PERSISTENCE AND LONG MEMORY IN MONETARY POLICY SPREADS

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Abstract

The overnight money market rate is a key monetary policy tool. In recent years, central banks worldwide have developed new monetary policy strategies aimed at keeping its deviations from the policy rate small and short-lived. This paper describes the main instruments used for this purpose by the US Fed, the ECB and the BoE and also their policy responses to the Great Financial Crisis (GFC). Fractional integration and long-memory methods are then applied to investigate how those affected the persistence of policy spreads (i.e., the difference between overnight rates and policy rates) during different sub-periods. It is found that this increased sharply during the GFC but has fallen back in recent years. In the case of the ECB the introduction of the new €-STR benchmark in particular appears to have made monetary policy more effective.

Keywords: Interest rates; persistence; central banks; long memory; fractional integration.

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1. Introduction

Overnight rates play a key role in the implementation of monetary policy. The mean and variance of the policy spreads, namely of the deviations of the overnight rates from the policy rates, can be seen as a measure of the effectiveness of monetary policy. Nautz and Schmidt (2009) showed that, if the policy spread is highly persistent and thus shocks have long-lived effects, the overnight rate loses its signalling role and the central bank loses control over interest rates. Cassola and Morana (2010) and Hassler and Nautz (2008) found that in the case of the European Central Bank (ECB) the policy spread exhibited long memory and overnight rates could not be controlled effectively. Following the seminal paper by Hamilton (1996), several studies have adopted a GARCH framework to analyse cross-country differences in overnight rate volatility (Bartolini and Prati, 2006) or its transmission along the yield curve (Colarossi and Zaghini, 2009; Nautz and Offermanns, 2008). Further, Perez Quiros and Rodriguez Mendizabal (2006) showed that the introduction of the ECB's symmetrical interest rate corridor had significant effects on the dynamics of overnight rates, while Thornton (2006) and Nautz and Schmidt (2009) discussed the impact of the operating procedures of the US Fed for its policy spread.

The present study uses fractional integration and long-memory techniques to investigate the degree of persistence of policy spreads of three major central banks, namely the US Fed, the ECB and the Bank of England (BoE). In particular, it examines whether monetary policy differences in terms of reserve requirements, standing facilities, open market operations etc. as well as in terms of policy responses have resulted in different degrees of persistence in policy spreads across countries before and after the global financial crisis (GFC) of 2007-8. Therefore our analysis updates the work by Nautz and Scheitenhauer (2011) on the persistence of monetary policy spreads by incorporating the crisis period and its aftermath. In the case of the ECB, we also provide evidence on the effects on persistence of introducing a new benchmark rate, namely the €-STR, which has replaced EONIA since October 2019, by using data for Pre-€STR, its synthetic version created to assess the likely behaviour of the new rate.

The structure of the paper is as follows. Section 3 provides a general overview of monetary policy instruments and their possible impact on the persistence of policy spreads. Section 3 reviews the monetary policy responses to the GFC of the three central banks examined, i.e. the US Fed, the ECB and the BoE. Section 4 outlines the methodology and presents the empirical results. Finally, Section 5 offers some concluding remarks.

2. Monetary Policy Instruments and Policy Spreads

This section describes the relationship between the persistence of policy spreads and four of the main monetary policy instruments used by the three central banks considered here, namely the reserve requirement system, the conduct of open market operations, the role of standing facilities, and the impact of the policy rate on overnight rates.

2.1 Reserve Requirements

Reserve requirements are an important smoothing tool for overnight rates within a maintenance period and can reduce the persistence of policy spreads. In the euro area, remunerated reserves were an effective liquidity buffer for the money market before the GFC. Until January 2012, European banks had to hold a minimum of 2% of certain liabilities, mainly customers' deposits, at their national central banks. This ratio has been lowered to 1%, with the total reserve requirements for euro area banks standing at around 113bn euro in 2016. At the end of the maintenance period the central bank pays interest ot banks on their minimum reserve holdings at a rate equivalent to the main refinancing operation (MRO) rate.

Nautz and Hassler (2009) explained why reserve requirements should make deviations of the overnight rate from the policy rate small and short-lived. In the UK, there was no requirement until May 2006, when the BoE encouraged banks to choose voluntary levels of required reserves. In the US, as argued by Carpenter and Demiralp (2009), the persistence of the policy spread might be higher due to the fact that banks have traditionally used sweep accounts on a large scale to avoid the opportunity costs of non-remunerated minimum reserve requirements.

2.2 Open Market Operations

Open market operations have a direct impact on overnight rates and should therefore decrease the persistence of policy spreads. Their impact may also depend on the refinancing risk perceived by the money markets. As long as banks are confident that their demand for reserves will be met, deviations of the overnight rate from the policy rate should be small and transitory. Therefore the higher persistence of the ECB's policy spread in the years leading up to the GFC may reflect a higher refinancing risk, as argued by Hassler and Nautz (2008).

Currently, the Eurosystem's regular open market operations include one-week main refinancing operations (MROs) and three-month longer-term refinancing operations (LTROs). MROs are used to manage the liquidity situation, to steer short-term interest rates and to signal the monetary policy stance in the euro area, while LTROs provide longer-term refinancing to the financial sector. [1] The targeted longer-term refinancing operations (TLTROs) provide long-term funding at attractive conditions to banks to ease private sector credit conditions further and thus stimulate bank lending to the economy.

2.3 Standing Facilities

The deposit and lending rates of standing facilities define the lower and upper bounds of overnight rates. The resulting interest rate corridor is meant to reduce their fluctuations.

[1] For more details please visit the official ECB website
https://www.ecb.europa.eu/mopo/implement/omo/html/index.en.html

According to Perez Quiros and Rodriguez Mendizabal (2006), an effective corridor will not only decrease the volatility of overnight rates but also the persistence of the policy spread.

Creating a well functioning corridor system is not an easy task for a central bank. For instance, in the US the financial sector has traditionally been reluctant to borrow from the central bank. In particular, using the Fed's discount credit has often been interpreted as a sign of management failure, as pointed out by Hakkio and Sellon (2000). Consequently, banks refrained from using the Fed's lending facility and the discount rate could not function as a ceiling for the Federal Funds rate. The Eurosystem currently offers credit institutions two standing facilities, namely the Marginal lending facility to obtain overnight liquidity against sufficient eligible assets, and the Deposit facility to make overnight deposits.

2.4 Policy Spreads

The persistence of policy spreads depends on the impact of the policy rate on market interest rates, which cannot be established a priori. For example, the relationship between the ECB's policy rate set as the minimum bid rate for its MROs and the overnight rate is not always very clear. As maturities and collateral requirements differ for the corresponding transactions, the policy spread is uncertain and can change over time (see Linzert and Schmidt, 2011). Marginal and average MRO allotment rates contain information on the liquidity condition in the money market in addition to the minimum bid rate (see Abbassi and Nautz, 2008).

3. Monetary Policy Measures during the Great Financial Crisis

This section describes the policies adopted by each of the three central banks of interest in an attempt to mitigate the negative impact of the GFC on financial markets.

3.1 Euro Area

In their analysis of the response of ECB to the crisis Dell'Ariccia et al. (2018) identify three different periods. During the first one, from September 2008 to the end of 2009, the ECB focused on supporting the banking sector using a variety of lender of last resort instruments. In the second one, which goes from early 2010 to late 2012 and includes the sovereign-debt crisis in the euro area, it purchased government bonds to inject liquidity into the system. Finally, during the third period which started in mid-2013 it implemented a more aggressive mix of forward guidance, large-scale asset purchases, negative interest rates and targeted credit supply policies.

Real GDP in the euro area fell by 6 percent in 2008, and with inflation below the 2 percent target the ECB decreased its main refinancing rate from 4.25 to just 1 percent during that year. The main goal of the ECB at the beginning of the crisis was to manage the higher risk that had led to a strong decrease in benchmark trading and affected the monetary transmission mechanism within the euro area. Its policy response was based on liquidity operations and several rounds of Longer-Term Refinancing Operations (LTROs), which differed from the standard Main Refinancing Operations (MROs) as they were conducted with fixed rates and full allotment, and were unlimited and with longer maturities. The LTRO balance increased by 90% between 2008 and early 2010. According to Gonzalez-Paramo (2011), this intensified intermediation by the ECB was meant to make up for the lower interbank market activity.

From the end of 2009 the euro area was also hit by a sovereign-debt crisis which affected in particular Greece (ultimately requiring assistance through an EU-IMF programme), Italy, Portugal, Ireland and Spain. The ECB had always been reluctant to engage in large-scale asset purchases of euro area government bonds which are not allowed by the EU treaties. Nevertheless the Security Markets Programem was implemented just one week after the Greek bailout in May 2010; this involved buying government debt issued by Greece, Ireland and

Portugal to reintroduce stability into the securities markets and facilitate monetary transmission. These purchases were eventually carried out in the secondary market to comply with the treaties.

The ECB then decided to take more action in mid 2012 when it introduced the Outright Monetary Transactions (OMT) programme allowing purchases of government bonds in secondary markets for member countries requesting such assistance and willing to accept monitoring. In actual fact no purchases under the programme were ultimately needed, but this commitment on the part of the ECB played an important role in reassuring markets and avoiding sovereign defaults.

By 2013 the euro area economy was showing some signs of recovery but growth was still low and inflation still below its target. The ECB decided at that point to adopt more unconventional monetary policy measures including the use of forward guidance to inform markets about the future path of interest rates, the introduction of negative interest rates by setting the deposit facility rate at a minimum level of -0.4 by 2016, and new Targeted Long Term Refinancing Operations (TLTROs), which were aimed at providing households and firms with more favourable financing conditions. In order to support these actions, the ECB also introduced a series of large-scale asset purchase programmes starting in 2014 and involving the purchase of asset-backed securities, covered bonds, corporate sector bonds and government bonds.

3.2. United States

During the GFC the US also adopted a number of unconventional monetary policy measures such as quantitative easing. This included Large-Scale Asset Purchases (LSAPs), specifically QE1, QE2, and QE3, and the Maturity Extension Program (MEP), also known as the second Operation Twist. QE1 was announced in November 2008, and was originally limited to purchasing $100 billion of debt that were provided by the government-sponsored enterprises Fannie Mae, Freddie Mac, and Ginnie Mae, and an additional $500 billion in agency-backed mortgage-backed securities; the main objective was to reduce costs and increase the availability of credit for housing purchases. In March 2009, the Federal Open Market Committe (FOMC) announced that it would enlarge its portfolio of agency debt and mortgage-backed securities and purchased $300 billion of longer-term Treasury securities with the aim of improving credit market conditions. QE2 was then announced in November 2010 and led to the purchase of $600 billion in longer-term Treasury bills.

The MEP was introduced in September 2011 and involved the purchase of $400 billion of 6- to 30-year Treasury bills, followed by the sale of the same quantity of 1- to 3-year securities, with the aim of putting downward pressure on longer-term interest rates and making credit more easily available. The Fed then extended this programme in 2012, up to a total amount of $667 billion. Unlike the previous three large-scale asset purchases, which had led to balance sheet expansions, this programme left the overall size of the balance sheet unchanged. QE3 started in September 2012 and included the purchase of $40 billion per month of mortgage-backed securities in a renewed effort to support mortgage markets. By the end of the year the programme was expanded to include $45 billion per month of Treasury securities.

3.3 United Kingdom

From the start of the GFC, three main phases can be identified in the policy response of the UK monetary authorities, namely the large-scale quantitative easing programs between 2009 and 2012 aimed at stopping the recession and promoting the economic recovery, the forward guidance announcements in 2013 and 2014 indicating that the BoE was not planning to increase the policy rates, and an additional round of quantitative easing after the Brexit vote.

The UK was severely hit by the GFC because of the size of its financial sector. Following a 6% fall in real GDP in just one year, the BoE decided to cut rates sharply, and by March 2009 these had been lowered from 5.75% to 0.5%. In order to avoid deflation, the first round of quantitative easing was introduced with the purchase of 75bn of government bonds that were financed with the expansion of central bank reserves. Purchases were increased to 200bn and completed in January 2010. GDP began to recover slowly by the end of 2009, but the worsening euro area sovereign debt crisis affected the UK economic outlook in 2011. Despite rising inflation reflecting higher energy prices and value-added-taxes, by the end of the year a new round of quantitative easing had been announced, followed a year later by a third round of asset purchases, which brought the total size of quantitative easing to 375 bn.

Despite economic growth remaining weak, the fact that inflation was persistently above target raised concerns that interest rates could soon be raised. Therefore in August 2013 the BoE decided to clarify the expected path of monetary policy by introducing forward guidance with explicit quantitative targets. Since the unemployment rate had fallen faster than expected towards 7%, in February 2014 additional forward guidance was provided by the BoE that pointed out that considerable spare capacity remained in the economy and thus rates could be expected to be kept low for longer and eventually be increased only gradually.

Even though the UK economy was growing at a steady pace, the BoE then decided on a new round of monetary stimulus in August 2016 following the Brexit referendum. Specifically, it launched a fourth round of asset purchases including £60 bn of government bonds and £10 bn of corporate bonds; further, it cut the policy rate from 0.5 to 0.25 percent and launched the Term Funding Scheme to provide banks with funding at a rate close to the policy rate and facilitate the pass-through of the policy rate cut to lower lending rates.

4. Persistence of Policy Rate Spreads

A notable problem with policy spreads is that it is often unclear to what extent they correspond to the targets of a central bank; a well-known example is the puzzling widening of the ECB's Eonia spread from 2005 to 2007 (see Linzert and Schmidt, 2011). Persistence in policy spreads complicates further the signal extraction problem for financial markets and can affect negatively communication about the monetary policy stance. Specifically, it can reduce the information content of overnight rates about future monetary policy, and also affect the central bank's ability to control long-term rates and thus the shape of the yield curve. Given its importance, the analysis below uses a fractional integration approach to shed light on the degree of persistence of policy spreads.

4.1 Long Memory and Fractional Integration

A series is said to exhibit long memory when observations far apart in time are highly correlated. This feature can be captured by fractionally integrated or I(d) models of the form:

$$(1 - L)^d x_t = u_t, \quad t = 0, \pm 1, \ldots, \tag{1}$$

where d can be any real value, L is the lag-operator ($Lx_t = x_{t-1}$) and u_t is I(0) and is defined for our purposes as a covariance-stationary process with a spectral density function that is positive and finite at the zero frequency. The polynomial $(1-L)^d$ on the left-hand side of equation (1) can be expressed in terms of its binomial expansion, such that, for all real d,

$$(1-L)^d = \sum_{j=0}^{\infty} \binom{d}{j} (-1)^j L^j = 1 - dL + \frac{d(d-1)}{2} L^2 - \frac{d(d-1)(d-2)}{6} L^3 \ldots$$

and thus

$$(1-L)^d x_t = x_t - dx_{t-1} + \frac{d(d-1)}{2} x_{t-2} - \frac{d(d-1)(d-2)}{6} L^3 \ldots \quad .$$

Although fractional integration can also occur at other frequencies away from zero, as in the case of seasonal and cyclical fractional models, the series analysed here do not have such features and thus a standard I(d) model as in equation (1) will be estimated. The idea of fractional integration was introduced by Granger and Joyeaux (1980), Granger (1980, 1981) and Hosking (1981), although Adenstedt (1974) had already showed awareness of its representation. Using the above expansion, it can be seen that x_t can be expressed in terms of its whole past history. In this context, d plays a crucial role since it indicates the degree of dependence of the series: the higher the value of d is, the higher the level of association between the observations and hence the higher the persistence level.

Given the parameterisation in (1), one can distinguish between different cases depending on the value of d. Specifically, if $d = 0$, then $x_t = u_t$ and x_t is said to be characterised by "short memory" or to be I(0), and if the observations are (weakly) autocorrelated, then the autocorrelation coefficients will decay at an exponential rate; if $d > 0$, x_t is said to exhibit long memory, so called because of the strong dependence between observations that are far apart in time. Note that if d belongs to the interval (0, 0.5), x_t is still covariance stationary, while $d \geq 0.5$ implies non-stationarity. Finally, if $d < 1$, the series is mean-reverting and the effects of shocks eventually disappear, whilst if $d \geq 1$ they persist forever. Hence the value of d provides useful information to policy makers.

There are several methods to estimate and test the fractional differencing parameter d. Some of them are parametric while others are semi-parametric and can be specified in the time or in the frequency domain. In this study we carry out the tests developed by Robinson (1994), which are based on a Whittle method in the frequency domain (Dahlhaus, 1989) and have various advantages. Specifically, they can be used to test any real value of d, including those in the non-stationary range, without prior differencing of the series; also, they allow for the inclusion of deterministic terms such as intercepts and time trends, and their limit distribution, which is standard normal, is invariant to their inclusion and the modelling assumptions about the differenced processes; finally, they are the most efficient in the Pitman sense against local departures from the null. The functional form used here is the same as in Gil-Alana and Robinson (1997).

4.2. Data and Empirical Results

The overnight rates used for the analysis are the following: Eonia (Euro Overnight Index Average) for the ECB, Sonia (Sterling Overnight Index Average) for the BoE, and FFR (Federal Funds rate) for the US Fed; these and the corresponding policy rates have been obtained respectively from the ECB's Statistical Data Warehouse, the Statistical Interactive Database of the BoE, and the Data Download Program of the US Fed. All series are daily and span the following sample periods: 22/03/1999 – 21/01/2019 in the case of the ECB; 02/01/1997 - 21/12/2018 for the BoE; 01/01/1995 -17/01-2019 in case of the US Fed. The policy spreads are calculated in each case as the difference between the overnight and the policy rate and are displayed in Figure 1.

We consider initially two sub-samples, before and after the onset of the GFC (the first sub-sample ending on 31 December 2008), and then also four sub-samples corresponding to the Great Moderation period (from the beginning of the sample till 8 August 2007), the Global Financial Crisis period (from 9 August 2007, when BNP Paribas announced a stop to the redemption of some major investment funds, a date often seen as the beginning of the subprime mortgage crisis, till 17 March 2009), the Unconventional Measures period (from 18 March 2009, when the US Fed launched the Term Asset-Backed Securities Loan Facility, till 31 December 2014) and the most recent period (from 1 January 2015 to the end of the sample). The estimated model is the following:

$$y_t = \alpha + \beta t + x_t, \qquad (1 - L)^d x_t = u_t, \tag{2}$$

where y_t is the observed time series, and the null hypothesis is H_o: $d = d_o$, for d_o-values equal to 0, 0,01, … (0.01), …, 1.99, and 2 under the assumption that the error term u_t in (2) is both uncorrelated and autocorrelated, in the latter case the exponential spectral model of Bloomfield (1973) being used. This is a non-parametric approach that approximates ARMA processes with very few parameters and has been shown to work well in the context of fractional integration (see Gil-Alana, 2004).

[Insert Tables 1 and 2 about here]

Table 1 displays the pre- and post-crisis estimates of d along with the 95% confidence bands of the non-rejection values of d_0 based on the tests of Robinson (1994) for the three standard specifications employed in the literature: i) without deterministic terms, i.e. assuming that $\alpha = \beta = 0$ in (2); ii) with an intercept, i.e., imposing $\beta = 0$, and iii) with an intercept and a linear time trend, i.e., estimating α and β along with the other parameters. In each case a model is selected on the basis of the statistical significance of the estimated coefficients and the corresponding value of d is reported in bold. It can be seen that the time trend is required only in the case of the UK. Table 2 shows the full pre- and post-crisis estimation results for the selected models. The estimated values of d for the euro area and the US are in the interval (0,5 1), which implies non-stationary but mean-reverting behaviour with shocks having long lasting effects; further, for the euro area there is almost no difference in the value of d across the two sub-samples. In the case of the US persistence is lower in the second sub-sample, the estimated value of d being 0.68 in the pre-crisis period and 0.59 inn the post-crisis one. By contrast, persistence in the UK increased from 0.38 to 0.70.

[Insert Tables 3 and 4 about here]

Tables 3 and 4 report the corresponding results under the assumption of autocorrelated errors. The time trend is now required in the majority of the cases, the exceptions being the euro area and the US in the post-crisis period. The estimated values of d are generally smaller than in the white noise case but all in the range (0,1), which implies the presence of long memory. Persistence is higher in all three cases in the second sub-sample, and its increase is statistically significant in the case of the UK and of the euro area.

[Insert Table 5 about here]

Table 5 summarises the results for the parameter d, which is shown in bold whenever there are statistically significant differences between the pre and post-crisis periods. There is a clear pattern only in the case of the UK, where persistence is higher in the second sub-sample regardless of the assumption made about the error term, d increasing from 0.38 to 0.70 with white noise errors, and from 0.35 to 0.79 with autocorrelated ones. In the case of the euro area the increase, from 0.45 to 0.56, is significant only under the assumption of autocorrelation, whilst in the case of the US persistence is significantly lower in the second sub-sample only with white noise errors.

[Insert Table 6 about here]

Next we discuss the results for the four sub-samples specified before. Since they are very similar irrespective of the specification chosen for the errors we only report those for the white noise case.

[Insert Table 6 and Table 7 about here]

The three central banks being considered appear to have been able to control monetary policy spreads during the Great Moderation period, since the estimated value d lies within the stationary band, which implies that the effects of shocks die away. By contrast, during the Financial Crisis period in both the US and the euro area persistence increased, the value of d lying in the non-stationary range, and the same was true was true of the UK during the Unconventional Measures period. In the most recent period persistence has decreased considerably, the value of d implying stationarity in all three cases. Overall this evidence suggests that monetary policy has become more effective as a result of the new measures adopted.

4.3 €-STR

The Eonia rate, which is a weighted average of the overnight lending rates used between the most active credit institutions in the euro area's money market, has played a crucial role in signalling the ECB's monetary policy stance in recent years. It has traditionally followed closely the ECB's policy rate, especially its deposit facility rate, and its volatility has been relatively low. In October 2019 it was replaced by the €-STR (euro short-term) rate. As specified by the ECB's Governing Council, this complements other already existing benchmark rates used in the private sector and can be seen as a backstop reference rate. It is based on a higher number of banks providing the data required for the estimation of the rate. Contingency procedures have been put into place to deal with data scarcity in case of a small number of banks participating. This new series is less erratic and lower by 9 bps on average than the Eonia rate.

[Insert Tables 8 - 11 about here]

Given the short span of available data for the new rate, to assess persistence we use a preliminary series, known as Pre €-STR, created by the ECB for a longer period; specifically, the sample period for the estimation is 15/03/2017-22/01/2019; the data source is again the ECB's Statistical Data Warehouse. These results are presented in Tables 8-11 and the two policy spreads, vis-a-vis the Eonia and Pre €-STR series, are displayed in Figure 2. It is clear that this series is less persistent than Eonia, and therefore the introduction of €-STR as a new benchmark seems to have been an appropriate decision by the ECB to pursue its goal of financial stability.

As a robustness check, we also employ a non-linear approach for the deterministic terms replacing the linear trend on the left-hand side of equation (2) with Chebyshev polynomials in time, which leads to the following model specification:

$$y_t \;=\; \sum_{i=0}^{m} \theta_i \, P_{iT}(t) \;+\; x_t\,; \qquad (1 - L)^d x_t \;=\; u_t, \qquad t \;=\; 1, 2, \dots, \qquad (3)$$

where y_t is the observed time series and m indicates the order of the Chebyshev polynomial $P_{i,T}(t)$ defined as:

$$P_{0,T}(t) \;=\; 1,$$

$$P_{i,T}(t) \;=\; \sqrt{2}\cos\big(i\pi(t-0.5)/T\big), \qquad t \;=\; 1, 2, \dots, T; \quad i \;=\; 1, 2, \dots \qquad (4)$$

As shown by Bierens (1997) and Tomasevic and Stanivuk (2009), it is possible to approximate highly non-linear trends with rather low degree polynomials. If $m = 0$ the model contains an intercept, and if $m > 1$ it becomes non-linear - the higher m is the less linear the approximated deterministic component becomes. Detailed descriptions of these polynomials can be found in Hamming (1973) and Smyth (1998). The results obtained using this approach (not reported to save space, but available upon request) provide no evidence of non-linearities, and thus support the linear specification adopted for the analysis.

5. Conclusions

This study assesses the persistence of policy spreads in the case of three major central banks, namely the US Fed, the ECB and the BoE, using fractional integration methods ideally suited to this purpose. This is an important issue since, as pointed out by Ho (2008), persistent deviations of overnight rates from policy rates make monetary policy ineffective. The analysis highlights differences in the behaviour of the policy spreads considered that can be attributed to the institutional and monetary policy differences between the countries discussed above.

Our analysis also considers possible changes in persistence over time by obtaining parameter estimates for various sub-periods. Overall we find that during the Great Moderation period the central banks under study managed to control rates effectively, whilst persistence of policy spreads increased sharply during the GFC period in both the US and the euro area and during the Unconventional Measures period in the UK. In the most recent years it appears to have fallen again in all cases, which points to greater effectiveness of monetary policy. Further, there is evidence that the new €-STR benchmark recently introduced by the ECB works better than the previously used Eonia rate to achieve financial stability.

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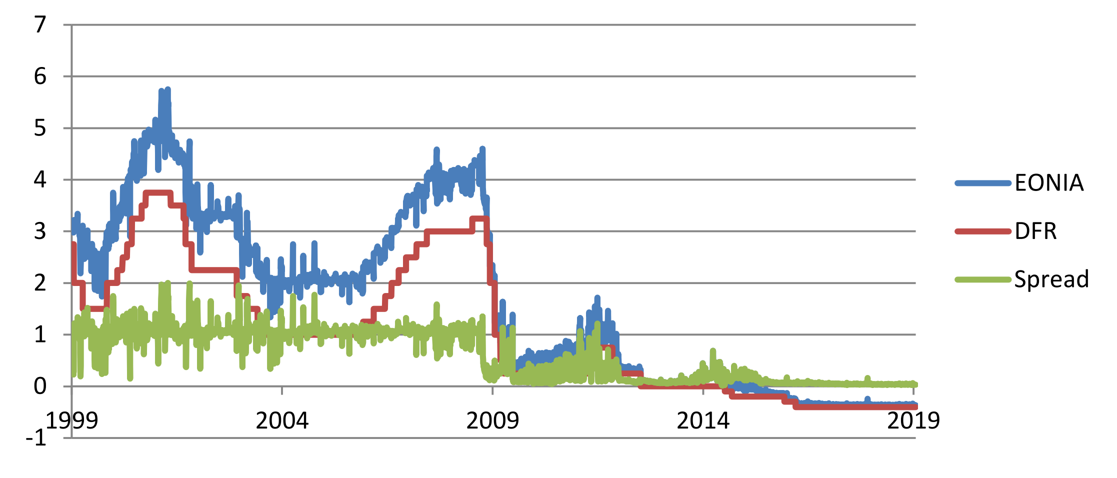
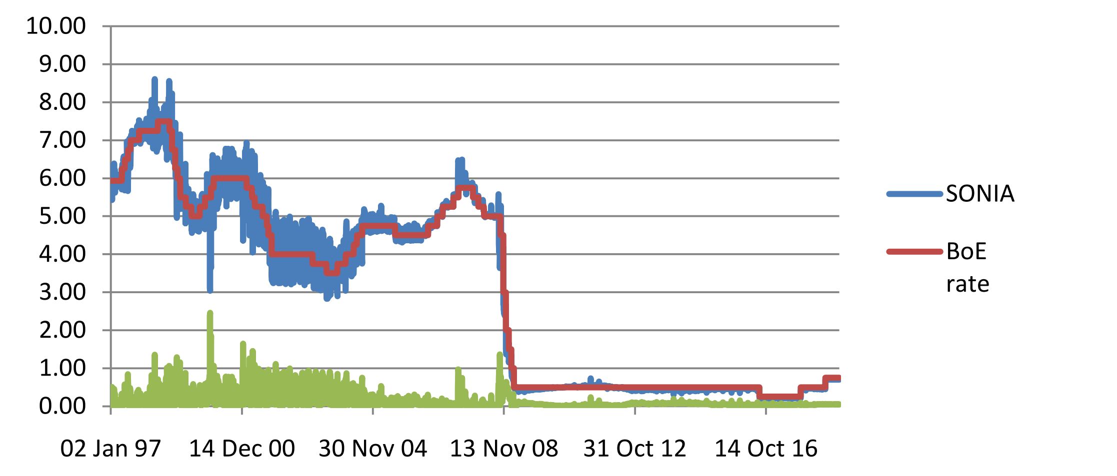
Figure 1: Policy rates and interest rate spreads

i) European Central Bank



ii) Bank of England



iii) US Federal Reserve Bank

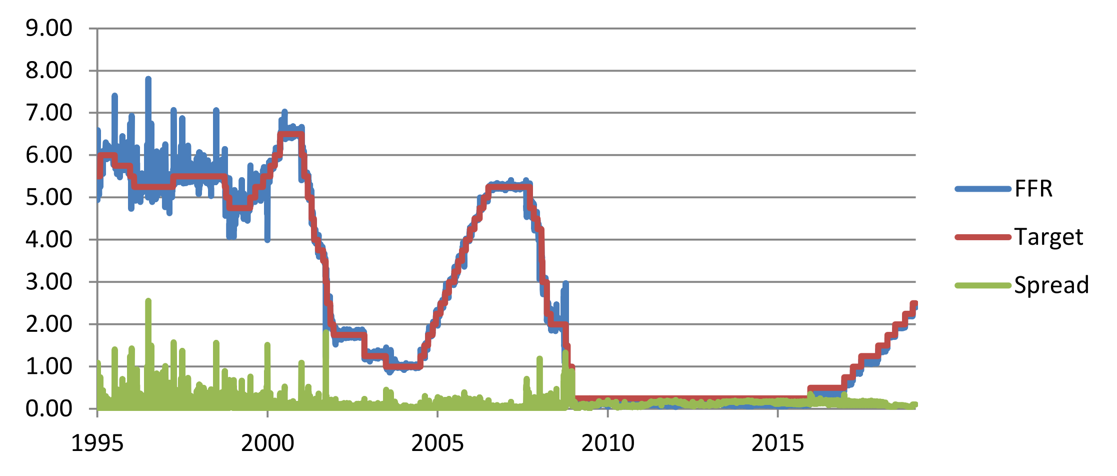


Figure 2: EONIA and Pre €-STR spread.

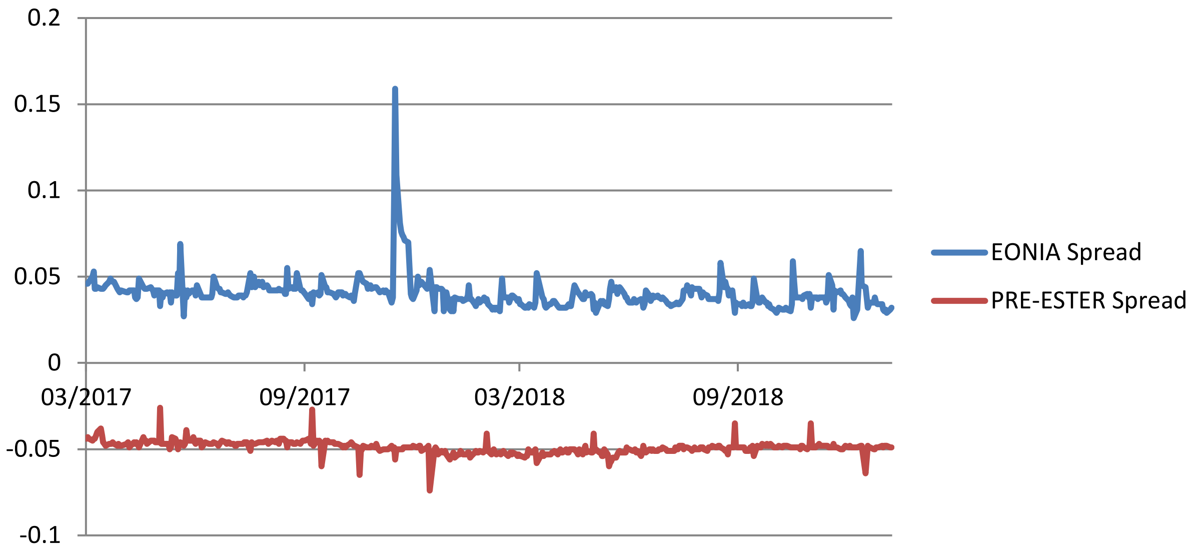


Table 1: Estimates of d pre- and post-crisis under the assumption of white noise errors

Series	No terms	An intercept	Intercept and trend
EU – pre	0.66 (0.63, 0.69)	**0.60 (0.56, 0.64)**	0.60 (0.56, 0.64)
EU – post	0.63 (0.60, 0.66)	**0.62 (0.59, 0.66)**	0.62 (0.59, 0.66)
US – pre	0.61 (0.57, 0.64)	**0.68 (0.64, 0.72)**	0.69 (0.65, 0.73)
US – post	0.61 (0.57, 0.63)	**0.59 (0.56, 0.61)**	0.59 (0.56, 0.61)
UK – pre	0.42 (0.39, 0.45)	0.39 (0.36, 0.42)	**0.38 (0.35, 0.41)**
UK – post	0.68 (0.65, 0.71)	0.68 (0.65, 0.71)	**0.70 (0.67, 0.72)**

In bold the selected models according to the deterministic terms. In parenthesis, the 95% confidence bands of the non-rejection values using Robinson's (1994) tests.

Table 2: Estimated coefficients for each selected model from Table 1

Series	d	Intercept	Time trend
EU – pre	0.60 (0.56, 0.64)	1.03872 (13.89)	---
EU – post	0.62 (0.59, 0.66)	0.21280 (4.05)	---
US - pre	0.68 (0.64, 0.72)	1.02559 (14.20)	---
US - post	0.59 (0.56, 0.61)	0.11446 (10.39)	---
UK - pre	0.38 (0.35, 0.41)	0.53168 (8.14)	-0.000018 (-3.57)
UK - post	0.70 (0.67, 0.72)	0.37397 (31.59)	-00.00011 (-3.86)

In parenthesis in the third and fourth columns, the corresponding t-values.

Table 3: Estimates of d pre- and post-crisis under the assumption of autocorrelated errors

Series	No terms	An intercept	Intercept and trend
EA - pre	0.58 (0.54, 0.62)	0.46 (0.42, 0.51)	**0.45 (0.41, 0.50)**
EA - post	0.59 (0.55, 0.63)	**0.56 (0.52, 0.62)**	0.56 (0.51, 0.62)
US - pre	0.42 (0.38, 0.46)	0.43 (0.39, 0.50)	**0.45 (0.40, 0.56)**
US - post	0.57 (0.54, 0.61)	**0.54 (0.52, 0.59)**	0.55 (0.52, 0.59)
UK - pre	0.41 (0.38, 0.45)	0.37 (0.33, 0.41)	**0.35 (0.31, 0.40)**
UK - post	0.65 (0.60, 0.71)	0.78 (0.74, 0.81)	**0.79 (0.75, 0.82)**

In bold the selected models according to the deterministic terms. In parenthesis, the 95% confidence bands of the non-rejection values using Robinson‘s (1994) tests.

Table 4: Estimated coefficients for each selected model from Table 3

Series	d	Intercept	Time trend
EA - pre	0.45 (0.41, 0.50)	1.10569 (21.39)	-0.00012 (-2.70)
EA - post	0.56 (0.52, 0.62)	0.20898 (4.64)	---
US - pre	0.45 (0.40, 0.56)	0.33619 (8.39)	-0.00005 (-2.01)
US - post	0.54 (0.52, 0.59)	0.11256 (10.56)	---
UK - pre	0.35 (0.31, 0.40)	0.51386 (9.05)	-0.000018 (-4.14)
UK - post	0.79 (0.75, 0.82)	0.40659 (32.20)	-0.00011 (-2.08)

In parenthesis in the third and fourth columns, the corresponding t-values.

Table 5: Summary of the estimates of d pre- and post-crisis

Series	No autocorrelation		With autocorrelation	
	Pre_	Post_	Pre_	Post_
EU	0.60	0.62	**0.45**	**0.56**
US	**0.68**	**0.59**	0.45	0.54
UK	**0.38**	**0.70**	**0.35**	**0.79**

In bold significant differences at the 5% level between the pre and post-crisis period.

Table 6: Estimates of d for four sub-samples with white noise errors

U.S. Federal Reserve

	No terms	A constant	Intercept and trend
Great Moderation	0.60 (0.56, 0.65)	**0.58 (0.54, 0.64)**	0.58 (0.54, 0.64)
Financial Crisis	0.41 (0.39, 0.45)	0.41 (0.38, 0.44)	**0.41 (0.38, 0.44)**
Unconventional Measures	0.85 (0.80, 0.90)	**0.77 (0.73, 0.81)**	0.77 (0.73, 0.81)
Recent Period	0.53 (0.50, 0.57)	0.43 (0.39, 0.47)	**0.41 (0.37, 0.46)**

Bank of England

	No terms	A constant	A time trend
Great Moderation	0.57 (0.51, 0.65)	**0.55 (0.48, 0.64)**	0.54 (0.46, 0.63)
Financial Crisis	0.40 (0.37, 0.42)	**0.39 (0.36, 0.42)**	0.39 (0.36, 0.42)
Unconventional Measures	0.47 (0.44, 0.50)	0.47 (0.44, 0.49)	**0.45 (0.42, 0.48)**
Recent Period	0.41 (0.38, 0.44)	**0.26 (0.23, 0.29)**	0.26 (0.23, 0.29)

European Central Bank

	No terms	A constant	A time trend
Great Moderation	0.76 (0.70, 0.84)	0.66 (0.60, 0.74)	**0.67 (0.62, 0.75)**
Financial Crisis	0.63 (0.59, 0.67)	**0.58 (0.53, 0.63)**	0.59 (0.54, 0.64)
Unconventional Measures	0.65 (0.60, 0.70)	**0.64 (0.60, 0.70)**	0.64 (0.60, 0.70)
Recent Period	0.66 (0.63, 0.69)	0.51 (0.48, 0.54)	**0.51 (0.47, 0.54)**

Table 7: Estimated values of d for the selected models from Table 6 with white noise errors

	Great Moderation	Financial Crisis	Unconvential Measures	Recent Period
U.S.A.	0.58 (0.54, 0.64)	0.41 (0.38, 0.44)	0.77 (0.73, 0.81)	0.41 (0.37, 0.46)
U.K.	0.55 (0.48, 0.64)	0.39 (0.36, 0.42)	0.45 (0.42, 0.48)	0.26 (0.23, 0.29)
EUROPE	0.67 (0.62, 0.75)	0.58 (0.53, 0.63)	0.64 (0.60, 0.70)	0.51 (0.47, 0.54)

Table 8: Estimates of d for the EONIA and PRE €-STR spreads with white noise errors

Series	No terms	An intercept	Intercept and trend
EONIA Spread	0.71 (0.64, 0.80)	**0.63 (0.54, 0.73)**	0.63 (0.54, 0.74)
PRE €-STR	0.67 (0.63, 0.71)	0.29 (0.25, 0.33)	**0.28 (0.24, 0.32)**

Table 9: Estimated coefficients for the selected models from Table 8

Series	d	Intercept	Time trend
EONIA Spread	0.63 (0.54, 0.73)	0.045 (8.38)	---
PRE €-STR	0.28 (0.24, 0.32)	-0.046 (-52.93)	-0.000009 (-3.30)

Table 10: Estimates of d for the EONIA and PRE €-STR spreads with autocorrelated errors

Series	No terms	An intercept	A linear trend
EONIA Spread	0.53 (0.44, 0.64)	0.32 (0.23, 0.45)	**0.32 (0.20, 0.44)**
PRE €-STR	0.84 (0.74, 0.92)	0.37 (0.32, 0.44)	**0.38 (0.31, 0.45)**

Table 11: Estimated coefficients for the selected models from Table 10

Series	d	Intercept	Time trend
EONIA Spread	0.32 (0.20, 0.44)	0.045 (18.43)	-0.00002 (-2.27)
PRE €-STR	0.38 (0.31, 0.45)	-0.045 (-34.61)	-0.00001 (-2.27)