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Abstract

In this study we aim to analyse the effects of leaving excess reserves in the banking sector by the central bank on the level and the variability of interest rates, as well as on money supply. To this end, we use mainly data for Poland, but in some cases, for robustness, also for a panel of Poland, the euro area, the Czech Republic and Hungary, as there had only been a limited variability in some policy variables in our sample for Poland. We estimate the parameters of GARCH, (P)VAR and (panel) linear regression models.

We find that excess reserves affect the level and the variability of an overnight money market interest rate. However, the variability of the overnight money market interest rate, shaped to a large extent by excess reserves, does not affect the level of longer-term interest rates, and we find little evidence of its impact on their variability. Neither do excess reserves translate into higher money supply.

Our results imply that the current monetary policy operational framework in Poland is adequate to ensure the transmission of the central bank policy rate to money market interest rates. Furthermore, it appears unlikely that raising the amount of excess reserves left, as proposed by some policymakers, would affect money supply. Instead, it would lower the money multiplier and the overnight money market interest rate, as well as increase its volatility.

JEL Codes: E52; E43; E51; C32; C33

Keywords: excess reserves; interest rate pass through; money multiplier; GARCH; VAR; panel data models

1 Introduction

During and after the last global recession policy rates in many developed economies, including the United States and the euro area, have hit their effective lower bounds. At the same time, economic activity and inflation developments appeared to require the additional easing of monetary conditions. In response, their central banks have introduced balance sheet policies, such as large-scale asset purchases, also known as quantitative easing. They have been aimed mainly at lowering market rates further. As a side effect, the amount of reserves in the banking sector has increased significantly above the reserve requirement, in contrast to the pre-crisis environment. It has brought a renewed interest in the consequences of excess reserves, surplus liquidity and monetary policy operation frameworks more generally (see, for example, Bindseil, 2016).

Interestingly, in some economies surplus liquidity has arisen even if their central banks have not introduced balance sheet policies. For example, in Poland it is mainly the effect of operations between the government and the central bank, in which the former exchanges euro-denominated European Union (EU) funds for zloty-denominated deposits at the latter. This eventually raises reserves, which then are absorbed by the central bank by open market operations (OMOs). However, although on average during reserve maintenance periods the amount of reserves broadly equals the reserve requirement, on a day-to-day basis the demand for reserves and the supply of them decouple from each other, as main OMOs are conducted only once a week. Furthermore, in 2010 the central bank has purposely left excess reserves in the banking sector. Also, some policymakers have argued for making it permanent to support bank lending and, in effect, money supply.[1] This appears to make a good case to analyse the consequences of excess reserves.

Taking these considerations into account, in this study we aim to analyse the consequences of excess reserves. Specifically, we research into the effects of leaving excess reserves in the banking sector by the central bank on the level and the variability of interest rates, as well as on money supply.[2] We use mainly data for Poland, a small, open, emerging market economy with structural surplus liquidity in the banking sector. However, in some cases we also resort to panel data for the euro area, the Czech Republic and Hungary.

First, we estimate the parameters of GARCH models to analyse the relationship between an overnight (ON) money market interest rate and excess reserves. Second, we check whether the level and the variability of longer-term money market interest rates are affected by the variability of the ON money market interest rate. Third, we

[1] See, for example, PAP (2014, 2016).

[2] The actual volume of reserves, of course, depends on both supply from the central bank and demand from commercial banks (with liquidity shocks on a day-to-day basis). However, even if the central bank does not purposely keep excess reserves in the banking sector for a longer period, in principle, it could design its operational framework to minimise the imbalance on a day-to-day basis. This is why we write of 'leaving excess reserves in the banking sector by the central bank'.

analyse to what extent the width of the interest rate corridor could be used to mitigate the effects of excess reserves on the variability of the ON money market interest rate, taking into account its impact on the ON money market turnover. In this case, for robustness, we carry out both time series and panel data estimation, as there had only been a limited variability in the interest rate corridor in our sample for Poland. We also attempt to determine the optimal interest rate corridor. Finally, we test whether changes in excess reserves affect money supply or are their effects balanced by changes in the money multiplier. To this end we use, among other methods, (P)VAR models. Here we use both time series and panel data estimation because in Poland the central bank has left a large amount of excess reserves in the banking sector for a longer period (visible at a monthly frequency) only in 2010.

According to authors' knowledge, the study is the first to make the following contributions for Poland. First, it analyses the effects of the variability of the ON money market interest rate on the level and the variability of longer-term interest rates. Second, it researches into the impact of the width of the interest rate corridor on the ON money market turnover. Third, it explores the relationship between excess reserves and money supply. Also, it appears to be the first to analyse the last two questions in a country-level panel data framework.

We find that the higher the excess reserves, the lower the level and the higher the variability of the ON money market interest rate. The variability of the ON money market interest rate does not affect the level of longer-term money market interest rates, however. We also find little evidence that it affects their variability. Narrowing the interest rate corridor could be used to mitigate the effects of excess reserves on money market interest rates, but it has large impact on the ON money market turnover. Excess reserves shocks do not affect money supply, as their impact is compensated by changes in the money multiplier.

The results suggest that the current monetary policy operational framework in Poland is adequate to ensure the transmission of the central bank policy rate to money market interest rates. Increasing the amount of excess reserve left, as proposed by some policymakers, would be an equivalent of lowering the policy rate, at least as far as its effects on money market interest rates are concerned. But it appears unlikely that it would translate into more lending and money supply.

The article is structured as follows. In the second section we review the literature. In the third section we compare the operational frameworks used in Poland, the Czech Republic, Hungary and the euro area. The fourth section analyses the relationship between excess reserves, interest rate corridor and money market interest rates. In the fifth section we research into the effects of interest rate corridor on the ON money market turnover. The sixth section analyses the impact of excess reserves on loans, money supply and the money multiplier. In sections 4-6 we describe models, data and estimation, as well as results. The last section concludes.

2 Literature review

Our study relates to several groups of articles. First, it is connected to more or less theoretical papers on monetary policy operational frameworks. Bindseil (2016) reviews operational frameworks pre- and post-crisis, discusses their objectives, evaluation criteria and outlines how an optimal framework may look like. He also explores the idea of scorecards for the evaluation of operational frameworks. Disyatat (2008) highlights misconceptions in regard to monetary policy implementation and shows their effect on the understanding of the monetary policy transmission mechanism. Particularly, he analyses the role of OMOs in the conduct of monetary policy, liquidity effects, the bank lending channel and sterilised OMOs. Borio (1997) reviews monetary policy implementation procedures in industrial countries at the time of writing the article. He also provides conceptual underpinnings, including factors affecting the demand for bank reserves, central bank liquidity management and its operating target.

Bech and Monnet (2016) present a search-based model of the interbank money market and monetary policy implementation. It fits the following stylised facts for the Eurosystem. An increase in excess reserves lowers the overnight money market interest rate towards the deposit facility rate and reduces its volatility, as well as reduces the ON money market turnover. It does not affect the recourse to the lending facility, however. Bindseil and Jabłecki (2011a) construct a structural model of central bank operations and bank intermediation. Among other things, it allows to understand the relationship between the width of the interest rate corridor and the stance of monetary policy in various regimes. The models of monetary policy implementation within the corridor system (also known as the channel system) can be also found, for example, in Berentsen and Monnet (2008), Whitesell (2006) or in the classical study of Poole (1968).

The second group of related articles concerns the impact of central bank operations on interest rates. Osborne (2016) assesses the consequences of reforms to the monetary policy operational framework in the United Kingdom between 1997 and 2014, by estimating the parameters of GARCH models explaining money market interest rates, for three sub-periods. He finds that the introduction of reserves averaging and voluntary reserve targets (second regime) has lowered the volatility of the ON money market interest rate, and the injection of excess reserves under the floor system (third regime) has reduced it further. However, under no regime the volatility of the ON money market interest rate affected the 3-month LIBOR rate, and it had little effect on OIS rate except for the zero reserves period (first regime). Queijo von Heideken and Sellin (2014) analyse the effect of the liquidity surplus on money market interest rates in Sweden between 2007 and 2014, by using linear regressions. They find that higher liquidity surplus is associated with lower ON and tomorrow next (TN) money market interest rate spreads versus the policy rate, but it does not affect the 1-month spread.

Furthermore, an increase in the absorption of the liquidity surplus by OMOs causes ON and TN spreads to increase.

Fiszeder and Pietryka (2018) compare the effectiveness of central bank operations in influencing spreads between the ON money market interest rate and the policy rate in the euro area and in Poland. To this end, they estimate the parameters of ARFIMA-GARCH models for three periods: of the global financial crisis, of the European sovereign debt crisis and of relative stability (post-crisis). According to their results, the euro area ON money market interest rate spread does have long memory, while its Polish equivalent does not. Most of the measures of central bank operations, liquidity conditions, market expectations and risk they analyse have affected the spreads during the global financial crisis, while the largest differences in their effects between the euro area and Poland have occurred throughout the period of relative stability. The authors also report substantial differences between the volatilities of the spreads.

Remaining articles from the second group use only data for Poland. Sznajderska (2016) constructs a liquidity management index, reflecting the share of excess reserves absorbed by the Narodowy Bank Polski (NBP). Then, she estimates its impact on spreads between money market interest rates and the policy rate, by using linear regression models for the period 2008-2015. She finds that the NBP liquidity management affects ON and 1-week money market interest rate spreads (the higher the liquidity management index, the lower the spreads). The relationship between central bank operations and the money market interest rate spread versus the policy rate is also analysed in the following studies: Kliber et al. (2016), Płuciennik et al. (2013), Lu (2012), Kliber and Płuciennik (2011). Osborne (2016) conducts an extensive literature review for other countries as well.

The third group of related articles researches into the trade-off between the volatility of the ON money market interest rate and its turnover, affected by the width of the interest rate corridor. Bindseil and Jabłecki (2011b) develop a model to analyse this trade-off, showing that the wider the corridor, the higher the volatility, but also the higher the turnover. Furthermore, they determine the optimal width of the interest rate corridor within the model. Finally, the authors test the model against data for the euro area and Hungary, finding that indeed wider corridor is associated with higher ON money market turnover. It is lowered by an increase in the volume of the deposit facility, however. A similar finding for Sweden (regarding the effect of a measure of surplus liquidity on the ON money market turnover) has been reported by Queijo von Heideken and Sellin (2014).

The last related group of literature concerns the relationship between central bank operations and money supply, through the money multiplier mechanism. Recently a large group of articles has questioned its operation in the modern economy, see, for example: Bundesbank (2017), Jakab and Kumhof (2015), Werner (2016, 2014a,b), McLeay et al. (2014) and Disyatat (2011). Carpenter and Demiralp (2012) undertake an empirical analysis of the interrelationship between reserves, money and loans. They use both aggregate and bank-level panel data for the United States, and estimate the parameters of (P)VAR models. The authors find no support for the operation of the money multiplier mechanism (nor do they find it for the working of the related bank lending channel of the monetary policy transmission mechanism). Jabłecki (2010) conducts Granger causality tests using data for Poland, for the period between 1998 and 2008. He finds that the liquidity of the banking sector (a category wider than reserves, particularly excess reserves) does not affect loans. Finally, Kot and Rozkrut (2004) discuss the proposal to liquidate the policy rate and to discontinue conducting OMOs in Poland, as suggested by some economists at the time of writing the article. They argue that OMOs absorbing excess reserves do not constitute a barrier for commercial banks to lend.

3 Monetary policy operational frameworks in Poland, the Czech Republic, Hungary and the euro area

In order to reach the operational target, an operational framework for monetary policy implementation is needed. A standard set of central bank instruments (defining an operational framework) consist of OMOs, standing facilities and minimum reserve requirements. The main features of the considered operational frameworks, as of 30 June 2017, are summarised in Table 1.

The NBP had explicitly stated an operational target in terms of the overnight rate. Since 2008 the NBP aims to keep the POLONIA rate close to the main policy rate (the reference rate). The Czech National Bank (CNB), the Magyar Nemzeti Bank (MNB) and the European Central Bank (ECB) all stated that they try to influence 'short-term money market rates' without stating a target for an interest rate with a specific maturity. The central bank typically sets a target for the overnight interest rate and then provides the banking sector with the amount of reserves ensuring that demand is met at this level for the overnight rate.

All considered central banks provided standing facilities in the form of a lending facility (in order to obtain overnight liquidity from the central bank, against the specified collateral) and a deposit facility (in order to make overnight deposits with the central bank). The interest rates on the lending and deposit facilities provided the ceiling and the floor for the overnight market interest rate. In determining the width of the corridor, central banks face a trade-off between controlling the volatility of the overnight rate and having an active interbank market. In the analyzed period discussed central banks used an interest rate corridor with a width of 65 to 200 basis points. The NBP maintained a symmetric corridor, i.e. deposit and lending rate were set symmetrically around the main policy rate. The CNB, MNB and the ECB used an asymmetric corridor. All considered central banks maintained a corridor approach, but due to excess liquidity in domestic banking systems the overnight rate was frequently close to the deposit rate.

Central banks in Poland, the Czech Republic, Hungary and the euro area used reserve requirements system. Reserve coefficient, which ranged from 1 to 3% in the analyzed countries, was applied to certain bank's liabilities. Reserves were remunerated approximately at central bank's main rate. Reserve requirements only had to be met on average over a reserve maintenance period of approximately one month.

The various types of transactions that central banks use to steer liquidity in the banking sector are called OMOs. Due to liquidity surplus in banking sector NBP regularly drained liquidity using OMOs in the form of issues of 7-day NBP bills. Main operations were offered in weekly auctions at a fixed rate at the level of the NBP reference rate. If needed, NBP also conducted fine tuning operations with maturities shorter than 1 week. Since the banking sector in the Czech Republic was in a liquidity surplus the CNB used the repo transitions three times a week with a maturity of two weeks to absorb liquidity. CNB conducted variable rate tenders with the declared repo rate as the maximum bid rate. To balance the liquidity conditions in the banking sector, irregular repos with maturities shorter than 2 weeks were used as well. The Hungarian banking sector was characterised by liquidity surplus. Therefore, the main policy instrument was the three-month liquidity-absorbing MNB deposit. In August 2014, the two-week bills issued by the MNB were replaced with a two-week deposit facility, and as of September 2015, the maturity of the main policy instrument was extended to three months. The transformations were intended to reduce the appeal of the main central bank sterilisation instrument, which increases the demand for non-central bank, eligible securities. The central bank deposit facility was offered for counterparties in monthly fixed rate tenders. From the tender held on 26 October 2016, access to the three-month deposit facility was subject to quantitative restrictions. There were two types of regular OMOs in the euro area: one-week liquidity-providing reverse transitions conducted with a weekly frequency and three-month liquidity-providing reverse transitions conducted on a monthly basis. The aim of main refinancing operations was to steer short-term interest rates, to manage the liquidity situation and to signal the monetary policy stance in the euro area, while longer-term operations provided additional, longer-term refinancing to the financial sector. Before the crisis main operations were usually executed in the form of variable rate tenders with a minimum bid rate, starting from 2008 a fixed rate full allotment policy was applied. In case of unexpected liquidity fluctuations, the EBC can execute fine-tuning operations. These are primarily executed as reverse transactions, but may also take the form of foreign exchange swaps or the collection of fixed-term deposits. The maturity is not-standardised and the frequency is non-regular. In recent years the ECB and the MNB had also conducted non-standard monetary policy measures, and the CNB intervened on the foreign exchange rate market to defend a (temporary, one-sided) exchange rate peg (see ECB, 2018; MNB, 2018; CNB, 2017).

Monetary policy in Poland was conducted in an environment of excess liquidity of the banking sector, mainly due to the inflow of EU funds and the conversion of them at the NBP. The overall surplus of funds maintained on accounts of banks (including deposit facility) over the required reserve level in Poland and its structure is presented in Figures 1 and 2, respectively. Since the financial crisis the NBP experienced underbidding in their liquidity draining operations. Banks preferred to keep liquidity buffers in the central bank on an overnight basis, resulting in an increase in the use of the deposit facility and hence downward pressure on the POLONIA rate. Another characteristic of the banking sector in Poland is liquidity segmentation occurring among market participants (NBP, 2017). Those holding surpluses of liquidity offered it at relatively high rates. At times it kept the POLONIA rate elevated despite the overall surplus of funds maintained on accounts of banks over the required reserve level.

4 Excess reserves, interest rate corridor and money market interest rates

4.1 Models

In this section we analyse the relationship between excess reserves, the interest rate corridor and money market interest rates. We define excess reserves as the difference between the sum of current accounts and ON deposits of commercial banks at the central bank, and required reserves.[3] By the interest rate corridor we mean the difference between the NBP lombard rate and its deposit rate. Particularly, we test whether excess reserves affect the level and the variability of the ON money market interest rate. Then, we estimate the effect of the variability of the ON money market interest rate on the level and the variability of longer-term money market interest rates. We also research into the role of the width of the interest rate corridor for the ON money market interest rate.

To this end, we use an empirical strategy similar to the one used by Osborne (2016), but adapted to Poland. In the first step, we estimate the parameters of the following GARCH(1,1) model, explaining the level and the variability of the ON money market interest rate:

$$\Delta POLONIA_t = \alpha_1 + \alpha_2 Period\ 2_t + \alpha_3 Period\ 3_t + \sum_{i=1}^{I} \alpha_{4i} \Delta POLONIA_{t-i} + \alpha_5 (POLONIA_{t-j} - Reference\ rate_{t-j}) + \sum_{k=0}^{K} \alpha_{6k} \Delta Reference\ rate_{t-k}^{sur} + \sum_{k=0}^{K} \alpha_{7k} \Delta Reference\ rate_{t-k}^{exp} + \sum_{l=0}^{L} \alpha_{8l} \Delta Excess\ reserves_{t-l} + \sum_{l=0}^{L} \alpha_{9l} \Delta Excess\ reserves_{t-l} * above\ threshold_{t-l} + \sum_{l=0}^{L} \alpha_{10l} \Delta Excess\ reserves_{t-l} * corridor_{t-l} + \alpha_{11} Calendar\ dummies_t + \varepsilon_t,$$

$$\sigma_t^2 = \beta_1 + \beta_2 \varepsilon_{t-1}^2 + \beta_3 \sigma_{t-1}^2 + \beta_4 Period\ 2_t + \beta_5 Period\ 3_t + \beta_6 Above\ threshold_t + \beta_7 Corridor_t + \beta_8 Calendar\ dummies_t,$$

where $POLONIA$ (Polish Overnight Index Average) is a Polish ON money market interest rate, $Period$ 2 is a dummy variable for the period between September 2008 and November 2010, $Period$ 3 is a dummy variable for the period between December 2010 and June 2017, $Reference\ rate$ is the NBP policy rate (sur and exp mean an unexpected an expected component of its change, respectively), $Above\ threshold$ is a dummy variable for periods, in which excess reserves exceed some threshold (see subsection 4.2.), and $Calendar\ dummies$ is a vector of dummy variables for month-ends, quarter-ends, year-ends and the ends of maintenance periods. α and β denote parameters, and i, j, k and l=1 ... 5.

[3] It means that the variable includes both positive and negative excess reserves (or, in other words, the balance of reserves).

Such a specification means the following. First, we use the weighted-average ON money market interest rate (POLONIA) rather than the unweighted one (WIBOR, Warsaw Interbank Offered Rate). Second, we allow for different constants in three regimes: the pre-crisis period, in which the NBP has been conducting only regular, main OMOs absorbing reserves, the crisis period, in which the Polish central bank introduced the 'Confidence Package', among other things providing reserves by repo operations, and the post-crisis period, in which not only has it been conducting regular OMOs, but also irregular, fine-tuning ones. Third, in the short run the effect of changes in the reference rate is allowed to vary depending on whether they are expected or not. This distinction should be more important for longer-term money market interest rates, as there is little reason for anticipatory changes in the ON rate. That said, we keep it an empirical question. Fourth, the model is non-linear (at least its mean equation). We test whether the effect of excess reserves differs depending on their volume and the width of the interest rate corridor. This is to take into account reserve averaging and the limit that the interest rate corridor imposes on changes in the ON money market interest rate.[4] Fifth, we introduce calendar dummies to absorb regular outliers related to the reporting of balance sheet data at end-months, quarters and years (raising the demand for reserves), and elevated excess reserves at the ends of maintenance periods. Finally, our model is within the error correction framework. To reduce the number of parameters to estimate we calibrate the long-run multiplier to one, which is consistent with empirical evidence (see, for example, Chmielewski et al., 2018). As a sensitivity analysis we also estimate the parameters of the mean equation by the OLS, as well as test for changes in parameters other than the constant in the mean equation (also using the OLS).

In the second step we estimate the parameters of GARCH models explaining longer-term money market interest rates: 1-month, 3-month and 1-year OIS (overnight index swap) and 3-month WIBOR. We augment both mean and variance equations with the conditional variance of POLONIA from the first step (see Figure 3). The equations of the models are the following:

[4] We also tested for other non-linearities. First, with respect to the imbalance between supply and demand on tenders for NBP bills (differentiating between the effects of under- and overbidding as well). Second, with respect to the weeks of maintenance periods. We found that the impact of excess reserves is the higher, the larger the difference between supply and demand (with higher effects in the periods of underbidding), and that the sensitivity is smaller in the initial weeks of maintenance periods, as compared to the last week (results available upon request).

$$\Delta OIS/WIBOR_t = \alpha_1 + \alpha_2 Period\ 2_t + \alpha_3 Period\ 3_t + \sum_{i=1}^{I} \alpha_{4i} \Delta OIS/WIBOR_{t-i} + \alpha_5 (OIS/WIBOR_{t-j} - Reference\ rate_{t-j}) + \sum_{k=0}^{K} \alpha_{6k} \Delta Reference\ rate_{t-k}^{sur} + \sum_{k=0}^{K} \alpha_{7k} \Delta Reference\ rate_{t-k}^{exp} + \sum_{l=0}^{L} \alpha_{8l} \Delta Conditional\ variance_{t-l} + \sum_{m=0}^{M} \alpha_{9m} Inflation_{t-m}^{sur} + \sum_{m=0}^{M} \alpha_{10m} GDP_{t-m}^{sur} + \sum_{n=0}^{N} \alpha_{11n} \Delta Excess\ reserves_{t-n}^{fil} + \sum_{o=0}^{O} \alpha_{12o} \Delta Default\ probability_{t-o} + \varepsilon_t,$$

$$\sigma_t^2 = \beta_1 + \beta_2 \varepsilon_{t-1}^2 + \beta_3 \sigma_{t-1}^2 + \beta_4 Period\ 2_t + \beta_5 Period\ 3_t + \beta_6 Conditional\ variance_t,$$

where $Inflation^{sur}$ and GDP^{sur} are the unexpected components of data releases on inflation and GDP, respectively, calculated as the difference between the actual release and the median of forecasts, $Excess\ reserves^{fil}$ are HP-filtered excess reserves (see subsection 4.2.), and $Default\ probability$ is the median of the default probabilities of commercial banks in a corresponding horizon. M, n and o=1 ... 5.

We use OIS rates because they are relatively risk-free and therefore they should reflect mainly the expected path of the POLONIA rate, the NBP operating target. In this way we can test whether the variability of the POLONIA rate affects the pass-through of the NBP policy rate to longer-term interest rates, arguably more important for economic activity and inflation, without having to control for the unobserved risk premium. But we also use the 3-month WIBOR, the benchmark for the most variable-rate loans. In the latter case we control for commercial banks default probabilities, a proxy for the risk premium (otherwise setting parameters before them to zero).

Data releases are used as one of our independent variables because they should affect the expected path of the policy rate, assuming the central banks follows a Taylor-type monetary policy rule. We subtract the expected component of them to account for the (assumed) efficiency of the financial market. Excess reserves are filtered to disentangle the day-to-day variability of the POLONIA rate, shaped to a large extent by day-to-day changes in excess reserves, from the effects of keeping excess in the banking sector by the central bank for a longer period, that could lower longer-term interest rates. We do not include calendar dummies because they turned out to be statistically insignificant for longer-term interest rates in early estimation. Also, we keep the variance equation possibly lean as otherwise the estimation process did not converge. Here we estimate the parameters of the mean equation using the OLS for robustness too (as a separate exercise – the baseline model is the GARCH), as well as test for changes in parameters other than the constant in the mean equation (also by the OLS).

As another sensitivity check we estimate the parameters of linear regression models explaining the monthly standard deviations of spreads between longer-term money market interest rates and the policy rate, similarly as Borio (1997). In the baseline specification we account for possibly regime-specific constants, and use the POLONIA-reference rate spread as the main independent variable. This is meant to be an alternative way of testing whether the variability of the ON money market interest rates affects the variability of longer-term market interest rates. In an extended specification we also include lagged dependent variable and control variables. Formally, the equation is the following:

$$OIS/WIBOR\,spread\,SD_t = \alpha_1{+}\alpha_2 Period\,2_t{+}\alpha_3 Period\,3_t{+}\alpha_4 POLONIA\,spread\,SD_t$$
$$(+\alpha_5 OIS/WIBOR\ spread\ SD_{t-1} + \alpha_6 Inflation^{sur}\ SD_t + \alpha_7 GDP^{sur}\ SD_t +$$
$$\alpha_8 Excess\ reserves^{fil}\ SD_t + \alpha_9 Default\ probability\ SD_t) + \varepsilon_t.$$

As an extension, in this case we also test for changes in parameters other than the constant.

4.2 Data and estimation

In the first two groups of models we use daily data, in the third one monthly data for Poland, for the period between January 2005 and June 2017. Our sources are: the NBP, Datastream and Bloomberg.

We use excess reserves in percent of required reserves. The threshold for excess reserves is relative to their standard deviation within a given maintenance period. This should correct for trends and structural changes on the money market. Differences are calculated in absolute terms (in percentage points). For the unexpected component of changes in the reference rate we take monetary policy shocks from Kapuściński (2017). We calculate the expected component as a residual, except for when the actual change is zero (then we take zero) or when the sign of the actual change is different than the sign of the unexpected component (then we take the actual change). For the median of forecasts of inflation and GDP we use the Bloomberg survey. The default probability of commercial banks is the median among banks listed on the Warsaw Stock Exchange, as estimated by Bloomberg.

Regarding the first two groups of models, we start by choosing the optimal numbers of lags for mean equations. We do so by estimating the parameters of models with all combinations of them using the OLS and choosing the ones with the lowest BIC and/or AIC criteria (depending on the results of the statistical significance tests). Then, we add dummy variables to absorb the three largest outliers, identified by the DFFITS (difference in fits) criterion. At these stages we exclude non-linearities from models explaining the POLONIA rate and use the default lambda (smoothing parameter) for the HP-filtering of excess reserves in models for longer-term interest rates (6 812 100 for daily data).

Next, in the model for the POLONIA rate we search for the optimal threshold for excess reserves, minimising the sum of squared residuals, over the grid between 0.5 and 2.0 standard deviations. The results of the search are presented in Figure 4. We find the optimal threshold to be at 0.89 standard deviation. It means that we allow excess reserves to affect the POLONIA rate differently below and at this level than above it. In models for longer-term interest rates we search for the optimal lambda in HP filter for excess reserves, applying a similar procedure. We search over the grid between 0 and 6 812 100. The results are shown in Figure 5. Interestingly, in the model for the OIS 1M rate it is optimal not to filter the data. For OIS 3M and 1Y rates the minimum sum of squared residuals is consistent with the maximum lambda. For the WIBOR 3M rate we found the optimal lambda to be at 88 646. However, excess reserves filtered in this way appear to capture the risk premium (see Lu, 2012). Therefore, for the WIBOR 3M rate we use the optimal lambda for the OIS 3M rate instead.

Following this pre-estimation, we turn to actual GARCH models. In models estimated by the OLS we reject the null hypothesis of no ARCH effects. Choosing optimal GARCH specifications for models explaining each of the analysed interest rate we searched over standard GARCH, GARCH-M, IGARCH, TARCH, EGARCH, PARCH and CGARCH models, with normal, Student's t and GED distributions. However, we encountered three major problems. First, in many specifications the estimation process did not converge. Second, we conducted a Monte Carlo exercise in which we tried different starting points, finding that estimated parameters varied between draws by a large margin. Third, in many non-integrated models we found the sum of ARCH and GARCH terms to be above one, implying an explosive process. Therefore, we decided to estimate the parameters of the standard GARCH models with the normal distribution (by quasi-maximum likelihood) as a default, which did not have convergence problems. If the sum of ARCH and GARCH terms was above one, we turned to IGARCH models with the normal distribution (also without convergence problems).[5] In this way we obtained consistent estimates from stable models.

Remaining models, estimated using the OLS and constituting the sensitivity analysis, did not require any pre-estimation.

4.3 Results

Table 2 presents results from models explaining the POLONIA rate: in the first column the baseline GARCH model, in the remaining columns models from the sensitivity analysis. Specifically, the second column contains the parameters of the mean equation estimated using the OLS, and columns 3-5 test whether parameters other than the constant have varied over time (the model also estimated by the OLS).

The POLONIA rate has been on average lower during the second period (the crisis one) than in the pre-crisis period, controlling for other factors. There are no statistically significant differences between the third and the first period, however. Furthermore, our models indicate that the surprise component of changes in the reference rate does

[5] The integration of the variance could also indicate that structural breaks have not been sufficiently treated (see, for example, Zivot, 2009). However, in an additional exercise, estimating the models in subsamples we obtained qualitatively similar results (available upon request).

not affect the POLONIA rate, in contrast to Chmielewski et al. (2018). But our result appears to be an artefact related to the low signal, as compared to the noise, in daily data (the other study uses monthly time series). The point estimate of the impact of the expected component of changes in the reference rate is also low (and the parameter is statistically insignificant) in the GARCH model, but it is statistically significant and closer to one in models estimated using the OLS. The error correction mechanism is operative for the POLONIA rate. The effect of excess reserves is non-linear: it is stronger when the volume of excess reserves is above the threshold of 0.89 and it is the stronger, the wider the interest rate corridor. The average variance of the POLONIA rate has been higher during the second period than in the first period. The point estimate is negative for the third period, but it is not different from zero. Also, the variability is higher in days in which the volume of excess reserves exceeds the threshold and is the higher, the wider the interest rate corridor.

Tables 3-5 show results from models explaining longer-term interest rates. Baseline GARCH models are presented in Table 3, in Table 4 there are the parameters of mean equations estimated by the OLS, and in Table 5 tests for changes in parameters other than constants (models also estimated using the OLS). The 1-month OIS rate has been on average lower during periods 2-3 than in the first period, and the 3-month WIBOR at least during the crisis period, controlling for other factors. The surprise component of changes in the reference rate is the more important, the longer the maturity. For the expected component it is the opposite. In cases of the OIS 1M rate and the WIBOR 3M rate there have been some differences over time. Again, parameter estimates are higher in OLS models. In daily data, the error correction mechanism appears to be operative only for the 1-month OIS rate. However, this results appears to be driven by the first period – for the remaining ones at least point estimates are lower. The conditional variance of the POLONIA rate does not seem to affect the level of longer-term interest rates. The effects of data releases are more visible, and in line with economic theory, in OLS models. Interestingly, unfiltered excess reserves negatively affect the OIS 1M rate. The effect of filtered ones is less robust for longer-term OIS rates, and statistically insignificant (with the 'right' sign, though) for the 3-month WIBOR rate. Default probability enters models for WIBOR 3M with the counterintuitive sign, but it is statistically insignificant (perhaps not being a sufficiently good proxy for the risk premium).[6] The average variance of longer-term interest rates has not varied between periods. The effect of the conditional variance of the POLONIA rate is statistically significant for all the analysed longer-term money market interest rates except the 3-month OIS rate. However, it does appear to be significant economically, with the point estimate at 0.0001 at best.

Tables 6-8 present results from models for the standard deviations of spreads between

[6] Furthermore, Maciaszczyk (2018) found that in 2015-2017 the WIBOR quotations of individual banks did not depend on their liquidity and capital positions.

longer-term money market interest rates and the policy rate. Columns 1-4 in Table 6 show results from the basic specification, while columns 5-8 from the extended one. Table 7 tests for changes in parameters other than constants for the former, and Table 8 for the latter. In the basic specification the standard deviation of the POLONIA-policy rate spread appears to positively affect the measure of the variability of all the analysed longer-term money market interest rates (for the 1-month OIS rate only at a 10% significance level, though). However, the point estimates of its effect are much lower once control variables are introduced, and for 3-month rates they are not different from zero. In models with period interaction terms the impact on the OIS 1M rate and the OIS 1Y rate remains only at a 10% significance level at best, and seems to be driven by the second, crisis period (perhaps also the first one for 1-month OIS rate).

Figure 6 presents results from the GARCH model for the POLONIA rate graphically, in the form of the market of reserves. Excess reserves are plotted against corresponding POLONIA-reference rate spreads. In general, the higher the excess reserves, the lower the POLONIA spread. But this effect is the stronger the higher the volume of excess reserves (in absolute terms) and the wider the interest rate corridor. This picture, although partly imposed by the specification of the model (but eventually shaped by parameter estimates) resembles the theoretical market for reserves, as, for example, in Borio (1997).

The results from this section can be summarised as follows. First, higher excess reserves are associated with a lower POLONIA rate. Second, an increase in excess reserves above the threshold of 0.89 standard deviation raises the variability of the POLONIA rate.[7] Third, the variability of the POLONIA rate does not affect the level of longer-term interest rate. Fourth, the results on the impact of the variability of the POLONIA rate on the variability of longer-term interest rates are ambiguous. Except for the 1-year OIS rate, they may be statistically significant, but economically negligible. If anything, they appear to be driven by the crisis period, when the NBP introduced the 'Confidence Package'. Finally, the wider the interest rate corridor, the higher the variability of the POLONIA rate.

[7] In contrast, for the euro area Bech and Monnet (2016) show that the increase in excess reserves lowered the volatility of the overnight money market interest rate. This is probably because in the euro area the increase in excess reserves was more persistent and on a larger scale.

5 Interest rate corridor and turnover on overnight money market

5.1 Models

In this section we analyse the effects of the width of the standing facilities corridor on the ON money market turnover. The standing facilities corridor is defined as the difference between the marginal lending facility rate and the deposit facility rate. By the ON money market turnover we mean overnight unsecured lending transactions on the interbank market, for banks participating in the POLONIA fixing. Due to limited variability in the interest rate corridor in our sample for Poland, we carry out both time series estimation for Poland, and panel data estimation for Poland, the Czech Republic, Hungary and the euro area – a set of economies with relatively similar monetary policy operational frameworks. We considered combining individual estimates for Poland with pooled estimates (partial pooling, see, for example, Canova, 2007), but pooled estimates appeared to be inconsistent in the first place, as fixed effects panel estimates turned out to be significantly different than mean group estimates, suggesting dynamic heterogeneity. As an extension, we try to determine the trade-off between the volatility of the POLONIA rate and the ON money market turnover in Poland for various widths of the standing facilities corridor. We also attempt to determine the optimal width of the interest rate corridor.

Firstly, similarly as Bindseil and Jabłecki (2011b), we estimate the parameters of the regression model explaining the volume of ON money market turnover in Poland using the OLS (they estimated models for Hungary and the euro area). Secondly, we estimate the parameters of the panel model for Poland, the Czech Republic, Hungary and the euro area. The general equation is the following:

$$Turnover_{(i)t} = \alpha_{1(i)} + \alpha_{2(i)} Corridor_{(i)t} + \alpha_{3(i)} Deposit\ facility_{(i)t} + \alpha_{4(i)} Period\ 2_{(i)t} + \alpha_{5(i)} Period\ 3_{(i)t} + \alpha_{6(i)} rr_{(i)t} + \alpha_{7(i)} Month\ end_{(i)t} + \alpha_{8(i)} Quarter\ end_{(i)t} + \alpha_{9(i)} End\ maintenance\ period_{(i)t} + \sum_{j=1}^{J} \alpha_{10(i)j} Turnover_{(i)t-j} + \varepsilon_{(i)t},$$

where $Turnover$ means the volume of overnight unsecured lending transactions on the interbank market, $Corridor$ denotes the difference between the marginal lending facility rate and the deposit facility rate, $Deposit\ facility$ means the volume of deposits held at the central banks by commercial banks under the deposit facility, $Period$ 2 is a dummy variable for the period between 9 August 2007 and 12 September 2008, $Period$ 3 is a dummy variable for the period between 15 September 2008 and 30 June 2017, rr is the reserve requirement ratio, $Month\ end$, $Quarter\ end$ and $End\ maintenance\ period$ are dummy variables for month-ends, quarter-ends and the ends of maintenance periods, α denotes parameters, i indicates country, and t means time (i=1 ... 4).

The dependent variable $Turnover$ is measured by the volume of overnight unsecured lending transactions on the interbank market, used for the construction of the POLONIA rate in Poland, and in the panel also of CZEONIA (Czech Over Night Index Average) in the Czech Republic, HUFONIA (Hungarian Forint Overnight Index Average) in Hungary and EONIA (Euro Overnight Index Average) in the euro area.

To check how the width of the standing facilities corridor affects the interbank market turnover, we include the $Corridor$ variable, which is defined as the spread between the borrowing and the deposit facility rates.

As the central banks offer liquidity absorbing facilities, which enable counterparties to place their end-of-day surplus liquidity at the central bank on a remunerated account and to some extent substitute for interbank market lending, we included the explanatory variable $Depositfacility$.[8] We allow for different constants for: the period before the start of the crisis-related turbulence when BNP Paribas halted redemptions of three investment funds, after this event and before the intensification of the turbulence when Lehman Brothers filed for bankruptcy, and after that event.[9] Furthermore, we control for the reserve requirement ratio and absorb regular outliers at month- and quarter-ends, as well as at the ends of maintenance periods.

5.2 Data and estimation

We use daily data from the NBP, the CNB, the MNB, the ECB and Datastream. Taking into account the availability of key variables, we use different periods for each country. In case of Poland the sample covers the period from 24 January 2005 to 30 June 2017, for the Czech Republic and Hungary – from 2 January 2002 to 30 June 2017, and for the euro area – from 1 January 1999 to 30 June 2017.

The variables $Turnover$ and $Deposit\ facility$ are expressed as the logarithm of an index with the reference year 2010 equal 100. The width of the interest rate corridor is in percentage points, while the reserve requirement ratio is in percent.

Firstly, we conduct a standard OLS estimation for Poland, regressing the volume of ON interbank turnover on the standing facilities spread, the deposit facility as well as on dummies, allowing for the time-varying constant and absorbing regular outliers. Next, due to limited variability in the interest rate corridor in our sample for Poland, we carry out panel data estimation for Poland, the Czech Republic, Hungary and the euro area. Having a large time dimension, the panel model is estimated using the mean group (MG) estimator. As mentioned above, we also tried fixed effects estimation,

[8] In the euro area, it appears that at some point commercial banks have become indifferent when choosing between the current account and the deposit facility (even before these accounts started offering the same interest rate). However, when replacing the deposit facility with its sum with the surplus current account (above the reserve requirement), we found no qualitatively significant differences (results available upon request).

[9] As a sensitivity analysis we also divided the last period into three subperiods separated by the start of the euro area government debt crisis and the 'whatever it takes' speech of the ECB governor Mario Draghi. The results, available upon request, remained qualitatively unchanged.

but we found the results to be significantly different than MG estimates, suggesting inconsistency of the former, due to dynamic heterogeneity.[10]

5.3 Results

Table 9 presents results from models for the ON interbank turnover. Both for Poland and for the panel model the width of the standing facilities corridor has a statistically significant, positive effect on the interbank turnover. It means that the narrowing of the corridor is associated with a reduction in the turnover. A similar conclusion was reached by Bindseil and Jabłecki (2011b) for the euro area and Hungary. The results also suggest that, in both cases (for Poland and for the panel), interbank trading with the one-day maturity increased in the first phase of the financial crisis (period 2) and decreased in the period of intense crisis (period 3), as compared to the pre-crisis period. Furthermore, the reduction of the reserve requirement ratio results in a lower turnover. For Poland, interbank trading seems to decrease at the end of months and at the end of reserve maintenance periods. The variable $Deposit\ facility$ and the dummy for quarter-ends are statistically insignificant.

As an extension, we try to determine the trade-off between the volatility of the POLONIA rate and its turnover, depending on the width of the standing facilities corridor. Assuming a certain level of the corridor and substituting sample averages for the remaining variables, we obtained the volatility and the interbank turnover based on the results of the estimation presented in Table 2 (the variance equation in the model for the POLONIA rate) and Table 9, respectively. For the latter, in order to improve the quality of coefficient estimates for Poland, we shrank them towards panel estimates using the Stein shrinkage (see, for example Canova, 2007). However, it should be noted that the shrinkage changed the estimates only slightly.

Figure 7 shows the volatility-turnover trade-off for various widths of the standing facilities corridor. Each point means a corridor different by 25 basis points, starting from a width of 1 percentage point on the left-hand side and ending at 4 percentage points on the right-hand side. As evident already from coefficient estimates, a narrower corridor reduces the interbank turnover and ON interest rate volatility. However, the analysis also reveals that small changes in the corridor cause relatively limited changes in the volatility, but rather large variations in the ON money market turnover. For example, lowering the corridor from the 2 percentage points at the time of writing the article to 1 percentage point would lower the expected value of the POLONIA variance by 0.8 percentage point (as measured by the standard deviation), but also decrease the turnover by PLN 622 mln.[11]

[10] For consistency, the MG estimator also requires a large number of cross sections (see, for example, Pesaran and Smith, 1995). While we consider our number of cross sections to be reasonable, in an online Appendix, available at `https://figshare.com/s/bac079559de32a85321d`, we also show country-by-country estimates.

[11] Of course, to some extent this results from functional forms.

As another extension, we attempt to determine the optimal interest rate corridor in Poland. Based on Bindseil and Jabłecki (2011b), we assume the central bank's utility function given by the following formula:

$$Utility = \frac{Turnover^{\alpha}}{Volatility^{\beta}},$$

where $Turnover$ means the ON turnover for the POLONIA rate, $Volatility$ denotes POLONIA rate volatility, and α, β are positive parameters, the sum of which is equal to 1. We obtained the variability of the POLONIA rate from the equations of conditional variance from the baseline GARCH(1,1) model, but for robustness also from the (analogous) EGARCH(1,1) model.

Similarly to Bindseil and Jabłecki (2011b), we consider three specifications of the central bank utility function. The first is neutral, where the central bank attaches equal importance to the interbank turnover and interest rate volatility (α=β=0.5). In the second specification, the increase of turnover is promoted at the expense of higher variability of the POLONIA rate (α=0.75 and β=0.25). The third specification assumes that the central bank actions are focused on reducing the volatility of POLONIA rate, thus allowing to reduce the interbank turnover (α=0.75 and β=0.25).[12]

Figure 8 shows the central bank utility for various widths of the corridor of interest rates, between 0.25 and 10 percentage points. The optimal corridor for the central bank depends on its preferences and the functional form of the volatility equation. According to our results, if the volatility is modelled as the GARCH(1,1) process, the central bank will find a 10 percentage points corridor to be optimal, regardless of its preferences. On the other hand, if the volatility is modelled as the EGARCH(1,1) process, a neutral and a turnover-promoting central bank will choose a 0.25 percentage points-wide corridor, while a volatility-averse central bank will prefer a wider corridor, of 10 percentage points.

To sum up this section, the most important results are as follows. Firstly, the width of the central bank standing facilities corridor affects banks' day-to-day liquidity management and the volatility of the POLONIA rate. Second, there is a trade-off between volatility and turnover for different widths of the standing facilities corridor: the narrower corridor, the smaller the interbank turnover and ON interest rates volatility. Third, the optimal width of the corridor depends on central banks' preferences and the functional form of the model for ON interest rate volatility.

[12] Bindseil and Jabłecki (2011b) also use the size of the central bank balance sheet as an argument in their utility function, as not only a narrower corridor might be associated with a lower ON money market turnover, but also with a higher resort to the lending facility. However, when modelling the volume of the lending facility we did not find it to be negatively correlated with the width of the corridor. This might require a more careful identification strategy though, and we leave it for future research.

6 Excess reserves and loans, money supply and money multiplier

6.1 Models

This section analyses the impact of excess reserves on loans, money supply and the money multiplier. We test whether changes in excess reserves affect money supply or are their effects balanced by changes in the money multiplier. We define excess reserves as the difference between the sum of current accounts and ON deposits of commercial banks at the central bank, and required reserves. *Required reserves* are the volume of deposits that commercial banks have to keep in the central bank on average during a given maintenance period, set as a percent of deposit liabilities in the previous maintenance period.[13] By *Loans* we mean loans to the private non-financial sector. *Money supply* is measured by the M3 aggregate. We compute the *Money multiplier* using the following formula:

$$Money\ multiplier = \frac{M3}{Reserves},$$

where $M3$ denotes money supply and $Reserves$ mean the reserves of commercial banks at the central bank, adjusted for changes in the required reserves ratio. It means that, compared to a more standard formula, in our baseline models we exclude cash from the denominator. However, we also tried different formulations (with M2 money supply in the numerator, monetary base in the denominator or controlling for changes in the required reserves ratio instead of adjusting reserves) and our results remained qualitatively unchanged.

Designing an empirical strategy to identify the causal effects of excess reserves on loans and money supply (or lack thereof) is non-trivial. Central banks with an overnight money market interest rate as an operating target provide reserves to commercial banks on demand. Otherwise they would not achieve the target. It implies that commercial banks do not have to wait to make loans and create deposits until they have reserves. They can do it first, and in the next maintenance period participate in OMOs so that they cover their increased needs (buying less central bank bills/using less reverse repo/using more repo). The question is: if the central bank provides more reserves than necessary first, will commercial banks lend more than otherwise?

In order to answer it, firstly, we conduct the (P)VAR analysis, with excess reserves, required reserves, loans and money supply as endogenous variables. Here we use both time series estimation for Poland and panel data estimation (for Poland, the euro area, the Czech Republic and Hungary) because in case of Poland the NBP has left a large

[13] The main function of the required reserves system is to stabilise money market interest rates. In the environment of a substantial liquidity surplus in Poland, the required reserves also serve to limit the liquidity surplus in the banking sector.

amount of excess reserves in the banking sector for a longer period only in 2010. We estimate responses to excess reserves impulses. The (P)VAR models are also used to test for Granger causality between the four variables.

Secondly, we approach the same problem from a different angle. We regress the money multiplier on a constant (both within time series and panel data framework) and use the Bai-Perron test for an unknown number of structural breaks at unknown dates. This is to test whether commercial banks multiply up central bank money by a constant factor, as in the textbook model. Then, we extend the model by adding lagged excess reserves. A time-varying money multiplier, affected by excess reserves, would make it a measure that always can be calculated, but with little policy relevance (it would imply that if the central bank increases excess reserves they translate into the money multiplier, not (or not only) loans and money supply; see Disyatat, 2008).[14] We use lagged excess reserves, because contemporaneously they affect the money multiplier by definition. The complete model is given by the following formula:

$$Money\ multiplier_{(i)t} = \alpha_{1(i)} + \alpha_{2(i)} Excess\ reserves_{(i)t-1} + \varepsilon_{(i)t},$$

where i indicates country, and t means time (i=1 ... 4).

6.2 Data and estimation

We use monthly data available from the NBP, the CNB, the MNB, the ECB, Datastream and Eurostat. We use different periods for each country. In case of Poland the sample covers the period from January 2005 to June 2017, for the Czech Republic and Hungary – from January 2002 to June 2017 and for the euro area – from January 1999 to June 2017. All variables are expressed in logarithms and seasonally adjusted. Moreover, the variable *Required reserves* is adjusted for the impact of changes in the reserve requirement ratio. We estimate the parameters of time series models using the OLS and panel data models using the MG estimator (for similar reasons as in models in the previous section).

6.3 Results

In order to explore the role of excess reserves in banking sector, we estimated a monthly, four-variable VAR model for Poland with excess reserves, required reserves, loans and money supply. We also estimated the PVAR model for Poland, the Czech Republic, Hungary and the euro area. In the baseline specification we chose arbitrarily 6 lags

[14] It could be argued that it takes time for an increase excess reserves to affect money supply, so although the multiplier decreases in the short run, in the longer run it broadly returns to its initial level. However, the long-run increase could also result from a policy change of the central bank (the absorption of excess reserves). Taking this considerations into account, provided that the number of lags in (P)VAR models is adequate, they appear to provide a more robust empirical strategy.

for the model in first differences and 3 for the model in levels. We identified shocks using the Cholesky decomposition, with variables ordered as they are listed above. However, we also made a number of robustness checks, which did not change our results qualitatively (they are available upon request). First, we computed generalised, instead of orthogonalised impulse response functions. Second, we added exogenous variables: nominal GDP, money market interest rates and nominal effective exchange rates. Third, we chose lags on the basis of information criteria. Finally, we estimated the parameters of VECM, instead of VAR models.

Figures 9-10 show the results from the impulse response analysis for Poland and for the panel model, respectively (models using variables in logs). Figures 11-12 present the cumulative impulse response functions for Poland and for the panel model, respectively (models using variables in log-differences). Most importantly, we found that neither loans nor money supply respond to excess reserves impulses (in all models). Also, required reserves respond to loans and money supply, which shows that our models capture lagged reserve accounting. Finally, although money supply responds to loans shocks, loans do not respond to money supply. This provides econometric support for the credit creation theory of banking (see Werner, 2014a,b, 2016).

To investigate the relationship between the four variables further we used the Granger causality test. Table 10 summarizes the results of this procedure. For the panel we indicatively show the averages of statistics across countries. Causality test results support these from the impulse response analysis. Both for Poland and on average in the panel money supply Granger-causes required reserves. Furthermore, for Poland required reserves are Granger-caused by loans, and loans themselves Granger-cause money supply. However, excess reserves do not cause any of the analysed variables (most importantly, loans and money supply). A comparable result was obtained by Jabłecki (2010) who shows that liquidity in banking system does not affect credit in Poland.

Next, we estimated the parameters of models for the money multiplier. In case of the model for Poland, we use the OLS method, for the panel model it was the MG estimator. First, to check whether the parameters can be regarded as structurally stable in a model only with a constant, and hence whether the money multiplier is stable, we used the Bai-Perron test of 1 to M globally determined breaks. Table 11 displays the scaled F-statistic and the Bai-Perron critical values (see Bai and Perron, 2003). The test indicated that there were 3 break-points in case of Poland, 2 for the euro area, 4 for the Czech Republic and 1 for Hungary, mostly in periods, in which central banks introduced measures increasing excess reserves.

Table 12 presents results from models assessing the impact of lagged excess reserves on the money multiplier. In both cases, for Poland and for the panel, there was a negative, statistically significant impact of excess reserves on the money multiplier.

The main results from this section are the following. An increase in excess reserves does not affect money supply (there was no statistically significant response of money supply to excess reserves impulses) and their effects are balanced by changes in the money multiplier. Also, the money multiplier is not time-invariant, and its estimated empirical relation with excess reserves is negative.

7 Conclusion

The aim of this study was to investigate the effects of leaving excess reserve in the banking sector by the central bank on the level and the variability of interest rates, as well as on money supply in Poland.

In the first part, we analysed the relationship between excess reserves, interest rate corridor and money market interest rates. The most important results are as follows. First, an increase in the level of excess reserves in the banking sector reduces the level of the POLONIA rate. Second, an increase in excess reserves above the threshold of 0.89 standard deviation raises the variability of the POLONIA rate. Third, the variability of the POLONIA rate is not transmitted to the level of longer-term interest rates. Fourth, the effect of the variability of the POLONIA rate on the variability of longer-term interest rates is ambiguous. In particular, the impact may be statistically significant, but economically negligible (except for the 1-year OIS rate). If anything, they appear to be driven by the crisis period, when the NBP introduced the 'Confidence Package'. Fifth, the wider the interest rate corridor, the higher the variability of the POLONIA rate.

In the second part, we researched into the effects of interest rate corridor on the ON money market turnover. Our results suggest that a narrower corridor is associated with a lower volume of turnover on the ovenight market.

In the third part, we investigated the impact of excess reserves on loans, money supply and the money multiplier. The main conclusion which can be drawn from this part of the analysis is that an increase in excess reserves is offset by a reduction in the money multiplier and does not lead to an increase in money supply.

The results imply that the current monetary policy operational framework in Poland is adequate to ensure the transmission of the central bank policy rate to money market interest rates. Furthermore, it appears unlikely that raising the amount of excess reserves left, as proposed by some policymakers, would affect money supply. Instead, it would lower the money multiplier and the overnight money market interest rate, as well as increase its volatility. However, it should be noted that we did not analyse the effects of particular measures resulting in higher excess reserves (or, of what corresponds to higher reserves on the asset side on central bank balance sheets), of which some could result in higher lending and money supply.

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Appendix

Figure 1: Excess reserves (in million PLN) and POLONIA rate (in percent) in Poland

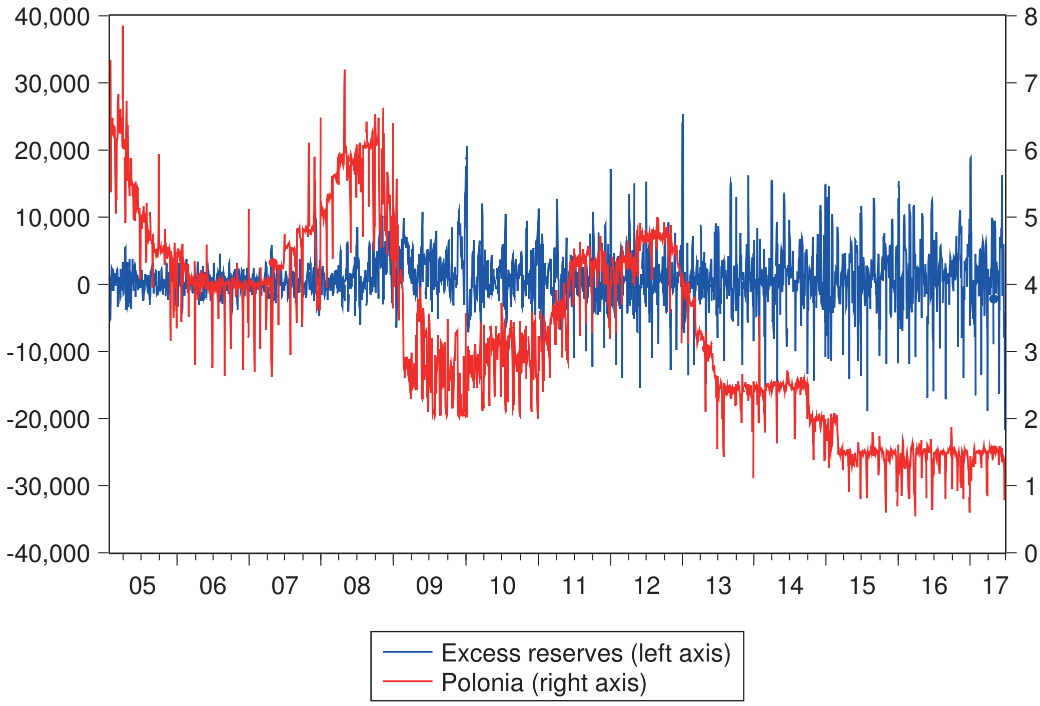

Figure 2: Current account, deposit facility and required reserves in Poland (in million PLN)

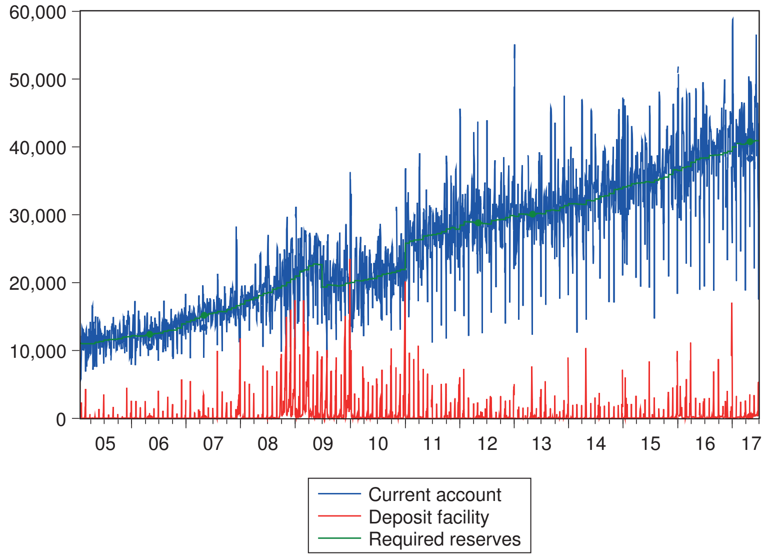

Figure 3: Conditional variance from model for POLONIA rate

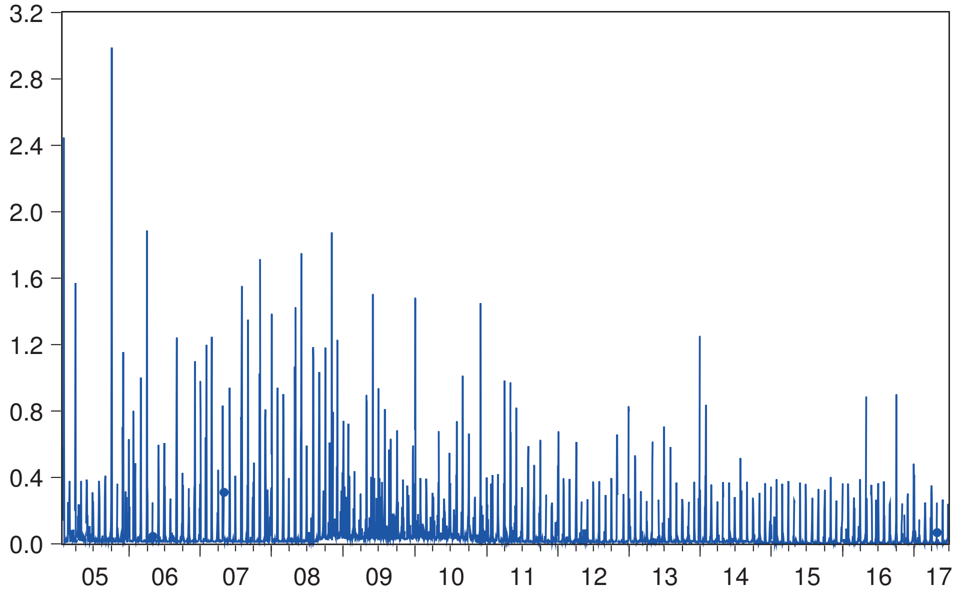

Figure 4: Optimal threshold for excess reserves – model for POLONIA rate

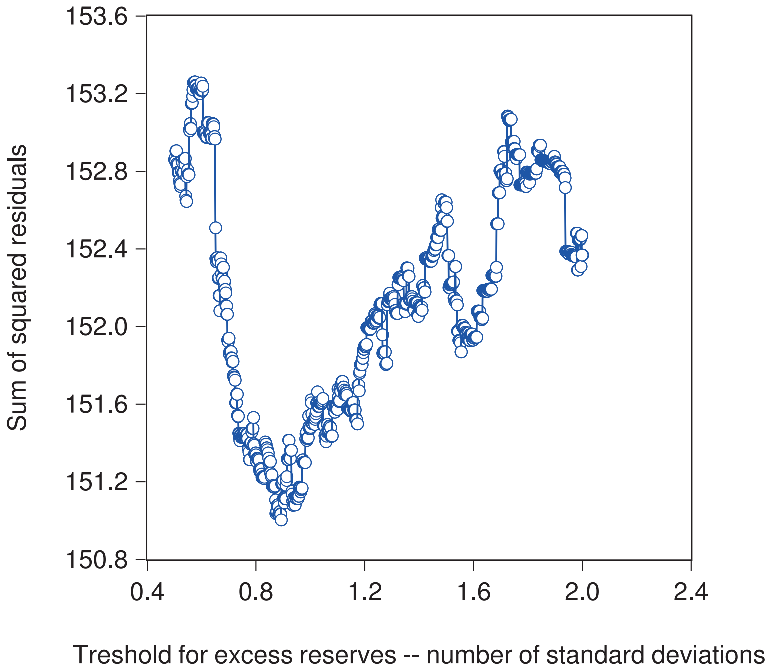

Figure 5: Optimal lambda in HP filter for excess reserves – models for longer-term money market rates

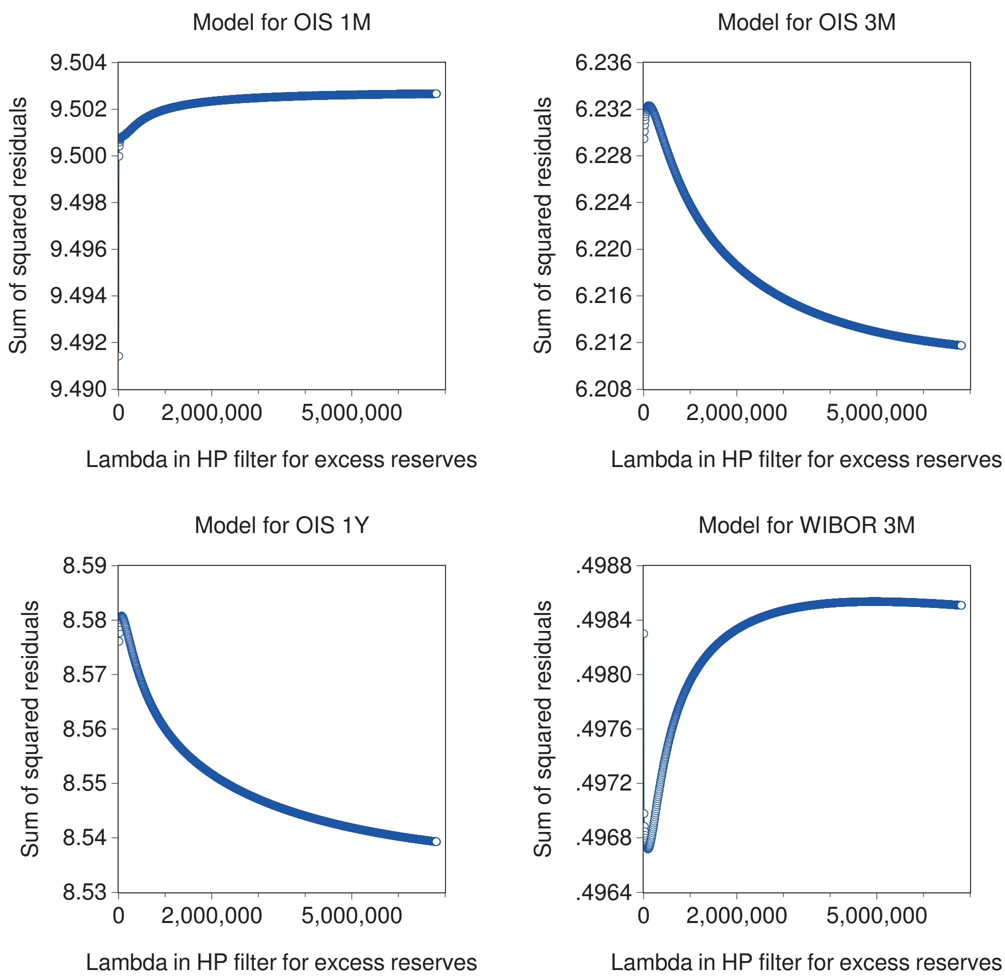

Figure 6: Market for reserves

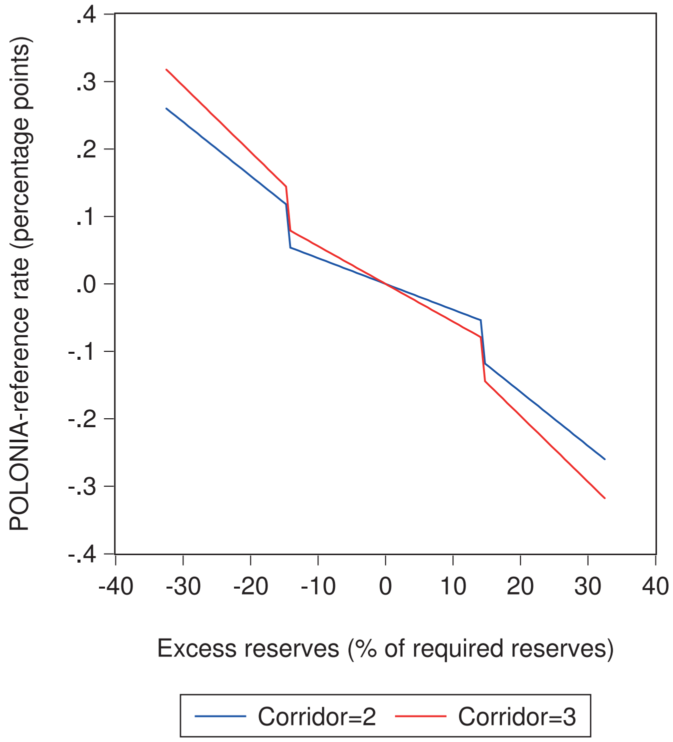

Figure 7: The volatility-turnover trade-off for different widths of the standing facilities corridor

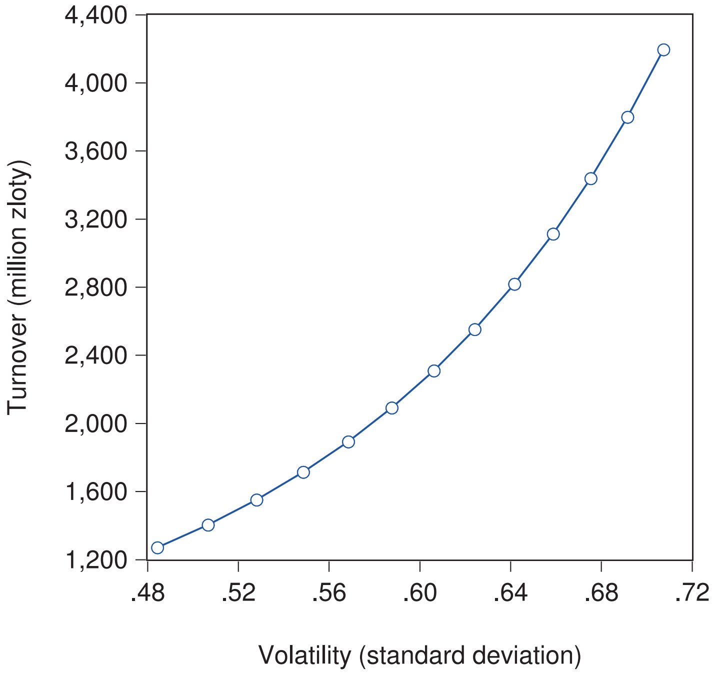

Figure 8: The optimal corridor of interest rates

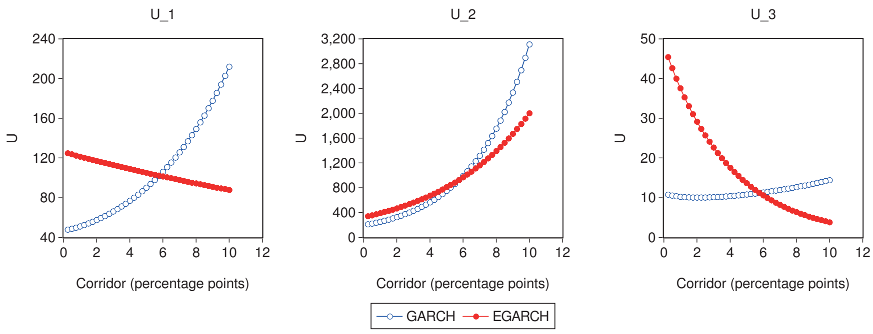

Table 1: The main features of the operational frameworks in Poland, the Czech Republic, Hungary and the euro area (as of 30 June 2017)

Country	Operational target of monetary policy	Standing facilities (corridor width in basis points and symmetry)	Open market operations (types of transactions and frequency)	Minimum reserve requirements (reserve coefficients in %, reserve requirement maintenance period and remuneration rate)
Poland	POLONIA rate	200; symmetric	liquidity absorbing; main operations: 1 week; fine tuning operations: less than 1 week	3.5; 1 month; 0.9 of the NBP main rate
Czech Republic	CZEONIA rate	20; asymmetric	liquidity absorbing; main operations: 2 weeks; fine tuning operations: less than 2 weeks	2.0; 1 month; the CNB two-week repo rate
Hungary	HUFONIA rate	95; asymmetric	liquidity absorbing main operations: three-month MNB deposit;	1.0; 1 month; the MNB main rate
Euro area	EONIA rate	65; asymmetric	liquidity providing; main operations: 1 week; longer-term operations: 3 months; fine-tuning operations: non-regular	2.0; inter-meeting (approximately 6 weeks); the ECB main rate

Table 2: Models for POLONIA rate

Dependent variable	Δ POLONIA	Δ POLONIA	Δ POLONIA		
Method	ML - ARCH	LS	LS		
Interaction				Period 2	Period 3
Mean					
C	-0,0118	-0,0278***	-0,0332***		
Period 2	-0,0249*	-0,1096***	-0,0755***		
Period 3	0,0083	-0,0101	0,0008		
AR	-0,0427*	-0,1127***	-0,1615**	0,0718	0,0989
Δ Reference rate – surprise	-0,1141	-0,6439	-0,6599	-1,3983	0,8113
Δ Reference rate – expected	0,4513	0,8636***	0,9581***	0,3196	-0,9399*
EC (-1)	-0,0491***	-0,1866***	-0,2457***	0,1111*	0,0942
Δ Excess reserves	-0,0003	0,0031	0,0006	-0,0062*	0,0003
Δ Excess reserves*above threshold	-0,0042***	-0,0063***	-0,0076***	0,0004	0,0017
Δ Excess reserves*corridor	-0,0018**	-0,0034***	-0,0018		
Variance					
C	-0,0094*				
MA	0,9268***				
AR	-0,0052***				
Period 2	0,0168***				
Period 3	-0,002				
Above threshold	0,006***				
Corridor	0,0069***				

Table 3: Models for longer-term money market rates – ML - ARCH

Dependent variable	Δ OIS 1M	Δ OIS 3M	Δ OIS 1Y	Δ WIBOR 3M
Method	ML - ARCH	ML - ARCH	ML - ARCH	ML - ARCH
Mean				
C	0,0016*	0,0008	-0,0035	-0,0003
Period 2	-0,0159***	0,0033	0,0039	-0,0041***
Period 3	-0,0032***	-0,0011	0,003	-0,0013**
AR	-0,2594***	-0,2361***	-0,1405***	0,1398***
Δ Reference rate – surprise	0,1743	0,4781***	0,7272***	0,2303***
Δ Reference rate – expected	0,5902***	0,3861***	0,0473	0,3083***
EC (-1)	-0,028***	0,0024	0,0072***	0,0063***
Δ Conditional variance	0,0004	0,0008	-0,0058*	-0,0004
Inflation	0,0073	0,0435***	0,0627***	0,0003
GDP	-0,0282	0,0066	0,045**	0,0103*
Δ Excess reserves – filtered	-0,0001**	-0,0348	-0,0696*	-0,004
Δ Default probability				-25,8865
Variance				
MA	0,0596**	0,0486***	0,078***	0,0298***
AR	0,9404***	0,9514***	0,922***	0,9702***
Period 2	0	0	0	0
Period 3	0	0	0	0
Conditional variance	0,0001**	0	0,0001**	0***

Table 4: Models for longer-term money market rates – LS

Dependent variable	Δ OIS 1M	Δ OIS 3M	Δ OIS 1Y	Δ WIBOR 3M
Method	LS	LS	LS	LS
C	0,0008	0,0004	0,0001	-0,0022***
Period 2	-0,027***	-0,006	-0,0073	-0,0055***
Period 3	-0,006***	-0,0023	-0,0017	-0,0008
AR	-0,2169***	-0,1969***	-0,172***	0,1475***
Δ Reference rate – surprise	0,4337*	0,8879***	0,9838***	0,4274***
Δ Reference rate – expected	0,2764**	0,2006***	-0,0372	0,2108***
EC (-1)	-0,0361***	-0,0017	0,0051	0,0093***
Δ Conditional variance	-0,0002	-0,0071*	-0,0047	-0,0016
Inflation	0,0228*	0,0641***	0,096***	0,0397***
GDP	0,0423**	0,0142	0,0583**	0,0283***
Δ Excess reserves – filtered	-0,0001*	-0,14**	-0,262***	-0,0048
Δ Default probability				-32,9322

Table 5: Models for longer-term money market rates – LS, continued

Dependent variable	Δ OIS 1M			Δ OIS 3M			Δ OIS 1Y			Δ WIBOR 3M		
Method	LS			LS			LS			LS		
Interaction		Period 2	Period 3		Period 2	Period 3		Period 2	Period 3		Period 2	Period 3
C	-0,0003			-0,0012			-0,0014			-0,0026***		
Period 2	-0,0271***			-0,0083			-0,0078			0,0023		
Period 3	-0,0054***			-0,0009			0			-0,0014		
AR	-0,2258***	0,0102	-0,0934	-0,2703***	0,1161	0,0316	-0,1355***	-0,0499	-0,0367	0,1019	0,0496	0,0511
Δ Reference rate – surprise	0,348	-1,1936**	0,5191*	0,7139**	0,5666	0,2434	1,0773***	0,7113	-0,3349	0,5051***	-0,1745	-0,1227
Δ Reference rate – expected	0,3964***	-0,2721	0,0093	0,3176***	-0,3211*	-0,1567	0,018	-0,2415	-0,1007	0,1237***	0,2025***	0,1065**
EC (-1)	-0,0093	-0,0264	-0,0295	0,0153**	-0,0238	-0,0163*	0,0065*	-0,0043	-0,0011	0,0157***	-0,0182***	-0,0021
Δ Conditional variance	-0,0014	-0,0002	-0,0017	-0,0039	-0,0189*	0,0037	-0,006	0,0099	-0,0099	-0,0019	0,0011	0,0011
Inflation	0,0133	-0,0626	0,022	0,1174**	-0,2079	-0,061	0,1732**	-0,1409	-0,1105	0,0967***	-0,0866**	-0,0866***
GDP	-0,0105	0,1551	0,0493*	-0,0439*	0,0217	0,0987**	-0,0046	0,0631	0,0965**	0,0005	0,0264	0,0434
Δ Excess reserves – filtered	0,0002*	-0,001***	-0,0003**	-0,0633*	-0,073	-0,1326	-0,1351**	-0,1945	-0,0093	-0,1059***	0,1413***	0,0701*
Δ Default probability										103,2495	-140,1821	-94,3848

Table 6: Models for standard deviations of spreads of longer-term money market rates

Dependent variable	OIS 1M spread SD	OIS 3M spread SD	OIS 1Y spread SD	WIBOR 3M spread SD	OIS 1M spread SD	OIS 3M spread SD	OIS 1Y spread SD	WIBOR 3M spread SD
Method	LS	LS	LS	LS	LS	LS	LS	LS
C	0,0186	0,0313**	0,0555***	0,0297***	-0,0016	0,0057	0,0183	0,0133*
Period 2	0,0389	0,0303	0,0169	-0,0072	0,0123	0,0072	0,0022	-0,0051
Period 3	-0,0028	-0,0103	-0,0255**	-0,0139	0,0024	0,0002	-0,0067	-0,0035
POLONIA spread SD	0,1071***	0,0779**	0,1015*	0,0506**	0,0653**	0,0431	0,0684*	0,0296
AR					0,6209***	0,6932***	0,5298***	0,5782***
Inflation SD					-0,0412	-0,0414	-0,0272	-0,0331
GDP SD					0,0259	-0,0204	-0,0339	-0,0927**
Excess reserves SD					0,0002	0,0033	0,0335	0,0017
Default probability SD								21,23

Table 7: Models for standard deviations of spreads of longer-term money market rates, continued

Dependent variable	OIS 1M			OIS 3M			OIS 1Y			WIBOR 3M		
	spread SD			spread SD			spread SD			spread SD		
Method	LS			LS			LS			LS		
Interaction		Period 2	Period 3		Period 2	Period 3		Period 2	Period 3		Period 2	Period 3
C	0,0319***			0,0392***			0,0788***			0,0346**		
Period 2	-0,0286			-0,007			-0,0887			-0,0312		
Period 3	-0,0087			-0,0145			-0,0391*			-0,0163		
POLONIA spread SD	0,0627*	0,1729*	0,0044	0,0515	0,0959	0,0065	0,0236	0,273*	0,0255	0,0343	0,0616	0,0026

Table 8: Models for standard deviations of spreads of longer-term money market rates, continued 2

Dependent variable	OIS 1M			OIS 3M			OIS 1Y			WIBOR 3M		
	spread SD			spread SD			spread SD			spread SD		
Method	LS			LS			LS			LS		
Interaction		Period 2	Period 3		Period 2	Period 3		Period 2	Period 3		Period 2	Period 3
C	-0,014			0,0108			0,0582**			0,0051		
Period 2	0,0287			-0,0053			-0,0773**			0,0092		
Period 3	0,0202			0,0025			-0,0302			0,0134		
POLONIA spread SD	0,0224	0,1426	-0,0033	0,0251	0,0221	0,0092	0,0103	0,2146*	0,019	0,0146	0,0664	0,0144
AR	0,5738***	-0,0358	0,1555	0,4838***	0,351**	0,1381	0,2964*	0,2778	0,0356	0,4694**	0,0891	0,1516
Inflation SD	0,1212*	-0,7989	-0,2085***	0,1141	-0,4867	-0,1827	-0,0399	-0,6977	0,1113	0,0994	-0,4474**	-0,1694
GDP SD	0,0226	0,293	-0,0355	0,0737	0,0765	-0,1196	-0,0273	0,4606*	-0,0685	0,0075	-0,3457*	-0,0849
Excess reserves SD	0,0014	-0,0016	-0,001	-0,0099	0,0616	-0,0003	0,0042	0,035	-0,0837	-0,022	0,0171	-0,0093
Default probability SD										2429,65**	-2645,616**	-4188,737**

Table 9: Models for ON interbank turnover

Dependent variable	Turnover	Turnover
Method	LS	MG
	Poland	Panel
C	1,7514***	1,05**
Corridor	0,1466***	0,0827***
Deposit facility	0,0073	-0,0019
Period 2	0,0656**	0,0517***
Period 3	-0,1373***	-0,0241**
RR	-0,1423**	-0,0555***
Month end	-0,2517***	-0,1734***
Quarter end	0,0036	0,0007
End maintenance period	-0,3427***	-0,021
AR	0,6316***	0,7772***

Figure 9: Impulse response functions and 95-percent confidence intervals – Poland

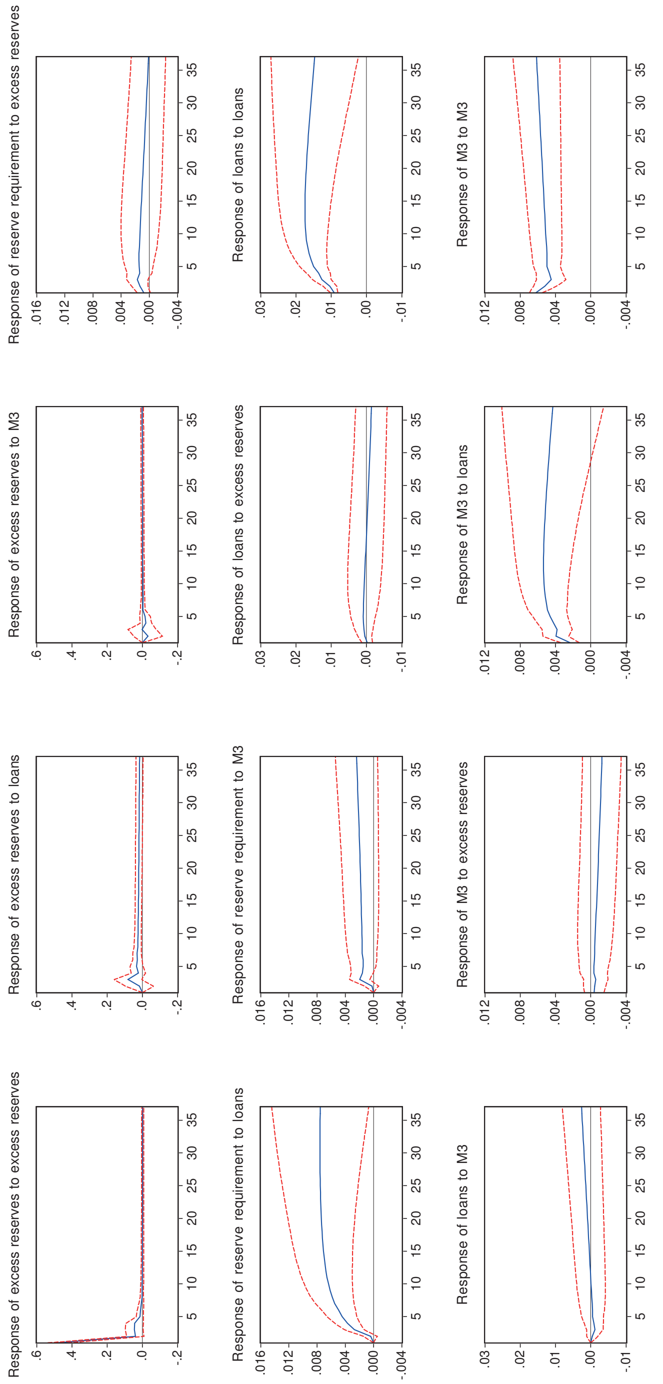

Figure 10: Impulse response functions and 95-percent confidence intervals – panel

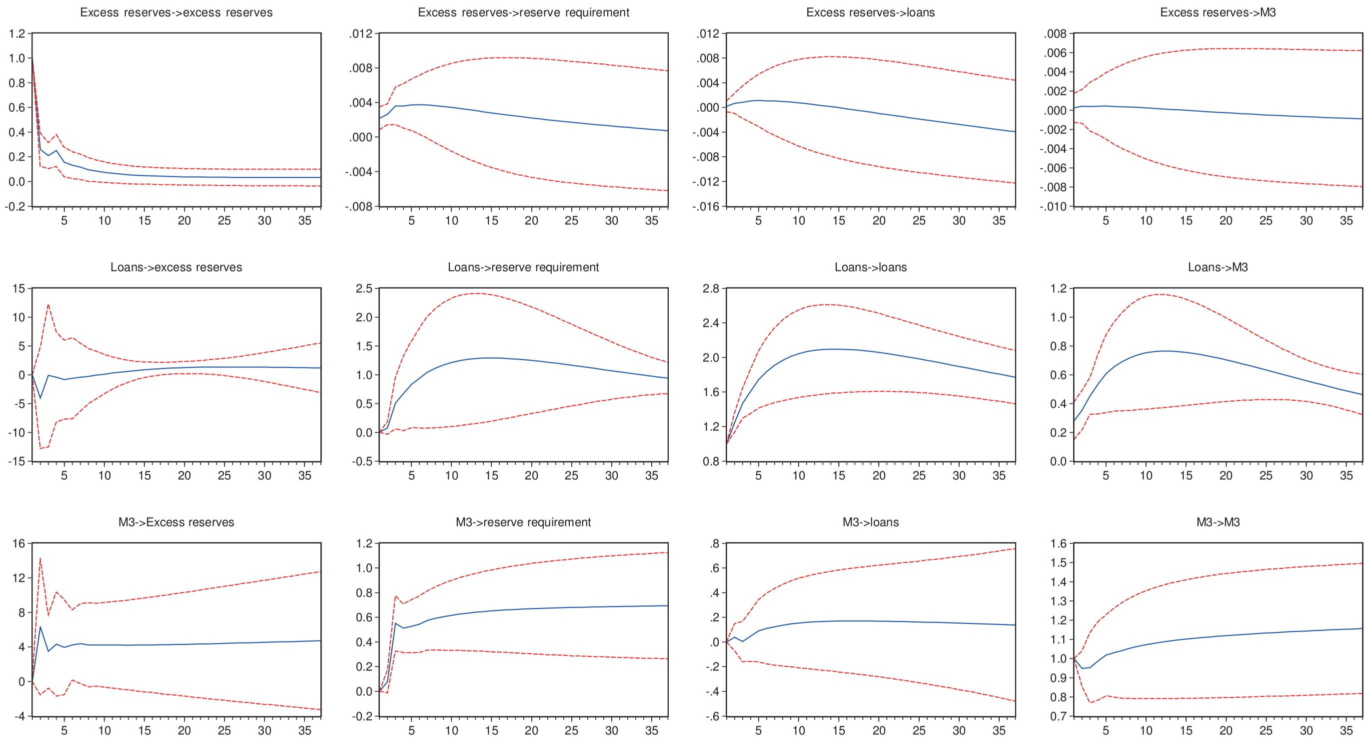

Figure 11: Cumulated impulse response and 95-percent confidence intervals – Poland, first differences

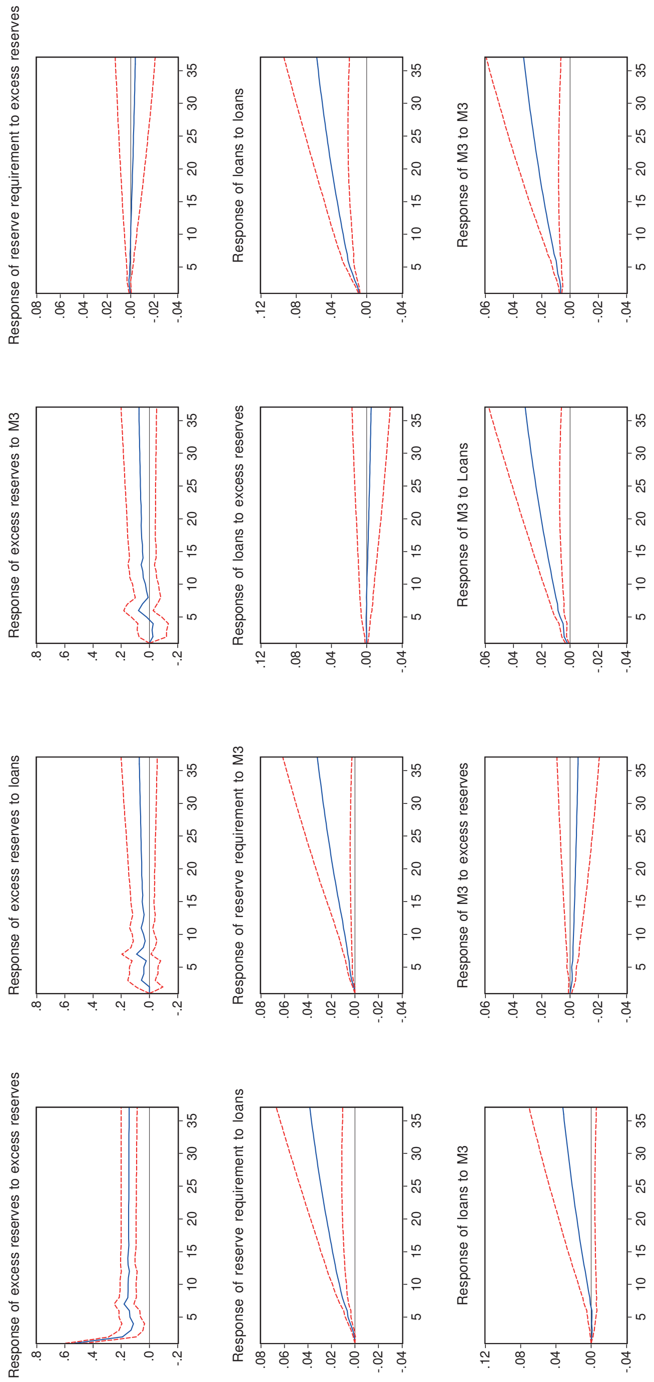

Figure 12: Cumulated impulse response and 95-percent confidence intervals – panel, first differences

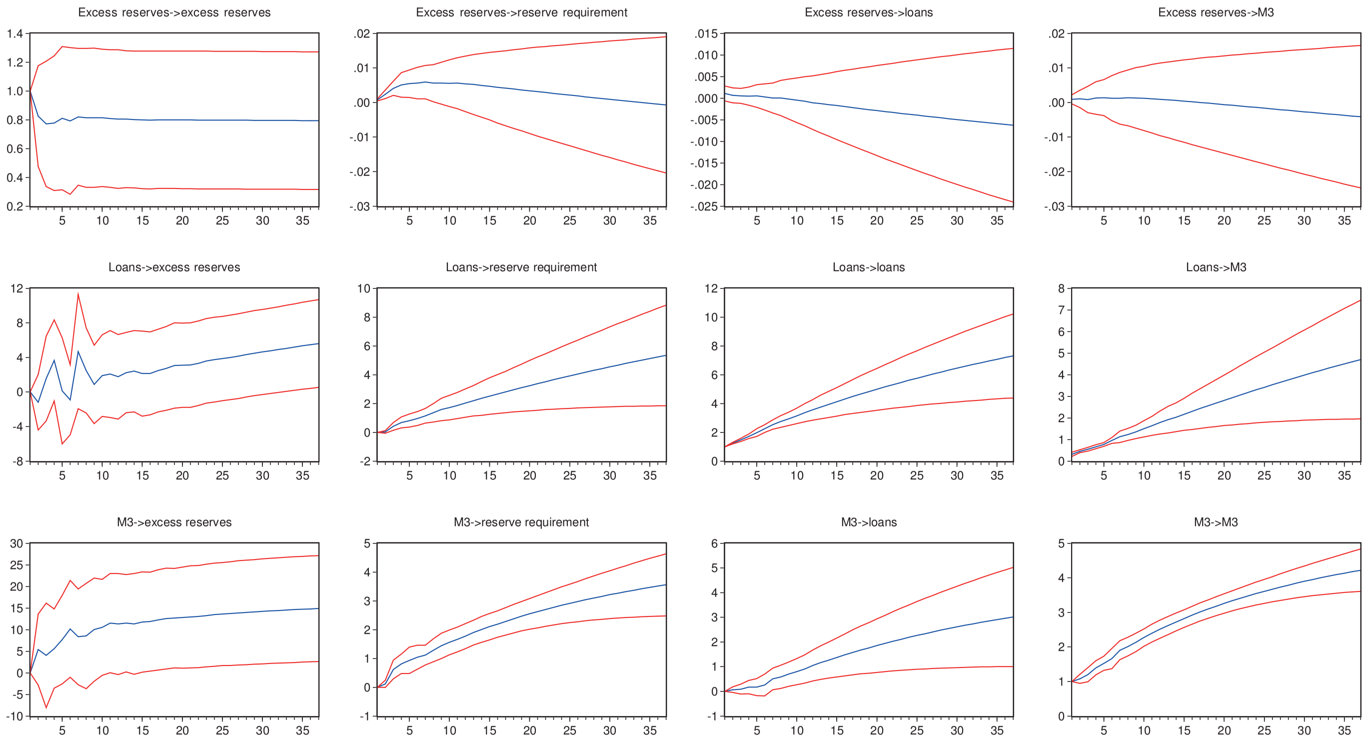

Table 10: Granger causality tests

Dependent variable	Δ Excess reserves	Δ Reserve requirement	Δ Loans	Δ M3	Δ Excess reserves	Δ Reserve requirement	Δ Loans	Δ M3
	Poland				Panel			
Δ Excess reserves		8,49	2,43	7,48		2,85	3,85	2,45
Δ Reserve requirement	6,52		7,83	1,92	10,74		11,67	9,26
Δ Loans	3,44	14,34**		18,38***	5,02	10,43		7,09
Δ M3	6,24	28,76***	7,93		11,62	45,39***	11,75	

Table 11: Models for the money multiplier and test for parameters stability

Dependent variable	Money multiplier Poland	Money multiplier Euro area	Money multiplier Czech Republic	Money multiplier Hungary
C	30,7713***	60,597***	39,5441***	67,758***
Multiple breakpoint tests (scaled F-stat)				
1 break	98,24	201,91	592,19	50,98
2 breaks	57,91	205,27	1818,11	42,5
3 breaks	215,79	148,47	1487,61	30,32
4 breaks	171,76	115,68	2214,93	25,1
5 breaks	141,4	103,39	1662,63	18,78
Critical value	8,88	8,88	8,88	8,88
Estimated break dates				
	Novermber 2006	September 2008	September 2004	May 2008
	September 2008	October 2011	September 2008	
	March 2011		November 2012	
			February 2015	

Table 12: Models for the money multiplier

Dependent variable	Money multiplier Poland	Money multiplier Panel
C	31,7397***	57,7461
Excess reserves (-1)	-0,2223***	-0,1478***

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