the Hungarian market which make it difficult or even impossible to perform these estimations. Theoretically, and probably also practically in countries with more developed security markets, equilibrium models with simultaneous equations can be built for capital and bond markets as well.

For the decision variables the adjustment cost parameters of which are estimable, we base our estimation strategy on Sóvágó (2011), who tried to decompose the developments in lending to the corporate sector to supply and demand factors by identifying supply and demand with a simultaneous econometric model estimated on a panel database. As he did, we also make use of some variables in the Bank Lending Survey conducted by MNB, which includes information about lending standards, banks' willingness to lend, as well as the demand for loans perceived by banks.

In performing the estimations of the simultaneous systems of equations, we focus mainly on the coefficient from which the adjustment cost parameter of that particular decision variable can be calculated. This is the coefficient of the "price" variable in the equation representing the bank's side, that is the supply equation in loan markets, and the demand equation in markets for funding. Nonetheless, we always take into consideration the intuitive signs of coefficients of other variables, as well as the signs of coefficients in the other equation, and also check tests examining the appropriateness of the model.

For the estimations, we employ a quarterly panel dataset of the eight banks in question, from 2003 Q1 to 2014 Q3. In contrast to Sóvágó (2011), we also estimate simultaneous equations models on various other markets than the corporate loan market. Another difference between the two articles is that we partition the (corporate) loan market according to maturity. Since the MNB's supervisory data supply for the maturity structure of exposures is only available with the necessary level of detail from 2010 Q1, in order to secure a time series dimension long enough for estimation, instead of separating loan and deposit stock at their remaining maturity on a cash-flow basis, we have partitioned these stocks according to the exposures' original maturity, in a contract-based manner. We believe this slight bias is acceptable since we are only using these equations for calibration.

In the models, we try to explain the difference of the decision variables' level. We estimate each equation separately by the two-stage-least-squares (2SLS) estimator[20], and check by a Hausman test whether it is necessary to use a fixed effects estimator. In addition, we also examine tests related to the identification. The endogeneity test assesses whether the specified endogenous

[20] This equation-by-equation estimation method might not be appropriate in case the equations are highly correlated. Thus, as a robustness check we stacked the equations representing the bank's side of each market together, and performed a system estimation using a two-step GMM estimator, taking cross-equation correlations into account. The resulting estimates are of the same sign as the equation-by-equation estimates for every estimated coefficient. In addition, they are very close to each other in terms of significance levels, and they are of the same magnitude, too, although there are some differences between the estimates received using the two methods. Nevertheless, the system estimates are not really robust in the

explanatory variables can actually be treated as exogenous. Under this null hypothesis, the test statistic follows a chi-squared distribution with degrees of freedom equal to the number of regressors tested. We always test the endogeneity of the "price" variable. If we could not reject the null hypothesis, it would not make sense to instrument this variable, and thus to perform the analysis applying a simultaneous equations model. The Sargan test for overidentifying restrictions examines whether the applied instruments are valid: the rejection of the null hypothesis casts doubt on the validity of our instruments. Sadly, this test can only be performed if our equation is overidentified, that is if we have more instruments than endogenous regressors, which also means we cannot test whether each of our instruments are valid.

For the *short-term corporate loan market*, we estimate the following simultaneous system of equations using fixed effects:

$$\Delta L_{C+P,<1,it} = \alpha_1^S r_{L_{C+P,<1},it} + \alpha_2^S stand_{it-2}^{+} + \alpha_3^S sup_{it-2}^{-} + \varepsilon_{it}^S \tag{10}$$

$$\Delta L_{C+P,<1,it} = \alpha_1^D r_{L_{C+P,<1},it} + \alpha_2^D inv_{t-4} + \varepsilon_{it}^D, \tag{11}$$

where $stand^{+}$ denotes the tightening of lending standards, sup^{-} means the decrease in banks' willingness to lend, and *inv* stands for gross fixed capital formation (which is not a bank-specific, but a macro variable). In the supply and demand equations, we apply *inv* and sup^{-} as instruments for the endogenous variable, respectively.

In order to approve the use of the above mentioned instruments in a simultaneous equations model, we need to argue that our instruments for the demand equation only determine the supply equation significantly, and vice versa. This is rather easy in case of sup^{-}, because it represents banks' willingness to lend: this is unambiguously a supply-side variable. In our opinion, the aggregate investment activity of corporates will also not be a significant explanatory variable for banks' loan supply, since banks' may take into account individual business plans in their decisions to lend, but not aggregate investment activity.

Table 2
Estimation results – short-term corporate loan market
(standard errors in brackets)

	Supply	Demand
Short-term lending rate to corporates	42372.4^{***} [6627.7]	-44656.3^{**} [22617.7]
Lending standards (+) (2nd lag)	-54242.4^{***} [12838.1]	–
Willingness to lend (-) (2nd lag)	-57400.5^{***} [11384.0]	– (instrument)
Gross fixed capital formation (4th lag)	– (instrument)	723257.5^{***} [214632.9]
Tests related to the identification – p-values		
Endogeneity test of endogeneous regressors	0.000	0.000
Sargan's test for overidentifying restrictions	$-^{a)}$	$-^{a)}$

***Significant at the 5% level.*
****Significant at the 1% level.*
$^{a)}$*Equation exactly identified.*

The estimation results are presented in Table 2. Both equations are exactly identified, thus unfortunately we cannot assess the validity of our instruments. The application of the instruments is, however, statistically verified, since the short-term corporate lending rate is endogenous according to the endogeneity test. As expected, we obtain a positive coefficient for the lending rate in the supply equation, and a negative coefficient in the demand equation. The tightening of lending standards contributes negatively to corporate loan supply. Similarly, the supply of corporate loans decreases when banks are less willing to lend. However, an increase in corporate investment activity boosts demand for corporate loans.

In the *long-term corporate loan market*, the simultaneous equations model can be specified as follows:

$$\Delta L_{C+P,\geq 1,it} = \beta_1^S r_{L_{C+P,\geq 1},it} + \beta_2^S sup_{it-1}^{+} + \beta_3^S sup_{it-1}^{-} + \eta_{it}^S \tag{12}$$

sense that using the system estimator, if only one of our equations is misspecified, all the parameter estimates resulting from the system estimator will be inconsistent. In contrast, using the equation-by-equation estimation technique, the misspecification of an equation only influences the consistency of that equation, which makes this approach more robust to misspecification. Therefore, we prefer the equation-by-equation estimates.

$$\Delta L_{C+P,\geq 1,it} = \beta_1^D r_{L_{C+P,\geq 1},it} + \beta_2^D inv_{t-4} + \eta_{it}^D, \tag{13}$$

where the only new variable is sup^+, capturing the increase in banks' willingness to lend. As before, *inv* is used to instrument the endogenous lending rate in the supply equation. For the estimation of the demand side, however, we apply both explanatory variables from the supply side, sup^+ and sup^- as instrumental variables. As visible in Table 3, although the coefficient of the lending rate in the demand equation becomes statistically insignificant, the coefficient of the lending rate in the supply equation is significant and of the right sign. Also according to our expectations, the increasing and the decreasing of banks' willingness to lend contributes to the rise and the reduction of the corporate loan stock, respectively. In addition, gross fixed capital formation again has a strongly positive effect on demand for corporate loans. The tests (i.e. the endogeneity of the supposedly endogenous regressors, and that the null hypothesis of valid instruments cannot be rejected) confirm the correct specification of our model.

Table 3
Estimation results – long-term corporate loan market
(standard errors in brackets)

	Supply	Demand
Long-term lending rate to corporates	54337.9*** [6199.4]	−59219.4 [46156.2]
Willingness to lend (+) (1st lag)	26740.3*** [9466.7]	– (instrument)
Willingness to lend (-) (1st lag)	−31569.6* [17527.5]	– (instrument)
Gross fixed capital formation (4th lag)	– (instrument)	1234662.0** [495185.6]
Tests related to the identification – p-values		
Endogeneity test of endogeneous regressors	0.000	0.001
Sargan's test for overidentifying restrictions	– a)	0.633

*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.
a) Equation exactly identified.

Table 4
Estimation results – long-term household loan market
(standard errors in brackets)

	Supply	Demand
Long-term household lending rate	23585.7** [9316.3]	−42111.6** [20075.7]
Willingness to lend (4th lag)	42501.9*** [12162.2]	– (instrument)
Yearly growth rate of certificates of flat occupancy (4th lag)	– (instrument)	210672.1*** [64713.5]
Constant	−202596.3** [85896.3]	430984.1** [189725.9]
Tests related to the identification – p-values		
Endogeneity test of endogeneous regressors	0.000	0.005
Sargan's test for overidentifying restrictions	– a)	– a)

**Significant at the 5% level.
***Significant at the 1% level.
a) Equation exactly identified.

Table 4 presents the estimation results of the simultaneous equations model for the *long-term household loan market*. We consider the estimation of the short-term household loan market model to be unfeasible, since banks' stocks of short-term household loans, which consist mainly of current account overdrafts and credit card debts, are rather low and, more importantly, they lack time-series dynamics and thus the necessary variability for a reliable estimation. Hence, for determining the adjustment cost parameter of short-term household loans in the optimisation programme, we have used the estimated parameter from the simultaneous equations model for long-term household loans.

We specify the simultaneous equations characterizing the long-term household loan market in the following manner:

$$\Delta L_{R,\geq 1,it} = \gamma_0^S + \gamma_1^S r_{L_{R,\geq 1},it} + \gamma_2^S sup_{it-4} + \zeta_{it}^S \tag{14}$$

$$\Delta L_{R,\geq 1,it} = \gamma_0^D + \gamma_1^D r_{L_{R,\geq 1},it} + \gamma_2^D flat\_use_{t-4} + \zeta_{it}^D, \tag{15}$$

where *sup* again stands for banks' willingness to lend. In contrast to the equations representing the corporate loan market, however, this variable (which, together with the variables describing changes in lending standards and demand for loans perceived by banks, is extracted from the Bank Lending Surveys) is not a dummy variable anymore, since the questions in the survey regarding bank lending practices to households are broken down into subcategories such as mortgage loans and consumption loans. Hence, for household loans we create a continuous variable by weighting the dummies for subcategories with the outstanding stocks of those loan subcategories. The other new explanatory variable, *flat_use* denotes the yearly growth rate of certificates of flat occupancy, with which we attempt to capture tendencies in the residential housing market.

Both equations are exactly identified: we have employed *sup* and *flat_use* as instruments of the endogenous "price" variable in demand and supply equations, respectively.[21] Therefore, however, we again cannot judge the validity of our instruments. We estimate the equations separately with pooled 2SLS, since the Hausman tests do not give us grounds for including fixed effects. The endogeneity tests show that the exogeneity of the supposedly endogenous interest rate can be rejected at high significance levels in both the demand and the supply equations, and thus the application of the simultaneous equations methodology seems justifiable.

As is visible in Table 4, the coefficient of the long-term household lending rate is significant in both the supply and the demand equations, and is of the intuitive sign: banks offer more loans if the interest rate on loans is higher *ceteris paribus*, and, also in a quite straightforward manner, households postpone their investments or consumption and reduce their loan demand if faced with higher lending rates. Also as expected, banks' stronger willingness to lend increases loan supply, and in the case there is growing demand in the housing market (captured here by new housing), households' demand for loans rises.

The next market we would like to describe is the *short-term corporate deposit market*. Here, since deposits are a type of liability for banks, the demand side will be the banks' side in the equations. We attempt to capture the market with the following simultaneous equations model, which we estimate using fixed effects:

$$\Delta D_{C+P,<1,it} = \delta_1^S r_{D_{C+P,<1},it} + \delta_2^S \Delta rgdp_{t-1} + \delta_3^S inv_{t+3} + \theta_{it}^S \tag{16}$$

$$\Delta D_{C+P,<1,it} = \delta_1^D r_{D_{C+P,<1},it} + \delta_2^D \Delta credit_{it-2} + \theta_{it}^D, \tag{17}$$

where $\Delta rgdp$ depicts the yearly real GDP growth rate, *inv* again stands for gross fixed capital formation, and $\Delta credit$ captures the yearly growth rate of the bank's credit stock.

Unfortunately, we find the reliable estimation of the market for long-term corporate deposits to be impossible, since corporates' long-term deposits represent a very small amount, and this amount has almost no dynamics. Therefore, we substituted the theoretical adjustment cost parameter of long-term corporate deposit funding with the estimated adjustment cost parameter for short-term corporate deposits in the optimisation programme.

Returning to the estimation results for the market of short-term corporate deposits, we apply the yearly growth rate in banks' credit stock as the instrument in the deposit supply equation, as well as the third lead of gross fixed capital formation in the demand equation. The results of the endogeneity tests confirm our simultaneous equations approach.

[21] We consider the growth rate of certificates of flat occupancy as a demand-side variable since we think banks do not take tendencies in new housing into account when deciding their credit supply.

When looking for explanatory variables, corporates' investment activity seemed to be a straightforward choice: the amount of planned investment by a firm has to influence the firm's deposits significantly and positively, since to undertake an investment, a firm would intuitively use the majority of its deposits to finance its investment and to reduce the amount of credit it would need for the investment, therefore it will collect some liquidity in the form of bank deposits before undertaking an investment. In order that the lead of gross fixed capital formation does not mainly capture business cycle fluctuations, which have a strong positive connection with corporates' deposit supply, we also include the yearly growth rate of real GDP in the equation, which includes the impact of business cycles, and thus corrects the meaning of our variable for corporates' investment activity, which now in our view truly captures the above explained effect.

We consider corporates' investment activity as a valid instrument for the demand equation, since its connection to banks' corporate deposit demand is very indirect, although it probably does exist. In our view, banks' corporate deposit demand is mainly influenced by the relative price and liquidity of corporate deposits compared to other funding sources, as well as by the bank's funding demand. The latter is governed by the development of the bank's credit stock and loan supply. As we argued above, the aggregate investment activity of corporates is probably not a significant explanatory variable for banks' loan supply.

Furthermore, we have chosen the yearly growth rate in the bank's credit stock as an explanatory variable of the bank's deposit demand, since in our opinion banks will increase their demand for deposits if they want to finance their growing credit stock. In addition, in our view, banks' growing credit stock has no significant connection to corporates' deposit supply. As shown in Table 5, except for the yearly GDP growth rate, which only has a role of a control variable, we obtain significant coefficients for the explanatory variables, and also of the right sign according to our above reasoning. Moreover, and more importantly, the coefficients of the short-term deposit rate are significant and of the intuitive sign as well.

Table 5
Estimation results – short-term corporate deposit market
(standard errors in brackets)

	Supply	Demand
Short-term deposit rate to corporates	25767.8*** [5794.2]	−17747.9* [10285.4]
Yearly growth rate in credit stock (2nd lag)	– (instrument)	103945.8*** [31439.3]
Yearly real GDP growth rate (1st lag)	−2012.9 [128593.9]	–
Gross fixed capital formation (3rd lead)	229583.4*** [63380.9]	– (instrument)
Tests related to the identification – p-values		
Endogeneity test of endogeneous regressors	0.006	0.010
Sargan's test for overidentifying restrictions	–$^{a)}$	–$^{a)}$

* *Significant at the 10% level.*
*** *Significant at the 1% level.*
$^{a)}$ *Equation exactly identified.*

For the long-term household deposit market, again we cannot provide a reliable econometric estimate, since there is a very low amount of long-term household deposits. Thus, we once again use our estimated adjustment cost parameter for short-term household deposits for long-term household deposits as well. For the *short-term household deposit market*, we estimated the following simultaneous system of equations:

$$\Delta D_{R,<1,it} = \kappa_0^S + \kappa_1^S r_{D_{R,<1},it} + \kappa_2^S \Delta disp\_inc_{t-2} + \varphi_{it}^S \tag{18}$$

$$\Delta D_{R,<1,it} = \kappa_0^D + \kappa_1^D r_{D_{R,<1},it} + \kappa_2^D bubor_t + \kappa_3^D \Delta credit_{it-3} + \varphi_{it}^D, \tag{19}$$

where $\Delta disp\_inc$ stands for the yearly growth rate of households' disposable income and *bubor* denotes the three-month BUBOR (i.e. Budapest Interbank Offered Rate). We have applied $\Delta disp\_inc$ as an instrument of the endogenous deposit rate in the demand equation, as well as used $\Delta credit$ as the instrument of the same "price" variable in the supply equation. We have already provided an intuition for including $\Delta credit$ in the demand equation: if the bank increases its lending, it will also need to increase its funding, of which probably the cheapest source will be deposits. Furthermore, in our opinion, the change in the bank's credit stock does not significantly influence the supply of household deposits. (One argument against this could be that the change in the bank's credit stock modifies its risk, and if depositors monitor the bank's risks, they may also change their behaviour. However, deposit insurance completely abolishes this monitoring motivation.) The short-term interbank rate is included in the explanation of the deposit demand as a substitute of funding through deposits (remember that NSFR which draws a cost distinction between interbank funding and deposits from households and non-financial corporates, has not been introduced yet). If the interbank interest rate rises, funding from the interbank market becomes more expensive, so banks rather choose to draw in additional deposits. In the other equation it is rather straightforward that a change in households' disposable income contributes significantly to their deposit supply: the more income at their disposal, the more they have the opportunity to save. On the other hand, changes in households' disposable income do not significantly determine banks' deposit demand.

Table 6
Estimation results – short-term household deposit market
(standard errors in brackets)

	Supply	Demand
Short-term household deposit rate	31192.9^{***} [3733.0]	-37074.8^{*} [22483.7]
BUBOR	–	44294.8^{***} [17302.2]
Yearly growth rate in credit stock (3rd lag)	– (instrument)	56280.2^{**} [23789.3]
Yearly growth rate of disposable income (2nd lag)	320426.5^{***} [103945.1]	– (instrument)
Constant	-143065.2^{***} [18591.2]	-119911.3^{***} [16484.7]
Tests related to the identification – p-values		
Endogeneity test of endogeneous regressors	0.001	0.009
Sargan's test for overidentifying restrictions	$-^{a)}$	$-^{a)}$

* *Significant at the 10% level.*
** *Significant at the 5% level.*
*** *Significant at the 1% level.*
$^{a)}$ *Equation exactly identified.*

We estimate the equations separately without using fixed effects, since Hausman tests do not provide conclusive evidence for their inclusion. Our estimation results are depicted in Table 6. The results of the endogeneity tests confirm our choice of modelling this market using a simultaneous equations model, although, as our equations are exactly identified, we do not have the opportunity to test the validity of our instruments. The estimated coefficients of the short-term household deposit rate are of the expected sign, and the coefficients of the other explanatory variables also coincide with our expectations.

Appendix C Robustness tests of the adjustment cost parameters

In order to ascertain how sensitive our results are to the modification of the adjustment cost parameters, we conduct various simulations according to the following logic. We attempt to impose shocks on individual adjustment cost parameters, but the results provide rather small impacts. In addition, it is also of paramount importance how much our results change if we modify the common level of adjustment cost parameters of similar magnitude, or the relation of the parameters within a group of similar magnitude. Therefore, we partition the adjustment cost parameters into three groups according to the intuitively assumed relations of the parameters in equation 6. The groups are shown in Table 7:

Table 7
Grouping of the adjustment cost parameters for robustness tests ($\times 10^{-6}$)

Group 1: intuitively small adjustment cost parameters							
λ_{Cash}	$\lambda_{GovBond}$	λ_S	$\lambda_{L_{FI,<1}}$	$\lambda_{L_{FI,\geq 1}}$	$\lambda_{D_{FI,<1}}$	$\lambda_{D_{FI,\geq 1}}$	
0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Group 2: Estimated, middle-level adjustment cost parameters							
$\lambda_{L_{C+P,<1}}$	$\lambda_{L_{C+P,\geq 1}}$	$\lambda_{L_{R,<1}}$	$\lambda_{L_{R,\geq 1}}$	$\lambda_{D_{C+P,<1}}$	$\lambda_{D_{C+P,\geq 1}}$	$\lambda_{D_{R,<1}}$	$\lambda_{D_{R,\geq 1}}$
11.800	9.201	22.120	22.120	28.172	28.172	13.486	13.486
Group 3: intuitively large adjustment cost parameters							
λ_{Cap}	λ_{Debt}						
1000	1000						

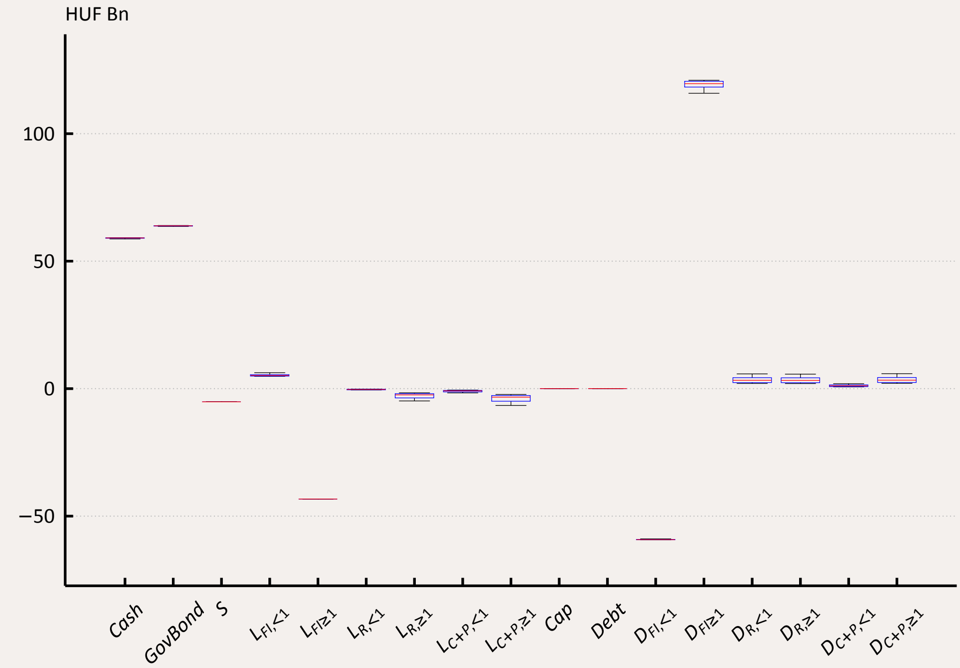
Through our tests, we change the distance of these categories from one another. Besides, we also experiment with changing the relation of the parameters within their group. In each case, we run 100 simulations. For each simulated adjustment cost parameter set, we solve the optimum problem. After solving the problem for all simulated parameter values, we finally illustrate the distribution of the resulting optimal values of decision variables in box plots.

The simulations are conducted for various financial institutions and time points, but we reach the same conclusions from all institutions and time points. Thus, for the ease of demonstration, we illustrate our results for a single institution and time point. First, we change the relation of parameters within the group of estimated parameters, i.e. the group containing adjustment cost parameters for loans and deposits of households and non-financial corporates. We fix the expected value of all these parameters at $20 \cdot 10^{-6}$, and give them uniformly distributed shocks, the same magnitude but different sign to loans than to deposits, with obtained parameter values in the range $[10, 30] \cdot 10^{-6}$. The resulting box plots, which are depicted in Figure 6, suggest that the relation of the parameters of deposits and loans of households and non-financial corporates are of minor importance.

However, it may well be that our results are only robust to changing the parameters of loans and deposits of households and non-financial corporates relative to each other because the small adjustment cost parameters are set very close to zero. After all, it seems rather intuitive that to reach compliance in the cheapest way possible, a bank will first adjust the level of exposures whose adjustment costs are the lowest. Thus, the higher we set the level of small adjustment cost parameters, the stronger banks' incentives will be to supplement (or to substitute) adjustments in variables with small adjustment cost to variables representing loan and deposit categories. Therefore, we will probably obtain higher variability in our results when performing the above exercise again with small adjustment cost parameters fixed at a higher level. Indeed this is the case, as can be observed in Figure 7,[22] which emphasises the instability of our results to the level of small adjustment cost parameters.

[22] Since we consider breaking the intuitive relations stipulated in equation 6 implausible, we fix all small adjustment cost parameters at $10 \cdot 10^{-6}$, i.e. at roughly their theoretical maximum, set the expected value of all the estimated, middle-level adjustment cost parameters at $20 \cdot 10^{-6}$ and give them uniformly distributed shocks with obtained parameter values in the range $[10, 30] \cdot 10^{-6}$.

Figure 6
Variability in decision variables' optimal adjustment due to the modification of adjustment cost parameters of deposits and loans relative to each other



Note: The edges of the box of the box plot mean the lower and upper quartile of the distribution; the horizontal red line in the box means its median. The lower whisker is the smallest value which is larger than the lower quartile minus 1.5 times the interquartile range; accordingly, the upper whisker is the largest value which is smaller than the upper quartile plus 1.5 times the interquartile range.

Furthermore, if we even break the intuitively assumed relation between the category of small adjustment cost parameters and adjustment cost parameters of loans and deposits of households and non-financial corporates (that is, in the above simulation we have also fixed the small parameter values at $20 \cdot 10^{-6}$), we can experience much higher variability (Figure 8).

Now, if we apply shocks to the small adjustment cost parameters without breaking the intuitive relation to higher parameters,[23] we see particularly strong variability (Figure 9). If we set the adjustment cost parameters of loans and deposits of households and non-financial corporates at a higher level, we obtain smaller deviations in their decision variables. This high variability can be significantly reduced if we can fix at least some of the small adjustment cost parameters.

Let us now turn to the robustness of the adjustment cost parameters in the large parameter group. If we set the expected value of their parameters to $1000 \cdot 10^{-6}$ and apply shocks of the same magnitude but different sign, we find that our model is completely robust to this type of modification (Figure 10). We also arrive at very similar results when shocking the distance of these parameter values to all the other parameters, without breaking the intuitive relations.

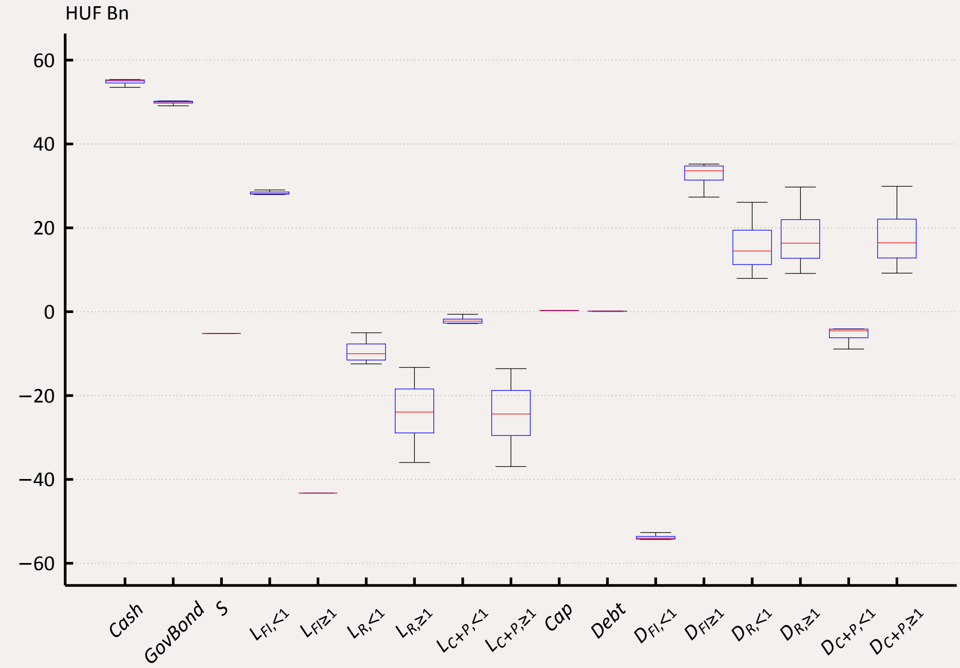
Also, if we break the intuitive relation between large parameters and the parameters of loans and deposits of households and non-financial corporates[24], although the results have a bit higher variation than for the former test, the model is still quite robust to these changes (Figure 11).

In summary, the adjustment cost parameters of capital, borrowings and own-issued debt securities, as well as deposits and loans of households and non-financial corporates behave robustly to their absolute and relative modifications, provided that we do not break the intuitive relations stipulated in equation 6. However, the results are very unstable to the modification of

[23] We fix the expected value of all small adjustment cost parameters at $3.75 \cdot 10^{-6}$ and apply separate random shocks with which they fluctuated in the range $[0.5, 7] \cdot 10^{-6}$.

[24] We performed this test by setting the expected value of adjustment cost parameters of capital and debt to the same level – $20 \cdot 10^{-6}$ – as the common value of the parameters of loans and deposits of households and non-financial corporates in this simulation, and giving shocks to the originally large parameters in the interval $[10, 30] \cdot 10^{-6}$.

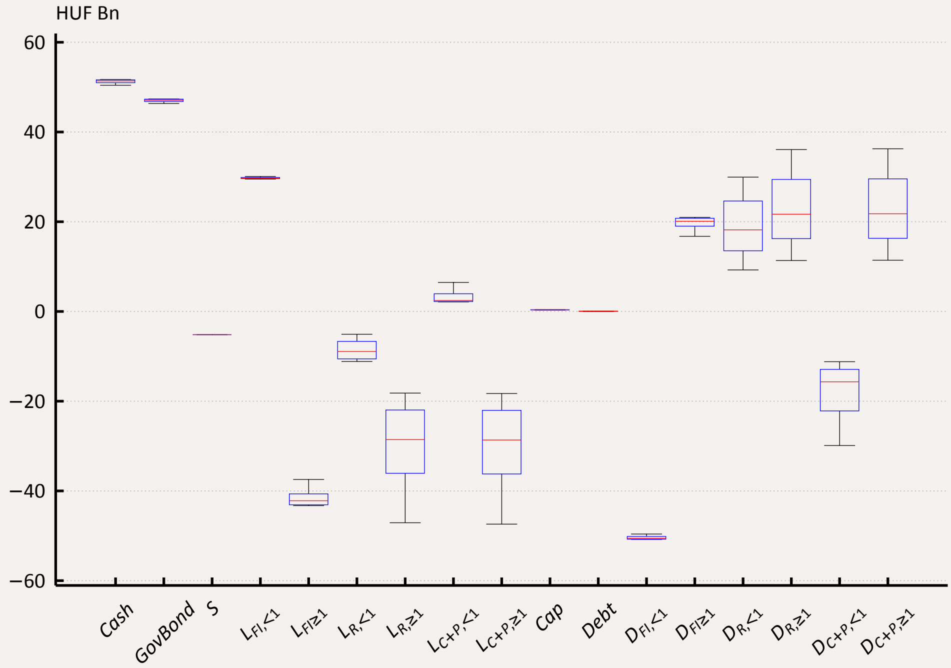
Figure 7
Variability in decision variables' optimal adjustment due to the modification of middle-level adjustment cost parameters relative to each other with small adjustment cost parameters set at their theoretical maximum



Note: The edges of the box of the box plot mean the lower and upper quartile of the distribution; the horizontal red line in the box means its median. The lower whisker is the smallest value which is larger than the lower quartile minus 1.5 times the interquartile range; accordingly, the upper whisker is the largest value which is smaller than the upper quartile plus 1.5 times the interquartile range.

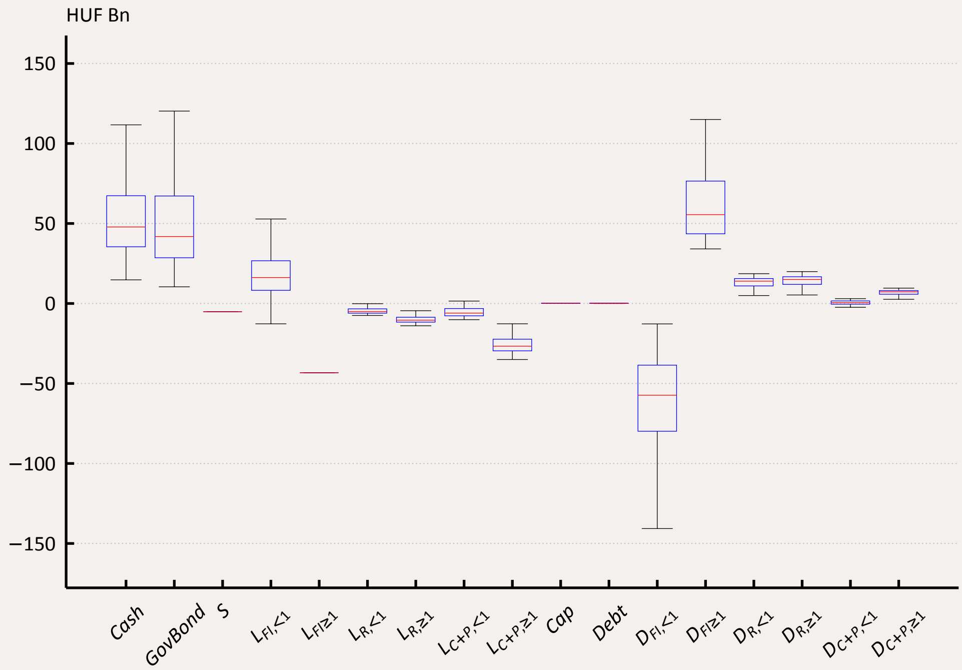
the small adjustment cost parameters, although the more of these values we are able to set reliably, the more stable results we will obtain. This instability is both observable when their parameters are changed relative to each other and in case the distance of their common level to other parameter categories is modified.

Figure 8
Variability in decision variables' optimal adjustment due to the modification of middle-level adjustment cost parameters by breaking the intuitive relation to small parameters



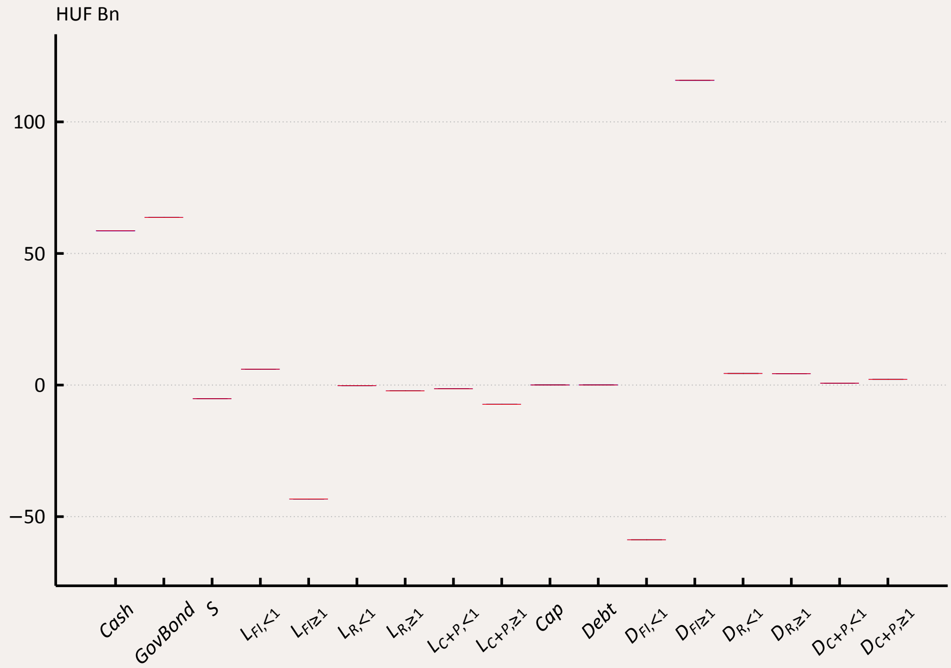
Note: The edges of the box of the box plot mean the lower and upper quartile of the distribution; the horizontal red line in the box means its median. The lower whisker is the smallest value which is larger than the lower quartile minus 1.5 times the interquartile range; accordingly, the upper whisker is the largest value which is smaller than the upper quartile plus 1.5 times the interquartile range.

Figure 9
Variability in decision variables' optimal adjustment due to the modification of intuitively small adjustment cost parameters relative to each other



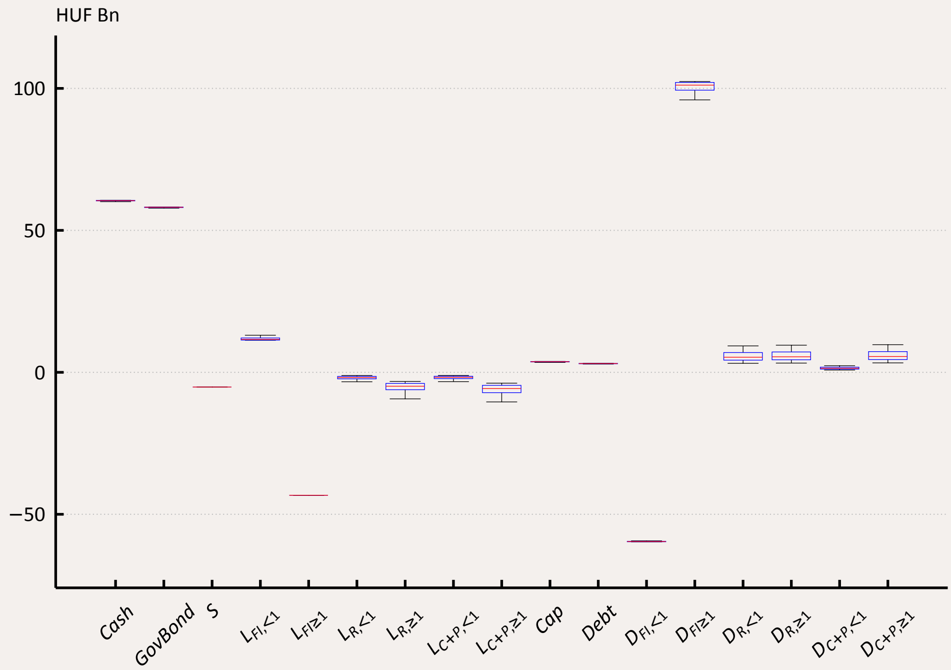
Note: The edges of the box of the box plot mean the lower and upper quartile of the distribution; the horizontal red line in the box means its median. The lower whisker is the smallest value which is larger than the lower quartile minus 1.5 times the interquartile range; accordingly, the upper whisker is the largest value which is smaller than the upper quartile plus 1.5 times the interquartile range.

Figure 10
Variability in decision variables' optimal adjustment due to the modification of large adjustment cost parameters relative to each other



Note: The edges of the box of the box plot mean the lower and upper quartile of the distribution; the horizontal red line in the box means its median. The lower whisker is the smallest value which is larger than the lower quartile minus 1.5 times the interquartile range; accordingly, the upper whisker is the largest value which is smaller than the upper quartile plus 1.5 times the interquartile range.

Figure 11
Variability in decision variables' optimal adjustment due to the modification of large adjustment cost parameters by breaking the intuitive relation to middle-level parameters



Note: The edges of the box of the box plot mean the lower and upper quartile of the distribution; the horizontal red line in the box means its median. The lower whisker is the smallest value which is larger than the lower quartile minus 1.5 times the interquartile range; accordingly, the upper whisker is the largest value which is smaller than the upper quartile plus 1.5 times the interquartile range.

MNB Working Papers 3

A model of bank behaviour for the assessment of the potential balance sheet impact of the NSFR liquidity requirement

Budapest, March 2017