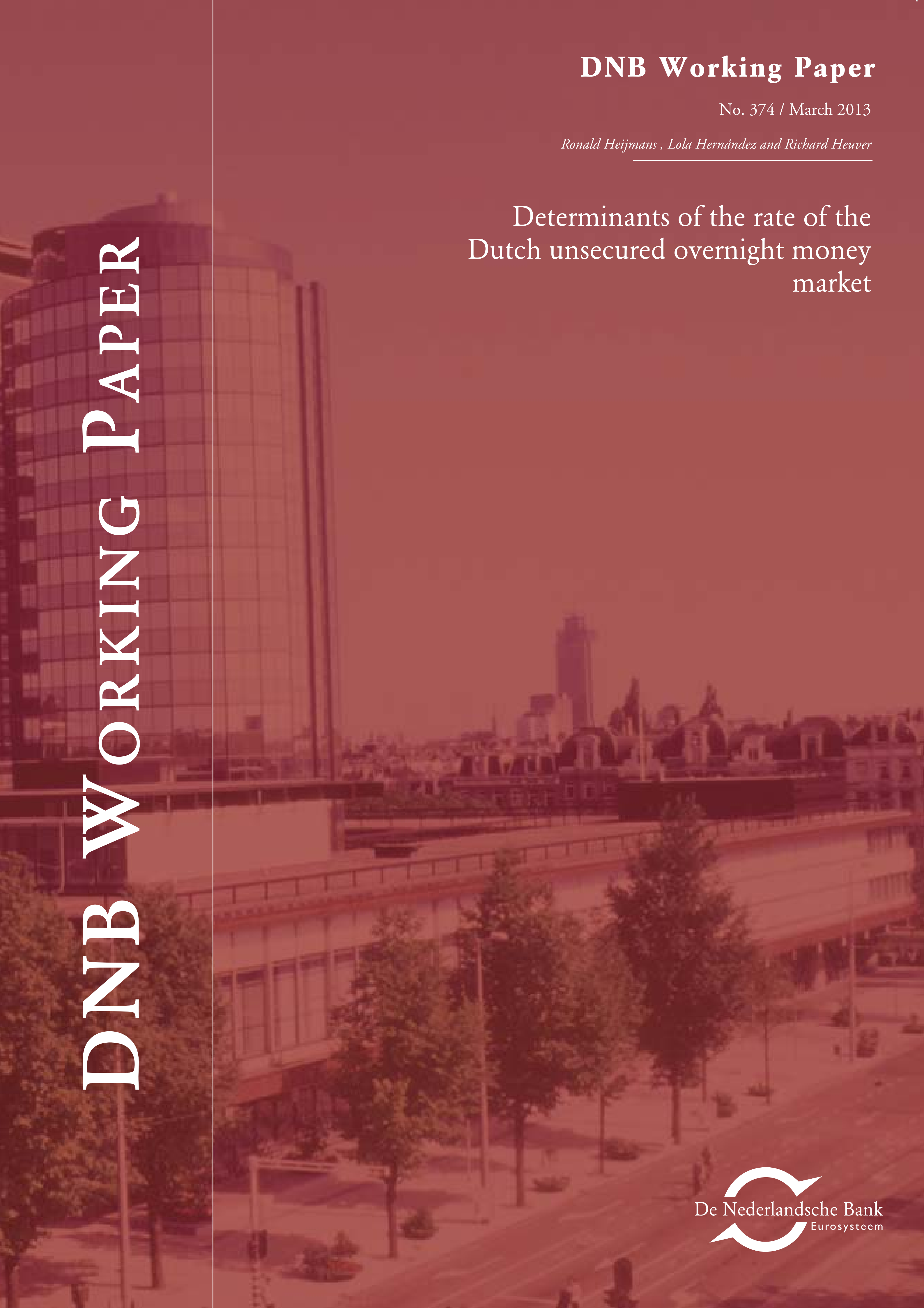

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De Nederlandsche Bank
Eurosysteem

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Determinants of the rate of the Dutch unsecured overnight money market

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Monday 4th March, 2013

Abstract

This paper investigates how changes in the monetary policy framework have affected the overnight money market lending rate for the Dutch segment of the euro area during tranquil and crisis times. We present an EGARCH model on the volatility of the overnight lending rate. The results show that modifications of the monetary policy framework in 2004 decreased the volatility of the rate. Since the turmoil of the crisis started the volatility increased again. Our method makes it possible for central banks to monitor the volatility of the rate and the impact of changes in the policy for the whole euro area.

Key Words: financial stability, unsecured interbank money market, EONIA, monetary policy

JEL Codes: E42, E43 E44, E52 G20

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1 Introduction

An efficient interbank money market plays an important role in the transmission of the monetary policy of a central bank. One of the aims of the policy is to steer the overnight interbank money market rates close to the refinancing rate set by the central bank. With this rate the central bank steers the rate at which banks lend liquidity to the real economy. Its importance was well illustrated by the financial crisis, that erupted in the summer of 2007. Especially after the failure of Lehman Brothers, in the fall of 2008, banks became very reluctant to lend liquidity to each other. For some banks this reluctance made it difficult (read expensive) or even impossible to obtain the desired liquidity from the interbank money market. To reduce counterparty risk banks reduced their bilateral limits and required high quality collateral for their loans (ECB, 2010). Central banks world-wide, including the European Central Bank (ECB), feared that the (un)secured money market would dry up. To prevent this, the ECB intervened by providing relatively inexpensive liquidity to the financial sector, resulting in a strong downward effect on the interest rate paid in the money market, see e.g. Heijmans et al. (2010) who studied the Dutch part of the euro interbank money market and Arciero et al. (2013) who studied the entire euro area interbank money market from June 2008. In many cases banks preferred depositing their surpluses at the ECB overnight deposit facility over lending in the money market. Banks that suffered from shortage preferred using the ECB lending facilities to obtain the required liquidity, so as to avoid the appearance of illiquidity among peers, and the associated stigma effect (Cappelletti et al., 2011).

The introduction of the euro in 1999 marked the start of the euro area monetary policy. Since then several modifications and adjustments have been made. In the initial framework, starting in 1999, the reserve maintenance period started on the 24^{th} and ended on the 23^{rd} of every month. The beginning or end of this period could fall on a weekend or a public holiday. The Main Refinancing Operations (MROs) provided by the ECB ran for two weeks, and were carried out every week, which resulted in an overlap between successive tenders. The ECB initially decided on the main refinancing rate every two weeks. In March 2004 the ECB introduced several modifications to the policy framework (ECB, 2004). The reason for these modifications was to decrease the disturbing impact of rate change expectations on the EONIA rate (ECB, 2004), (as high interest rate volatility is perceived as risky). The ECB changed the maturity of its main refinancing operations (from 2 weeks to 1 week) and synchronised the timing of the reserve maintenance periods with the interest rate decisions by the Governing Council. ECB (2006) and Durré and Nardelli (2008) argue that the modified operational framework decreased the volatility of EONIA. The contribution of our paper is to shed light on the behaviour of the modified framework during crisis times and to investigate how it has affected the overnight lending rate and its volatility. Besides making formal changes to the framework, the ECB also began to carry out more fine-tuning operations, to provide liquidity to the market as the need arose. These fine-tuning operations were already provided for in the initial framework, but very few had been carried out. As the crisis persisted, the ECB further adjusted its policy several times to support the financial system, see e.g. ECB (2010) or Cassola and Huetl (2010). Initially, the ECB allowed euro area banks to draw the full amount of liquidity they required at the main refinancing rate. In the months following August 2007, the ECB allowed tenders of 6 months. After the failure of Lehman Brothers in September 2008, central banks world-wide, including the ECB, feared the total collapse of the financial system. To prevent potential spill-over from the financial markets to the real economy, central banks lowered their main policy rates rapidly and introduced unconventional policy measures. The ECB decreased the tender rate by 325 basis points to 1.00% between October 2008 and May 2009. As the first amongst other (unconventional) measures taken since October 2008, it introduced fixed rate full allotment tender procedures.[1] Secondly, it extended the list of eligible assets, to make it easier for banks to access the ECB's liquidity tenders. Lastly, it provided tenders with maturities up to 12 months starting July 2009 and 3-year tenders starting in December 2011. [2].

The research question of this paper is: How have changes in the monetary policy framework affected the (interbank) lending rate in the Dutch overnight unsecured money market? In particular, we zoom in on the effect of the modifications in the framework on the rate since the start of the crisis. Although the ECB tries to steer the entire euro area market rather than just the Dutch segment of that market, we shed light on the extent to which the ECB's policy is effective in a subset of the euro money market. As the ECB aims to steer the overnight money market rate close to the main refinancing rate, we expect volatility to decrease after the modification to the initial framework and after further changes to the modified framework. The analysis in this paper only focusses on the unsecured money market due to lack of data on the secured part of this market. In order to gain a better understanding of the fluctuation of the overnight lending rate, we first study the effects on the rate with respect to calendar effects (end of month, end of quarter, public holidays, etc), mantainance period effects (periodic movements towards the end of a mantainance period, and several other variables regarding the composition of the market, such as number of lenders and borrowers, amount of excess liquidity, etc. Secondly, we look at the impact which major changes in the monetary policy instrument have had on the volatility of the rate. We distinguish four periods in our analysis, which are linked to the major changes in the way the money market functioned that occured after modifications in the operational framework of the European Monetary Union:

I. Initial framework: January 1^{st} 1999 to March 9^{th} 2004.

II. Modified framework until the start of turmoil: March 10^{th} 2004 to July 31^{st} 2007.

III. Start of the turmoil period: August 1^{st} 2007 to October 7^{th} 2008.

IV. Crisis period: October 8^{th} 2008 to May 31^{st} 2012. It refers to the period after the collapse of Lehman Brothers and the following introduction of the fixed rate full allotment (FRFA) policy.

Our paper relates to the literature in the following way. Hamilton (1996) initiated the empirical literature on overnight rates. He introduced an approach to measuring the volatility of Federal Funds rate, taking into account the tails and infrequent spikes that characterise such rate changes. He finds that the behaviour of the federal funds rate turns out to be close to a martingale over the reserve

[1] Initially the ECB provided tenders at a minimum bid rate.

[2] National governments also supported their financial systems by providing state support to systemically important financial institutions or even nationalising them. For an overview of the euro area's fiscal policy measures during the crisis, see van Riet (2010)

maintenance period, though there is enough predictability in daily movements of the federal funds rate to reject the martingale hypothesis over the reserve maintenance period. [3]

Gaspar et al. (2004) use an EGARCH model to analyse the individual interest rates reported by the banks contained in the EONIA panel. Bartolini and Prati (2006) analyse the volatility of the daily overnight rates for a set of countries, including the euro area. They study how interest rate volatility is affected by national differences in monetary policy implementation. Soares and Rodrigues (2011) model the volatility of the EONIA spread as an EGARCH model.[4] They state that the nature of the EGARCH will be different in the period before the fixed-rate full allotment (FRFA) policy where they follow Hamilton (1996). They find, for the period after the introduction of FRFA (2008-2009), that a conventional EGARCH is sufficient to capture the behaviour of volatility. Their results suggest a greater difficulty for the ECB to steer the level of the EONIA spread during the turmoil relative to the main refinancing rate. They also find that the liquidity effect declined from 2007 and in particular since the FRFA policy. Nautz and Offermans (2006) empirically investigate the transmission of EONIA volatility to longer term money market rates.[5] Würtz (2003) presents a model on the spread between the euro overnight rate and the key policy rate of the ECB. He shows that the most important variables driving the level and the volatility of the spread are expectations at the end of the reserve maintenance period. His research focusses on data between April 1999 and April 2002. Pérez-Quirós and Mendizábal (2006) state that the range of the standing facilities and the degree of asymmetry relative to the main reference rate influences the market interest rate. A reduction in the amplitude of the corridor allows EONIA to be more stable and closer to the policy rate. Pérez-Quirós and Mendizábal (2010) argue that if banks have a strong preference for liquidity due to expectations of tight liquidity conditions in the future, the corridor amplitude will only impact the demand for reserves if the corridor is asymmetric relative to the main reference rate. Cassola and Huetl (2010) analyse the impact of the beginning of the crisis, summer of 2007 to August 2008, on EONIA and interbank market trading and assess the effectiveness of the ECB liquidity policy in this period. They build their model on Pérez-Quirós and Mendizábal (2006). Facing this uncertainty about the end-of-day liquidity shocks, banks manage their reserves by trading on the interbank market in such a way as to minimise the cost of borrowing liquidity shortages from or lending surpluses to the ECB. They find that liquidity frontloading is a small scale central bank intervention which is capable of stabilising interest rates in both frictionless and distorted markets.[6] Their simulations suggest that without frontloading the EONIA would have been, on average, 23 basis points above the policy rate. With frontloading the overnight rate is, on average, equal to the policy rate. Acharya and Merouche (2010) study liquidity demand of large settlement banks in the United Kingdom and its effect on the Sterling money markets before and during the sub-prime crisis of 2007 and 2008. They use the algorithm developed by Furfine (1999) to identify loans from large value payment systems (LVPS)

[3]The martingale is a stochastic process in which the conditional expectation of future values remains constant in time.

[4]Their data set ranges from March 2004 until December 2009.

[5]Their data set ranges from July 2000 until August 2006. This period includes the introduction of the ECB's new operational framework (NOF).

[6]Frontloading liquidity policy: additional liquidity was provided via allotments above benchmark, which is the amount of refinancing that allows banks to fulfil their reserve requirements smoothly over the reserve period, during the early stage of the reserve maintenance period with the surplus gradually reduced throughout the reserve maintenance period either through allotments below benchmark or via liquidity draining fine-tuning operations.

data. One of their findings is that the liquidity demand by settlement banks caused overnight interbank rates to rise.

We follow the approach of e.g. Gaspar et al. (2004) and Soares and Rodrigues (2011) by using an EGARCH model to analyse the volatility of the overnight lending rate in the Dutch segment of the euro money market. Like Acharya and Merouche (2010) we use an algorithm (Heijmans et al., 2010) to identify unsecured loans from LVPS transaction data. In contrast to other papers we make use of a long time series, ranging from January 1999 until May 2012. This includes the start of the euro area, the introduction of the modified operational framework, the start of the turmoil period of the crisis and the failure of Lehman Brothers. Unlike previous analysis on EONIA, we include all banks active in the Dutch overnight money market, instead of only the panel banks which contribute to calculating the euro area-wide EONIA rate.

Our results indicate that the 2004 modifications in the monetary policy framework decreased the volatility of the interest rate, as expected. However, the unconventional measures during the turmoil period and after the collapse of Lehman Brothers has not made the rate less volatile. On the contrary, during the turmoil the rate became more volatile and during the crisis period volatility persistence remained high. Although during the financial crisis the primary concern of the ECB has not been to control volatility but to save the financial system from collapse, the increase in volatility can be considered as the price of preserving relative financial stability.

The outline of this paper is as follows. Section 2 describes the large value payment system and its data. Section 3 describes the developments of the (volatility of the) rate. Section 4 describes the model and section 5 describes the results of the developments of the volatility analysis. Section 6 concludes.

2 Payment Systems Data

2.1 TARGET

TARGET2 is the main euro area real time gross settlement system (RTGS). Currently, all the euro area countries and six non-euro area countries are connected to TARGET2. [7] [8] It has been designed to handle large value transaction in euro in a reliable and efficient manner. TARGET2 complements the Eurosystem's operational framework for the implementation of monetary policy and falls within the responsibility of the Governing Council of the ECB. TARGET2 handles the transactions of roughly 4,500 credit institutions and of other financial institutions, that meet the access criteria, directly or indirectly. As TARGET2 is an RTGS, each transaction is settled directly (in real time) and individually (gross). Apart from processing transactions between (in)direct participants, it is also used for settlement payments of many other payment systems (Kokkola, 2010).

TARGET2 has several advantages for commercial banks. 1) Payments are made immediately (in real time) and irrevocably. Due to the irrevocability of the payment, a payment can never be made undone, not even in case of bankruptcy. 2) TARGET2 puts no limits on the amount of a payment whether for

[7] Trans European Real Time Gross Settlement Express Transfer

[8] The six non euro area countries are Bulgaria, Denmark, Latvia, Lithuania, Poland and Romania. (status July 2012).

Table 1: Statistics on TARGET2-NL and TOP.

Year	Number of participants	Number of direct participants	Average daily number of transactions (thousands)	Average daily value of transactions (EUR billion)
1999	158	108	12.5	71.2
2000	163	105	14.9	83.1
2001	166	108	16.2	94.9
2002	166	108	18.7	97.9
2003	155	106	19.3	103.1
2004	161	102	18.1	116.4
2005	155	102	18.4	120.4
2006	148	99	18.7	125.5
2007	132	90	28.5	153.1
2008	102	60	36.3	230.9
2009	103	61	36.8	249.7
2010	99	55	33.7	303.8
2011	100	54	32.7	310.6
2012	100	53	32.3	314.0

domestic or for cross-border transactions. 3) It provides a uniform cost structure for the same services thus ensuring a level playing field across all participating countries. This is of particular advantage to banks operating in more than one euro country.

Each transaction in TARGET2 involves two participants (mainly banks) and/or two central banks. Each bank is assigned to one of the central banks. Although banks are free to choose any central bank in the Euro-system to handle their account, most banks choose (at least) the central bank in which they have their headquarter. Many banks hold accounts at more than one central bank. The payment takes place between accounts held at two central banks. The sending bank must have sufficient liquidity in its central bank account. Banks are allowed to obtain free collateralised overdrafts, which they have to repay by the end of the business day, otherwise an overnight fee will apply to the overdraft. The balance on the account can be obtained either from monetary policy refinancing operations or from incoming payments. An important incoming payment type is unsecured interbank loans, which we are looking for in this paper.

Another RTGS system in euro is EURO1, which is a privately owned payment system for domestic and cross-border single payments in euro between banks operating in the European Union.[9] Although EURO1 offers the opportunity to settle interbank money market loans, most of such loans and refunds are settled through TARGET2. The daily turnover of TARGET2 (EUR 4005 billion) far outstrips that of EURO1 (EUR 238 billion).[10]

[9]This system numbers 65 participating (mainly large) banks.

[10]see $https://www.ebaclearing.eu/Statistics-on-EURO1\%2fSTEP1-N=E1_statistics-L=EN.aspx)$

2.2 Statistics on large value payment systems

We use transaction data from two payment systems operating throughout the past twelve years, corresponding to our sample period. The first one called TOP existed from the start of our sample, the 1st of January 1999 until the 17th of February 2008. The second system is TARGET2-NL, introduced on the 18th of February 2008. Table 1 shows statistics on the Dutch segment of TARGET2: number of participants, number of transactions and value settled. The table shows that the number of direct participants drops from 90 in 2007 to 60 in 2008. The drop is mainly related to the introduction of TARGET2 as the new payment system. Some TOP participants did not meet the access criteria of TARGET2. Some (international) banks, which used the account in TOP mainly for their reserve requirements, have since the introduction of TARGET2-NL been able to hold these reserves in the so-called Home Accounting Module (HAM). These HAM account holders, which can reach direct participants in TARGET2, do not count towards the (in)direct number of participants of TARGET2.[11] Although the number of participants since the introduction of TARGET2-NL (2008) is much lower, we do not expect this decrease to cause a decrease in active lenders and borrowers. This is because most of the large and active participants in the Dutch money market remain present from the change-over from TOP/TARGET to the new TARGET2-NL system. Many former participants in TOP that no longer participate directly in TARGET2-NL did not operate as (active) traders in the Dutch money market.

The daily average number of all transactions in TOP/TARGET and TARGET2-NL shows an increase over the years until 2009, from 12,500 to 36,800. [12] The value increased every year across the investigated period. Even though the number of direct participants decreased with the introduction of TARGET2, the average daily number and corresponding value of transactions continued to increase. This is because some large British banks participate in TARGET2-NL. [13] Some of these banks used to be either absent or inactive in the days of TOP. Therefore, our sample is not constant over the investigated period.

3 Developments of the interest rate

3.1 Statistics on Dutch unsecured interbank money market

The Unsecured money market loans are identified distinguished from other transaction data present in the TOP and TARGET2-NL systems, using by means of an algorithm developed by Heijmans et al. (2010). This algorithm is able to identify the lender, borrower, maturity, interest rate and loan value.[14] In our analysis we focus on participants active in TARGET2-NL. In case If a TARGET2-NL

[11] Transactions between HAM account holders and TARGET participants are mainly liquidity transfers.

[12] The increase of the number of transactions in 2007 is mainly caused by the introduction of an urgent retail payment system mid 2007. They are high in volume but relatively low in value.

[13] These British banks are relatively large ones in TARGET2-NL.

[14] Furfine (1999) was the first to develop an algorithm for identification of unsecured interbank loans from large value payment system's data. His algorithm was suitable for the US market. The algorithm of Heijmans et al. (2010) is suitable for the Dutch part of the euro area. Their algorithm uses a corridor around EONIA for overnight rates. The algorithm is able to identify loans with maturities up to one year. However, in this analysis we focus on the overnight money market. Around the EONIA rate a corridor of 50 bps is placed for most of the investigated period. For the pre-crisis period of the

participant borrows from or lends to a non-TARGET2-NL participant, e.g. with a participant in the Italian part of TARGET2, we do can see the Italian counterparty. However, we do not have data on all loans from and to this Italian counterparty. Therefore we analyse the money market from a lending perspective. This means that we look at transactions where at least the lender is a TARGET2-NL participant. Most TARGET2-NL consists mainly of participants are Dutch banks, however although there are some foreign banks are also present participants in TOP and TARGET2-NL systems, which are either a registered branches or subsidiaryies in the Netherlands.[15] Some of these foreign banks, with have their headquarters in the UK, and are relatively large participants in TARGET2-NL.

3.1.1 Number of lenders and borrowers

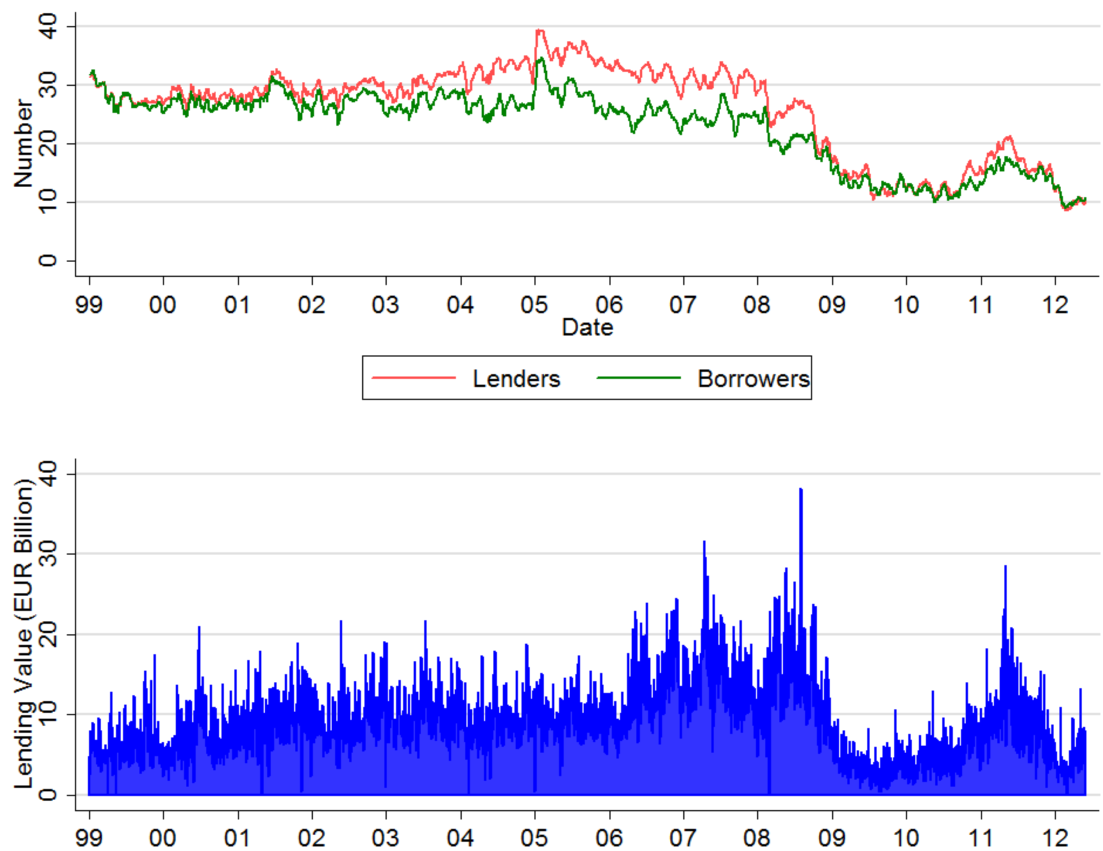
Figure 1 shows the number of lenders and borrowers (Figure 1,top graph) and the corresponding lending value/volume (Figure 1, bottom graph) of all TOP and TARGET2-NL participants. The top graph of Figure 1 illustrates that the numbers of lenders and borrowers hover around 30 until 2002. From 2003 until the end of 2008 the number of lenders is larger than the number of borrowers. This difference is caused by trades with banks in other euro countries (not being part of TOP or TARGET2-NL). After the collapse of Lehman Brothers, banks became more reluctant to lend to each other due to increased perceived counterparty risk. There were banks which could not obtain liquidity easily from the market and therefore dropped out of the market. At the same time the ECB introduced unconventional measures such as fixed-rate full allotment in the weekly MROs. This means that banks that need liquidity can obtain it from the ECB at a fixed price. As a consequence both the number of lenders and borrowers decreased from roughly 20 in the fourth quarter of 2008 to just above 10 in mid-2009. The number of lenders and borrowers increased again from around 10 (second half of 2010) to just below 20 (mid-2011). Since the political problems in Italy started (August 2011) these numbers fell back to 10 again. Part of the interbank money market loans (not shown in the figure) are loans extended at rates below the ECB overnight deposit rate, by parties that do not have access to the ECB standing facilities and that prefer low interest rate (below overnight deposit) above no interest at all. These parties could either be non-euro banks within the European Economic Area having access to TARGET2 through the Dutch central bank, or non-banks, e.g. large companies or pension funds, which instruct their banks to execute payments on their behalf.

The group of lenders and borrowers changes over the years. Some banks joined or left TOP/TARGET2-NL. Especially at the introduction of TARGET2-NL some large British banks joined TARGET2-NL that were not part of the TOP system or were much smaller participants (in terms of turnover and money market activity) in TOP. Even within a maintenance period the group of lenders and borrowers can change from day to day. Not every bank will be active in the money market every day, either as lender nor as borrower. It might be that some banks are more active at certain parts of the reserve maintenance period (e.g. on the last day).

modified framework Heijmans et al. (2010) extended the lower bound of the corridor to 100 bps due to the deviation from EONIA for the Dutch market. The algorithm is not without uncertainty. However, it provides a representative picture of the money market, especially for short maturities.

[15]Dutch banks refers to those that have their headquarters in the Netherlands and are supervised by the Dutch central bank.

Figure 1: Daily number of lenders and borrowers (bottom graph) and turnover (top graph) for the Dutch part of TARGET (1999 - 2012). Both represent one-month moving averages.



3.1.2 Total loan value

The lower graph of Figure 1 shows the total overnight lending amount of banks in the Dutch payment system. The daily turnover and the number of lenders follow similar trends. Especially after the collapse of Lehman Brothers, the number of lenders follows the trend of the overnight value quite closely. The amount ranges from approximately EUR 8 to EUR 22 billion from 1999 to 2006. The loan value showed higher values (between EUR 15 and EUR 38 billion) from the beginning of 2006 until the collapse of Lehman Brothers in September 2008. After this date the activity in the Dutch unsecured money market decreased. Simultaneously, the number of lenders and borrowers also decreased. The value decreased to below EUR 5 billion, which is lower than the turnover at the time of the introduction of the euro in 1999. This low turnover can partly be explained by the first one-year liquidity providing tender of the ECB, which was used by many banks as a security against potential future shocks. The Dutch market showed some signs of recovery, with ups and downs, until the summer of 2011. After the contagion of the Italian sovereign debt crisis in August 2011, the turnover in the Dutch market decreased again to low values similar to those of mid 2009.

3.2 The overnight lending rate and its volatility

Figure 2 shows the evolution of the overnight lending rate in TARGET2-NL here referred as the rate) relative to the Main Refinancing Operation (MRO) rate and ECB's standing facilities since February 1999.[16]

Under the initial operational framework, the lending rate was characterised by high levels and great jumps. The introduction of the modified monetary policy framework implied significant changes in the way the overnight money market works. Figure 3 shows the rate change (with respect to the previous business day) from the introduction of the modified framework onwards. As can be seen, it is characterised by large swings most of the time; however the volatility increases dramatically as of August 2007. The volatility shown here is only for the Dutch overnight money market. The Eurosystem, however, will judge the effectiveness of its policy not from the Dutch case but by looking at the whole euro area. Arciero et al. (2013) developed a method to filter the unsecured interbank loans from TARGET2 data. Their results show that the differences in the rates paid by banks vary significantly between the different countries in the euro area. This suggests that the volatility of the rate is likely to be higher for the Eurosystem as a whole than for just the Dutch overnight money market.

3.3 Evolution of the overnight lending

The behaviour of the change of the rate (Δr) was relatively stable until the start of the financial crisis. Although the rate experienced its largest increase under the initial operational framework (reaching a maximum increase of about 116 basis points) the change in the rate was characterised by the occurrence of occasional jumps, mainly linked to the reserve maintenance period calendar. With the introduction of the Modified Operational Framework in 2004 the volatility decreased, meaning the changes in the monetary framework resulted in a lower volatility. In other words, the ECB was better able to steer the interest rates in the money market, thus achieving its policy aim of reducing volatility in the money market. The rate showed a clear change in behaviour from August 2007, when it turned much more volatile. Table 2 shows the descriptive statistics of the different behaviour of the rate and its first difference during the periods under analysis. From the amplitude of the first difference interval (maximum - minimum) one can notice a clear increase in the dispersion of Δr after the implementation of the Fixed Rate Full Allotment tender procedure. The pre-crisis period of the modified operational framework presents the lowest value of the standard deviation of Δr, which increased after the FRFA policy. This last period shows a daily average standard deviation of around 11 basis points and a (Δr) interval range of of 160 basis points - turning into the widest range for the past eight years.

Figure 4 shows the average change of the rate over the reserve maintenance period (MP). Under the initial operational framework (top left graph of Figure 4), the rate shows greater variations within a maintenance period. During the pre-crisis period of the modified framework a more stable pattern appears within the MP (top right graph of Figure 4). It started with higher changes at the beginning

[16] DEONIA or Dutch EONIA refers to the quoted EONIA of the EONIA panel banks. The overnight lending rate is a weighted average of all loans identified with an algorithm of all TARGET2-NL participants.

Figure 2: Overnight lending rate and ECB rates, from January 1999 to May 2012.

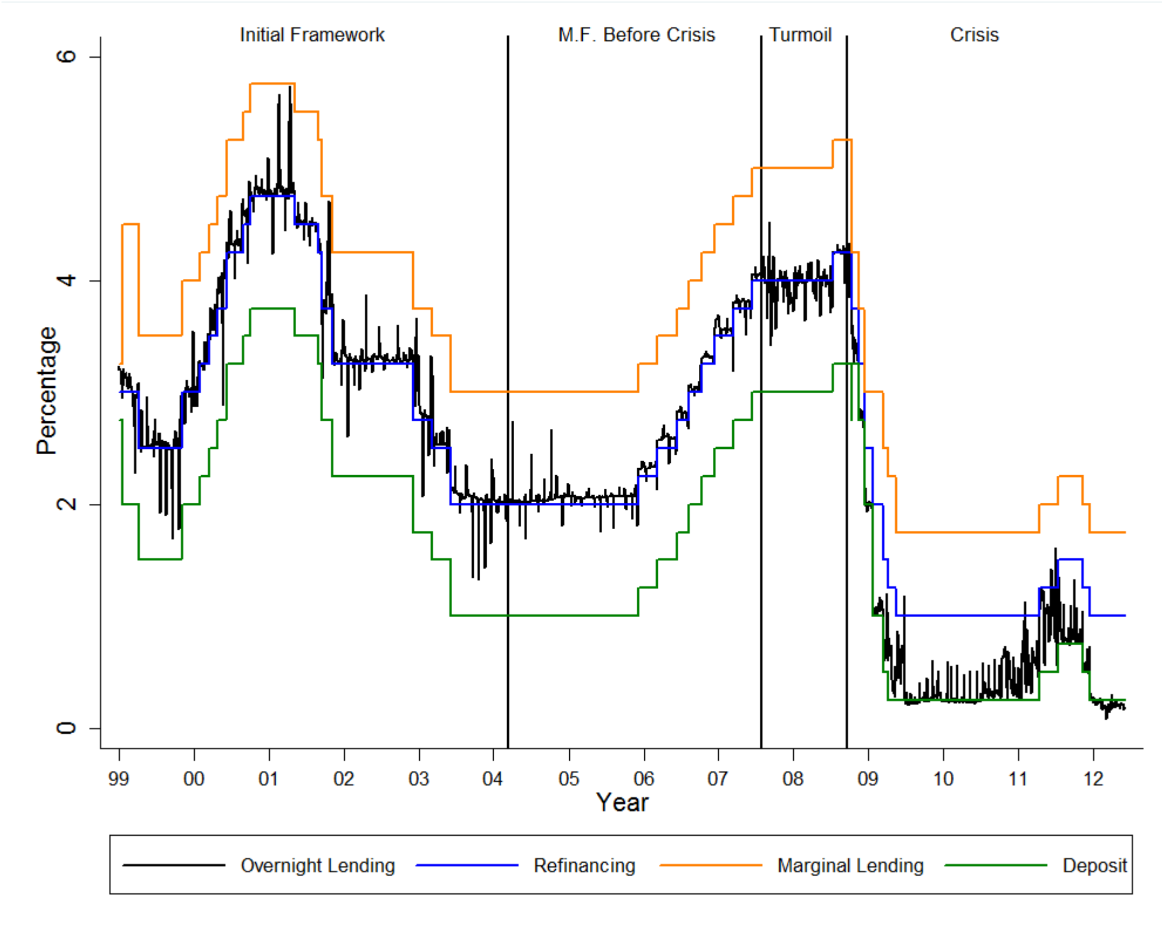


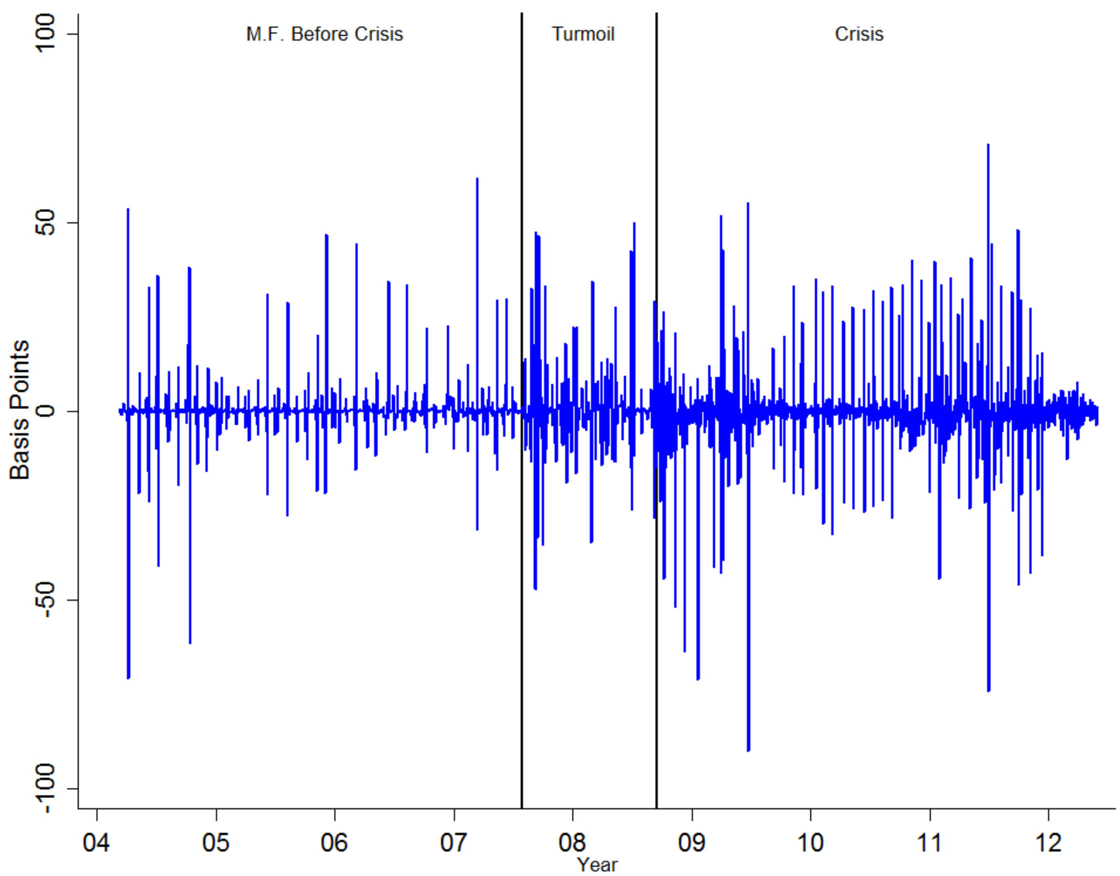
Table 2: Descriptive statistics of the overnight lending rate 1999-2012 (Δr in bp).

	Initial framework		M.F. before crisis		turmoil		Crisis	
	r	Δr	r	Δr	r	Δr	r	Δr
Mean	3.31	−0.09	2.58	0.24	4.01	0.09	0.77	−0.43
Median	3.28	−0.18	2.14	0	4.01	−0.08	0.41	−0.3
Minimum	1.33	−95.74	1.7	−71.05	3.42	−47.29	0.08	−90.07
Maximum	5.73	115.96	4.12	61.65	4.52	49.8	4.33	70.73
Std. Dev	0.92	12.96	0.67	7.18	0.16	10.84	0.9	11.41

of the period followed by a decrease that led (Δr) to oscillate around zero up to one week before the last day, when it showed negative changes. During pre-crisis period, the rate increased until one day before the end of the maintenance period.

During the initial turmoil of the crisis (bottom left graph of Figure 4), the rate varied substantially with positive and negative changes until the last day of the maintenance period, when it underwent

Figure 3: Volatility of the overnight lending rate after the implementation of the Modified Framework. The volatility of the rate refers to the first difference of the rate.



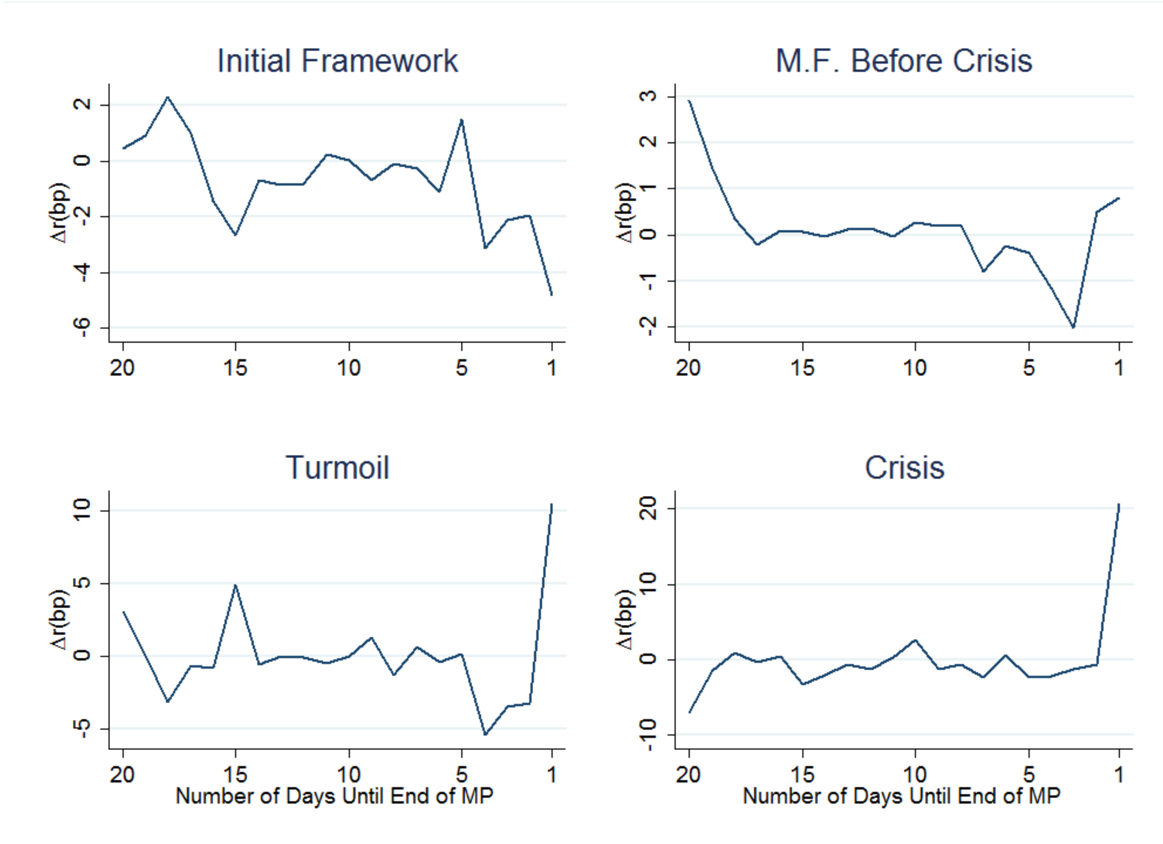
a significant increase. Unlike the pre-crisis period, after the introduction of the Fixed Rate Full Allotment policy the behaviour of the rate shows negative changes from the beginning of the MP until two weeks before the end (bottom right graph of Figure 4). It appears that the rate moves by very small increments in the second half of the MP but barely varies until the last day of the maintenance period when it has a sharp increase of, on average, 20 basis points.

The sudden increase of the lending rate can be partly explained by the liquidity absorbing tenders of the ECB on the last day of the maintenance period. On this day, banks that have access to the ECB facilities can deposit their excess liquidity at the ECB at a higher rate than the overnight deposit, which results in a more attractive option for banks with a surplus of funds. Consequently, the supply of money in the market drops, resulting in an increase of the interest rate in the money market.

3.4 Distributional characteristics of the data

To test distributional characteristics of the data two methods were used. As a first approach, graphical analysis was applied. Distributional diagnostic plots and histograms in Figures 5 and 6 suggest that

Figure 4: Average change of the rate over the reserve maintenance period.



the overnight lending rate does not follow a normal distribution. Figure 5 plots the quantiles of the rate against quantiles of the normal distribution per sample period. If the data were distributed perfectly normally, the dots should all be on the 45 degree line. As shown in the graph, the lending rate diverges from this line; implying that it does not follow a normal distribution. On closer observations more points appear to fall on the 45 degree line during the second and third period, suggesting that the rate is perhaps closer to a normal distribution during these periods. Furthermore, Figure 6 presents the histograms of the overnight lending rate showing high levels of asymmetry and leptokurtosis. Additional to graphical analysis, the skewness and kurtosis tests were used to check the distribution of the rate and its first difference. The null and alternative hypothesis are:

H_0 = *The data follows a normal distribution*

H_1 = *The data does not follows a normal distribution*

Results in Table 3 lead us to reject the null hypothesis that the sample is normally distributed. The excess kurtosis estimate of the first difference of the rate (see Table 3) also implies that the distribution of returns has fat tails (leptokurtosis) relative to the normal distribution. This shows that neither the rate or its first difference follow a normal distribution.

Figure 5: Normal quantile plot.

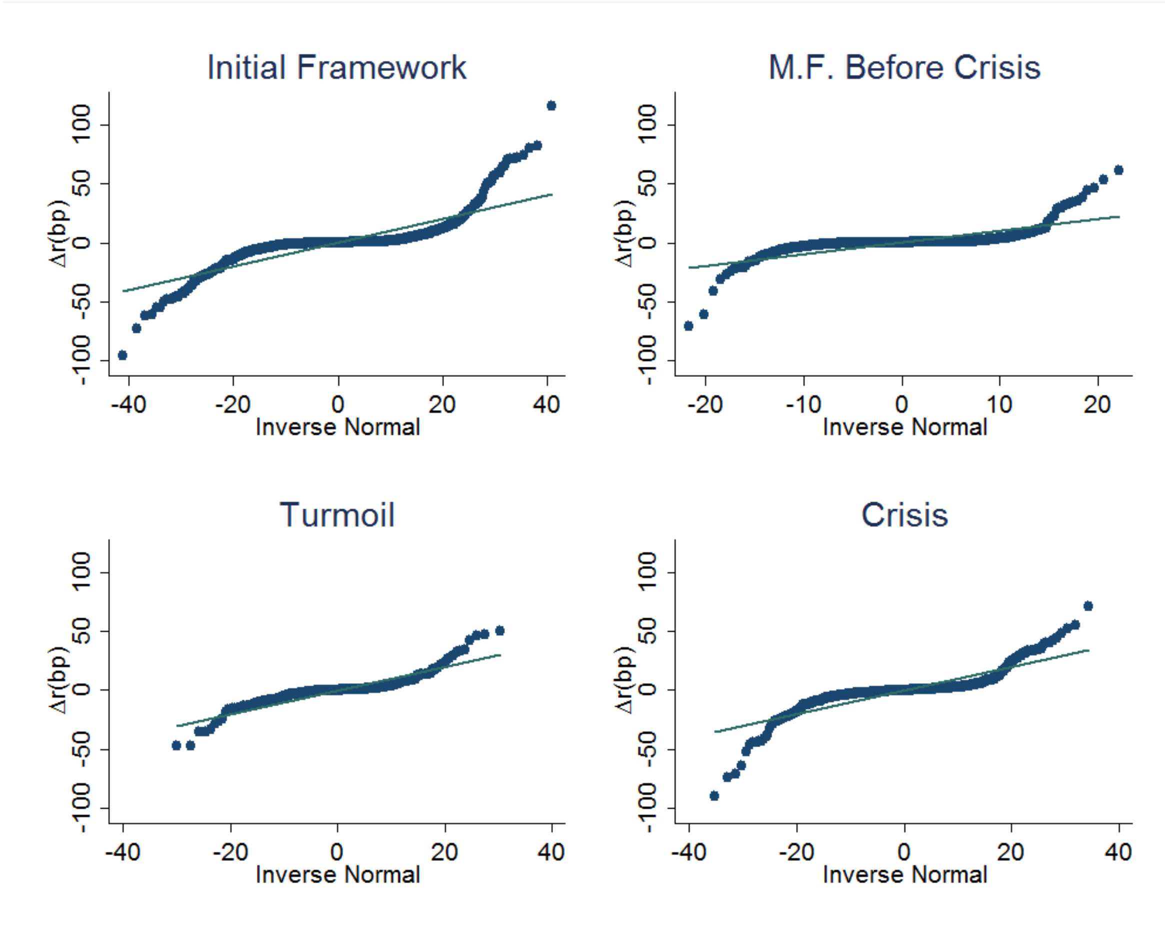


Table 3: Skewness and kurtosis test (Δr in bp).

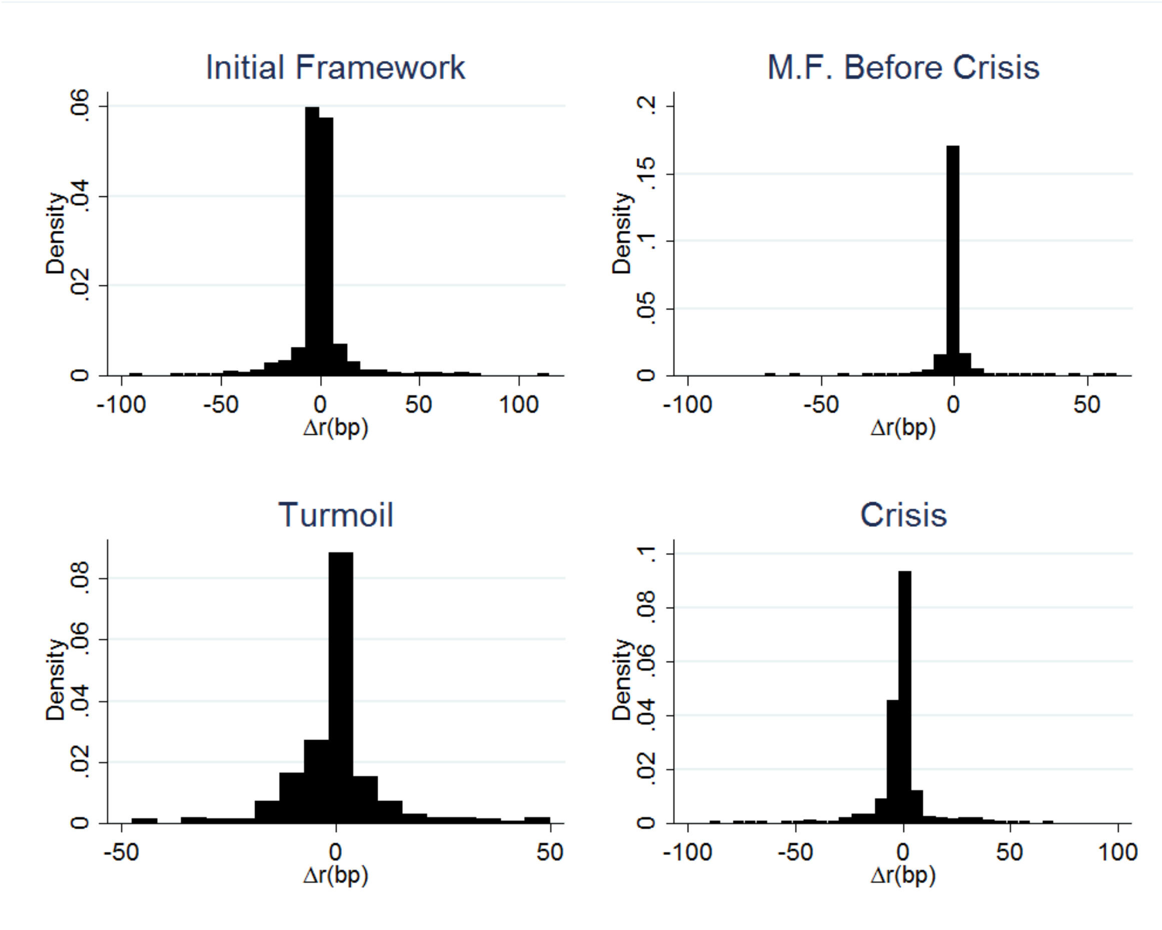
	Initial framework				M.F. before crisis			
	r		Δr		r		Δr	
Skewness	0.32	***	1.13	***	0.9	***	0.37	***
Kurtosis	2.1	***	20.92	***	2.31	***	38.68	***

	Turmoil				Crisis			
	r		Δr		r		Δr	
Skewness	−0.29	*	0.54	***	2.54	***	−0.58	***
Kurtosis	4.08	**	10.61	***	8.97	***	16.69	***

4 Methodology

We consider a GARCH model to study the overnight lending rate for the Dutch overnight money market. The standard GARCH model allows the conditional variance to be dependent upon previous own

Figure 6: Histogram of the overnight lending rates.



lags. However, there are some limitations: GARCH models have the disadvantage of not allowing for asymmetric shocks in the conditional volatility. Since the distribution of the overnight lending series is stated as non-linear, we apply the asymmetric Exponential GARCH (EGARCH) analysis of Nelson (1991) instead. Two essential strengths of this model are highlighted in the literature. First, the limitations of positive constraints on the ARCH and GARCH coefficients are eased by using the exponential formulation. Second, an EGARCH model has the ability to capture the negative asymmetry that is commonly observed in financial time series.

The following AR(p) EGARCH model is conducted to scrutinise the relationship between the conditional volatility of the Dutch overnight lending rate and seasonal, calendar and monetary policy effects by considering asymmetric effects. The econometric implementation of the model is built on the methodology of studies in the US and European markets (see e.g. Hamilton, 1996; Prati et al., 2002). The empirical model has the form:

$$\Delta r_t = \mu_t + \sigma_t v_t \tag{1}$$

where r is the rate change (in basis points), μ is the conditional mean, v is a mean-zero, unit variance, i.i.d error term and standard deviation σ_t of μ_t evolve over time.

Conditional mean of the interest rate has the form:

$$\mu = c + \Delta r_{t-1} + \delta mp_t + \delta c_t + \alpha' h_t + \varepsilon_{t-1} \tag{2}$$

Where c is a constant, Δr_{t-1} is the first lag of the rate, δmp_t the maintenance period effect, δc_t calendar effects (end of month, holidays) and the vector h controls for specific changes in monetary policy (like the unlimited fixed rate full allotment LTROs for shorter and longer term tenders).

$$log(\sigma_t)^2 = c + \lambda[log(\sigma_{t-1}^2)] + \phi \mid \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \mid + \theta \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \tag{3}$$

The specification allows for fixed calendar effects, denoted by ξmp_t and $\xi' c_t$, for maintenance period days and holidays respectively. The set of variables exploring maintenance period effects refer to the last five days of the maintenance period and an additional dummy variable to capture any effect in the middle stretch of the maintenance period. Calendar effects are captured by dummy variables for before and after the end of 1) the month, 2) the quarter, 3) the year and 4) holidays. The vector h_t captures the effect of specific monetary policies as the ECB's refinancing rate, standing facilities (marginal lending and deposit rate) and long-term liquidity providing tenders. Other explanatory variables include the growth rate of deposits at the European Central Bank and the number of lenders participating each day in the overnight money market (see section 3.1.1). The variance equation allows for "Exponential GARCH" effects (see Nelson, 1991) to capture persistent deviations of the log conditional variance from its unconditional expected value. Residual analysis reveals that an EGARCH (1,1) model is appropriate.

4.1 Model comparison: Gaussian vs Student-t distribution

In order to investigate what model best fits financial time series on Dutch overnight lending, we compared EGARCH (1,1) models with alternative probability density functions for the error term. Specifically, the analysis was carried out using normal and Student-t distribution. The criteria used to determine the performance of a model include the comparison of the log likelihood value and the likelihood ratio test (Alexander, 2009). We propose an EGARCH model using Student-t distribution since the prevailing concern about the distributional characteristics of the Dutch overnight lending rate, presenting fat tails and high levels of skewness and kurtosis. Table 4 reports the log-likelihood values for each estimated model. Those models based on the Student-t distribution produced the largest values. On the contrary, models assuming a Gaussian distribution were consistently outperformed by the those associated with the Student-t distribution. This test demonstrates that the alternative leptokurtic alternative of adopting the Student-t distribution performs better in modeling overnight lending data. The second phase of residual diagnostics consisted in determining whether the results under the assumption of the t-distributions were statistically different from those obtained under the normal distribution. To do this, we calculated likelihood ratio statistics following the definition given by Brooks (2008):

Table 4: Log-likelihood value and likelihood ratio test.

	EGARCH		Student-t	
	Gaussian	Student-t	LR^{EGARCH}	
Initial framework	−4494.49	−3851.08	1286.83	***
Modified framework: before crisis	−1846.5	−1601.73	489.54	***
Turmoil	−1028.54	−950.35	156.39	***
Crisis	−3040.56	−2791.22	501.3	***
Alternative period: Initial framework	−4494.49	−3851.08	1286.83	***
Alternative period: Modified framework	−6581.75	−5693.06	1679.4	***

Note: Fist two columns refer to the log-likelihood values of EGARCH models following a Gaussian and Student-t distribution. LR^{EGARCH} refers to the Likelihood ratio test of an EGARCH model following a Student-t distribution.

Table 5: ARCH-LM test.

Period	F-statistic	Obs∗R-squared
Initial framework	1.27	1.27
	−0.26	−0.26
Modified framework: before crisis	0.15	0.15
	−0.7	−0.7
Turmoil	0.36	0.37
	−0.55	−0.55
Crisis	0.46	0.46
	−0.5	−0.5

Note: Probability values are in parentheses.

$$LR = -2(L_R - l_u\ \chi^2(1)) \tag{4}$$

L_u denotes the given maximised log likelihood value of the Gaussian model while L_r comes from the model following a Student-t distribution. Basically LR statistic follows a Chi-square distribution. Table **??** reports the likelihood ratio test between EGARCH models for each period and their Gaussian counterparts. Results show that an EGARCH model with student-t distribution is more fit to the sample data.

Additional to the first two phases of residuals diagnostics, we conduct the ARCH-LM test in order to test whether the model adequately captures the persistence of volatility and there is no ARCH effect left in the residuals. Results in Table 5 show high probability values indicating there is no serial correlation in the residuals. The F−statistic is an omitted variable test for the joint significance of all lagged squared residuals. The Obs*R-squared statistic is Engel's Lagrange Multiplier (LM) test statistic for the null hypothesis of no serial correlations. Furthermore, the results of the diagnostic tests show that the EGARCH models are specified correctly. The standardised residuals and standardised square residuals have been diagnosed, while Q-statistics show that both the mean and variance equations for each sub-sample period are specified correctly. All statistics are insignificant with high p-values, suggesting that the EGARCH models are successful at modeling the serial correlation structure in conditional means and conditional variances.

All of our tests indicate that the EGARCH model with student-t distribution is the best fit for the Dutch overnight lending rate as it fully captures the leptokurtosis and the serial correlation of the standardised residuals.

5 Results

Table 6 presents the results of the model, defined in section 4 for four sample periods between 1999 and May 2012. We observe changes in the pattern of behavior between the four different periods, with significant changes of direction soon after the collapse of Lehman Brothers and the subsequent adoption of the fixed rate full allotment policy. A distinction can be made between results before the start of the turmoil period and after it.

The overnight lending rate followed a (somewhat) similar pattern during the first two sample periods. The introduction of the modified framework increased the ECB's ability to steer the overnight lending rate, witness a decrease in volatility. Whereas under the initial operational framework the ECB's refinancing rate had a negative near-zero effect on the rate, during the second period the effect of the refinancing rate increased the overnight lending rate by more than one basis point. Results for the turmoil and crisis period show ECB's decreased capacity to influence the market and an increase in the volatility of the overnight lending rate. In comparison to the pre-crisis period, the effect of the refinancing rate decreases to around zero (0.6 basis points) during the crisis period.

Until the summer of 2007, the effect of the number of lenders participating in the overnight money market is as expected. During the first two periods, the number of lenders has a negative effect on the lending rate, unlike during the turmoil and crisis periods, when the number of lenders participating in the market stop showing statistically significant effects. During the crisis the growth rate of ECB deposits first begins to have negative effects on the overnight lending rate (specifically, a small but statistically significant effect of -0.05 basis points).

During the first two periods, the rate increases at the beginning of the reserve maintenance period (MP) and decreases at the end of it. However, with the arrival of the crisis this pattern is reversed.

Under the initial operational framework the rate increases by roughly 2 basis points (bps) at the beginning and decreases by more than 3 bps at the end of the maintenance period. Half way through the MP, the rate already presents a small but statistically significant negative effect, turning positive until 2 days before the end of the MP. Although more subdued, the direction at the beginning (+ 0.9 bps) and end (− 0.7 bps) of the maintenance period is the same for the modified operational framework before the crisis period. During this period the negative effect at the end of the MP would be apparent from one week before the end date, although only significant for 5, 3 and 1 day before the end of the MP. A potential explanation for this could be that banks apply frontloading in the first half of the MP to make sure that they can fulfil the reserve requirements. In the second half of the period they have a (small) surplus which they lend again in the market to obtain a return on it. If there are enough banks, using the frontloading strategy, this will lead to an increase of the rates in the first half of the MP and consequently there will be a downward pressure on the rate in the second half. Dialogue with commercial banks has taught us that some banks did in fact actively pursue this strategy before the crisis erupted.

Maintenance period effects show a change of direction after the onset of the turmoil period, suggesting a change of behaviour within the reserve maintenance period. During the turmoil period the rate decreases more than 3 bps at the beginning of the maintenance period and increases three times more on the last day (by almost 10 bps). In the following crisis period the rate presents an abrupt decrease of 20 bps at the beginning of the maintenance period and an increase of almost 19 bps at the end of it. This would suggest that there is a potential arbitrage effect, in that banks use the opportunity to lend on the last day, when rates are significantly higher. A possible explanation of the increase at the end of the maintenance period could have been the extensive use of the liquidity absorbing tenders on the last day of the maintenance period, yielding rates above the market rates of the preceding days. These tenders offer an alternative opportunity of 'investment' at no risk to banks that have access to ECB standing facilities. Banks that require liquidity at the end of the maintenance period would have to pay a higher price that day. However, this effect is not significant. Another possible explanation could be that banks do not want to lend to certain counterparties. However, we have not investigated this possibility. The stronger decrease on the first day is partly because of the strong increase on the last day of the previous maintenance period. It should be noted that trading volumes vary within a maintenance period, intimating that the alleged arbitrage effect may be non-existent.

The liquidity providing 1-year and 3-year tenders did not have a significant effect on the rate. Conceivably, injection of an enormous amount of liquidity in the system might have a decreasing effect on the rate. However, the first 1-year tender settled mid 2009 was used by many banks as a precautionary measure. Due to the uncertainty in the market at that time, banks took the loan from the central bank as a precautionary measure even though most banks did not need it. At the same time, banks used this relatively cheap liquidity as an investment opportunity. This means that the liquidity does not stay on the bank's account and therefore cannot be lent to other commercial banks, which is a potential reason behind the 3-year tender. However, further research explore this phenomenon. A side-effect of the abundant low cost liquidity provided by the central bank has been a diminishing stigma to its use. Unlike in previous times, borrowing from the central bank is no longer considered a sign of a bank's problems per se.

Table 6 shows consistent results for the calendar effects across all sample periods. The initial operational framework presented stronger calendar effects tending to increase by almost 5 bps at the end of the month, around 4 bps at the end of the quarter and 17 bps on the last day of the year. The pre-crisis period of the modified framework showed effects in the same direction, although much smaller. Like the initial operational framework period, the turmoil period exhibits one of the largest calendar variations, increasing almost 7 bps at the end of the month, 12 bps at the end of the quarter and 11

bps the day after the end of the year. Holiday effects show contrary patterns between the period under the modified operational framework and the crisis period. In the first period the rate decreases before holidays (1.9 bps) and increases the day after (2 bps). However, during the crisis period the rate tends to increase by 1.92 bps before holidays.
As with the holiday effect, the rest of calendar effects in the crisis period are smaller than in previous years but have the same direction. During the crisis the rate decreases at the end of the month (2 bps) and before the end of the year (7 bps). While it increases 5bps at the end of a quarter.
The (EGARCH[1]) parameter measures the persistence in conditional volatility irrespective of anything happening in the market. Under the initial operational framework, volatility was more persistent (0.61). The value of the parameter decreases with the introduction of the modified monetary policy framework. However, with the start of the turmoil period, volatility persistence increased and remained fairly high (0.51) showing the capacity of past volatility to explain current volatility.

6 Conclusions

This paper investigates the changes in the interbank overnight lending rate of the euro area unsecured money market for the Dutch segment of TARGET2. We describe the movements of the rate by splitting up the sample from 1999 to 2012 into four different periods corresponding to the most important changes in the monetary policy framework of the euro area.

To study the rate movements we look in detail at the calendar effects, the day within the maintenance period, the number of lenders as a proxy for lending volume and the effect of the excess liquidity provided by the Eurosystem. In order to capture the effect of the rate changes we present an EGARCH model which best fits the characteristics of the overnight lending rate. This model can also be used in the future to measure the effect of changes in the monetary policy framework on the volatility of the rate. In order to measure the volatility from a Eurosystem point of view it is essential to look at all banks in the euro area instead of just the Dutch part of it.

The modifications in the monetary policy framework in 2004 succeeded in reducing the volatility of the interest rate, as expected. However, the unconventional measures during the turmoil period and after the collapse of Lehman Brothers, such as the fixed rate full allotment policy, including the long term refinancing operations with 1-year and 3-years maturities has not been able to reduce the volatility of the rate. On the contrary, the volatility increased during the turmoil, although the spikes did not. During the crisis period, volatility remained high as did the volatility compared to the previous periods since the start of the modified operational framework in 2004. Note that the primary concern of the policy since the start of the crisis has not been controlling volatility, but preventing the collapse of the financial system. The increase in volatility can be considered as the price of preserving (relative) financial stability.

Since the turmoil started the interest rate decreased significantly on the last day of every maintenance period, jumping up 10 basis points during the turmoil period and 20 basis points during the crisis period. Banks aware of this jump, would prefer to lend on the last day of the maintenance period while banks that need to borrow would do so before the last day. This ‘behaviour’ would not cause

Table 6: Mean and variance equation. The rate changes are in basis points.

	Initial framework		M.F. before crisis		Turmoil		Crisis	
mean equation:								
Constant	−0.08		−0.05		−0.74		−0.12	
Delta Refinance	−0.64	**	1.33	***	2.11		0.66	***
Delta Marginal lending	0.34	***						
Delta Deposit rate	0.5	***						
Growth rate of ECB deposits	0		0		0		−0.05	***
Number of lenders	−0.02	*	−0.01	*	0.08		0.04	
Begin MP	2.09	***	0.9	***	−3.37	**	−20.28	***
End MP	−3.22	***	−0.72	***	9.76	***	18.77	***
Day 2 from end of MP	0.58	**	−0.03		2.42	***	0.33	
Day 3 from end of MP	0.15		−0.65	***	−0.22		−0.11	
Day 4 from end of MP	−0.18		−0.01		−0.22		−0.37	
Day 5 from end of MP	−0.2		−0.24	**	1.45		0.21	
Half of MP	−0.32	**	0.07		0.77		0.05	
Settlement 1-year tender							0.62	
Settlement 3-year tender							−1.51	
Before end of the month	0.56	*	0.01		1.2		0.24	
End of the month	4.64	***	1.54	***	6.86	***	0.79	
After end of the month	−4.2	***	−1.53	***	−4.02	***	−1.69	***
First day of the quarter	−5.73	***	−3.21	***	−12.71	***	0.59	
Last day of the quarter	3.68	***	2.72	***	12.18	***	5.21	***
Day before end of the year	17.28	***	0.73		−17.82		−7.39	***
Day after end of the year	−1.71		−0.71		11.25		−0.79	
Before holidays	−1.91	**	−0.19		0.94		1.93	**
After holidays	2.14	**	0.23		1.27		1.21	
variance equation:								
Constant	2.27	***	2.06		2.82		2.49	**
—RES—/SQR[GARCH[(1)	10.54		9.1		5.52		3.63	
RES/SQR[GARCH](1)	−1		1.62		−0.33		−0.09	
EGARCH(1)	0.61	***	0.48	***	0.51	***	0.46	***
Log likelihood	−3851		−1602		−950		−2791.22	

jumps on the last day. Part of the jump in the crisis period is due to the liquidity absorbing tenders of the Eurosystem, which is used extensively by the banks. Such tenders offers banks an opportunity to deposit their excess liquidity at the ECB at rates above the overnight deposit rate. As banks used this overnight deposit facility extensively during the crisis period, this was a logical and very secure alternative 'investement' opportunity for banks on the last day of the maintenance period. Possibly, banks are aware of the higher interest rate on the last day, but do not see this as a suitable investment option given the uncertainty in the market. It might also be the case that the subset of the banks borrowing on the last day differs significantly from banks lending or borrowing during the rest of the maintenance period. However, this is still to be investigated, as we have not looked into the data at bank level.

The calendar effects are consistent across the four different periods. The initial operational framework caused stronger effects (increases of around 5, 4 and 17 basis points at the end of the month, quarter and year, respectively). The pre-crisis period shows similar but smaller results. The turmoil period shows some of the strongest calendar effects increasing in around 7, 12 and 11 basis points at the end of the month, end of the quarter and on the last day of the year, respectively). Holiday effects make for different results. In the first period there was a decrease of 1.9 basis points before the public holiday and an increase after, by 2 basis points. During the crisis period the rate increases by 1.9 basis points before the holidays.

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