RĪGAS EKONOMIKAS AUGSTSKOLA
STOCKHOLM SCHOOL OF ECONOMICS IN RIGA

SSE Riga Student Research Papers
2009: 5 (114)

LATVIAN OVERNIGHT INTERBANK RATES: DETERMINANTS AND PREDICTABILITY

Authors: Mārtiņš Bajārs
Arvis Tilgalis

ISSN 1691-4643
ISBN 978-9984-842-17-2

November 2009
Riga

Latvian Overnight Interbank Rates: Determinants and Predictability

Mārtiņš Bajārs

and

Arvis Tilgalis

Supervisor: Morten Hansen and Jevgenijs Babaicevs

May 2009
Riga

Abstract

In this paper the determinants of the spread between the daily Latvian interbank market rates and the Bank of Latvia target rates are determined. Moreover, the possibility of performing predictions on this spread is analyzed, the result of which is that the spread can be forecasted. Basing on out-of-sample one-step and multi-step predictions, EGARCH specification was declared to have the best predictive power of the Latvian interbank spread. The variables included in the model are based on martingale hypothesis, which is adjusted to deal for irrationality of the market participants. Clear and exact implications for the Bank of Latvia and the commercial banks are given as the result of the research.

Keywords: interbank rates, martingale hypothesis

Acknowledgments

We are grateful to our thesis supervisors Morten Hansen and Jevgenijs Babaicevs for help and guidance throughout the project. Moreover, we thank Uldis Berzins and Armands Jasevs, the employees of Swedbank, for useful comments in the initial phase of the thesis, and suggestions on the topic. Moreover, the Bank of Latvia employees Armands Pogulis un Egils Kauzens were extremely helpful with providing the data for research. Also, we thank Daina Berzina for assistance in the thesis writing process. And the comments from Vitalijs Jascisens, Mara Bukovska, Donatas Nemura, Zymantas Bausys, Jevgeni Beloussov, and Danielius Valuckas are highly appreciated.

Abbreviations

ADF – augmented Dickey Fuller unit root test
ARCH – autoregressive conditional heteroskedastic
EGARCH – exponential general autoregressive conditional heteroskedastic
EONIA – euro overnight index average
GARCH – general autoregressive conditional heteroskedastic
GARCH-M – general autoregressive conditional heteroskedastic in mean
MAE – mean absolute error
MAPE – mean absolute percent error
RIGIBID – Riga interbank bid rate
RIGIBOR – Riga interbank offered rate
RMSE – root mean squared error
SIBOR – Singapore interbank offered rate

Table of Contents

1. Introduction

Rigibor and Rigibid are the Latvian interbank interest rates – commercial banks trade liquidity, based on them. Another use of these indices is for commercial banks, while setting the Latvian lat (LVL) deposit and lending rates for private and legal entities. Recently both the volatility and the nominal value of Rigibor and Rigibid have increased significantly, the overnight values reaching almost 12% at the end of November, 2008. The most extreme fluctuations were observable after Latvia-specific events that raised mistrust in the currency peg's credibility, and after worldwide critical phenomena that shocked numerous markets, including Latvia. In the absence of such severe disturbances, the main argument for fluctuations in the interbank rates is credit factors (or creditworthiness), which is a slowly moving variable (Michaud & Upper, 2008). In Latvia's situation these factors are also sided with macroeconomic imbalances (i.e. large current account deficit, high inflation rate, etc.), which mainly have an impact on the longer term values and levels of the rates, instead of daily fluctuations (Bank of Latvia, 2008a).

The calculation of Rigibid and Rigibor started on December 8, 1997. The goals of this were to reduce the ambiguity and to foster the development of the money market (Bank of Latvia, 2009a). Since the beginning of quotation, the overnight deposits have been traded more often than other maturities – in 2007 their share was 69.5% (Bank of Latvia, 2008a). The rates are calculated on a daily basis by the Bank of Latvia, following the quotes of the 7 most active Latvian commercial banks (Bank of Latvia, 2009b). Therefore, at the first sight it appears that the Bank of Latvia has no influence over Rigibid and Rigibor, since their calculation is purely arithmetical, following the quoted figures of the commercial banks; however, as it will be shown later, the Central Bank can influence the interbank rate.

In large economies with a floating exchange rate, such as the USA and the Eurozone, interbank rates are strongly influenced by Central Banks, as they follow the Central Bank's target rate very closely. The situation is different in small economies with a fixed exchange rate, like Latvia. Taking a look at the plot of the Central Bank's target rates (in Latvia's case it is also the refinancing rate[1]) and the interbank rates in different countries (see Appendix 1, Figures 1, 2, and 3 for the plot), clear deviations from the refinancing rate are visible in the case of Latvia. Moreover, the mean test[2] of the spreads indicates that they are statistically significantly different in Latvia, Eurozone, and the USA. The spread between the interbank rate and the refinancing rate (hereafter: the interbank spread) represents the difference between the Central Bank's intended policy and the real events in the money market. The questions we attempt to tackle with this study are: what exact factors determine this spread in the short run and can be forecasted? Therefore, our research question is: "What factors influence the spread between the Latvian interbank market rates and the Central Bank's policy rate?"

It is rather important to find out the determinants and to evaluate the predictability of the mentioned spread, since in the case of Latvia, where the policy rate is changed very rarely, it would, to a certain extent, imply forecasting the actual interbank rates. This, in turn, is necessary primarily for commercial bank managers in order to optimize the short term allocation of funds (be it the interbank market or the Central Bank's marginal standing facilities[3]). The results of the thesis will be used by a leading commercial bank in Latvia (Swedbank) for this purpose. Secondly, the interbank spread and its determinants are of high interest for the Bank of Latvia, since a higher spread shows higher uncertainty in the market. Additionally, the monetary policy

[1] the minimum bid rate for the market operations, when the Bank of Latvia grants funds in lats to credit institutions against a securities' collateral (Bank of Latvia, 2008c)
[2] Two mean tests were carried out to compare the spreads between Latvia and the Eurozone, and Latvia and the USA. The means of the spreads are different at a 5% significance level.
[3] credit institutions can make use of these to lend or deposit funds in the Central Bank (Bank of Latvia, 2008c)

has an effect on the real economy via the long term interbank interest rates, which are relevant for investments and savings, since they are used to set the commercial bank interest rates for loans. Moreover, the long term values are the determinants of output and prices – these in turn are of high interest for the Central Bank's policies. The short term interest rates are one of the determinants of the longer term values and the monetary policy transmission mechanism to the real economy starts at the short term interest rates (Linzert & Schmidt, 2008). Hence, controlling the short term interest rate is of interest to the Bank of Latvia. This also corresponds with one of the Central Bank's targets – to reduce uncertainty and promote stability in the Latvian money market (Bank of Latvia, 2009c). Taking into account the abovementioned relationship, a lower spread even for short term maturities might be an indicator of a better implementation of monetary policy. Thirdly, the determinants of the spread are of high interest for researchers who wish to perform studies in countries with a similar economic setting.

The paper proceeds as follows. At first the literature review is presented. Then the descriptions of methodology and data follow. The paper continues with the description and interpretation of results and, finally, the conclusions and suggestions for further studies are presented.

2. Literature Review

This paper explains the interbank market rates and their determinants in a relatively open small economy with a fixed exchange rate – Latvia. This setting is important, since the basic interest rate parity condition states that the interest rate in one country is equal to the interest rate in the second country plus the expected change in the exchange rate and a risk premium that accounts for the risk of default (Krugman & Obsfeldt, 2006). The varying exchange rate condition is released if the two countries operate under a fixed exchange rate regime; thus, the interest rates are identical in both countries. However, there are extensions to this model that add ambiguity and lack of trust in the credibility of the fixed exchange rate. This is also the case for Latvia, where we can observe clear inconsistencies between the interbank spreads in the Eurozone and Latvia (see Appendix 1, Figures 1 and 2).

The interest parity condition mainly deals with explaining longer term values; the additional included component is related with macroeconomic factors. Hence, the model is inappropriate for explaining daily movements, where market microstructure factors play a significant role.

There are models for explaining the interbank rates that extend beyond the basic interest rate parity condition. However, the fixed exchange rate and the small economy setting with respect to the interbank interest rates is particularly thrilling, as there is little amount of research done for such economies in this field. Some of the researched countries with a similar setting include Hong Kong (see for example Chiu, Lai, Leung & Wong (2001), Gerlach (2003), Schmukler & Servén (2002), Chen & Wong (2004)), Singapore (The Monetary Authority of Singapore (1999)), Mauritius (Jankee (2003)), Ukraine (Conway (2006)), Latvia (Ajevskis & Vītola (2006)), and Lithuania (Jurgilas (2005)); however, the exact focus differs with each case.

An additional important factor is the existence of several theories that deal with explaining the interbank market. Usually researchers try to analyze the interest rate spread with some other variable rather than interest rates as such. There are two options: intra country analysis, where the second variable is the Central Bank’s interest rate, and inter country analysis, which analyzes the spread between the same interest rate in two different countries. The above mentioned interest rate parity condition is one of the examples of inter country analysis.

There are several interbank spread types that can be analyzed either within a country or between different countries, each of them, of course, having a somewhat different inference and approach. The most common method is to make inferences from the term structure of the interest rate in question. Another emerging branch of studies looks at the intra country's spread – between the rates in the interbank market and the Central Bank's policy rate. This spread indicates the success of implementing monetary policy – a smaller spread means that the actual events in the market coincide with the Central Bank's intentions.

In the following sections the two most prominent methods for intra country spread modeling are presented. We explain only the methods, as the majority of the models include an extensive list of variables. For detailed results of these studies, the reader is suggested to review Appendix 5.

2.1. Liquidity and Credit Risk Premia Approach

First, there is a method developed by the Bank of England (2007), which attempts to decompose the spread between the interbank market rates and other variables that measure the market's expectations for the future. In the original version, overnight index swap rates are used as a proxy, but the method can also be applied to the Central Bank's policy rate, since in an ideal case it should portray the market's expectations. The interpretation of the results in such a case might differ. The Bank of England researchers using the former method with overnight index swap rates divide the premium in credit premium and non-credit premium, the first being measured as the premium paid on credit default swaps, and the second being the residual.

Michaud and Upper (2008) extend the analysis by further disentangling the non-credit premium (which is considered as the residual in the original version). The factors proposed are:

the risk of default, market’s liquidity, borrowing bank’s liquidity, and market microstructure factors (the latter two are included in the residual, due to the lack of a common, representative measure). Moreover, they perform an event study for the banks that constitute Libor quotes, and apply the analysis to panel data (Michaud & Upper, 2008). The former helps the authors in dealing with the problem of market microstructure factors, which originally are included in the residual. The latter, in turn, is meant to determine the differences across banks that constitute the Libor panel.

The scholars of Hong Kong’s Monetary Authority have extended the model’s results to see whether the credit and non-credit premiums are different in the USA and Hong Kong; moreover, they attempt to find the direction of causality for the shocks between money markets in different countries. The most important finding is that the tightening of the Hong Kong’s interbank market is caused by the effects in the US dollar market (Hong Kong Monetary Authority, 2008). Imakubo, Kimura, Nagano (2008) also apply the disentangling to explain the cross currency transmission mechanism between JPY, USD, and EUR, and, as a result, they determine the direction of causality of the shocks.

There are several problems with this approach - the main one being the assumptions it makes. The most crucial and debated one is the assumption about the perfect independence between different types of risks and the entirely unique risk representativeness of the chosen variables. Moreover, as Michaud and Upper (2008) state, the results have little predictive power. Another important factor that curbs the attempts to perform a similar analysis in the Latvian market comes from problems with the extreme lack of liquidity for financial instruments (sometimes even their non-existence); hence, the results of the analysis would be severely biased or datasets would be unobtainable.

2.2. Multivariate Approach

The second method was first applied by the scholars of the European Central Bank. Würtz (2003) presents a model to determine the spread between the euro overnight rate and the key policy rate of the European Central Bank. This model is an extension of the martingale hypothesis. In a pure martingale hypothesis scenario there is perfect substitutability of the commercial banks' reserve holdings on any day within a reserve maintenance period[4]; hence, the rate is always equal to the expected rate in the remaining days of the reserve maintenance period (Würtz, 2003). If these funds are not substitutable, arbitrage opportunities would arise and commercial banks would be able to exploit them. The author's suggestion is that the spread between the interbank and the Central Bank's interest rate depends on two main variables: (1) the Central Bank's key policy rate change expectations and (2) liquidity expectations. In the case of Latvia the former might appear insignificant, since the policy rate of the Bank of Latvia is changed very rarely. The latter variable reflects the market's expectations whether the current level of liquidity supply would force market participants to use any of the Central Bank's standing facilities (either lending or borrowing).

Due to the fact that sometimes we can observe market anomalies that deviate from the pure form martingale hypothesis (the most evident example being calendar effects), additional variables are added to the model. Taking into account that there is no single specific theoretical model that captures the whole interbank market, the decision on whether to include a particular variable in the model comes from several different theories (Würtz, 2003). Importantly, these theories may be inconsistent with the rational behaviour of market participants. A wide range of variables is used; they are classified into 8 broad groups.

---

[4] In Latvia – "a period over which compliance with reserve requirements is established; it starts on the 24th calendar day of each month and ends on the 23rd calendar day of the following month" (Bank of Latvia, 2008d)

Linzert and Schmidt (2008) in their article extend the original analysis; they also create a model to determine the spread between the euro overnight rate and the European Central Bank's key policy rate. The main difference is that this article is done more recently and, therefore, a newer dataset is analyzed. They use several variables from Würtz (2003); however, new determinants are suggested, as well.

There are additional studies that confirm the influence of some of the used variables under different settings. Avakiat (2001) shows that the forward rate, changes in the net loans and net foreign assets influence interbank rates, which correspond to Würtz (2003) and Linzert and Schmidt (2008). Moschitz (2004) concludes that the mean of the overnight rate tends to be higher at the last day of the month, which is also in accordance with Würtz (2003) and Linzert and Schmidt (2008). Additionally, in the annual reports of the Central Bank of Latvia, the authors include predictions, based on internal research, about variables that might explain the fluctuations of interbank rates in the long term. The annual reports of 2000, 2001 and 2007 suggest that those variables were excess liquidity factors, the monthly amount of issued loans, the growth in deposits received by banks, and the reserve requirement[5] (Bank of Latvia, 2001, 2002, 2008a).

3. Methodology

We have chosen to follow the methodology proposed by Würtz (2003), because it offers comprehensive short run modeling that can later be used to infer possible movements in the spread. Moreover, it is adjustable for Latvia's case by adding several Latvia-specific variables, which are supported by additional theories, and correspond to the variable categories provided by

[5] "the requirement for a commercial bank to hold Central Bank's set ratio-adequate reserves on its reserve account" (Bank of Latvia, 2008d)

Würtz (2003). As this is a short run model for predicting overnight rates, the long run variables that may have influence on longer term interbank spread values are not included in the variable list.

The methodology part is divided as follows: firstly, the overall structure of the model is presented, then the econometric specification is explained in more detail, and afterwards the predictability tests are discussed.

3.1. The Overall Structure of the Model

This paper deals with financial data sets, which are non-linear. For example, studies find that the martingale hypothesis does not hold because of significantly different variances of data in different days of the reserve maintenance period (see e.g. Mendizabal & Quiros, 2001). Data is usually leptokurtic, which means that its distribution has fat tails and excess peakedness at the mean (Brooks, 2008). Considering these factors, we use autoregressive conditional heteroskedastic (ARCH) econometric models, as they do not assume a constant variance of the data, but rather describe how the variance of the error term evolves.

Three ARCH models are selected to see, which model has the best predictive power. Firstly, general autoregressive conditional heteroskedastic model (GARCH) is applied, because it allows the conditional variance to be dependent upon its own previous values. Secondly, the exponential general autoregressive conditional heteroskedastic model (EGARCH) is used, as it takes into account that positive and negative shocks may have asymmetric effects on the volatility (for example, an increase in the value of one variable may cause a larger change in the volatility of the interbank spread than a decrease would). And, finally, the GARCH-M model is utilized, as it also measures the effect of the spread's previous volatility on the mean value of the interbank spread.

The general ARCH estimation model can be written as in the equation (1). This is a simplistic presentation of the model, and it is described thoroughly in the econometric specification part.

$$s_t = \alpha + \sum_{i=1}^{33} \beta_i \cdot x_{i,t} + \varepsilon_t , \qquad (1)$$

where s_t is a time-series variable of the interbank rate spread, α is a constant, $x_{i,t}$ are 33 explanatory time-series variables presented in Appendix 2, subdivided into groups, and explained later in the text, β_i are 33 coefficients to be estimated for the corresponding explanatory variables, and ε_t is the error term. In the following paragraphs the explanatory variables ($x_{i,t}$) chosen for the model are described.

The value of the interbank spread on the previous trading day ($x_{1,t}$) is included in the model, as, according to the martingale hypothesis, it should be the best predictor of today's interbank spread (Linzert & Schmidt, 2008).

The spread is influenced by expectations regarding accumulated liquidity conditions over the reserve maintenance period ($[x_{2,t}; x_{6,t}]$), as the commercial banks will have to make recourse to the deposit[6] or lending[7] facilities in the Central Bank (this is supported by Linzert and Schmidt (2008), Würtz (2003), and Avakiat (2001)). The variables that describe this category include (i) daily net recourse to the standing facilities, (ii) the net recourse to the standing facilities realized on the preceding trading day, (iii) the accumulated reserve surplus, (iv) the average spread experienced on the last days of the previous reserve maintenance period, and (v) a dummy

---

[6] "commercial banks deposit funds in lats with the Bank of Latvia with overnight maturity" (Bank of Latvia, 2008b)
[7] "commercial banks borrow funds in lats from the Bank of Latvia against a securities' collateral with overnight maturity " (Bank of Latvia, 2008c)

variable equal to one if the spread on the last trading day of the two previous reserve maintenance periods exceeded 150 basis points. The latter is an extension of the variable proposed by Würtz (2003). Due to the fact that he analyzed a more developed market with lower fluctuations, the dummy variable for 25 basis points is adjusted to 150 basis points. This allows capturing approximately the same proportion of the Latvian dataset.

Daily liquidity conditions ($x_{7,t}$) measure the Central Bank's daily deposit availability, not taking into account the reserve maintenance period. The motivation is the same as for the first group of variables. The variable used to capture this effect is the daily reserve surplus (supported by Würtz (2003)).

Tender outcomes ($[x_{8,t}; x_{12,t}]$) refer to the marginal rates[8] and allotment volumes[9] in the previous main refinancing operations[10]. The motivation for the relationship with the spread is that market participants sometimes look at the previous rates and volumes to determine the fair price of liquidity (Würtz, 2003). The variables include: (i) the marginal rate of the most recent main refinancing operation, (ii) the marginal rate of the second most recent main refinancing operation, (iii) the marginal rate of the last main refinancing operation in the previous reserve maintenance period, (iv) the average of the marginal rates, realised since the beginning of the reserve maintenance period less the prevailing refinancing rate, and (v) the change in the total outstanding main refinancing operations volume.

As main refinancing operations are a major source of liquidity, bidding behavior in the main refinancing operations ($x_{13,t}$) should be reflected on the spread (Linzert & Schmidt, 2008). Thus,

[8] rates at which commercial banks obtain liquidity from the Central Bank via main refinancing operations
[9] volume allotted in a main refinancing operation
[10] "market operations, when the Bank of Latvia grants funds in lats to credit institutions against a securities' collateral" (Bank of Latvia, 2008c)

a variable called bid-to-cover ratio is included. It shows to what extent the demand for liquidity has been met by the Central Bank.

Calendar effects ($[x_{14,t}; x_{26,t}]$)capture patterns that occur regularly and influence the spread (this is supported by Moschitz (2004) and Würtz (2003)). The variables include (i) Monday effects, (ii) Friday effects, (iii) end of month effects, (iv) up to an end of month effects, (v) beginning of month effects, (vi) end of quarter effects, (vii) end of semester effects, (viii) end of year effects, (ix) holiday effects, (x) first reserve maintenance period day effects, and (xi) last three reserve maintenance period day effects (separate for each day).

There are several other effects ($[x_{27,t}; x_{33,t}]$) that are particularly relevant to the Latvian market. The change in the key policy rate directly influences the spread (proposed in Würtz (2003), Linzert and Schmidt (2008)). The variables include (i) the difference between the key policy rate on time t and the average key policy rates on time t-1 and t-2 (this is to make a smoother change in the case the policy rate has been changed), and (ii) dummy variables after a policy rate change. Moreover, some dummy variables for specific days, that had influence in the Latvian market, are included. These variables are: (iii) dummy variable that takes into account the Latvian government's public announcement of its takeover of Parex bank, (iv) a dummy variable, that is equal to one, when news questioning the lat and euro currency peg's sustainability were released, and (v) dummy variables that deal with changes in the reserve requirements.

Additionally we considered the inclusion of foreign exchange related swap variables. However, according to the employees of the Bank of Latvia, they are not liquid enough to be included in the model (A.Pogulis, personal communication, February 23, 2009).

3.2. Econometric Specification

In this section, the econometric specification is provided for the three chosen models: GARCH, EGARCH and GARCH-M. As they all use lagged terms, we run the ARCH Lagrange multiplier test to determine how many ARCH terms should be specified in the model. The test is described and the output is provided in Appendix 3. The test suggests that 2 ARCH terms should be used.

For all of the models we use Marquardt optimization, as it is one of the most widely used algorithms (Amaral, Cristóstomo & Pires, 2004). The convergence error for iterations is 10^{-7}. Generalized error distribution is used, because it is the EGARCH model's default distribution specified by Nelson (1991), and for consistency we apply it for GARCH and GARCH-M, as well. Backcasting of moving average terms is used, as it is believed to define the coefficients for the independent variables with more precision (Ma, Van Gelder, Vrijling & Wang, 2005). The parameter of backcasting is 0.7, as it is the default value provided by the Eviews software. The following model descriptions are an adaptation from Brooks (2008).

The GARCH (*q*,*p*) model for the interbank spread can be written as:

$$s_t = \alpha + \sum_{i=1}^{33} \beta_i x_{i,t} + \varepsilon_t ,\ \varepsilon \sim N(0, \sigma^2) \tag{2}$$

where s_t is a time-series variable of the interbank rate spread, α is a constant, $x_{i,t}$ are 33 explanatory time-series variables presented in Appendix 2, β_i are 33 coefficients to be estimated for the corresponding explanatory variables, and ε_t is an independently distributed error term with a mean of zero, and a conditional variance σ^2. The conditional variance is expressed as follows:

$$\sigma_t^2 = \omega_0 + \sum_{i=1}^{q} \omega_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \phi_j \sigma_{t-j}^2 + \sum_{m=1}^{33} \nu_m x_{m,t} \quad (3)$$

where ω_0 is a constant, ε_{t-i}^2 is the squared *i*-th lag of the error term, σ_{t-j}^2 is the squared *j*-th lag of the conditional volatility itself, $x_{m,t}$ are the same explanatory variables as $x_{i,t}$ in equation (2), ω_i, ϕ_j, and ν_m are coefficients for estimation, and *q* and *p* are orders of the GARCH model. In our case $q = 2$ and $p = 2$. The basic idea of the model is that the variance of the error term is influenced by *q* past values of the error term, *p* past values of the volatility, and the 33 explanatory variables.

The EGARCH (*q*,*p*) model for the interbank spread can be written as:

$$s_t = \alpha + \sum_{i=1}^{33} \beta_i x_{i,t} + \varepsilon_t,\ \varepsilon \sim N(0, \sigma^2) \quad (4)$$

where s_t is a time-series variable of the interbank rate spread, α is a constant, $x_{i,t}$ are 33 explanatory time-series variables presented in Appendix 2, β_i are 33 coefficients to be estimated for the corresponding explanatory variables, and ε_t is an independently distributed error term with a mean of zero, and a conditional variance σ^2. The natural logarithm of the conditional variance is expressed as follows:

$$\log(\sigma_t^2) = \omega_0 + \sum_{i=1}^{q} \omega_i \left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| + \sum_{j=1}^{p} \phi_j \log(\sigma_{t-j}^2) + \sum_{k=1}^{r} \gamma_k \frac{\varepsilon_{t-k}}{\sigma_{t-k}} + \sum_{m=1}^{33} \nu_m x_{m,t}\ , \quad (5)$$

where ω_0 is a constant, ε_{t-i} is the *i*-th lag of the error term, σ_{t-i} is the *i*-th lag of the conditional volatility itself, σ_{t-j}^2 is the squared *i*-th lag of the conditional volatility itself, ε_{t-k} is the *k*-th lag of the error term, σ_{t-k} is the *k*-th lag of the conditional volatility itself, $x_{m,t}$ are the 33 explanatory variables, ν_m, ω_i, ϕ_j, and γ_k are the coefficients to be estimated, *q* and *p* are orders of the EGARCH model, and *k* is the order of asymmetry. In our case *q* = 2, *p* = 2, and *k* = 1. The model has an asymmetric order of 1, since positive or negative changes in the explanatory variables may have a different effect on the volatility of the interbank spread. The basic idea of EGARCH is similar to the GARCH model; in addition, natural logarithms are used to express variance, and a term is added to measure asymmetry.

The GARCH-M (*q*,*p*) model for the interbank spread can be written as:

$$s_t = \alpha + \sum_{i=1}^{33} \beta_i x_{i,t} + \delta\sigma_{t-1} + \varepsilon_t, \ \varepsilon \sim N(0,\sigma^2) \quad (6)$$

where s_t is a time-series variable of the interbank rate spread, α is a constant, $x_{i,t}$ are 33 explanatory time-series variables presented in Appendix 2, β_i are 33 coefficients to be estimated for the corresponding explanatory variables, σ_{t-1} is the conditional variance, which appears directly in the mean equation, and δ is the coefficient to be estimated, and ε_t is an independently distributed error term with a mean of zero, and a conditional variance σ^2. The conditional variance is expressed as follows:

$$\sigma_t^2 = \omega_0 + \sum_{i=1}^{q} \omega_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \phi_j \sigma_{t-j}^2 + \sum_{m=1}^{33} \nu_m x_{m,t} \ , \quad (7)$$

where ω_0 is a constant, ε_{t-i}^2 is the squared *i*-th lag of the error term, σ_{t-j}^2 is the squared *j*-th lag of the conditional volatility itself, $x_{m,t}$ are the same explanatory variables as $x_{i,t}$ in equation (2), ω_i, ϕ_j, and ν_m are coefficients for estimation, and *q* and *p* are orders of the GARCH model. The basic idea of GARCH-M is similar to the GARCH model; in addition, the direct effect of volatility on the spread is measured.

3.3. Predictability tests

In order to evaluate the predictability of the three proposed models, we will compare their predicted values to a benchmark model, which is a pure random walk generated values. Its ordinary least squares specification is:

$$s_t = s_{t-1} + \varepsilon_t,\ \varepsilon \sim N(0, \sigma^2) \qquad (8)$$

Real out-of-sample forecasting will be performed, and the forecast parameters will be estimated for every model, since out-of-sample forecasting demonstrates the usefulness of the developed model (recently several authors have pointed out to the importance of out-of-sample rather than in-sample forecasting, see e.g. Inoue & Kilian (2002) or Hjalmarsson (2006)). There are 2 types of forecasting: one-step and multi-step. One-step forecasting predicts the value of the interbank spread for the next trading day, and then uses the next real, observed value to continue the forecast. Thus, $\hat{s}_{t+1}$ will be predicted, and the real s_{t+1} value will be used to re-run the models, obtain new coefficients, and forecast $\hat{s}_{t+2}$. Multi-step forecasting, on the other hand, uses its own predicted interbank spread values to continue the estimation for the next trading day. Thus, $\hat{s}_{t+5}$ will be predicted, and the real s_{t+1} value will be used to re-run the models, obtain new coefficients, and forecast $\hat{s}_{t+6}$. Both of these methods will be used, as one may be interested in forecasting not only tomorrow's value, but also the value a after a longer time period. We limit the out-of-sample forecast to 19 working days due to availability of recent data. Moreover, one-week forecasts are chosen for multi-step forecasting; thus, there are 5-day steps, because there are 5 working days in a week. The predictions will be compared with the actual values of the interbank spread by the following four methods:

Root mean squared error (RMSE): $$\sqrt{\sum_{t=T+1}^{T+h} (\hat{s}_t - s_t)^2 / h} \qquad (9)$$

Mean absolute error (MAE): $$\sum_{t=T+1}^{T+h} |\hat{s}_t - s_t| / h \tag{10}$$

Mean absolute percent error (MAPE): $$\sum_{t=T+1}^{T+h} \left| \frac{\hat{s}_t - s_t}{s_t} \right| / h \tag{11}$$

Theil inequality coefficient (Theil): $$\frac{\sqrt{\sum_{t=T+1}^{T+h} (\hat{s}_t - s_t)^2 / h}}{\sqrt{\sum_{t=T+1}^{T+h} \hat{s}_t{}^2 / h} + \sqrt{\sum_{t=T+1}^{T+h} s_t{}^2 / h}}, \tag{12}$$

where T is the first observation of the sample for estimation, and h is the number of observations in the sample. The smaller the errors, the better the forecasting power of the model.

To compare the models by the 4 criteria, Diebold-Mariano test will be applied (Diebold & Mariano, 1995). The test compares two forecasts to determine whether one of them is significantly more accurate, in terms of the 4 error criteria. Hence, the two best models, according to the 4 error criteria, will be chosen for every prediction, and compared, using the Diebold-Mariano test statistic. Thus, the test will show whether there is a “best” forecast model for single and multi-step forecasts. The null hypothesis is:

$$d_t = E[e_t^A - e_t^B] = 0, \tag{13}$$

where d_t stands for the difference in errors of models A and B, e_t^A and e_t^B are the errors of one of the 4 criteria for models A and B respectively. If it is rejected, it implies that one of the models is significantly more accurate in its predictive power. The Diebold-Mariano test statistic is:

$$DM = \frac{\bar{d}}{\sqrt{\hat{V}(\bar{d})}}, . DM \overset{A}{\sim} N(0,1), \tag{14}$$

where DM is asymptotically normally distributed, $\bar{d}$ is the average value of d_t for the whole forecast period (n), and

$$\hat{V}(\bar{d}) = \frac{1}{n}\left[\hat{\gamma}_0 + 2\sum_{k=1}^{m-1}\hat{\gamma}_k\right], \tag{15}$$

where n is the number of observations (19 for single-step forecasts, and 15 for multi-step forecasts), m is the number of total steps to forecast in the future (18 for single-step forecasts, and 14 for multi-step forecasts), and

$$\hat{\gamma}_k = \frac{1}{n}\sum_{t=k+1}^{n}(d_t - \bar{d})(d_{t-k} - \bar{d}), \tag{16}$$

where t and k are integers, d_t is given in equation 13, and $d_{t\text{-}k}$ is the k-th lag of d_t, and (Cuaresma, Fortin & Hlouskova, 2005).

4. Data description

We use daily frequency data, and, as a result, there are extreme fluctuations that hold only for short periods of time. The Bank of Latvia started quoting the interbank rates on December 8, 1997; the target rates were available before that. The spread is calculated as the average of bid-ask quotes less the refinancing rate. This is done from the date Latvia pegged LVL to EUR, and, additionally, taking into account the reserve maintenance period restrictions. Therefore, our dataset is from January 3, 2005 until February 26, 2009. Most of the data concerning the economy of Latvia was obtained from the Bank of Latvia (E. Kauzens, A. Pogulis, personal communication, February 23, 2009). Additionally, the data for RIGIBOR and RIGIBID was obtained from the web site of the Bank of Latvia (Bank of Latvia, 2009a).

Differently from the European interbank market, where the spread fluctuates closely above zero, in Latvia's case the fluctuations are extremely high, and they are both above and below zero. There was a relatively calm time up till the end of 2005 only with minor peaks (notably shocks in September). In 2006 the interbank rates started to fluctuate a lot more, but becoming less volatile closer to the end of the year. In the beginning of 2007, several shocks hit the Latvian economy; hence, the volatility of the interbank rates increased significantly. Additionally, the Bank of Latvia decided to increase the refinancing rate twice in 2007. The most extreme fluctuations ended in the beginning of 2008, when an obvious change in the pattern is observable. In 2008 for several months both the volatility and the nominal value of the interbank market rate became very low. The situation changed in the end of 2008, when volatility rose back to its high levels (reference to Appendix 1, table 1, 2, and 3).

A Bank of Latvia representative (A.Pogulis, personal communication, February 23, 2009) explains the fluctuations both above and below zero for the Latvian interbank market's spread with the fact that refinancing operations require collaterals, which are not required in unsecured interbank markets. This is different from the Eurozone, where the spread is mainly positive. The issue is that Latvian commercial banks often are not able to provide this collateral. An additional influencing factor is that the amount of funds in the refinancing operations is limited; hence, if commercial banks want to borrow more, they have to turn to the interbank market again.

Structural breaks are visible in February 19, 2007, February 22, 2008, and September 29, 2008; this is also supported by the econometric test of comparing the levels of data volatility[11]. The test suggests that there are statistically significant differences between the volatilities of the time periods before and after the mentioned dates. Taking this into consideration, the econometric models will be run on the 4 sub-periods to determine the model's robustness (to see whether the signs of the variable coefficients are equal in the whole sample and the different sub-samples).

The econometric models that we use require stationary data of the interbank spread over time. To test the stationarity, we use the Augmented Dickey Fuller (ADF) unit root test to see whether

[11] The variances are statistically different at a 5% significance level.

a unit root exists for the interbank spread series, or if they are stationary over time. The null hypothesis that a unit root exists is rejected at a 1% level, implying that the developed model should not rely on a spurious relationship and that the data is stationary (see Appendix 4).

5. Results

In this section the results of the regression analysis are presented. Firstly, the predictability test results are reviewed, and further the best forecasting model is discussed in detail.

5.1. Predictability Tests

Out-of-sample predictions for 19 working days after the analyzed sample period were made for the Latvian interbank spread, using the 4 models: GARCH, GARCH-M, EGARCH, and random walk.[12] The predictions were compared to the actual values of the interbank spread. The results of the error criteria were obtained, and their averages are reported in Appendix 8, table 1. As EGARCH and random walk proved to be the best predictors of the interbank spread in single-step forecasts, and EGARCH and GARCH-M in multi-step forecasts, these three models were compared using the Diebold-Mariano test.

In Appendix 8, Table 2 the results of the Diebold-Mariano tests are given. The EGARCH model is significantly better than the other model in both categories: single and multi-step forecasts (at a 15% significance level for single-step forecasts, and at a 1% significance level for multi-step forecasts). This also implies that random walk is a significantly worse predictor of the interbank spread. Thus, EGARCH is taken as the primary model for analysis, as it is the best

[12] The residuals of GARCH, GARCH-M, and EGARCH do not follow a normal distribution (see Appendix 7). This is because of their high kurtosis.

predictor of Latvian interbank spread, particularly for multi-step forecasting, compared to the alternatives.

5.2. EGARCH Results

In this section, the EGARCH model is discussed in detail. The focus is on how each group of variables influences the interbank spread. A full table of the final estimated variable coefficients can be found in Appendix 6, tables 1 and 2. The results are interpreted in the following section.

The past value of the interbank spread (x_1) has a coefficient of 0.9853. This implies that the interbank spread is closely dependent upon its own value on the previous trading day. This is in accordance with the martingale hypothesis.

There are four significant variables of expectations on accumulated liquidity in a reserve maintenance period that influence the interbank spread. Firstly, the daily net recourse to the standing facilities (x_2) proves to be statistically significant, with a coefficient of 2.38×10^{-7}; thus, an increase in the daily net recourse by LVL 100 million would on average imply a 0.0238% increase in the interbank spread [13]. Secondly, the net recourse to standing facilities realized on the preceding trading day (x_3) is also statistically significant with a coefficient of -1.05×10^{-7}; therefore, an increase yesterday in the daily net recourse by LVL 100 million would on average imply a 0.0105% decrease in the interbank spread. Thirdly, the accumulated reserve surplus (x_4) with a coefficient of -1.88×10^{-8} is statistically significant; hence, an increase in the accumulated reserve surplus by LVL 100 million would on average imply a 0.00188% decrease in the interbank spread). Finally, the average spread experienced on the last days of the previous reserve maintenance period (after the last main refinancing operation of the previous research

[13] we remind the reader that the values of allotments typically are measurable in millions, so the GARCH coefficients for the effect on the spread (measured in percentages) might only at first seem negligible.

maintenance period) (x_5) is significant with a coefficient 0.0113, implying on average a 0.00113% increase in the interbank spread if the average spread rises by 0.1%. The last variable in this group is not a rational liquidity expectation, and did not prove significant.

The only variable that is included in the daily liquidity conditions section – the daily reserve surplus (x_7) – proves to be significant with a coefficient value of -1.90×10^{-7}; thus, an increase in the daily reserve surplus by LVL 10 million would on average imply a 0.0019% decrease in the interbank spread.

Four variables from tender outcomes group proved to be statistically significant. Firstly, the marginal rate of the most recent main refinancing operation (x_8) has a coefficient of 0.0454 (a 0.1% increase in the previous marginal rate would on average imply a 0.00454% increase in the interbank spread). Secondly, the marginal rate of the second most recent main refinancing operation (x_9) has a coefficient of -0.0252 (a 0.1% increase in the second latest marginal rate would on average imply a 0.00252% decrease in the interbank spread). Thirdly, the marginal rate of the last main refinancing operation in the previous reserve maintenance period (x_{10}) has a coefficient of -0.0197 (a 0.1% increase in the latest marginal rate of the previous reserve maintenance period would on average imply a 0.00197% decrease in the interbank spread). And finally, the change of the total outstanding main refinancing operations volume on the settlement day (x_{11}) has a value of 1.65×10^{-6} (implying that if the change in the volume would be by LVL 1 million higher than on the previous trading day, the interbank spread would on average increase by 0.00165%).

The only variable from bidding behavior in main refinancing operations, bid-to-cover ratio (x_{13}), is significant with a coefficient value of 0.0064. Therefore, an increase in the bid-to-cover ratio by 1 would on average lead to a 0.0064% increase in the interbank spread.

Six calendar effects are statistically significant in the developed model. There is a lower spread on Fridays (x_{15}), a higher spread on holidays (x_{22}) and on the first trading day of the reserve maintenance period (x_{23}). Additionally, the relationship between the last three trading days of a reserve maintenance period ($x_{24,}$ $x_{25,}$ and x_{26}) and the interbank spread is negative. These coefficients imply that the interbank spread tends to be smaller in the last trading days of a reserve maintenance period, and tends to rise when the new maintenance period begins.

Three other effects turn out to be significant – the difference between the key policy rate on time t and the average key policy rates on time *t-1* and *t-2* (x_{27}) has a negative relationship, there was an increase in the spread after news questioning the LVL peg's sustainability were released (x_{31}), and a negative effect, when the reserve requirements were changed (x_{33}).

What concerns the volatility of the interbank spread, the asymmetry coefficient has a negative value, implying that positive changes in the explanatory variables have lower effects on the volatility of the spread than negative changes do. ARCH and GARCH terms drive the volatility of the interbank spread positively. This implies that past values of volatility and the error term are significant in explaining the future volatility development. There are also several explanatory variables that have an effect on the volatility of the interbank spread. Firstly, there is a positive effect from the lag of the interbank spread. Secondly, there is a positive effect from the daily net recourse to the standing facilities, thirdly, a negative effect from the accumulated reserve surplus, and fourthly, a negative effect from the average spread experienced on the last days of the previous reserve maintenance period. Additionally, there are positive Monday, end of month, and semester effects, and negative up to end of month, beginning of month, and end of quarter effects on the volatility. The reserve maintenance period constraints also are observable in the data set.

The first and 3 last days of the reserve maintenance periods have a positive influence on the volatility. Moreover, a policy rate change influences the volatility positively, as well.

It must be noted that the differences between the coefficients of the main variables of interest were statistically insignificant for the 4 sub-samples. Thus, the results are robust over the whole sample period.

6. Discussion of the Results

In this section the results will be interpreted, and implications for both the Bank of Latvia and the commercial banks will be discussed. As it was already mentioned in the previous section, the EGARCH specification yields the best fit; hence, the discussion will be based on this model. Moreover, predictions, if any, should be based on this specification.

In the expectations of accumulated liquidity in the reserve maintenance period the most important variables are the daily net recourse and the yesterday's value of daily net recourse. The two variables have opposite signs, however, the overall relationship between them and the interbank spread is positive. This is in accordance with the martingale hypothesis, because if the Central Bank has made a recourse to the marginal lending facility (the two variables increase), a greater marginal deposit facility is expected in the end of the reserve maintenance period. Thus, there will be less liquidity supplied in the market, and, as a result of the expectations of the market participants, the interbank spread should increase. The relationship between the accumulated reserve surplus and the spread is negative, contrary to the two previously discussed variables, because if the accumulated reserve surplus increases, there is an expectation of more liquidity in the market in the end of the reserve maintenance period, thus, implying a lower interbank spread, because of self-fulfilling expectations. Also, the average spread experienced on the last days of the previous reserve maintenance period has a positive relationship with the interbank spread, as market participants do refer to historic spreads as an expectation for the tomorrow's spread.

In the daily liquidity conditions group, the only variable – daily reserve surplus – has a negative relationship with the interbank spread, according to the same logic as for the accumulated reserve surplus variable.

In the tender outcomes category, the marginal rates are significant. The overall link is positive and the interpretation of the coefficients is as follows: as the marginal rates rise, the price of liquidity increases, and, thus, the interbank spread rises. However, the past values of the marginal rates work in the opposite direction, as they are expected to decline after an increase in the previous periods. Tender outcomes are not a part of the martingale hypothesis, as some market participants may only refer to the previous values of marginal rates as a fair price of liquidity. However, three of them are significant, thus, implying deviations from the martingale hypothesis in the Latvian interbank market. Not only the marginal rates, but also the change of the total outstanding main refinancing operations volume has an effect on the spread. The relationship is positive, because higher volumes imply a lack of funds in the interbank market and, thus, a higher price for liquidity, as the demand for it rises.[14]

The only variable in the bidding behavior in the main refinancing operations category – bid-to-cover ratio – has a positive relationship with the spread, because if less money is covered by the Central Bank, commercial banks will turn to the interbank market, and also bid to the Central Bank more aggressively at higher marginal rates to obtain the necessary bid amount. The price of liquidity will increase, thus, the interbank spread will increase.

[14] We remind the reader that the rates in the main refinancing operations typically are higher than in the interbank market.

6.1. Implications for the Bank of Latvia

As argued previously, the results of the analysis are relevant for the Bank of Latvia, since its target is to reduce uncertainty in the money market, and, in the longer term, to maintain price stability (Bank of Latvia, 2009c). As a result of our study, the most important and specific factors are determined. Two relevant factors that the Bank of Latvia can influence will be reviewed in the following paragraphs.

The most important variable is the net recourse (defined as the recourse lending to commercial banks less the Central Bank's recourse borrowing from commercial banks). This comes from the fundamentals of the martingale hypothesis (the interest rate today will be equal to the interest rate at the end of the reserve maintenance period, since the funds are perfectly substitutable). The economic meaning is that when commercial bank managers see an increase in the net recourse (the Central Bank lends in total), there is more money in the market today, and its participants comprehend that in the future there will be a smaller need for liquidity to fulfill the reserve requirements (a constant figure for each particular period) and they expect an intervention by the Central Bank to decrease the liquidity in the market. This action will increase the interbank rate, because of self-fulfilling expectations. The result also corresponds with the studies for the Eurozone market (e.g. Würtz (2003), Linzert & Schmidt (2008)). The lag of the net recourse is negative (but has a lower absolute value); hence, the effect is partially offset, and the market participants overreact to daily net recourse figures. The implication for the Bank of Latvia is to try to have the net recourse value at a level, which is close to the satisfied total required reserves over the reserve maintenance period. By doing so, the Central Bank will minimize the fluctuations in the interbank rate.

The accumulated reserve surplus and the daily reserve surplus indicate that the commercial banks are willing to buffer out the daily liquidity shocks, by having higher than required reserves. This reduces the required amount of reserves closer to the end of the reserve maintenance period; therefore, the market participants expect a smaller need for funds in the future (in other words, they will be willing to pay less for additional liquidity). Again, the implication should be taken within the constraints of the reserve maintenance period – if the Bank of Latvia wishes to decrease the spread in the short run, it can encourage commercial banks to hold more reserves; however, in the longer term the solution is to encourage having the required amount of reserves, since at the end of the period rational commercial bank managers will try to have the reserve ratio closer to the required value.

6.2. Implications for Commercial Banks

Due to the fact that the effects are analyzed with respect to the reserve maintenance periods, taking into account the adjustments in the martingale hypothesis, we believe that the results should also have implications for similar periods in the future. Therefore, the managers of commercial banks can at least know which events are important to look at, and what is the anticipated reaction of the interbank spread. Moreover, predictions are possible; for this purpose the commercial bank managers should use the EGARCH specification. The most important result of the analysis is that the pure form martingale hypothesis does not hold; hence, the funds are not perfectly substitutable on different days of the reserve maintenance period; moreover, the spread can be forecasted with a level of accuracy higher than a random walk model. Therefore, speculative positions may be taken in the market by observing the current events. However, the managers should approach the method cautiously, and perhaps even rerun the analysis in order to be sure that the effects have not changed over time.

7. Conclusions

This paper answers the following questions: (1) “what exact factors determine the Latvian interbank spread in the short run?”, and (2) “can it be forecasted?” For econometric modeling the methodology proposed by Würtz (2003) was chosen, which is based on martingale hypothesis. Three ARCH models (GARCH, GARCH-M, and EGARCH), and a simple random walk model were developed, afterwards they were compared by their predictability power. Daily data was chosen for the research, and the time period selected was from January 3, 2005 till February 26, 2009. The models were robust on time periods of different volatilities.

Two types of forecasting were done: one-step and multi-step. One-step forecasting predicted the “tomorrow’s” values of the interbank spread, using the “today’s” value and explanatory variables as the reference point. Multi-step forecasting, on the other hand, used interbank spread values “today” (in the beginning of the period) to predict future values for longer periods of time – in our case – 19 working days ahead. Both of these methods were compared, and the best performing model, irrespective of the method chosen, was EGARCH. Thus, we conclude that the Latvian interbank spread can be forecasted, as EGARCH performed significantly better than random walk.

The factors that influence the spread are divided into two groups. Firstly, the variables that are in accordance with the martingale hypothesis: the past value of the interbank spread, net recourse to the standing facilities (accumulated over a reserve maintenance period, and daily), the reserve surplus (accumulated over a reserve maintenance period, and daily), the average value of the spread in the last days of the previous reserve maintenance period (after the last main refinancing operation), and the bid-to-cover ratio. Secondly, the variables that are not in line with the martingale hypothesis, but are significant, and deal with the irrationalities in the market, are: the marginal rates of the two previous main refinancing operations, the marginal rate of the last main refinancing operation in the previous reserve maintenance period, the change of the total outstanding main refinancing operations volume on the settlement day, and calendar effects that deal with the beginning and the end of reserve maintenance periods, Fridays, holidays, changes in the key policy rate, changes in the reserve requirements, and news questioning the LVL peg's sustainability. Moreover, the factors influencing the volatility of the spread were discussed in the paper, as well.

As the result of the research, the implications for the Bank of Latvia to reach a minimum spread are: to promote keeping the net recourse value at a level, which is close to the satisfied total required reserves over the reserve maintenance period, and to encourage commercial banks to hold more reserves. The implication for the commercial banks, on the other hand, is to take into account the explanatory factors, as it may help them to predict the future values of the interbank spread.

We believe that the obtained results will be useful and important for commercial banks, as they can optimize their short term allocation of funds, for the Bank of Latvia to reduce uncertainty, and for researchers that wish to perform studies on similar economies, as there is a lack of research in this field.

At this point we have recognized several further research opportunities. The first and most important is to perform the same research in countries that have similar characteristics – most notably the fixed exchange and small economy restrictions –, and then to compare the results with our study. Furthermore, we strongly suggest applying the methodology used in this paper and seeing, whether the determinants and the predictability change in the future Latvian interbank market (e.g. after the global financial turmoil is over). A further suggestion is to determine the exact transmission mechanism from the short term to the longer term interbank rates – test the yield curve effects in Latvia, since these are not researched.

8. References

Ajevskis, V., & Vītola, K. (2006). *A factor model of the term structure of interest rates and risk premium estimation for Latvia's money market.* (Working paper No. 1). Bank of Latvia.

Amaral, T. G., Cristóstomo, M. M. & Pires, V. F. (2004). *Neuro-fuzzy Modeling with a New Hybrid Learning Algorithm*. Retrieved February 23, 2009, from ACTA Press: http://www.actapress.com/PaperInfo.aspx?PaperID=15901&reason=500

Avakiat, S. (2001).The determinants of the interbank interest rate in the Thai banking system. *Dissertation Abstracts International, 62*(10), 3465A. (UMI No. 3029830)

Bank of England. (2007). An indicative decomposition of Libor spreads. *Quarterly bulletin 2007 Q4* [Newsletter], 47(4), 498-499.

Bank of Latvia. (2001). *Bank of Latvia: Annual report 2000*. Riga, Latvia: Premo

Bank of Latvia. (2002). *Bank of Latvia: Annual report 2001*. Riga, Latvia: Premo

Bank of Latvia. (2008a). *Bank of Latvia: Annual report 2007*. Riga, Latvia: Premo

Bank of Latvia.. (2008b). Data retrieved February 23, 2009, from http://www.bank.lv/eng/main/all/noract/mon_oper/transact/

Bank of Latvia. (2008c). Data retrieved February 23, 2009, from http://www.bank.lv/eng/print/?86604

Bank of Latvia. (2008d). Data retrieved February 23, 2009, from http://www.bank.lv/eng/main/all/noract/mon_oper/reserve/reserve/

Bank of Latvia. (2009a). Data retrieved January 11. 2008, from http://www.bank.lv/lat/main/fa/finfo/nt/rgbidrgbor/

Bank of Latvia. (2009b). Data retrieved January 11, 2009, from http://www.bank.lv/lat/top/faq/nti/

Bank of Latvia. (2009c). Data retrieved February 23, 2009, from http://www.bank.lv/eng/main/all/lvbank/vizija/

Brooks, C. (2008). *Introductory Econometrics for Finance* (2nd ed.). New York: Cambridge University Press.

Chen, Y. C., & Wong, K. Y. (2004). *Interbank behavior and financial crisis: the case of Hong Kong.* Retrieved January 14, 2009, from University of Washington Web site: http:/ /faculty.washington.edu/karyiu/papers/interbank-rt.pdf

Chiu, P., Lai, K., Leung, F., & Wong, S. (2001). *Interest rate spreads.* Hong Kong Monetary Authority.

Conway, P. (2006).*The Three Sources of Risk Premia in Ukrainian Inter-bank Markets.* USA: University of North Carolina.

Cuaresma, J. C., Fortin, I. & Hlouskova, J. (2005). *Macroeconomic Forecasts and Models for Austria: Evaluating euro exchange rate predictions from a battery of multivariate models*. (Workshop No. 5/2005). Oesterreichische Nationalbank.

Diebold, F. X. & Mariano, R .S. *(*1995*).* Comparing predictive accuracy. *Journal of Business and Economic Statistics*, *13*(3), 253-263.

Engle, R. F. (1982). Autoregressive Conditional Heteroscedasticity with Estimates of Variance of United Kingdom Inflation. *Econometrica*, *50*(4), 987-1007.

Friedman test. (2004). Retrieved February 23, 2009, from Statistical Engineering Division: http://www.itl.nist.gov/div898/software/dataplot/refman1/auxillar/friedman.htm

Gerlach, S. (2003). Interpreting the term structure of interbank rates in Hong Kong. *Pacific-Basin Finance Journal*, *11*, 593–609.

Hjalmarsson, E. (2006). *Should we expect significant out-of-sample results when predicting stock returns?* (International finance discussion Paper No. 855). Federal Reserve Board.

Hong Kong Monetary Authority. (2008). *Half-yearly monetary and financial stability report, December 2008*. Hong Kong.

Imakubo, K., Kimura, T., & Nagano, T. (2008). *Cross-currency transmission of money market tensions* (Review No. 2008-E-2). Japan: Bank of Japan.

Inoue, A. & Kilian, L. (2002). *In-sample or out-of-sample tests of predictability: Which one should we use?* (Working Paper No. 195). European Central Bank.

Jankee, K. (2003). Interest rate determination in the post- liberalisation period in Mauritius. *Law, Management and Social Sciences – Research Journal, 5*.

Jarque, C. M. & Bera, A. K. (1987). *A test for normality of observations and regression residuals.* (International Statistical Review No. 55), 163-172.

Jurgilas, M. (2005*). Interbank market under the currency board: Case of Lithuania.* USA: University of Connecticut.

Krugman, P. R., & Obstfeld M. (2006). *International Economics: Theory and Policy* (7th ed.). Boston: Addison Wesley.

Linzert, T., & Schmidt, S. (2008). *What explains the spread between the euro overnight rate and the ECB's policy rate?* (Working Paper No. 983). European Central Bank.

Ma, J., Van Gelder, P. H. A. J. M., Vrijling, J. K. & Wang, W. (2005). Testing and modelling autoregressive conditional heteroskedasticity of streamflow processes. *Nonlinear Processes in Geophysics, 12*(1), 55–66.

MacKinnon, J.G. (1996). Numerical Distribution Functions for Unit Root and Cointegration Tests. *Journal of Applied Econometrics, 11*(6), 601-618.

Michaud, F. L., & Upper, C. (2008). What drives interbank rates? Evidence from the Libor panel. *BIS Quarterly Review, March 2008*, 47-58.

Moschitz, J. (2004). *The determinants of the overnight interest rate in the euro area.* (Working Paper No. 393). European Central Bank.

Nelson, D. B. (1991). Conditional heteroscedasticity in asset returns: A new approach. *Econometrica, 59*(2), 347-370.

Mendizabal, H. R. & Quiros, G. P. (2001). *The daily market for funds in Europe: Has something changed with the EMU?* (Working Paper No. 067). European Central Bank.

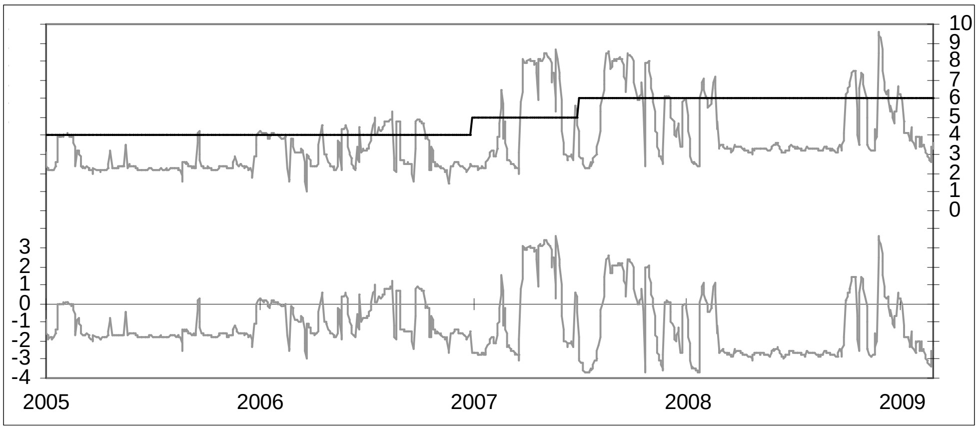
Schmukler, S. L., & Servén, L. (2002). Pricing currency risk under currency boards. *Journal of Development Economics*, *69*(2), 367-391.

The Monetary Authority of Singapore. (1999). *Interbank interest rate determination in Singapore and its linkages to deposit and prime rates* (Occasional Paper No. 16). Singapore: Author.

Würtz, F. R. (2003). *A comprehensive model of the euro overnight rate* (Working Paper No. 207). European Central Bank.

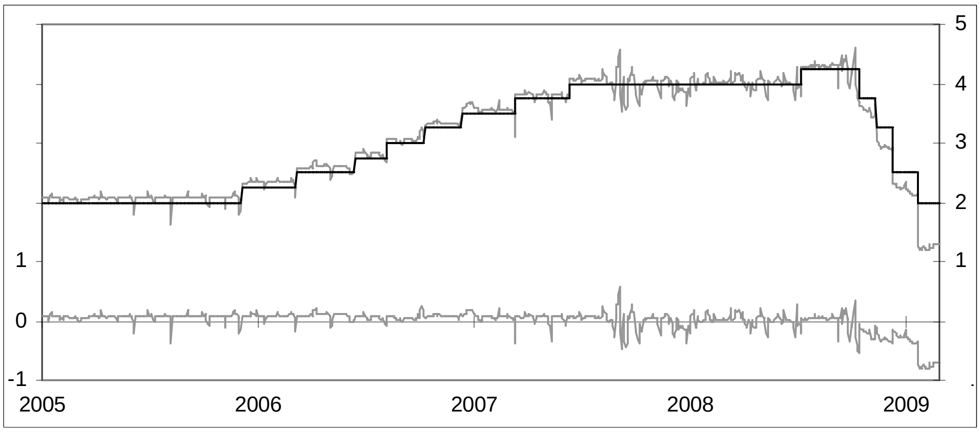
Appendix 1: LVL, EUR, USD rates, spreads

Figure 1: Latvian overnight interbank rates (bid-ask average), refinancing rate, their spread



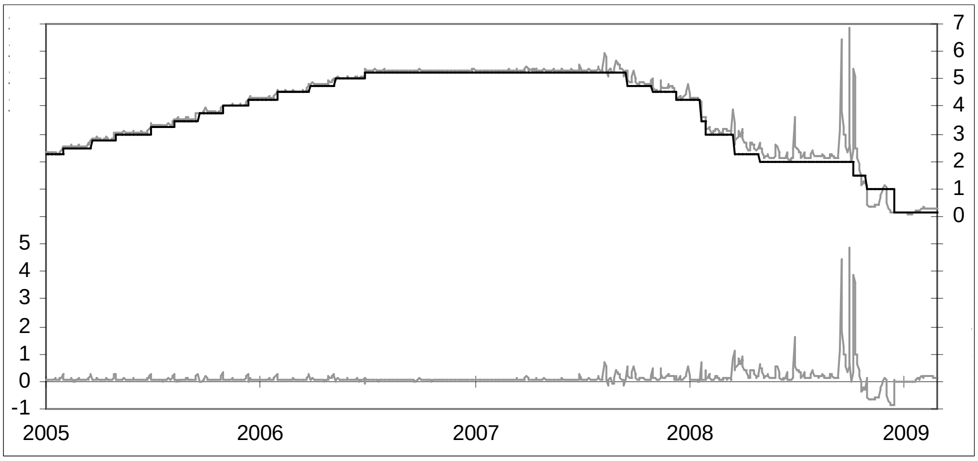
Note: Latvian overnight interbank rates, LVL refinancing rate (right scale), and their spread (left scale).

Figure 2: European overnight index average (EONIA), refinancing rate, their spread



Note: EONIA, EUR refinancing rate (right scale), and their spread (left scale).

Figure 3: U.S. overnight interbank rates (bid-ask average), refinancing rate, their spread



Note: US overnight interbank rates, USD refinancing rate (right scale), and their spread (left scale).

Appendix 2: Definition of variables

Variable	Formula	Symbol	Reference
1. Lag of the interbank spread.			
Lag of the interbank spread	value of the interbank spread on the previous trading day	x_1	Linzert and Schmidt (2008)
2. Expectations on accumulated liquidity in reserve maintenance period.			
Daily net recourse to the standing facilities	recourse to the marginal lending facility less recourse to the deposit facility	x_2	Würtz (2003), Avakiat (2001)
The net recourse to standing facilities realized on the preceding trading day	marginal lending facility less the deposit facility on the preceding trading day	x_3	Würtz (2003), Avakiat (2001)
The accumulated reserve surplus	current account holdings[15] less the reserve requirements that have been experienced since the beginning of the maintenance period	x_4	Würtz (2003)
The average spread experienced on the last days of the previous reserve maintenance period (after the last main refinancing operation of the previous reserve maintenance period)	the mean value of the spread experienced on the last days of the previous reserve maintenance period (after the last main refinancing operation of the previous reserve maintenance period)	x_5	Würtz (2003)
Dummy variable for liquidity	dummy variable equal to 1 if the spread on the last trading day of the two previous reserve maintenance periods exceeded 150 basis points, otherwise 0	x_6	Würtz (2003)
3. Daily liquidity conditions.			
Daily reserve surplus	current account holdings less reserve requirements	x_7	Würtz (2003)
4. Tender outcomes.			
The marginal rate of the most recent main refinancing operation		x_8	Würtz (2003)
The marginal rate of the second most recent main refinancing operation		x_9	Würtz (2003)
The marginal rate of the last main refinancing operation in the previous reserve maintenance period.		x_{10}	Würtz (2003)
Average of the deposit facility rates, realized since the beginning of the reserve maintenance period.		x_{11}	Würtz (2003)
The change of the total outstanding main refinancing operations volume on the settlement day		x_{12}	Würtz (2003)
5. Bidding behavior in the main refinancing operations.			
Bid-to-cover ratio	the ratio between total bid volume and the amount covered	x_{13}	Linzert and Schmidt (2008)

Note: Table continued on the next page.

[15] “cash account of a commercial bank with the Bank of Latvia for settlements in lats.” (Bank of Latvia, 2008a)

Variable	Formula	Symbol	Reference
	(table continued from the previous page)		
6. Calendar effects.			
Monday effect	dummy variable equal to 1 on the first trading day of a week, otherwise 0	x_{14}	Würtz (2003),
Friday effect	dummy variable equal to 1 on the last trading day of a week, otherwise 0	x_{15}	Würtz (2003),
End of month effect	dummy variable equal to 1 on the end of months, otherwise 0	x_{16}	Würtz (2003), Moschitz (2004)
Up to end of month effect	dummy variable equal to 1 for the days leading up to an end of month, defined as the first 6 trading days of a reserve maintenance period, otherwise 0	x_{17}	Würtz (2003)
Beginning of month effect	dummy variable equal to 1 on the first day of the month, otherwise 0	x_{18}	Würtz (2003)
End of quarter effect	dummy variable equal to 1 on the end of quarters, otherwise 0	x_{19}	Würtz (2003)
End of semester effect	dummy variable equal to 1 on the end of a semester, otherwise 0	x_{20}	Würtz (2003)
End of year effect	dummy variable equal to 1 for the end of year, otherwise 0	x_{21}	Würtz (2003)
Holiday effect	dummy variable equal to 1 for trading days before and after holidays, otherwise 0	x_{22}	Würtz (2003)
First reserve maintenance period day effect	dummy variable equal to 1 for the first trading day of a reserve maintenance period, otherwise 0	x_{23}	Würtz (2003)
Last 3 reserve maintenance period day effect	dummy variable equal to 1 for each of the three last trading days of a reserve maintenance period, otherwise 0	$x_{24,25,26}$	Würtz (2003)
7. Other effects.			
Key policy rate differences	the difference between the key policy rate on time t and the average key policy rates on time t-1 and t-2.	x_{27}	Würtz (2003)
Policy rate change effect	dummy variable equal to 1 after a policy rate change, otherwise 0	x_{28}	Würtz (2003)
Parex bank takeover effect	dummy variable equal to 1, when the Latvian government publicly announced its takeover of Parex bank, otherwise 0	x_{29}	
Parex bank takeover effect until the end of reserve maintenance period effect	dummy variable equal to 1 until the end of the reserve maintenance period, after the Latvian government publicly announced its takeover of Parex bank, otherwise 0	x_{30}	
News effect	dummy variable equal to 1, when news questioning the lat and euro currency peg's sustainability were released, otherwise 0	x_{31}	
News effect until the end of reserve maintenance period	dummy variable equal to 1 until the end of the reserve maintenance period, when news questioning the lat and euro currency peg's sustainability were released, otherwise 0	x_{32}	
Reserve requirement change effect	dummy variable equal to 1, when the reserve requirements have been changed, otherwise 0	x_{33}	(Bank of Latvia, 2008a)

Appendix 3: Heteroscedasticity test for ARCH lags

The ARCH test is a Lagrange multiplier test for ARCH in the residuals (Engle, 1982). This test statistic is computed from an auxiliary test regression. To test the null hypothesis that there is no ARCH up to order q in the residuals, we run the regression:

$$e_t^2 = \eta_0 + \left(\sum_{i=1}^{q} \eta_i e_{t-s}^2 \right) + \upsilon_t , \qquad (17)$$

where e^2 is the squared residual of the primary regression, η_i are the coefficients to be estimated, q is a chosen number of lags, and v_t is the residual of this particular regression. Overall, this is a regression of the squared residuals on a constant and lagged squared residuals (Ma et al., 2005).

Table 1: Heteroscedasticity test for ARCH lags

Variables	Coefficient estimate
constant	0.1220**
residual^2_{t-1}	0.0562*
residual^2_{t-2}	0.1633**
residual^2_{t-3}	0.0313
residual^2_{t-4}	-0.0058
residual^2_{t-5}	-0.0126

Notes: *, and ** indicate 10%, and 1% significance levels respectively.
H_0: There are no ARCH effects for the residual q.
H_A: There are ARCH effects for the residual q.

Appendix 4: Augmented Dickey Fuller test

Table 1: Augmented Dickey Fuller test for non-stationarity in the interbank spread

	With constant	No constant, no trend
t-statistic	-6.3376 *	-4.8503 *
Test critical value at 1% level	-3.4364	-2.5672
Test critical value at 5% level	-2.8641	-1.9411
Test critical value at 10% level	-2.5682	-1.6165

Notes: H_0: interbank spread series has a unit root (it is not stationary).
H_A: interbank spread series is stationary.
* indicates 1% significance level, according to MacKinnon (1996) one-sided p-values.

Appendix 5: Comparison of literature

Author (year)	Intra/ inter country analysis	Country	Period	Results
Chiu et al (2001)	Inter	Hong Kong, USA	1993–2000	The authors find out that during the Asian financial turmoil investors were more concerned with currency risk, however, they do not withdraw the possibility that credit risk, liquidity risk and other structural factors have been at work. Moreover, they perform a factor analysis and find out that there is a significant degree of interplay among the various risk components. In regression analysis they find out that the interest spreads are negatively associated with real GDP growth and Hang Seng Index movements, and positively associated with the Aggregate Balance and the yield spreads of emerging markets.
Gerlach (2003)	Intra	Hong Kong	1992–2000	In this study the author has analyzed term structure of interest rates. The major finding is that the term spreads contain no information about future short-term rates. Moreover, he rejects the existence of expectations hypothesis in Hong Kong in this time period.
Schmukler & Servén (2002)	Inter	Argentina, Hong Kong, USA	1993–2001	The authors look at two currency board regime countries and analyze the implied currency risk. The most important finding is that almost always there is a positive currency premium, that its term structure is usually upward sloping. This premium depends on domestic and global factors, related to devaluation expectations and risk perceptions.
The monetary authority of Singapore (1999)	Intra	Singapore	1990–1999	The scientists of this institution have found out that the interest rate could be presented as a weighted average of the interest rate level based on uncovered interest rate parity (as in an open economy), and internal equilibrium factors (as in fully closed economy). Interestingly the results show that changes in money supply or factors affecting the demand for money have no effect on the domestic interbank rate. The only significant factors are changes in US interest rates and market expectations on future movements in the exchange rate.
Jankee (2003)	Intra	Mauritius	1988–2002	The author develops an empirical model to determine the impact of foreign interest rate (adjusted for changes in exchange rate), money supply, real income and expected inflation rate on interest rate. The interest rate parity theory and the Fisher effect are rejected for Mauritius. Moreover, the interest rates are found to be more sensitive to domestic rather than external factors.
Conway (2006)	Inter	Ukraine, Eurozone	1999–2005	In this study three sources of premia in interest rates on interbank markets relative to Eurozone markets are analyzed. The main finding is that the result of the peg versus US dollar eliminated the risk of currency depreciation, however, other risks (convertibility and liquidity) are not dealt with yet.
Ajevskis & Vītola (2006)	Intra	Latvia	2000–2005	The authors of this paper analyze the term structure of interbank interest rates in Latvia. The results indicate that the risk premium was significant and very volatile in 2000 – 2002. Afterwards the premium decreased.
Jurgilas (2005)	Intra	Lithuania	2002–2005	In this paper the liquidity effect on Lithuanian interbank interest rates is estimated. Importantly, the study shows a result that is contrary to the results in the developed countries – overnight interest rates tend to fall at the end of the reserve holding period in Lithuania (and they are higher at the beginning of the period). Therefore, the author rejects the martingale hypothesis of the interest rates, hence the Lithuanian interbank market is inefficient. Moreover, commercial banks do not use the aggregate information provided by the Central Bank and the treasury account holdings are not important in interbank rate determination.

Note: Table continued on the next page.

Author (year)	Intra/ inter country analysis	Country	Period	Results
		(table continued from the previous page)		
Bank of England (2007)	Intra	UK	2006–2007	The scientists of Bank of England have decomposed the spread between Libor and overnight indexed swaps in credit and non-credit premium. The non-credit premia is the main cause of the high fluctuations in the market.
Michaud and Upper (2008)	Intra	UK	2007–2008	The authors extend the methodology suggested by Bank of England, identify the drivers of the increase in risk premia in interbank markets, in particular the role of credit and liquidity factors. Liquidity factors are the main determinants of the recent volatility.
Hong Kong monetary authority (2008)	Intra, extend to inter	USA, Hong Kong	2006–2008	The scholars of Hong Kong monetary authority have also applied the methodology suggested by Bank of England. They find that liquidity factors, instead of credit factors, are the most important in the Hong Kong's market – they cause the most fluctuations. Moreover, they find out that the tightened money market was caused by the effects in USD market.
Imakubo, Kimura, Nagano (2008)	Inter	Japan, USA, Eurozone	2007–2008	In this paper three major markets are analyzed. The main finding is that increased volatility in these markets mainly comes from changes in the variances of shocks impacting the market and also changes in the structures of the markets. They also find that the interdependent relationship between the markets is extended with the risk-averse investors during financial turmoil. However, due to the fact that the shocks in the US market were not absorbed in the global money markets, there is a persistent upward pressure on yen and euro.
Würtz (2003)	Intra	Eurozone	1999–2002	The author analyzes the determinants of the spread between the euro overnight rate and the key policy rate of the European Central Bank. The most important variables that influence this spread and its volatility are expectations about changes of the key policy rate and the estimated liquidity conditions at the end of the reserve maintenance period. The model used is constructed on the basis of martingale hypothesis (the rate is equal to the expected rate at the end of reserve maintenance period).
Linzert & Schmidt (2008)	Intra	Eurozone	2000–2006	The authors apply similar methodology to Würtz (2003), but they add additional variables to the model. The most important determinant of the spread is the change in liquidity deficit. Moreover, less liquidity in the market and higher uncertainty about them also significantly increase the spread.
Avakiat (2001)	Intra	Thailand	1991–2000	In this paper the author finds the main determinants of the Thailand interbank rates. They are: SIBOR, Central Bank's repurchase rate, forward rate, the change in commercial bank deposits, change in foreign assets, and the change in foreign liabilities.
Moschitz (2004)	Intra	Eurozone	1999–2004	Here the author models the reserve market. There are predictable patterns for the mean and the volatility of the overnight rate, these stem from monetary policy implementation. Moreover, some calendar day effects are observed. The mean is high at the last day of a month, even higher on the end of a semester or a year.

Note: For full lists of variables in each study the reader is referred to the each particular study.

Appendix 6: Results

Table 1: Mean equation

Coefficient	EGARCH	GARCH	GARCH-M
GARCH-M term.			
Δ			0.0875
1. Lag of the interbank spread.			
β_1	0.9853 ***	0.8698 ***	0.8699 ***
2. Expectations on accumulated liquidity in reserve maintenance period.			
β_2	2.38E-07 ***	2.18E-06 ***	1.98E-06 ***
β_3	-1.05E-07 ***	-1.14E-06 ***	-9.73E-07 ***
β_4	-1.88E-08 ***	-5.19E-08	-5.10E-08
β_5	0.0113 ***		
3. Daily liquidity conditions.			
β_7	-1.90E-07 ***	-1.42E-06 ***	-1.35E-06 ***
4. Tender outcomes.			
β_8	0.0454 ***	0.1917 ***	0.1907 ***
β_9	-0.0252 ***	-0.1069 *	-0.1058 **
β_{10}	-0.0197 ***	-0.1070 *	-0.1104 **
β_{12}	1.65E-06 ***		
5. Bidding behavior in the main refinancing operations.			
β_{13}	0.0064 ***	0.0952 ***	0.0953 ***
6. Calendar effects.			
β_{15}	-0.0107 ***		
β_{22}	0.0113 ***		
β_{23}	0.4004 ***	0.7215 ***	0.7180 ***
β_{24}	-0.0337 ***	-0.2397 **	-0.2415 **
β_{25}	-0.0509 ***	-0.3032 **	-0.3052 **
β_{26}	-0.0227 ***	-0.2680 **	-0.2694 **
7. Other effects.			
β_{27}	-1.0849 ***		
β_{30}		-0.5751 **	-0.5714 **
β_{31}	0.8075 ***		
β_{33}	-0.1165 ***		

Diagnostic statistics	EGARCH	GARCH	GARCH-M
Observations	1050	1050	1050
R-squared	0.9108	0.9337	0.9332
Adjusted R-squared	0.9071	0.9324	0.9318
Standard errors of regression	0.4902	0.4183	0.4198
Sum squared residuals	242.0058	180.0062	181.2091
Log likelihood	475.3813	-635.3492	-633.5745
Durbin-Watson statistic	1.7034	1.6624	1.6608
Mean dependent variance	-1.0958	-1.0958	-1.0958
Standard deviation dependent variance	1.6082	1.6082	1.6082
Akaike information criterion	-0.8236	1.2502	1.2487
Schwarz criterion	-0.6206	1.3493	1.3526
Hannan-Quinn criterion	-0.7466	1.2878	1.2881

Notes: Mean results of the 3 specifications: EGARCH, GARCH, and GARCH-M.
Sample period: January 3, 2005 to February 26, 2009, daily observations.
*, **, and *** indicate 10%, 5%, and 1% significance levels respectively.
β correspond to the respective explanatory variables (x), see Appendix 2 for full details of the variables.

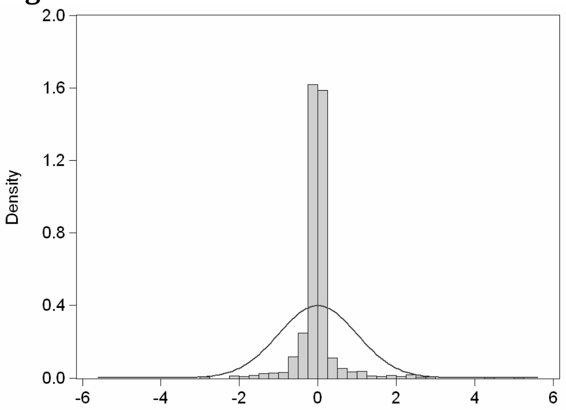
Table 2: Variance equation

Coefficient	EGARCH	GARCH	GARCH-M
Constant in variance equation.			
c	-2.5143 ***	0.1700 ***	0.1697 ***
Asymmetry coefficient			
γ	-0.1705 **		
ARCH term			
ω_1	0.8552 ***	0.1500 ***	0.1500 ***
GARCH term			
φ_1	0.4323 ***	0.6000 ***	0.6000 ***
φ_2	0.2610***		
1. Lag of the interbank spread.			
v_1	0.1116 ***		
2. Expectations on accumulated liquidity in reserve maintenance period.			
v_2	2.57E-06 ***	2.52E-07 ***	2.34E-07 ***
v_4	-4.05E-07 **	-7.86E-08 ***	-8.43E-08 ***
v_5	-0.1584 ***		
3. Daily liquidity conditions.			
v_7	-2.10E-06 ***	-2.48E-07 ***	-2.31E-07 ***
4. Tender outcomes.			
v_{10}	0.2196 ***		
6. Calendar effects.			
v_{14}	0.4729 **		
v_{16}	1.2059 **		
7. Other effects.			
v_{17}	-1.4567 ***		
v_{18}	-1.2452 ***		
v_{19}	-2.8232 ***		
v_{20}	2.7806 **		
v_{23}	4.0331 ***		
v_{24}	0.7061 *		
v_{25}	0.8509 *		
v_{26}	0.6720 **		
v_{28}	3.9183 **		

Notes: Variance results of the 3 specifications: EGARCH, GARCH, and GARCH-M.
Sample period: January 3, 2005 to February 26, 2009, daily observations.
*, **, and *** indicate 10%, 5%, and 1% significance levels respectively.
v correspond to the respective explanatory variables (x), see Appendix 2 for full details of variables.

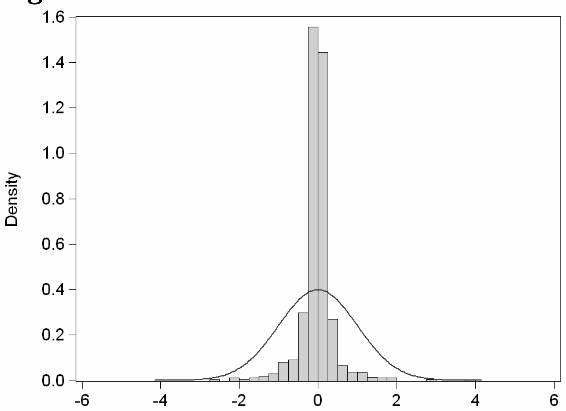
Appendix 7: Standardized residual tests

Figure 1: EGARCH residual test



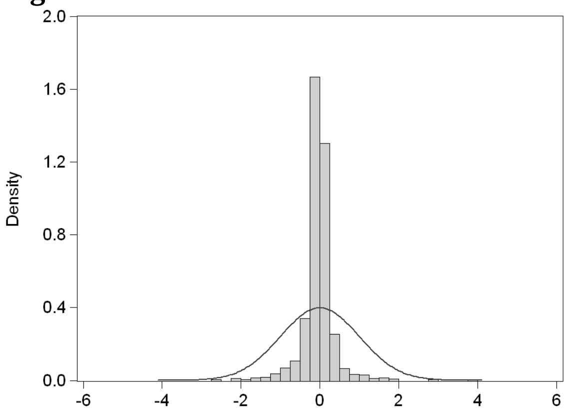
Notes: The graph shows the histogram of EGARCH model's residuals for the whole sample period (1050 observations), and a standard normal curve.

Figure 2: GARCH residual test



Notes: The graph shows the histogram of GARCH model's residuals for the whole sample period (1050 observations),, and a standard normal curve.

Figure 3: GARCH-M residual test



Notes: The graph shows the histogram of GARCH-M model's residuals for the whole sample period (1050 observations),, and a standard normal curve.

Table 1: Standardized residual test results

	EGARCH	**GARCH**	**GARCH-M**	**Random Walk**
Observations	1050	1050	1050	1050
Mean	-0.0207	-0.0171	-0.0455	-0.0403
Median	-0.0204	-0.0205	-0.0526	-0.0689
Maximum	13.3317	3.6272	3.5623	5.3601
Minimum	-8.7295	-3.7685	-3.8057	-3.0082
Std. Dev.	1.1355	0.6267	0.6351	0.5167
Skewness	1.9808	-0.1596	-0.0710	2.9457
Kurtosis	33.0669	10.8450	11.1267	30.0315
Jarque-Bera	40237.34	2696.984	2890.286	33486.68
Probability	0.0000	0.0000	0.0000	0.0000

Notes: Jarque-Bera shows the goodness of fit of the residuals to the standard normal distribution (Jarque & Bera, 1987).
H_0: The residuals follow a standard normal distribution.
H_A: The residuals do not follow a standard normal distribution.
The normal distribution of residuals is rejected at 1% level for all models.

Appendix 8: Predictability tests

Table 1: The average values of out-of-sample forecast errors

	EGARCH	**GARCH**	**GARCH-M**	**Random Walk**
(One-step forecast)				
RMSE	**0.18978**	0.256833	0.253811	**0.23009**
MAE	**0.16597**	0.238454	0.238282	**0.19887**
MAPE	**5.63395**	7.942907	7.894356	**6.48858**
Theil	**0.03253**	0.042448	0.041855	**0.03865**
(Multi-step forecast)				
RMSE	**0.26921**	0.538554	**0.51926**	0.62628
MAE	**0.22071**	0.484439	**0.46781**	0.564394
MAPE	**7.18709**	15.29353	**14.7447**	17.40991
Theil	**0.04405**	0.086828	**0.08391**	0.110144

Notes: Predictability test results for 3 model and random walk specifications.
RMSE stands for Root mean squared error.
MAE – mean absolute error.
MAPE – mean absolute percent error.
Theil – Theil inequality coefficient.
See pp. 19 for an explanation of the test values!
Bolded values show the two best performing models in each error measure category.

Table 2: Diebold-Mariano test statistics and its p-values

	Diebold-Mariano statistic	**p-value**
(One-step forecast EGARCH vs. Random Walk)		
RMSE	-1.6934	0.0452
MAE	-1.5584	0.0596
MAPE	-1.1057	0.1344
Theil	-1.3809	0.0837
(Multi-step forecast EGARCH vs. GARCH-M)		
RMSE	-3.5248	0.0002
MAE	-3.6019	0.0002
MAPE	-3.5382	0.0002
Theil	-3.3450	0.0004

Notes: Predictability test results for the two best performing models in both categories: one-step and multi-step forecast.
H_0: The predictive power of the models is not significantly different.
H_A: The predictive power of the models is significantly different.
RMSE stands for Root mean squared error.
MAE – mean absolute error.
MAPE – mean absolute percent error.
Theil – Theil inequality coefficient.
See pp 19 for an explanation of the test values!