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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

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

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

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 sets the minimum bid rate for its MROs and the overnight rate is not always set

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.

4. Persistence of Policy Rate Spreads

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

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).

where y_t is the

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 bank[redacted] considered appear [redacted]

Gil-Alana, L.A. and P.M. Robinson (1997) Testing of unit root and other nonstationary hypotheses in macroeconomic time series, *Journal of Econometrics* 80, 2, 241-268.

Gonzalez-Paramo, J.M. (2011) Sovereign contagion in Europe, 5pe,Sover4.M. (,)-0Sc.vRe,cme see34(r Fs)

Figure 1: Policy rates and interest rate spreads

i) European Central Bank

ii) Bank of England

iii) US Federal Reserve Bank

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

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

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