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An assessment of monetary policy effectiveness in POLONIA rate stabilization during financial crisis

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Abstract

Starting from the year 2008, the official goal of the National Bank of Poland is to influence the liquidity of the money market via open market operations in such a way so as to enable the POLONIA rate to run close to the NBP reference rate. In the paper we aimed to prove that the central bank retained its ability to steer the POLONIA rate even in the situation of considerable decline in confidence in the Polish interbank market after the bankruptcy of the Lehman Brothers. We assessed the ability investigating the properties and behaviour of the spread between the POLONIA rate and the NBP reference rate.

Keywords: GARCH models, interest rate, long-memory, monetary policy, percentage spread

JEL: C14, C22, E43, E58

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1. Introduction

First problems in the world interbank markets could be observed as early as in 2007. As a result of the mortgage loans crisis in the USA and following news about financial problems of some of the leading banks we could observe some signs of confidence crisis among commercial banks. The European Central Bank increased the number of main refinancing operations in order to counteract the confidence crisis. It also reopened foreign exchange swap lines with FED to enable banks to obtain dollar liquidity. After the bankruptcy of Lehmann Brothers on 15 September 2008 the aversion to money lending in interbank markets was rising considerably. In consequence, the ECB started to provide refinancing well above the levels that banks had used to absorb to fulfil their reserve requirements in normal times, and existing swap lines were increased.

The world financial crisis was transmitted also to the Central Europe, due to diminished inflow of capital and decreased lending. In Poland the effects of international turbulences were relatively low, but the confidence crisis in the interbank market was very perceptible. In October 2008 the National Bank of Poland introduced the so called Confidence Pact in order to provide banks with zloty and foreign currency funds. The possibility to obtain zloty liquidity were extended; the central bank introduced repo transactions of maturity up to 3 months, reduced the haircut of the security for the marginal lending facility and expanded the list of assets, which may have acted as a security for the marginal lending facility with the NBP.

In the article we are going to determine whether the National Bank of Poland was capable of effectively influencing the POLONIA[1] rate in the situation of the crisis transmission to Poland. The problem of the effectiveness of monetary policy in affecting the interbank rates has been already raised in literature, but the quantitative approach to this problem so far has not been considered. Panigirtzoglou, Proudman, Spicer (2000) tested how closely the money market rates followed the policy rates. The authors used the augmented AR-GARCH model to check the divergence between the money rates and the policy rates of three European countries, and they identified the properties of the series based upon the strength of the parameters' estimates. Vila Wetherilt (2002) showed that in the period 1994–2001 the Bank of England – appropriately adjusting its monetary policy – minimized the level and the volatility of the spread between the key market rates and the policy rate. Linzert, Schmidt (2008) and Hassler, Nautz (2008) analysed the long memory of the spread to determine how the new operational framework introduced in 2004 by the ECB influenced the spread between EONIA rate and the key policy rate. Nautz and Scheithauer (2009) analysed spreads from four markets and showed that in three cases the change of monetary policy framework had significant impact on the ability of central banks to steer the overnight rates. In many publications it was also verified how other aspects of monetary policy influence the key money market rates or the spread between the key market rate and the key policy rate. Würtz (2003) considered among others the rational and adaptive liquidity expectation, MRO Allotment volumes and the under- and overbidding. Linzert, Schmidt (2008) verified the influence of liquidity policy, which is understood to mean the difference between actual allotment and benchmark allotment, as well as bid-to-cover ratio, expectation of interest rates, uncertainly of interest rates, aggregated liquidity deficit and etc.

[1] POLONIA (Polish Overnight Index Average) is the average overnight rate weighed with the values of transactions on the unsecured interbank deposit market. It is determined on the basis of all transactions of 21 banks – participants of the fixing – realized before 4 p.m. The levels of the POLONIA rate are published by the NBP at the Reuters information website daily at 5.00 p.m.

Similar studies were conducted by Moschitz (2004), Ejerskov, Moss, Stracca (2003), Pérez Quirós, Rodríguez Mendizábal (2006) and Abbassi, Nautz (2010).

2. Data description

In the research we consider the spread between the POLONIA rate and the NBP reference rate over the period 2 January 2006 – 30 June 2010. Formally, since 2008 the NBP has influenced the liquidity in the banking sector by stabilizing the POLONIA rate around the reference rate. However, the properties of the spread between the POLONIA rate and the NBP reference rate show that the POLONIA rate was being stabilized since the beginning of 2006. The change of the official policy goal from stabilizing the WIBOR SW to stabilizing POLONIA rate was prompted by the tendencies in the term structure of the money market (See NBP 2007 and NBP 2009 for more details). The share of the overnight deposits in the total turnover of the interbank deposit market increased in recent years. Moreover, the overnight rates have been stabilized by central banks of highly developed countries for several years, albeit many of them have not confirmed it. For instance, the European Central Bank formally admits that it steers the short-term interbank interest rates publishing the information about the level of the minimum bid rate. However, the properties of the spread between the EONIA rate and the key monetary policy rate suggest that the ECB aims at steering mainly the EONIA rate (see Linzert, Schmidt 2008 and Hassler, Nautz 2008).

Descriptive statistics of the spread (Table 1) and the histogram (Figure 7) suggest strong left-side asymmetry. Distribution of the spread is mesokurtic. The negative value of the mean signifies that the POLONIA rate usually run below the NBP reference rate.

In Figure 1 there are presented historical values of the following interest rates: the POLONIA rate, the NBP reference rate, the lombard rate and the deposit rate. The amount of credits and deposits taken over the period under study are presented in Figure 2. Based upon the chart, some features of the spread can be observed. Until the third quarter of 2008 the dynamics of the spread was quite small. The regular monthly jumps can be related to the average required reserve framework which is obligatory in Poland. Therefore, the POLONIA volatility and the average level of the spread are particularly high at the end of the maintenance periods (Figure 8). The disturbances at the end of both 2006 and 2007 appeared because the commercial banks aim at proving their liquidity in their annual reports.

Since the third quarter of 2008, when the world financial crisis hit Polish economy, the properties of the spread have changed. In Poland, the consequences of the global crisis were relatively mild. As the crisis had spread to the Polish interbank market, the banks have lost confidence in each other and drastically decreased credit limits for interbank transactions. The results of the so called “confidence crisis” intensified after the spectacular fall of the Lehman Brothers on 15 September 2008. The rise of the WIBOR-OIS spread is a reliable sign of the crisis transmission to the Polish market.[2] In Figure 3 we observe substantial growth of the 3-month WIBOR-OIS spread at the beginning of the fourth quarter of 2008. The response to the crisis of

[2] WIBOR-OIS spread is the difference between the WIBOR rate and the overnight indexed swap rate of the same maturity. The spread between the interbank and OIS rates is considered to be a measure of credit risk in the interbank market. When the confidence in the interbank market decreases, banks charge higher interest rate to compensate for the higher risk. WIBOR-OIS spread is independent of the policy rate. Thus, it is a better measure of the credit risk than the WIBOR rate.

1-month spreads was slightly delayed. The shape of the yield curve also reflects the confidence crisis. The growth of the spread between the short- and long-term rates (Figure 4) was caused by the rising aversion of the commercial banks to lend for long terms and the fact that the transactions concentrated mostly on the market of instruments of maturity shorter than a week. Furthermore, making the information about the condition of the world biggest bank groups public, resulted in a decrease of the value of the household deposits.

As a result of the rising uncertainty on the market, the liquidity demand grew. Commercial banks aimed at maintaining significant liquidity surpluses on their current accounts. Since the reserves above the required ones, held with the NBP, are not remunerated, banks placed the accumulated excess funds with the central bank using standing deposit facility. In Figure 3 a substantial growth of the standing deposit facility is observed (the earlier increase at the end of 2007 was connected with reporting period and efforts of commercial banks to demonstrate their good liquidity positions). At the same time, banks participated less actively in tenders for main open market operations. This was reflected in so called "underbidding" (appearing for the first time at the end of June) which in turn affected significantly the volatility of the POLONIA rate.

In order to avoid situations in which the demand for open market operations would exceed the supply, on 17 October 2008 the NBP decided not to announce the volume of the bills supply. This so called "passive" monetary policy (each time the NBP accepted the total demand received from banks in the tender) weakened the central bank's ability to steer the POLONIA rate. In order to stimulate the interbank market and reactivate lending, in February 2009 the NBP decided to leave the liquidity surplus in the market, which limited the supply of NBP bills. As a consequence, commercial banks overstated their demand in order to purchase as much bills as possible. In the two tenders in March 2009 banks reported demand which exceeded their reserves held in the current accounts. The huge rise of the demand translated into the undesirable fall of the POLONIA rate, which almost reached the level of the deposit rate. Return to the active monetary policy did not revive the interbank market: the limits for transactions remained low, and commercial banks – unable to purchase the desired volume of the bills - held deposits with the central bank. However, the relation between the demand and the supply of the bills (unfavourable to banks) caused the POLONIA rate to return to the deposit rate level. Therefore, since April 2009 the NBP has been gradually increasing the bills supply. The POLONIA rate returned to the reference rate level at the beginning of June, but in mid-June it decreased again due to the aforementioned underbidding.

The highest underbidding was observed in tenders in November and December 2009, when the biggest Polish insurance company PZU accumulated money in order to pay dividends. Moreover, with regard to the upcoming reporting period, banks wanted to improve their liquidity positions. In consequence, we experienced the long-lasting fall of the POLONIA rate.

At the beginning of 2010 the interbank market was slightly more liquid. The POLONIA rate remained about 75 basis points below the reference rate, but its fluctuations were significantly smaller. Furthermore, the 3- and 6-month interest rate spread was decreasing.

For the above reasons, the spread between the POLONIA rate and the NBP reference rate was stationary until the third quarter of 2008, but starting from the end of 2008 it showed completely different properties. Therefore, we decided to divide the period under study into two parts. Arbitrarily, we chose the date of the Lehman Brothers collapse as the optimum moment for the data division.

3. Methodology

3.1. Testing for the long memory

Empirical analysis shows that simple division of time series into integrated of order 0: $I(0)$ (i.e. not integrated) and of order one: $I(1)$ may not explain some of their properties. Therefore, there was proposed a new class of time series – a fractionally integrated one, usually denoted by $I(d)$. This class of model was considered by Taqqu (1975), Granger and Joyeux (1980), Granger (1981) and Hosking (1981). The authors introduced an ARFIMA (p, d, q) model which can be presented in the following form:

$$\phi(L)(1-L)^d(y_t-\gamma)=\theta(L)\varepsilon_t \tag{1}$$

where $\varphi(L)$ and $\theta(L)$ denote the lag-polynomials of the form

$$\phi(L)=1-\phi_1 L-\ldots-\phi_p L_p \quad \text{and} \quad \theta(L)=1-\theta_1 L-\ldots-\theta_q L_q \tag{2}$$

and ε_t is the sequence of the *iid* random variable. The parameter d is the fractional integration parameter, and the expression $(1-L)^d$ is called fractional difference operator. Based upon the value of d, we can identify the following features of the financial time series:

– if $d\in(0,0.5)$, then the process is covariance stationary and has long memory; the speed of autocorrelation decay depends on the value of d;

– if $d\in(0.5,1)$, then the process is non-stationary, but mean-reverting; the autocorrelation disappears after a long time;

– if $d>1$, then the process is non-stationary and it does not revert to the mean; the effects of shocks are durable;

– if $d\in(-0.5,0)$, then the memory of the process is of average length.

In order to identify the parameter d we used several popular methods. We applied the estimator of Robinson (1994), and used two nonparametric tests of long memory – the GPH test and the Whittle test. The first one was introduced by Geweke and Porter-Hudak (1983). The estimation of d is determined by the regression:

$$\ln I(\omega_j)=\ln I_u(\omega_j)-d\ln[4\sin^2(\omega_j/2)] \tag{3}$$

where $I(\omega_j)$ is a periodogram of y_t and $I_u(\omega_j)$ is a periodogram of the stationary short memory disturbance process with zero mean. The periodograms are evaluated at different spectral ordinates $\omega_j=2\pi j/T$ for $j=0,1,\ldots,T/2$, where T is the sample size. To test hypothesis $\hat{d}=d_0$ we use the following statistic, the distribution of which is standard normal under the null hypothesis

$$t_{d_0}^{GPH}=(\hat{d}-d_0)\cdot\left(\frac{\pi^2}{6\sum_{j=1}^{g(T)}(U_j-\bar{U})^2}\right)^{-0.5} \tag{4}$$

where $U_j=\ln[4\sin^2(\omega_j/2)]$, $\bar{U}$ is the sample mean of U_j for $g(T)=T^{\alpha}$ where $0<\alpha<1$.

The second test was described by Shimotsu and Phillips (2006). The local Whittle estimator of d can be obtained by minimizing the function

$$R_m(d) = \frac{1}{m}\sum_{j=1}^{m}\left[\log \hat{G}(d) - 2d\frac{1}{m}\sum_{j=1}^{m}\log(\omega_j)\right] \tag{5}$$

where m is the bandwidth parameter and

$$\hat{G}(d) = \frac{1}{m}\sum_{j=1}^{m} I_{\Delta^d y_t}(\lambda_j)\lambda_j^{2d} \tag{6}$$

The test hypothesis is: $\hat{d} = d_0$ and the test statistic $t_{d_0}^{LW} = m^{1/2}(\hat{d} - d_0)$ is normally distributed: $N(0,1/4)$ (see Shimotsu, Phillips 2006 for more details).

The most popular tools for discovering long memory in time series are the nonparametric tests. An alternative, proposed by Sowell (1992), is a maximal likelihood estimator. However, estimation of the parameter d is computationally very demanding, because it requires inverting the $T \times T$ matrices. For further discussion on the maximal likelihood estimator of the parameter d we refer the Reader to the article by Doornik and Ooms (2003).

3.2. C-GARCH model

In the standard GARCH model introduced by Bollerslev (1986), the conditional variance converges monotonically to the unconditional one, which equals $\overline{\omega} = \frac{\omega}{1-\alpha-\beta}$. Standard GARCH(1,1) model can be presented in the following form:

$$\begin{aligned} y_t &= \sqrt{h_t}\varepsilon_t \\ h_t &= \overline{\omega} + \alpha(y_{t-1}^2 - \overline{\omega}) + \beta(h_{t-1} - \overline{\omega}) \\ \varepsilon_t &\sim iid(0,1) \end{aligned} \tag{7}$$

where y_t is the residual series from the linear model. Engle, Lee, Granger (1993; 1999) substitute trend for $\overline{\omega}$. The trend is described by the second equation and usually is called the long-run variance component. The model was called C-GARCH (Component GARCH) and can be described by the following system of equations:

$$\begin{aligned} h_t - m_t &= \alpha(y_{t-1}^2 - m_{t-1}) + \beta(h_{t-1} - m_{t-1}) \\ m_t &= \omega + \rho(m_{t-1} - \omega) + \phi(y_{t-1}^2 - h_{t-1}) \end{aligned} \tag{8}$$

The parameter h_t again describes the variance, while m_t is its long-run component. Furthermore, the value of α indicates the negative significant initial impact of a shock to the transitory component, and β – the positive and significant degree of memory in the transitory component. The sum of α and β is the measure of the persistence of transitory component. The long-run variance component converge to ω with powers of ρ. The parameter ρ usually takes value between 0.99 and 1, meaning that the long-run variance component approaches ω very slowly.

Moreover, Engle, Lee, Granger (1993) show that C-GARCH model can be written in the GARCH(2,2) representation

$$
\begin{aligned}
h_t &= (1-\alpha-\beta)(1-\rho)\omega + (\alpha+\phi)y_{t-1}^2 - (\alpha\rho + (\alpha+\beta)\phi)y_{t-2}^2 \\
&+ (\beta-\phi)h_{t-1} - (\beta\rho - (\alpha+\beta)\phi)h_{t-2}
\end{aligned}
\tag{9}
$$

Engle, Lee, Granger (1999) and Christoffersen et al. (2008) prove that using C-GARCH explains the variance better than the standard GARCH. Application of the C-GARCH model is justified if the variance of the series is not stationary, i.e. the sum of α and β is close to 1. Non-stationarity is often caused by stochastic trend (see Bollerslev, Andersen, Diebold 2004).

If the impact of positive and negative returns on the transitory component is asymmetric, we can apply the Component Threshold GARCH, which is described by the formulas:

$$
\begin{aligned}
h_t - m_t &= [\alpha + \gamma I(y_{t-1} < 0)](y_{t-1}^2 - m_{t-1}) + \beta(h_{t-1} - m_{t-1}) \\
m_t &= \omega + \rho(m_{t-1} - \omega) + \phi(y_{t-1}^2 - h_{t-1})
\end{aligned}
\tag{10}
$$

where $I(y_{t-1} < 0)$ is a dummy variable for asymmetric effect. An additional parameter γ is called an asymmetry parameter. The expression $\alpha + \beta + 0.5\gamma$ is the measure of the transitory component persistence.

4. Empirical results

In the following section we present empirical results obtained for the POLONIA spread. First, we tested the stationarity of the spread. Table 2 presents the results of $I(0)$ and $I(1)$ tests. The former was introduced by Robinson and Lobato (1998). It allows to identify the negative order of integration (we can assume that $d < 0$ with rejection in the lower tail). We apply Kwiatkowski et al. (1992) test for maximum lag equal to $4(T/100)^{0.25}$, similarly as Schwert (2002). The last test of $I(0)$ is based upon the long-range autocovariances and is called HML (named after authors: Harris, McCabe, Leybourne 2008). The HML statistic depends on two parameters, a truncation parameter c where $k = cT^{1/2}$ is the lowest-order lag, and L, where $l = LT^{12/25}$ is the bandwidth truncation of the variance parameter. We decide to choose $c = 1$ and $L = 2/3$, based upon simulation research of Harris, McCabe and Leybourne (2008). For such values the test has both big power and small size.

Next, we tested the data for the unit root. We took advantage of the ADF test (Said, Dickey 1984) with the maximum lag chosen based upon the Hahn-Quinn information criterion, as well as of the PP test (Phillips, Perron 1988), with the maximum lag equal $4(T/100)^{0.25}$ as in Perron (1988). We also used the modified ADF test and the feasible likelihood ratio test – the P test (Elliott, Rothenberg, Stock 1996). Eventually, we display the results of Ng and Perron (2001), denoted by MSB and MPT.

The results of the test indicate the lack of unit root in the spread between the POLONIA rate and the NBP reference rate over the period 02.01.2006–30.06.2010. The stationarity test results show that the spread in the aforementioned period was not stationary. However, if we examine the two periods separately (02.01.2006–15.09.2008 and 16.09.2008–30.06.2010) all the tests fail to reject the null hypothesis. Therefore, we can assume that the results of the stationarity test for the whole period are the consequence of the structural change at the end of the third quarter of 2008. For that reason, we decided to model the spread, not its first differences, using the linear model.

In order to better identify the properties of the POLONIA spread we tested also the long memory. We applied the methods described in Section 3. In the case of the GPH test we applied the bandwidth equaled $T^{0.5}$ (see Koong, Tsui, Chan 2005). In the Whitlle test we determined the bandwidth using the formula proposed by Henry (2001) :

$$m^{opt} = \left(\frac{3}{4\pi}\right)^{4/5} \left|\frac{1}{d^*/12-2}\right|^{2/5} T^{4/5}$$

We substituted the estimate of the parameter d from the ARFIMA model for the value of the unknown parameter d^*. Similarly to Hassler and Nautz (2008), we assume that the order of fractional integration of the POLONIA spread is a measure of the central bank's ability to control the POLONIA rate. The stationarity of the spread is the necessary condition for retaining the full control over the POLONIA rate by the central bank. The non-stationarity of the spread can be interpreted as loss of control.

In the case of the POLONIA spread over the period 02.01.2006–30.06.2010, test results do not provide clear evidence concerning its properties. On the one hand, all the methods show that the parameter d takes value from the range (0.37, 0.44) and the $t_{0.5}^{LW}$ statistics rejects the null hypothesis. On the other hand, the $t_{0.5}^{GPH}$ test does not reject the hypothesis $d = 1$, which suggests that the spread can be non-stationary.

If we take into account the two sub-periods (02.01.2006–15.09.2008 and 16.09.2008–30.06.2010) and apply the long memory tests to both sub-periods separately, we obtain entirely different results. The tests showed that the POLONIA spread before the Lehman Brothers bank bankruptcy was stationary and had at most "small" long memory. It suggests that before the fall of Lehmann Brothers, the NBP had strong control over the POLONIA rate. In the case of the spread over the period 16.09.2008–30.06.2010 the results of the tests are more convincing. All estimates of the parameter d take value from the range (0.22, 0.29) and the GPH and White tests reject the hypothesis $d = 0$ and $d = 0.5$. Therefore, we can assume that, after the fall of Lehman Brothers and the transmission of the confidence crisis to Poland, the NBP retained control over the POLONIA rate, but the degree of controllability was smaller than before.

Since the two considered sub-periods are too short, we decided to model the POLONIA spread over the whole period. Following Schianchi and Verga (2006) and Linzert, Schmidt (2008) we use AR(1) model with additional explanatory variables. The presence of long memory in the spread suggests that conditional mean should be described by the ARFIMA process. However, in the case under discussion the persistency is explained by the exogenous variables linked to pre-specified aspects of monetary policy, and the ARFIMA d parameter is insignificant.

Hassler and Nautz (2008) regressed the EONIA spread on a small set of calendar dummies, i.e. end-of-month, end-of-quarter, and end-of-year observations. Subsequently, they excluded the observations from the last reserve maintenance days. Since in Poland the last maintenance days is the last day of the month (sometimes a day earlier or later), we omitted the end-of-month dummy variable. Moreover, the end-of-quarter and end-of-year dummies were statistically insignificant.

Linzert and Schmidt (2008) used a bid-to-cover ratio to describe the spread. The bid-to-cover ratio is defined as the ratio between the total bid volume of monetary bills and the amount covered. This variable reflects the degree to which the overliquidity was absorbed by the central bank. The part of the surplus which was not absorbed by the central bank tends to be/was located in the interbank market. This affects the money supply in the interbank market and naturally influences the interbank rates levels. The degree of influence is the biggest for EONIA rate. Therefore, a positive relation exists between the spread and the bid-to-cover ratio. The idea by Linzert and Schmidt (2008) proves correct under the assumption that the underbidding does not occur in the monetary bills auction. As we mentioned above, the underbidding causes a decrease in the spread, but when it occurs the value of bid-to-cover ratio is the highest. Therefore, we decided to introduce two variables instead of the bid-to-cover ratio. If a monetary bills auction ends with underbidding, the first variable *bidtocovo* equals 1; otherwise it is equal to bid-to-cover ratio. The second variable, *covertobidu,* is equal to the cover-to-bid ratio if the underbidding occurs, and otherwise it is equal to 1.

Analysing the spread we can observe changes that are related to the so called "crisis of confidence". In the second half of 2008 the value of the spread diminished and its volatility increased. We introduced the variable $3mwos_t$, which represents the level of 3-month WIBOR-OIS spread and is the measure of intensity of the confidence crisis in the Polish interbank market. We chose it over 1-month WIBOR-OIS, based upon the values of R^2 coefficient and information criteria.

Similarly to Linzert and Schmidt (2008), we introduced to the model the spread between one-week OIS rate and the reference rate (*1wois_ref*). The variable represents the interest rate expectations of commercial banks participating in main refinancing operations as held over the maintenance period. High rate expectations within the maintenance period cause an increase in the bid rate in the interbank market. In particular, the growth of the cost of overnight money drives the increase of the POLONIA spread. Linzert and Schmidt (2008) explain the relation between the EONIA spread and the interest rate uncertainty. Analogously, we decided to introduce the conditional variance of the one-week swap rate to the POLONIA spread as an interest rate uncertainty measure (variable *var_1wois*).

Following Nautz and Offermanns (2007), Haldrup and Nielsen (2007), Hassler and Nautz (2008), and Schianchi and Verga (2006) we decided to filter the POLONIA spread to minimize the influence of the required reserve maintenance system on the test results.

Similarly to Schianchi and Verga (2006), we took into consideration the influence of the difference between making deposits and taking loans in the central bank. This variable allows us to explain the results of reserve maintenance cycle, since it represents the liquidity surplus at the end of the reserve maintenance period, which is a consequence of the preterm fulfilment of reserve requirements by a commercial bank. Schianchi and Verga (2006) assumed that the influence is nonlinear. Thus, they introduced a variable equal to the balance of taking loans and making deposits to the third power. However, in the case of the Polish market we were not able to identify any nonlinear relationship between the deposits made and loans taken in the NBP and the spread value. Therefore we modelled only linear dependencies between the spread and the variables. Finally we arrived at the following linear model:

$$x_t = a_1 x_{t-1} + c_1 bidtocovero_t + c_2 covertobidu_t + c_3 3mwos_t + c_4 1wois\_ref + c_5 \text{var\_}1wois + c_6 depo\_cred_t + y_t \tag{11}$$

where x_t denotes the level of the spread at the moment t, and $y_t \sim N(0, \sigma)$.

In Table 4 we present the descriptive statistics of the residuals from the model (11), and in Figure 9 – the histogram of the residuals from the model. We stress the fact that the asymmetry of the empirical distribution of the residual series is very small, as compared to the spread distribution. It means that we managed to describe most of the factors which led to the negative fluctuations of the spread. In Figure 10 we present the ACF and PACF values of the residuals with the results of the Ljung, Box (1978) test. It is observable that model (11) eliminated autocorrelation from the POLONIA spread time series. The significance level is slightly exceeded by the 10$^{\text{th}}$- and 20$^{\text{th}}$-order autocorrelation.

In Table 5 we present the results of the two conditional heteroskedasticity tests – the ones introduced by Engle (1982) and White (1980), respectively. Both of them were applied in two versions. The tests results show unanimously that conditional heteroskedasticity is observed in the spread over the period 02.01.2006–30.06.2010. In the third quarter of 2008 the so called "confidence crisis" was transmitted to Poland, which resulted in a significant increase in the conditional variance. Hence, we applied the C-GARCH model with Gaussian innovations so as to model nonlinear relations in the spread. We decided to introduce additional explanatory variables to the C-GARCH model. We took into consideration the underbidding and overbidding which appeared in the monetary bills tenders. We introduced the following two variables to the model – $underbid_t$ and $overbid_t$. The former equals the difference between the number of bills offered and bid during a single day of monetary bills tender and the underbidding. If the difference is negative the $underbid_t$ is 0. Analogously, the $overbid_t$ equals the difference between the number of bills bid and offered in the case of overbidding in the monetary bill tender, or else it equals 0. The influence of both variables on the spread should be positive. The underbidding in the monetary bills tender means that the central bank absorbed less liquidity than it had planned. Short-term loss of ability to stabilize the POLONIA rate by the central bank causes growth of the volatility. In the case of the overbidding, commercial banks do not invest the whole surplus in central bank. In consequence, they invest the surplus in the interbank market for one day. This generates negative shocks to the POLONIA level, and accordingly the variance of the POLONIA is growing. Empirical studies of Vila Wetherilt (2002) show that the impact of exogenous variables in C-GARCH model on endogenous variable is similar irrespectively of the equation in which they are added. We decided to add the $underbid_t$ and $overbid_t$ variables to the long-term variance equation, since it improves the fit of the model. Below we present model (11) with residuals described by the C-GARCH:

$$\begin{aligned} x_t &= a_1 x_{t-1} + c_1 bidtocovero_t + c_2 covertobidu_t + c_3 3mwos_t + c_4 1wois\_ref \\ &\quad + c_5 var\_1wois + c_6 depo\_cred_t + y_t \\ y_t &= \sqrt{h_t}\,\varepsilon_t \\ h_t - m_t &= \alpha(y_{t-1}^2 - m_{t-1}) + \beta(h_{t-1} - m_{t-1}) \\ m_t &= \omega + \rho(m_{t-1} - \omega) + \phi(y_{t-1}^2 - h_{t-1}) + \gamma_1 underbid_t + \gamma_2 overbid_t \end{aligned} \tag{12}$$

where $\varepsilon_t \sim N(0,1)$.

In Table 6 we present the estimates of the parameters of the linear model with the residuals described by the C-GARCH model. The significance of the parameters is assessed with the help of the *t*-ratio test. As we can see in Figure 5, the C-GARCH model successfully *filtered the autocorrelation* in the squared residuals.

To verify hypothesis of the influence of the open market operations on the spread, we introduced additional explanatory variables to model (12) which represent their scale. The balance of the open market operation is presented in Figure 6. All of them were considered separately. The variables $main^1$ and $main^2$ represent the scale of the main refinancing operations, performed before 15 September and after 15 September respectively. According to the Monetary Policy Guidelines for the years 2008, 2009 and 2010 the NBP strived to impact the liquidity condition in the banking sector through main operations in such a way so as to enable the POLONIA rate to run close to the NBP reference rate. In order to assess the impact of the liquidity-providing long-term repo operations on the liquidity conditions of the commercial banks, we introduce the variable *repo*, which represents the scale of performed operations. The variable *bills* represents the scale of the additional issuance of the NBP bills with maturity shorter than the maturity of the basic operation. Issuance of such instrument took place only twice. Estimates of the explanatory variables and their diagnostics are presented in Table 7 and Table 8.

Analysing the results of the *t*-ratio tests of all additional explanatory variables we can assess which operations influenced the value and variance of the spread. Our results show that the main operations performed before 15 September 2008 affected the spread with 2-day delay, and after 15 September 2008 the spread reacted to the operations immediately or with 1-day delay. The degree of the influence is too small to maintain the POLONIA rate on the level of NBP reference rate. The NBP was unable to effectively manage the liquidity in the banking sector due to the aforementioned underbidding. Moreover, as mentioned before, starting from October 2008 the central bank stopped announcing the supply of the bills and sold them in amounts covering the total demand, while after February 2009 it introduced strong limitations on the supply of the bills.

Based upon the results of the *t*-ratio tests for individual explanatory variables we conclude that the *repo* operations influenced immediately the level of the spread. The banks possessing long-term liquidity could lend money to other banks for short periods, and this could cause the increase of the short-term deposits. However, this strategy would be profitable in the interbank market only in the case of the loans of maturity not shorter than 3 months. In the situation of the confidence crisis, the market of such long maturity loans practically did not exist. The reasons for introducing the repo operations were different. They were performed during the period in which some banks were ready to absorb practically unlimited amount of liquidity. Other banks profited from low interest rate of repo operation borrowing money to purchase treasury bills of interest rates higher than the those of the repos. That is why the repo operations could not have the immediate influence on the POLONIA spread. The short-term response of the spread to the repo operation can be explained differently. When liquidity is supplied into the interbank market in huge amount, the risk of insolvency of commercial banks diminishes and the effects of confidence crisis become less perceptible. In consequence, the spread between the short- and long-term WIBOR rates reduces (short-term rates rise and long-term rates plummet). Thus, the POLONIA spread increases. On the other hand, if we take into account that the estimate of the *repo* parameter is small, as well as the scale of the repo operations, then the influence of the latter on the increase of the spread amounts to 0.01% – 0.2%. Thus, it is not significant from our point of view.

The estimates of the parameters representing the turnover of 2- and 3-day NBP bills are not significant, which suggests that these operations did not influence the spread. We assume that the operations were conducted in order to absorb liquidity in the situation of growing aversion to purchasing 7-day bills. However, the demand for the 2- and 3-day bills was very small (and probably that is why the NBP abstained from implementing this kind of policy later on) and thus the impact of the operations on the POLONIA rate could not be significant. The authors of *Report on Monetary Policy Implementation in 2008* state, that the impact of both operations on the POLONIA rate was “rather slight and temporary”.

The main operations had significant impact on the long-term component of conditional variance of the POLONIA spread both before and after 15 September 2008. In the former period the main operations led to a decline in volatility. Therefore, we can assume that before 15 September 2008 the main operations stabilized the POLONIA rate. In the crisis period they led to the growth of the volatility of the spread. The growth of the scale of the POLONIA rate disturbances was caused also by the aforementioned underbidding as well as by the problems with forecasting the liquidity conditions. There exists a significant influence of the main operations on the transitory variance component. The parameters estimates have different signs depending on the lag. Therefore, the significance of variable $main_t^1$ in the transitory variance component equation may be illusory. The main operations are conducted on Fridays, when the variance of POLONIA rate is usually raised.

Our results show that the repo operations influenced conditional variance of the spread. Sudden changes of liquidity conditions in the interbank market caused the increase of the volatility of the POLONIA rate. The repo operations were performed always on Thursdays, and their scale was determined by the demand. Thus, it was even more difficult to determine the supply of 7-day bills, the tenders of which were organized on following Fridays. Therefore, the ability of the NBP to stabilize the POLONIA rate was decreasing, and the volatility of the POLONIA rate was growing. Variable representing one day delayed *bills* is significant in the long-term and transitory variance equation. If we take into account that the demand for 2-day and 3-day bills is very small, we can assume that the impact on the variance is negligibly small.

5. Conclusions

Our results of the examination of long memory in the spread between POLONIA rate and the NBP reference rate show that the National Bank of Poland retains control over the spread. However, the increased persistence of the spread suggests that the degree of controllability of the POLONIA spread after 15 September 2008 may have declined considerably. The main operations performed after the bankruptcy of Lehman Brothers had influence on the spread, but their strength was too small to maintain the POLONIA rate on the level of the NBP reference rate, and many factors connected with the confidence crisis made effective liquidity management difficult.

On the other hand, there exist channels of monetary policy transmission other than main operations. The NBP deposit rate and the NBP lombard rate are the lower and upper ceilings of the POLONIA rate fluctuations, respectively (the lombard rate may be exceeded if a bank does not possess adequate collateral to secure repayment of the lombard loan in the NBP, and it borrows the money from other banks at higher interest). Naturally, the NBP was able to restrict the fluctuation band of the POLONIA rate. However, the experience of the European Central Bank shows that such a move causes strong decrease of turnover in the interbank market. In the situation of low confidence in the interbank market, the NBP aimed to revive it, and therefore it kept fluctuation band of the POLONIA rate unchanged at +/-1.5 percentage point. On 17 October 2008 the Confidence Pact came into force. The Pact introduced the long-term repo operations (which enabled banks to obtain liquidity for longer periods) and extended the list of securities acceptable as collateral for NBP refinancing operations (which enabled banks to obtain liquidity for shorter periods). The Confidence Pact allowed commercial banks to obtain funds in the central bank if they were unable to obtain them from other banks. Unfortunately, the Pact did not stimulate the reconstruction of the confidence. After 15 September 2008 commercial banks made rushed decisions to reduce limits of interbank transactions, and they are still increasing them reluctantly. However, as we can observe in Figure 5, the amount of overnight transactions has been constantly increasing since the third quarter of 2009.

It is worth mentioning that at the end of the examined period, when the signs of the end of the crisis kept appearing, we observe positive changes. The volatility of the POLONIA rate has been decreasing and the value of the spread has been tending slowly to 0. Number of deposits made in the central bank has been diminishing, the total turnover in the interbank market rising, and the yield curve becoming more flat.

The rise of the divergence between the POLONIA and the NBP reference rate was caused by the change of the priorities of the central bank after the fall of Lehman Brothers as, first of all, the NBP aimed at providing liquidity into the interbank market. On the other hand, the central bank was effectively influencing the POLONIA rate over the third quarter of 2008. Taking this into account, we support the thesis, that the National Bank of Poland can efficiently stabilize the POLONIA rate.

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Appendix

Table 1
The descriptive statistics of the spread between the POLONIA rate and NBP reference rate over the period 02.01.2006–07.05.2010

Mean	**Median**	**Maximum**	**Minimum**	**Std. deviation**	**Asymmetry**	**Kurtosis**
-0.334575	-0.05	1.47	-1.55	-0.536089	-0.669179	2.818439

Table 2
The results of unit root and stationarity tests applied to the spread between the POLONIA and NBP reference rate

Series	**I(0)**			**I(1)**					
	RL (1998)	**KPSS (1992)**	**HML (2008)**	**ADF (1984)**	**PP (1988)**	**DF--GLS (1996)**	**P (1996)**	**MSB (2001)**	**MPT (2001)**
Spread 02.01.2006–30.06.2010	8.23887 (0)	5.97155 (<0.01)	6.614 (0)	-11.228 (<0.01)	-10.717 (<0.01)	-11.207 (<0.01)	0.23056 (<0.01)	0.08968 (<0.01)	0.40433 (<0.01)
Spread 02.01.2006–15.09.2008	-0.545 (0.707)	0.04547 (>0.1)	0.42518 (0.335)	-17.381 (<0.01)	-15.561 (<0.01)	17.395 (<0.01)	0.51304 (<0.01)	0.04768 (<0.01)	0.11353 (<0.01)
Spread 16.09.2008–30.06.2010	-3.2526 (0.999)	0.01335 (>0.1)	1.2401 (0.107)	-23.323 (<0.01)	-23.374 (<0.01)	-23.013 (<0.01)	0.06547 (<0.01)	0.13571 (<0.01)	0.90271 (<0.01)

Table 3

The results of long memory tests applied to the spread between the POLONIA and NBP reference rate

Series	**Robinson *d***	**Semiparametric long memory tests**		
			GPH test	**Whitlle's test**
Spread 02.01.2006–30.06.2010	0.34369	est. of d	0.43929	0.36511
		t_0^{GPH} / t_0^{LW}	4.0255 (1.42E-5)	5.9886 (0)
		$t_{0,5}^{GPH} / t_{0,5}^{LW}$	-0.55632 (0.1445)	-2.2125 (0.0067)
Spread 02.01.2006–15.09.2008	0.24669	est. of d	0.06237	0.09752
		t_0^{GPH} / t_0^{LW}	2.0039 (0.01126)	1.3058 (0.0479)
		$t_{0,5}^{GPH} / t_{0,5}^{LW}$	-2.44369 (0.003635)	-5.3891 (0)
Spread 16.09.2008–30.06.2010	0.24199	est. of d	0.22528	0.2628
		t_0^{GPH} / t_0^{LW}	2.0039 (0.01127)	2.9815 (0.0007)
		$t_{0,5}^{GPH} / t_{0,5}^{LW}$	-2.44369 (0.003635)	-2.6911 (0.0018)

Table 4

Descriptive statistics of residuals from the model (11)

Mean	**Median**	**Maximum**	**Minimum**	**Std. deviation**	**Asymmetry**	**Kurtosis**
0.05282	0.08250	1.34668	-1.015171	0.233276	-0.002377	7.771248

Table 5

The results of the conditional heteroskedasticity tests applied to the residuals of the spread between the POLONIA rate and NBP reference rate

	Engle's test	**White's test**
F test	541.2430 (0)	40.69604 (0)
nR^2 test	367.4376 (0)	173.4586 (0)

Table 6

Parameters estimates of model (12) with residuals described by the C-GARCH model (Gaussian innovation)

Parameter	Parameter estimates (standard error)	*t*-ratio test (*p*-value)
a_1	0.689132 (0.022775)	30.25812 (0)
c_1	0.053749 (0.012720)	4.225460 (0)
c_2	0.406233 (0.060761)	6.685729 (0)
c_3	0.242695 (0.030819)	7.874866 (0)
c_4	-0.100553 (0.014227)	-7.067655 (0)
c_5	1.047499 (0.459042)	2.281925 (0.0227)
c_6	8.49E-05 (3.78E-06)	22.45708 (0)
α	0.390176 (0.051589)	7.563184 (0)
β	0.568628 (0.050192)	11.32901 (0)
ω	0.298940 (0.040505)	7.380266 (0)
ρ	0.981213 (0.003116)	314.9266 (0)
ϕ	0.546091 (0.049761)	10.97433 (0)
γ_1	2.36E-05 (3.33E-6)	7.078319 (0)
γ_2	1.14E-06 (6.84E-8)	16.67356 (0)

Table 7

Estimates of the parameters of additional explanatory variables introduced in conditional mean equation of model (12)

Parameter	Parameter estimates (standard error)	*t*-ratio test (*p*-value)
$main_t^1$	-6.90E-7 (9.09E-7)	-0.758184 (0.4485)
$main_{t-1}^1$	2.05E-7 (9.12E-7)	0.225092 (0.8220)
$main_{t-2}^1$	1.83E-6 (9.06E-7)	2.024639 (0.0432) **
$main_t^2$	-2.58E-6 (5.93E-7)	-4.347329 (0) ***
$main_{t-1}^2$	1.96E-6 (5.97E-7)	3.284622 (0.0011) ***
$main_{t-2}^2$	-5.24E-7 (5.99E-7)	-0.87521 (0.3817)
$repo_t$	2.31E-5 (9.41E-6)	2.452964 (0.0143) **
$repo_{t-1}$	-5.45E-6 (9.44E-7)	-0.577532 (0.5637)
$repo_{t-2}$	8.37E-6 (9.45E-6)	0.886157 (0.3757)
$bills_t$	-3.85E-6 (5.28E-5)	-0.072839 (0.9419)
$bills_{t-1}$	7.95E-6 (5.28E-5)	0.150542 (0.8804)
$bills_{t-2}$	-2.17E-5 (5.28E-5)	-0.411445 (0.6808)

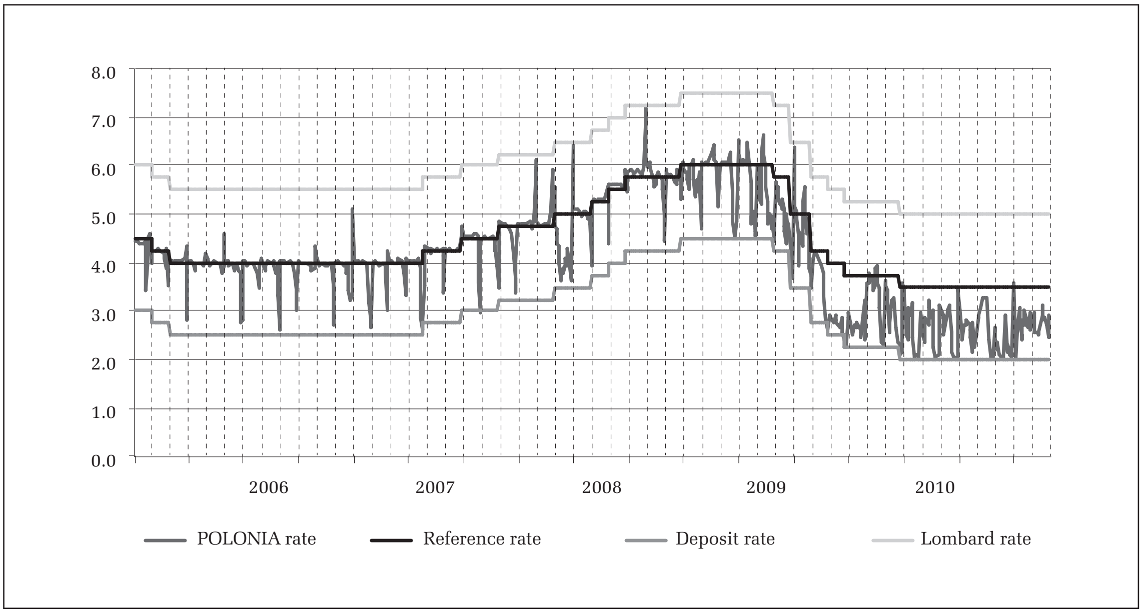
Table 8
Estimates of the parameters of additional explanatory variables introduced into conditional variance equations of model (12)

	The long-run variance component		**The transitory variance component**	
	parameter estimates (standard error)	***t*-ratio test (*p*-value)**	**parameter estimates (standard error)**	***t*-ratio test (*p*-value)**
$main_t^1$	-9.62E-7 (2.16E-8)	-44.4965 (0)	-9.31E-7 (4.21E--8)	-22.10619 (0)***
$main_{t-1}^1$	6.88E-7 (7.65E-8)	8.99871 (0) ***	1.02E-6 (8.23E-8)	12.41914 (0)***
$main_{t-2}^1$	–	–	-9.76E-7 (3.80E-8)	-25.67522 (0)***
$main_t^2$	7.67E-7 (4.26E-7)	1.79821 (0.072)*	2.39E-8 (1.43E-7)	0.16717 (0.867)
$main_{t-1}^2$	2.41E-6 (6.08E-7)	3.9633 (0)***	2.38E-6 (6.26E-7)	3.80725 (0)***
$main_{t-2}^2$	8.05E-7 (2.82E-7)	2.85221 (0.004)***	-1.83E-7 (4.11E-8)	-4.45945 (0)***
$repo_t$	3.87E-5 (1.51E-5)	2.56798 (0.01)***	7.92E-6 (2.89E-6)	2.74393 (0.006)**
$repo_{t-1}$	-1.57E-6 (3.43E-6)	-0.45656 (0.648)	-2.15E-6 (3.09E-6)	-0.69639 (0.486)
$repo_{t-2}$	-1.25E-6 (1.51E-6)	-0.8261 (0.409)	1.16E-6 (1.70E-6)	0.68214 (0.495)
$bills_t$	-1.08E-5 (3.19E-6)	-3.40025 (0)***	-1.18E-5 (1.36E-5)	-0.8729 (0.383)
$bills_{t-1}$	-8.60E-6 (3.21E-6)	-2.67414(0.008)***	-8.65E-6 (9.05E-5)	-0.09553(0.924) ***
$bills_{t-2}$	-5.00E-6 (5.00E-5)	-0.10009 (0.92)	-1.32E-5 (5.55E-6)	-2.37522 (0.017)***

Note: the lack of values means that maximization algorithm failed to converge for the model with this additional explanatory variable.

Figure 1

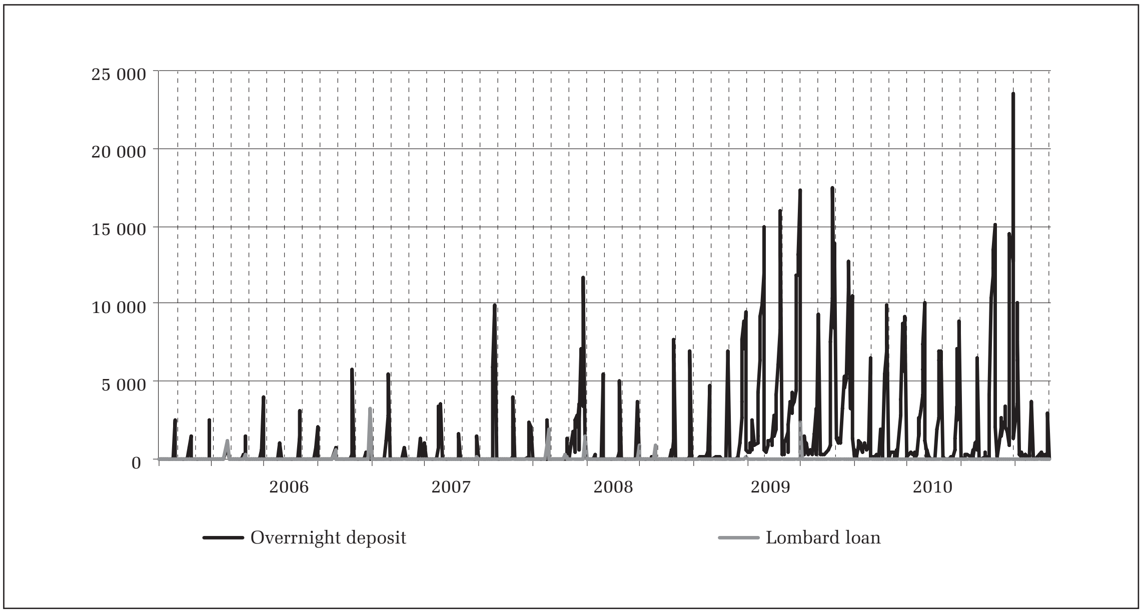
The POLONIA rate with the NBP reference rate, the NBP deposit rate, and the NBP lombard rate



Note: vertical dashed lines mean the end of the reserve maintenance period.

Figure 2

Amount of the overnight loans and deposits taken with the NBP (PLN million)



Note: vertical dashed lines mean the end of the reserve maintenance period.

Figure 3
Spread between the WIBOR rates and the OIS rates of maturities from 1 week to 1 year

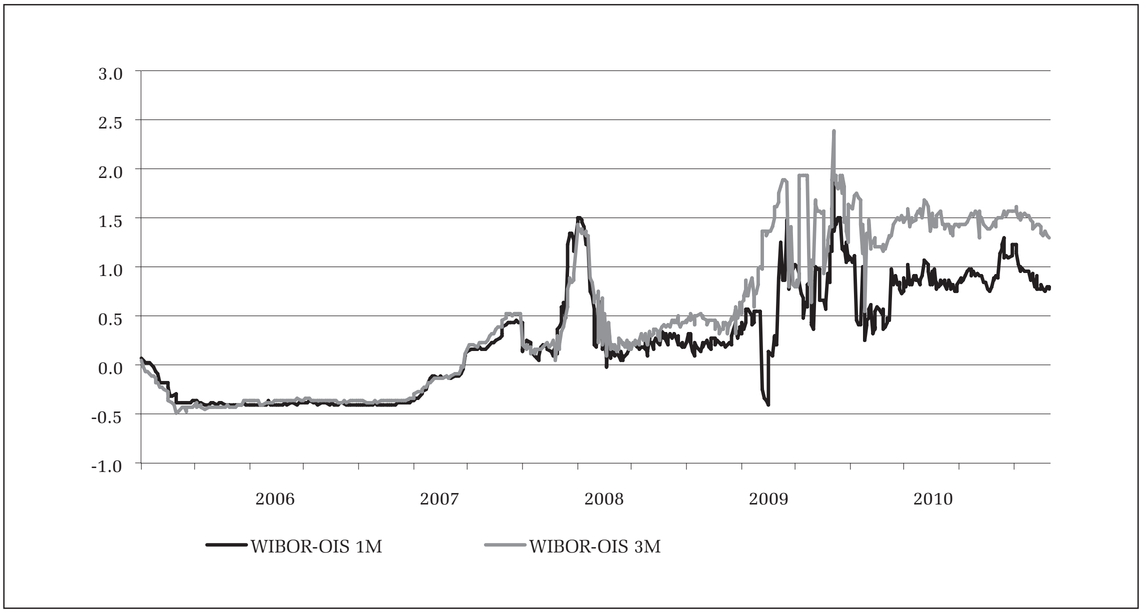


Figure 4
The POLONIA rate and the WIBOR rates of maturities from 1 week to 1 year

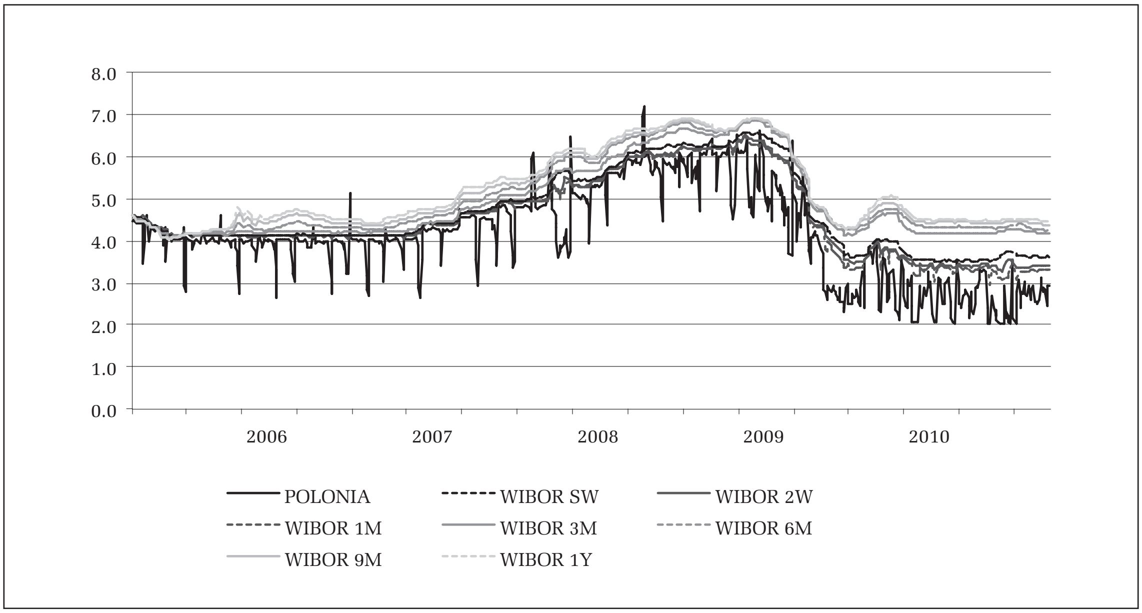


Figure 5
Monthly aggregated daily transactions in overnight (PLN million)

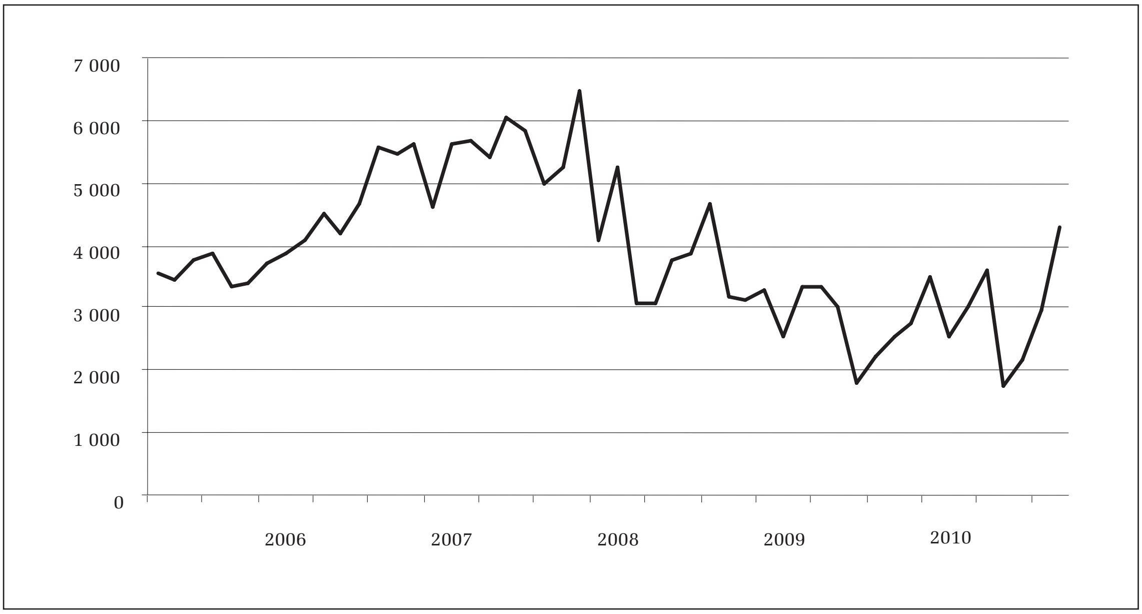


Figure 6
Monthly aggregated daily transactions in overnight (PLN million)

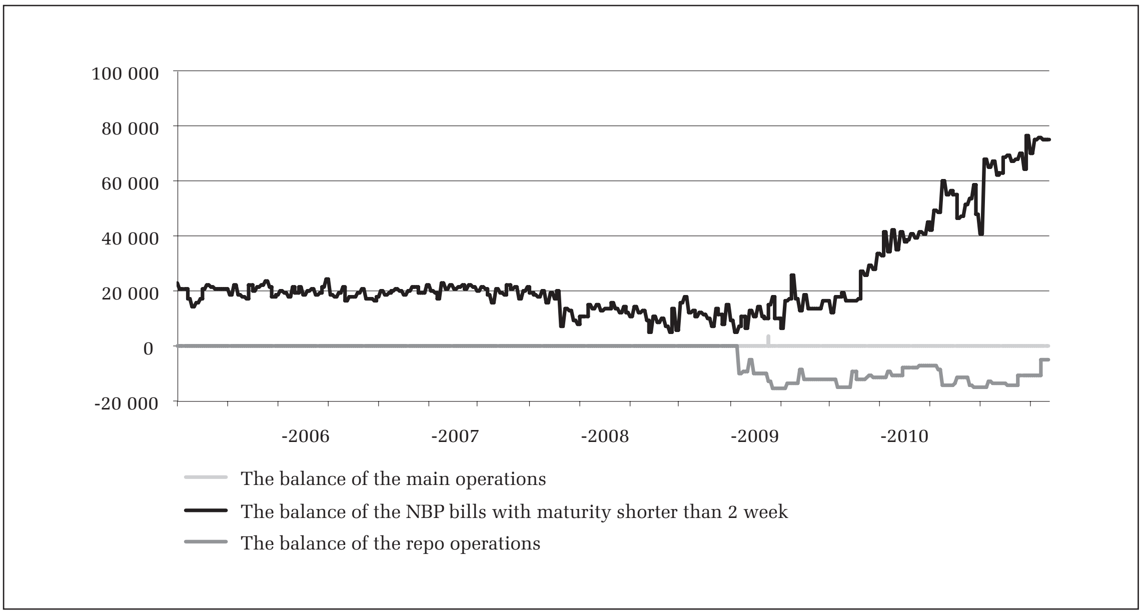


Figure 7

The histogram of the spread between the POLONIA rate and NBP reference rate over the period 02.01.2006–30.06.2010

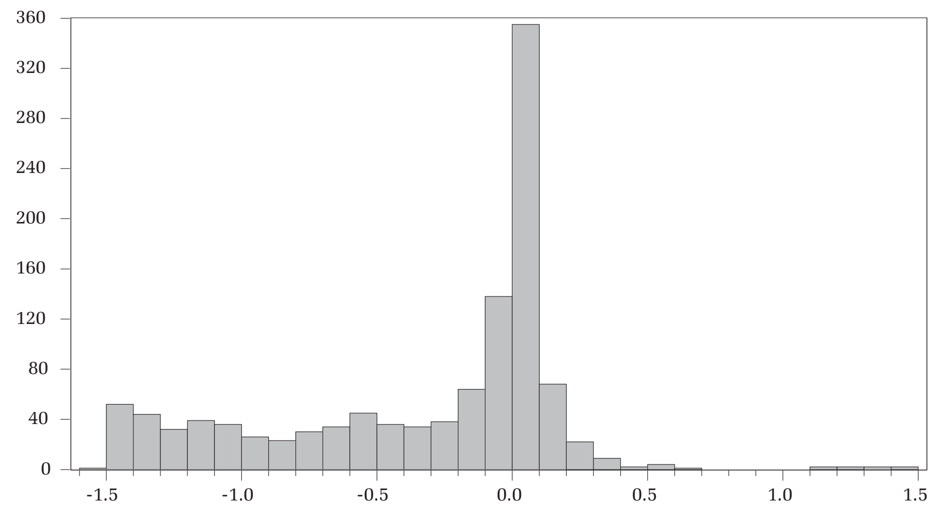


Figure 8

Average POLONIA spread and average volatility of the spread before the end of the minimum reserve maintenance period

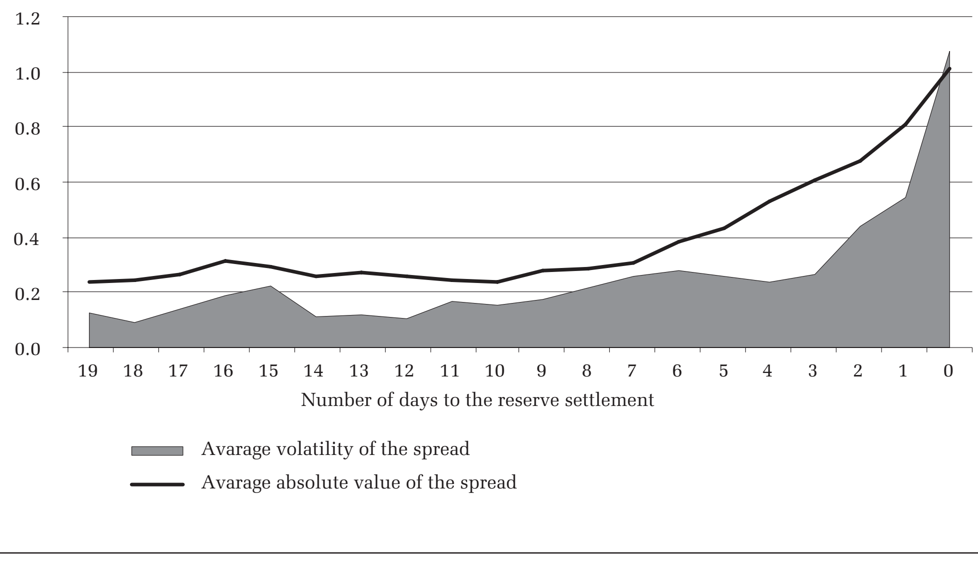


Figure 9
Histogram of the residuals from the model (11) of the spread between the POLONIA rate and NBP reference rate from the period 02.01.2006–30.06.2010

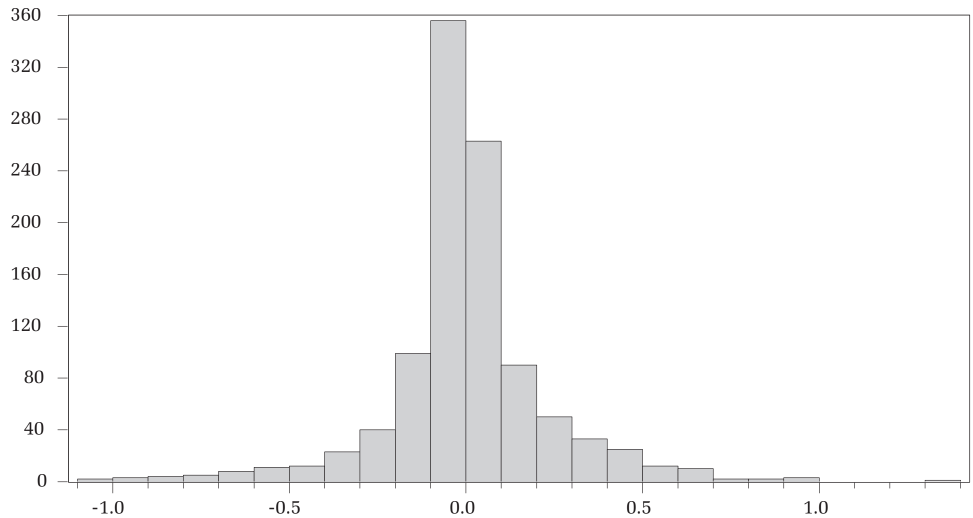


Figure 10
The ACF and the PACF of the residuals from the model (12) and results of the Ljung-Box *Q*-test

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.047	0.047	2.3296	0.127
		2	-0.036	-0.038	3.6830	0.159
		3	-0.006	-0.003	3.7215	0.293
		4	-0.026	-0.027	4.4363	0.350
		5	-0.045	-0.043	6.5612	0.255
		6	-0.025	-0.023	7.2420	0.299
		7	0.011	0.010	7.3765	0.391
		8	-0.005	-0.009	7.4021	0.494
		9	-0.012	-0.013	7.5508	0.580
		10	0.061	0.059	11.500	0.320
		11	0.020	0.012	11.934	0.369
		12	0.000	0.003	11.934	0.451
		13	-0.058	-0.057	15.513	0.276
		14	-0.032	-0.025	16.580	0.279
		15	-0.046	-0.043	18.817	0.222
		16	-0.069	-0.064	23.896	0.092
		17	-0.039	-0.041	25.563	0.083
		18	-0.007	-0.015	25.611	0.109
		19	0.019	0.011	26.010	0.130
		20	0.057	0.046	29.529	0.078

Figure 11
The ACF and the PACF of the squared standardized residuals from the model (12) with results of the Ljung-Box *Q*-test

Lag	AC	PAC	Q-Stat	Prob
1	-0.008	-0.008	0.0602	0.806
2	0.046	0.046	2.2813	0.320
3	0.014	0.015	2.4851	0.478
4	-0.018	-0.020	2.8344	0.586
5	-0.033	-0.035	3.9835	0.552
6	0.004	0.005	4.0004	0.677
7	-0.028	-0.024	4.8260	0.681
8	-0.017	-0.018	5.1458	0.742
9	-0.039	-0.039	6.7741	0.661
10	-0.026	-0.025	7.4897	0.679
11	-0.045	-0.042	9.6158	0.565
12	-0.024	-0.024	10.231	0.596
13	-0.020	-0.019	10.674	0.638
14	0.005	0.004	10.700	0.709
15	-0.020	-0.022	11.129	0.743
16	0.005	-0.002	11.152	0.800
17	-0.019	-0.022	11.523	0.828
18	0.009	0.004	11.615	0.866
19	0.045	0.042	13.778	0.796
20	0.067	0.062	18.620	0.547