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Money market rate stabilization systems over the last 20 years: the role of the minimum reserve requirement

by Patrizia Ceccacci*, Barbara Mazzetta*, Stefano Nobili*, Filippo Perazzoli* and Mattia Persico*

Abstract

The paper analyses the Eurosystem's minimum reserve requirement system with averaging provision and compares it with the mechanisms for stabilizing money market rates adopted by other central banks (such as minimum reserves with carry-over provision, voluntary reserves with compliance bands and the quota system). The effectiveness of different approaches to stabilizing money market interest rates is then empirically investigated using data from nine central banks over the time period 2002-22. The results show that in corridor systems with scarce or no liquidity surplus, all the mechanisms examined contributed to stabilizing money market rates, although not all mechanisms proved equally effective. In floor systems with ample excess liquidity, these mechanisms would not be needed, since central banks can control the stance by adjusting the policy rate at which reserves are remunerated. However, the minimum reserve mechanism could also be used in floor systems to rapidly adjust the structural amount of liquidity in the system and as a benchmark when tiered reserve remuneration schemes are adopted.

JEL Classification: E41, E43, E51, E52, E58.

Keywords: central bank reserves, minimum reserve requirement, money markets rates, monetary policy.

Sintesi

Il lavoro analizza il sistema di riserva obbligatoria con mobilizzazione dell'Eurosistema e lo confronta con i meccanismi di stabilizzazione del tasso del mercato monetario adottati da altre banche centrali (come la riserva obbligatoria con riporto, il sistema delle riserve volontarie con bande di adempimento e il sistema a quote). Viene poi indagata empiricamente l'efficacia dei diversi approcci nello stabilizzare i tassi di interesse del mercato monetario, impiegando dati relativi a nove banche centrali sull'orizzonte temporale 2002-2022. I risultati mostrano che in sistemi a corridoio con nullo o limitato eccesso di liquidità tutti i meccanismi considerati hanno contribuito a stabilizzare i tassi del mercato monetario, sebbene con un diverso grado di efficacia. In sistemi *floor* con ampio eccesso di liquidità questi meccanismi non sarebbero necessari, in quanto la banca centrale può controllare l'orientamento di politica monetaria mediante la fissazione del tasso di remunerazione delle riserve. Tuttavia, anche in un sistema *floor* il meccanismo di riserva obbligatoria potrebbe essere utilizzato per aggiustare rapidamente l'ammontare strutturale di liquidità nel sistema e come parametro di riferimento in caso di adozione di un metodo di remunerazione a più livelli.

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CONTENTS

1 Introduction[1]

The monetary policy frameworks of central banks generally include mechanisms aimed at facilitating the stabilization of money market rates (usually overnight). The volatility of the overnight money market rate affects the achievement of monetary policy targets for at least two reasons. First, an extreme variation of this rate with respect to the monetary policy reference rate can hinder the correct functioning of the transmission mechanism, reducing the central bank's ability to influence financial conditions. Second, high volatility increases uncertainty, which generates higher costs for banks in managing liquidity, and, in extreme cases, can dissuade them from participating in the market.

These stabilization mechanisms vary according to the characteristics of the overall operational framework, such as, for example, the frequency of monetary policy operations carried out by the central bank, the type of eligible counterparties, the monetary policy reference rate, the use of a corridor or floor system.

In the Eurosystem, one of the tools that contributes to stabilizing money market rates is the minimum reserve requirement, which requires each credit institution resident in the euro area to hold a compulsory deposit with its national central bank (NCB) as a percentage of its funding. Such obligation can be fulfilled on average over the maintenance period (reserve mobilization). Under a corridor system, the minimum reserve requirement creates (or increases) a structural liquidity shortage, allowing the central bank to control money market rates more easily through periodic refinancing operations. However, the unconventional monetary policy measures[2] implemented in the last fifteen years have led to a structural liquidity surplus which diminishes the relevance of the aims pursued through the minimum reserve requirement.

This paper: i) analyzes the Eurosystem's minimum reserve system, the evolution of its role over time and in the current context (paragraph 2); ii) describes the reserve systems adopted by other central banks, contextualizing them in the overall operational framework of monetary policy and assessing their main advantages and disadvantages (paragraph 3); iii) carries out an empirical analysis of the effectiveness of the various mechanisms for stabilizing money market rates (paragraph 4); iv) compares alternative stabilization mechanisms, also taking into account different liquidity scenarios that could take place in the coming years (paragraph 5).[3] Paragraph 6 shows the main conclusions. The study is completed by three appendices, which provide empirical evidence and theoretical elements on the various stabilization mechanisms adopted by central banks in the last 20 years.

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1 Any views expressed in this paper are the authors' and do not necessarily represent those of the Bank of Italy. We are grateful to Luigi Cannari, Gioia Cellai, Alberto Locarno, Salvatore Nasti, Franco Panfili, Stefano Siviero, Livio Tornetta and one anonymous referee for valuable comments and suggestions.

2 In recent years, the ECB has enriched its operational framework with many non-standard operations implemented in order to address the 2008 financial crisis (monetary policy operations with "fixed rate full allotment", LTRO), the deflationary pressures starting from 2015 (TLTRO, APP, PSPP) and the consequences of the Covid-19 pandemic from 2020 (TLTRO III, PEPP).

3 Looking at the ECB, see Monetary policy decisions, December 2022: "By the end of 2023, the Governing Council will also review its operational framework for steering short-term interest rates, which will provide information regarding the endpoint of the balance sheet normalization process". https://www.ecb.europa.eu/press/pr/date/2022/html/ecb.mp221215~f3461d7b6e.en.html. See also the speech by Christine Lagarde at the Hearing of the Committee on Economic and Monetary Affairs of the European Parliament, September 2023: "We aim to conclude this review [of the operational framework] by spring 2024". https://www.ecb.europa.eu/press/key/date/2023/html/ecb.sp230925~036083efca.en.html

2 The Eurosystem's minimum reserve requirement

2.1 Features

In general, minimum reserve systems differ according to the following main elements: a) the liabilities that are subject to the reserve requirement; b) the reserve ratio; c) the reserve maintenance period, (i.e. the number of days with respect to which the compliance with the obligation is assessed); d) the time lag between the maintenance period and the period over which the amount of the reserve is calculated; e) the methods for fulfilling the obligation (punctual daily compliance, on average over the maintenance period or within a tolerance band); f) the remuneration of the reserve; g) the application of penalties in the event of non-compliance.

The Eurosystem's minimum reserve system was introduced in the third stage of European Monetary Union (EMU,1 January 1999). Its legal framework is based on Article 19 of the Statute of the ESCB and on various Council and ECB Regulations. The system was designed taking into account that not all NCBs had used a similar mechanism before the start of EMU.

The value of the minimum reserve is determined by applying specific coefficients to the so-called "reserve base", defined in relation to some bank balance sheet items, reported at the end of the second month preceding the start of the maintenance period to which the reserve relates.

In more detail, the reserve base includes bank liabilities in the form of deposits and debt securities issued; liabilities vis-à-vis the ECB, the Eurosystem NCBs and the banks subject to reserve requirement are excluded. The applicable coefficients are currently 0 for liabilities with a maturity above 2 years and 1 per cent for the remaining items of the aggregate. All banks can deduct a lump-sum allowance of 100,000 euros from the reserve due, introduced in order to reduce the operational burden of managing the mechanism for small banks. To this end, the legislation provides for the possibility of fulfilling the obligation indirectly, through an intermediary bank, also subject to the minimum reserve.

The reserve requirement is deemed to be fulfilled when the average of the daily balances of the reserve accounts held by each bank during the maintenance period is equal to or greater than the value of the reserve requirement.

In the design of the mechanism, the objective of stabilizing money market rates is pursued through three elements:

1) The possibility to fully mobilize the reserve, associated with the average compliance mechanism. This allows the banking system to manage its liquidity in a flexible manner, absorbing the daily fluctuations in liquidity needs and taking advantage of short-term arbitrage opportunity in the money market.
2) The setting of a sufficiently high reserve ratio in order to force banks to have a liquidity buffer that can be used to absorb any liquidity shocks in the market, once settlement needs are met.
3) The setting of a sufficiently long maintenance period (currently, on average, 6-7 weeks), to allow banks to perform the balancing function of rates, and with a starting date coinciding with the settlement day of the main refinancing operation (MRO) following the Governing Council meeting dedicated to monetary policy decisions. The latter arrangement ensures that

the change in the ECB's policy rates generally takes effect only starting from the next maintenance period, thus avoiding expectations of changes in official interest rates during the maintenance period.

In particular, the possibility to mobilize reserves gives banks some flexibility in determining how to meet their liquidity needs. In general, banks will try to hold more reserves on days when they expect the market interest rate to be lower than the expected future interest rates and fewer reserves on days when they expect the rate to be higher. In other words, the reserve mobilization within a maintenance period tends to flatten the demand curve at least in the days preceding the last day of the maintenance period and thus makes it easier for the central bank to control the variability of the money market rate around the policy rate.

With regard to the other characteristics of the Eurosystem's reserve regime, both a remuneration system and the application of penalties in the event of non-compliance are featured. The remuneration of minimum reserve was set at 0% starting from September 2023 to improve the efficiency of monetary policy.[4] Such decision has, indeed, reduced the overall amount of interest that needed to be paid on reserves in order to implement the appropriate monetary policy stance. At the same time, it has preserved the effectiveness of monetary policy by maintaining the current degree of control over the stance and ensuring the full pass-through of interest rate decisions to money markets.

In the event of non-compliance, a financial penalty is imposed, calculated by applying a penalty rate 2.5 percentage points higher than the average interest rate of the marginal lending facility to the amount of the non-compliance. There is also a higher penalty in the event of repeated non-compliance.

In the operational framework of the euro area, the minimum required reserve was combined with a symmetrical corridor system around the policy rate, with upper and lower limits being the rates of the two standing facilities: the marginal lending facility and the deposit with the Eurosystem. An analysis of the trend in money market rates from 2002 to 2022 (see Appendix II[5]) shows that, in a period characterized by a liquidity deficit, the mechanism proved to be quite effective in stabilizing money market rates around the policy rate, with the exception of the last days of the maintenance period. Since November 2005, the Eurosystem has regularly used fine-tuning operations to offset unexpected liquidity changes on the last day of the maintenance period. Subsequently, with the structural excess of liquidity created by non-standard operations, the system has *de facto* turned into a floor system, where the overnight money market rate is aligned to the deposit facility rate, and the minimum reserve requirement lost its original function.[6]

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4 ECB Governing Council decision on 27 July 2023. Before that date, the rate was equal to the weighted average rate of the main refinancing operations carried out during the maintenance period, up to 20 December 2022, and it was equal to the weighted average of the deposit facility rate starting from 21 December 2022.

5 Appendix II presents an overview of what has happened in the main central banks over the last 20 years, highlighting how the various operational frameworks have changed in a context characterized by a structural excess of liquidity. Moreover, it analyzes the effectiveness of monetary rate stabilization mechanisms through specific indicators.

6 In the period from October 2019 to September 2022, minimum reserve requirement worked as a benchmark for the remuneration of excess reserves. With the negative rates and the growth of excess liquidity, ECB established a two-tier system (TTS) for remuneration of excess reserves, which exempted part of the banks' excess liquidity holdings, equal to a multiple of the required reserve, from the application of the negative interest rate of the deposit facility. Following the increase above zero of the rate on deposits with the ECB, the system became unnecessary and was revoked by the Governing Council at its meeting on 8 September 2022.

2.2 Shortcomings

Over the years, starting even earlier than the 2008 global financial crisis, a number of possible improvements to the Eurosystem's minimum reserves have been identified.

1) As empirical evidence shows, in a structural liquidity deficit regime the mechanism requires the use of additional instruments to prevent volatility at the end of the maintenance period. This issue, in theory, could be eliminated through mechanisms used by other central banks, such as compliance with the obligation within a tolerance band or the possibility of carrying over a liquidity balance to the next maintenance period. These features are analyzed in paragraphs 2.3 and 3.1. On the other hand, in a situation of structural excess of liquidity, such as the present one, the mechanism becomes not (strictly) needed, against the persistence of operational costs for central banks and intermediaries.
2) The aggregate subject to minimum reserves (or reserve base, i.e. the amount to which the ratios for calculating the obligation apply) is made of balance sheet items (liabilities with a maturity of up to two years), which do not necessarily reflect the liquidity needs of banks for the purpose of fulfilling their payments. Therefore, wide divergences can arise between the reserve base and the banks' real liquidity needs, which would require a re-composition of the items or recalibration of the coefficients. We considered three variables as proxies of the liquidity needs of each bank: the transactions on the TARGET2 payment system, the volatility of deposits and the width of swings in excess liquidity deposited with the central bank.[7] We analyzed the relationship between the reserve base and these proxies of the liquidity needs. The results show non-significant coefficients for all the considered variables for the sample between the fourth maintenance period 2021 and the fourth maintenance period 2022 (see Table 1).

Table 1 – Relationship between reserve base and TARGET2 transactions, excess liquidity swings, bank's deposits volatility

Dependent variable: reserve base

	IV per '21	V per '21	VI per '21	VII per '21	VIII per '21	I per '22	II per '22	III per '22	IV per '22
TARGET2 transactions	169.134	-34.018	10.969	-26.928	-2.432	-22.379	8.584	14.169	89.898
	(154.696)	(87.996)	(104.523)	(111.674)	(124.915)	(133.967)	(135.41)	(160.342)	(201.185)
Excess liquidity swings	6.749	3.639	0.906	7.365	-2.152	0.392	4.011	-0.147	-1.789
	(5.395)	(8.438)	(11.442)	(14.878)	(6.39)	(13.494)	(11.271)	(12.444)	(10.576)
Deposits volatility	-1.379	-1.594	-1.424	-1.805	-75.249	-34.229	-39.967	-47.861	-43.216
	(4.826)	(4.98)	(5.049)	(5.039)	(123.883)	(112.933)	(103.02)	(101.365)	(83.736)
R^2 *adj*	-0.001	-0.047	-0.054	-0.048	-0.048	-0.054	-0.051	-0.052	-0.046

Standard errors in brackets: $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$.

3) The mechanism can be seen as an inefficient imposition in times of crisis, when the banking system may have to resort to the central bank to obtain funds by pledging collateral and a shortage of guarantees may arise. In such cases, banks may wish to use the buffer constituted

7 These variables are calculated for each bank as the average, per maintenance period, of the sum of daily inflows and outflows, the standard deviation of the monthly variation rate of bank's deposits (households and non-financial corporations), the difference between liquidity deposited with the central bank (in excess of the minimum reserve requirement) at the end of the month and its average of the last 12 months, respectively.

by the minimum reserve, but this would result in non-compliance and would be subject to a penalty. This inefficiency is accentuated by the fact that in the euro area the minimum reserve cannot be included in the LCR numerator, and so it does not contribute to compliance with the aforementioned liquidity requirement, which becomes more difficult in times of market tension. During a crisis, the problem could be solved by setting to zero the ratio (in the euro area, this is always possible through a decision of the ECB Governing Council), which would also facilitate the fulfilment of the prudential liquidity requirements imposed by the Supervisory Authority.[8]

4) The mechanism is operationally burdensome for banks. In fact, the fulfillment on average compels banks to keep track of their fulfillment path; in addition, the shock absorbing capacity decreases as the end of the maintenance period approaches. Various studies (Bindseil, 2016 and 2018; Perez - Quiros and Rodriguez, 2016) show that the mechanism based on the optimal reserve fulfillment path in a maintenance period is far from obvious, even under simplified model assumptions. In fact, each day of the maintenance period is different, and the path of the interest rate during the remainder of the maintenance period depends on past events within the maintenance period.

Before comparing the Eurosystem's minimum reserve requirement with other tools with the same aim adopted by other central banks, it is useful to consider that, in the past, minimum reserve requirements were also imposed for reasons other than stabilizing monetary rates, such as prudential and monetary control (S. Gray, 2011).[9] With reference to the prudential objective, the minimum reserves provided some protection against the liquidity and solvency risks of the banks. However, the prudential benefits of such mechanism are now obsolete, as the same objectives are more effectively achieved through the combination of supervision and regulation (with related capital adequacy and liquidity requirements), deposit insurance and central bank financing. Furthermore, the prudential role is substantially weakened where the fulfillment of the reserve requirement on average is allowed.

Similarly, the use of the reserve for monetary control purposes (exercised through two channels: the money multiplier and the impact on the spread between deposits and lending rates) is no longer widespread among central banks of world's advanced economies. However, if there are excess reserve balances in the economy, central banks may consider increasing minimum reserve requirements as a cheap way of sterilizing the impact of the surplus. Recently, De Grauwe and Ji (2023a, 2023b, 2023c) advocated the raising of minimum reserve requirements in the euro area as a tool to avoid the excessive subsidies to banks following the increases in monetary policy rates. According to the authors, the introduction of a two-tier system whereby part of the bank reserves

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[8] In April 2020, following the outbreak of the Covid 19 pandemic crisis, in order to support the flow of credit to the real economy, a supervisory measure was introduced, which allowed banks to temporarily operate below the liquidity level defined by the LCR. Since the establishment of the Eurosystem, the minimum reserve ratio has been changed only once in 2011, when it was lowered from 2 to 1 percent.

[9] This was also the case in some of the countries that joined the Eurosystem. Della Valle et al. (2022) recall that minimum reserve requirement could be used as a macroprudential tool to contain systemic risks from both broad-based credit growth and systemic liquidity shocks. However, the authors highlight that now the central banks and the macroprudential authorities have other options to manage these risks. Specifically, the countercyclical capital buffer offers an effective alternative to the minimum reserve requirement to smooth credit cycles and central banks can buy or sell marketable securities, manage the issuance of their own securities, and deal in more complex instruments such as cross-currency swaps markets (e.g., New Zealand) to manage the systemic liquidity shocks. These market-based instruments are less likely to be distortive than the minimum reserve requirement.

would be converted into unremunerated minimum reserves can reduce the banks' equity channel effect, contributing to enhance the effectiveness of monetary policies.[10]

2.3 Minimum reserve with tolerance band

Besides the mobilization of reserves within a maintenance period, another instrument for the central bank to control the volatility of money market rates around the policy rate is the introduction of tolerance (or compliance) bands. In this case the penalizing rates do not apply when the balance (daily or calculated as an average of the maintenance period)[11] falls below or exceeds the level of the required reserves, but only where the balance deviates by a percentage greater than the tolerance band, for example +/- 10 per cent around the exact value of the reserve requirement. The tolerance band may be associated with a minimum reserve or with a voluntary reserve (see paragraph 3.2): for example, it was used by the Bank of England in conjunction with the voluntary reserve from 2006 to 2009. The wider the fulfillment band, the lower the sensitivity of money market interest rates to liquidity shocks is. This implies a reduction in interest rate volatility (Armenter, 2016). However, very large compliance bands reduce the incentive for banks to exchange funds (Armenter, 2016; Lee, 2016; Ennis and Keister, 2008).

3. Alternative reserve systems adopted by other central banks

This paper analyzes nine central banks (in addition to the ECB, the central banks of Australia, Canada, Japan, Norway, New Zealand, the United Kingdom, the United States and Sweden). Among these, only the Eurosystem and the Bank of Japan currently use a minimum reserve system with mobilization. Over the past twenty years, some central banks have adopted reserve systems with different characteristics from those of the Eurosystem, as shown in the following sub-paragraphs.

[10] In the first article, De Grauwe and Ji (2023a) suggested transforming all the existing bank reserves into unremunerated minimum reserves. As a consequence, banks would have a larger proportion of their balance sheet in the form of assets that have no return. In order to restore their overall interest spread (the difference between the interest earned on their assets and the interest paid on their liabilities), they would have to increase the interest rate they apply on their loan portfolio: this would lead to a generalized increase in interest rates, contributing to the central banks' strategy to fight inflation. At the same time the increase in the minimum reserve requirement would facilitate the return to a reserve scarcity regime, such as the one before the financial crisis. With this proposal, however the central bank would lose the opportunity to use the interest rate on bank reserves as policy rate. To avoid this effect, in following articles (De Grauwe and Ji, 2023b and 2023c) the authors propose an increase of non-interest-bearing minimum reserve requirements on part of bank reserves. This would reduce the excessive subsidies to banks while maintaining the current operating procedure used by central banks. According to the authors, by imposing unremunerated minimum reserves the central bank could reduce the positive equity effect of a rate hike. A such use of the minimum reserve requirement, however, would have the negative consequence of penalizing more banks with higher amount of deposits, with possibly unintended distributional consequences on the banking sector (Deuber and Zobl, 2023; Kwapil, 2023). Furthermore, it can create incentives for banks to erode the reserve base in order to circumvent the measure (McCauley and Pinter, 2024).

[11] Tolerance bands may be applied to the balance calculated both daily and as an average of the maintenance period. In the first case, the band would be an alternative to mobilization. In the second case, the two systems can coexist: the average level of the balance in the maintenance period may deviate from the exact value of the requirement up to the amount of the band.

3.1 Carry-over of reserve balances

Carry-over was a feature related to reserve requirements employed in the United States by the Federal Reserve (Fed) from 1981 to 2012 (see Y. C. Obrien 2007). The carry-over provision allows banks to avoid non-compliance with the reserve requirement if they register a shortfall in a maintenance period, since they may carry-over the reserve balances - in excess or in deficit - to the following maintenance period, where they are to be used or recovered. The carry-over facilitates banks' liquidity management by providing a buffer to partially compensate for unexpected payment flows, with the likely effect of reducing overnight interest rates fluctuations, especially at the end of the maintenance period.

However, the carry-over provision can also be critical: firstly, it complicates central bank monitoring of reserve requirements; secondly, it could lead to speculative behaviors by banks on the occasion of policy rate decisions. For example, if banks expect policy rates to rise in the following maintenance period, they will tend to carry forward a higher balance than required to the future; similarly, if they expect rates to fall, they tend to carry forward a balance lower than the obligation to the future.

3.2 Voluntary reserve

3.2.1 Main features

In a voluntary reserve (VR) system, each bank commits in advance to a target for reserves at the central bank, taking into account a number of factors such as preference for liquidity, the characteristics of the collateral framework, the regulatory requirements and the reserve remuneration. The central bank still maintains the control of the aggregate reserves by setting a range for individual targets, within which each bank must place its own target. Within a VR system, the central bank may use tolerance bands (or compliance bands, see paragraph 2.3) to better control the variability of rates around the policy rate.

To date, the VR system has only been applied by the Bank of England (BoE), which adopted it in May 2006 and then suspended it in March 2009, due to the excess liquidity provided through the activation of the quantitative easing (QE) programme.[12] The BoE's reserve system also included tolerance bands (Bank of England, 2006; Clews, 2005)[13], as well as a narrowing of the corridor on

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[12] A system that had some features of voluntary reserves was the Fed's Contractual Clearing Balance (CCB), an instrument which supplemented the minimum reserve system with carry-over provision. The CCB was an additional period-average amount that a depository institution (DI) could voluntarily contract to maintain with a Federal Reserve Bank in addition to its required reserve balance held in its account with the central bank. It was remunerated in the form of credits, which could be used to offset charges of Federal Reserve services, such as check clearing, and Fedwire transfer of funds and securities. The amount of the CCB had to be determined before the start of a maintenance period. A DI's daily average of the clearing balances in a given maintenance period had to be within a tolerance band. The CCB system reduced the likelihood that a bank would have to recur to the Fed's overnight overdrafts. Indeed, in order to ensure the proper functioning of the payment system, the Fed allows banks to use daily overdrafts which, if not reset to zero at the end day, become overnight overdrafts. This exposure can be risky for the Fed, as it is not mandatory to collateralize this credit. Therefore, with the aim of discouraging banks from using the overnight overdraft, the Fed applies a very high penalty rate, equal to the primary credit rate + 4% for the first three days of use during the year; from the fourth day onwards, 100 basis points are added for each additional day of use. Sometimes, the additional requirement could be imposed by the central bank (required clearing balance, RCB), rather than being voluntary, if a DI had frequent overdrafts (during the day or overnight). For more details, see M. Naber, R. Sambasivam, and M-F. Styczynski (2017).

[13] Prior to September 2007, the BoE's tolerance band was limited to only ±1 percent around the target. During periods of market tension, the BoE widened the band to ±60 percent and offered additional liquidity above banks' aggregate

the last day of the maintenance period (from ±100 bps to ±25 bps). In the BoE system, if the effective reserves, as an average of the maintenance period, were positioned within the tolerance bands, they were remunerated at the BoE's official interest rate (known as the *bank rate*).

In the case of reserves outside the tolerance band (above the upper limit or below the lower limit), remuneration was subject to a penalty: excess reserves were remunerated at the bank rate minus a spread, while banks in deficit would have to borrow the missing part from the BoE at the bank rate plus the same spread. The remuneration scheme acted similarly to a corridor system, with the remuneration rate for excess reserves acting as a floor and the penalty rate for deficiencies acting as a ceiling (Armenter, 2016; Berentsen and Monnet, 2008).

Banks had to specify their (non-negative) reserve targets at least two business days before the start of each maintenance period, within individual ceilings. The latter were determined by the BoE twice a year and were equal to the higher between £1 billion and two per cent of average eligible liabilities in sterling in the six months preceding May and November.[14]

In a series of papers, Baughman and Carapella (2019a, 2019b) proposed the adoption of this tool for the Fed's operational framework, as an alternative to a system based exclusively on the floor system.[15]

From the bank's point of view, this system is more flexible than minimum reserve requirements. If market stress leads to an increase in banks' demand for reserves, banks may adjust their reserve target for the following period. Awareness of being able to meet changing liquidity needs from one period to the next can help reduce liquidity premiums and make banks more inclined to trade in the interbank market. Furthermore, compared to a system of required reserves, the VR system allows banks with different business models to "correctly size" their reserve requirements, which would otherwise be fixed according to the same formulas for all banks.

From the point of view of the central bank, too, the system appears advantageous in theory: the central bank, in fact, can still target an aggregate level of reserves by setting maximum and minimum limits for the individual banks commitments and can foresee more easily the liquidity demand as banks reveal their expectations of liquidity needs (Winters, 2012). As long as banks have a fairly good understanding of the factors affecting their reserve holdings, VRs eliminate the need for the central bank to continuously adjust supply in order to meet the interest rate target. Banks would adjust their targets to respond to the expected change in supply, leaving market rates unchanged and neutralizing the shock, thus making the central bank intervention necessary only in exceptional cases. This reduces administrative and operational costs associated with frequent fine-tuning operations. Furthermore,

reserve targets through its refinancing operations. These measures provided banks with additional flexibility in their liquidity managing, which contributed at least in part to reduce the monetary rate volatility (Lee, 2016).

14 Eligible liabilities included: deposits with an original maturity of up to 2 years (sight deposits, time deposits and certificates of deposit); commercial paper and other issues with an original maturity of up to 5 years; reverse repurchase agreements (repo); other residual and pending items.

15 For a similar proposal for the Fed see Filardo A. (2020). This proposal is based on "strengthening a Corridor-Type Framework with a Sequestered Reserves Rule (SRR)". Under the SRR, monetary and supervisory authorities should regularly negotiate with financial institutions the appropriate level of reserves needed to meet liquidity regulations. Being solely centered on financial stability purposes, the negotiations would focus on the objectives of avoiding excessive accumulation of reserves and incentivizing the use of reserves as part of a well-diversified basket of high quality liquid assets (HQLA). According to the author, the negotiations would also aim to clarify the intentions of the authorities and encourage a better mutual understanding of each other's expectations.

the VR system offers the central bank flexibility in choosing its counterparties: the system can also be applied to intermediaries with a different liability structure than banks.

VRs allow central banks flexibility in determining the size of their balance sheets, regardless of their interest rate targets, and encourage money market activity, regardless of the amount of reserves held by each individual bank. From a theoretical point of view, Baughman and Carapella (2019b) show that banks will be induced to set VR targets that bring the expected money market rate to the target reserve rate, determined by the central bank, provided that the remuneration function of reserves is additively separable into a portion depending on the reserve target chosen by each bank and into a portion depending on the difference between the reserves held and the target (for further details, see Appendix I[16]). Under this condition, the authors show that the VRs deliver the condition of separation between interest rate control and liquidity provision. Thus, by simply setting the rate on target reserves, a central bank moves the money market rate, without the need for frequent refinancing operations, having a simple and flexible system (such as a floor system), but still providing an incentive for money market activity (a feature not present in a floor system).[17]

If banks expect a shortage of reserves, i.e. the money market rate will be higher than the VR rate, they will reduce their targets and have an incentive to lend on the market, thus eliminating the scarcity phenomenon. On the other hand, if they expect reserves to be abundant, i.e. the money market rate will be lower than the VR rate, they will raise their targets and borrow from the market. The only assumption consistent with an equilibrium is that expected money market rate is equal to the VR rate (Armenter, 2016; Baughman and Carapella, 2019b).

In the event of unexpected changes in the autonomous factors leading to a deviation between the aggregate reserves in the system and the aggregate targets, with the money market rate drifting away from the VR rate, the central bank wishing to control rate volatility could inject or drain reserves. In this regard, Baughman and Carapella (2019a) argue that, in order to inject or drain liquidity into the system without affecting money market volatility, it is important that the central bank credibly announces the details of the intervention before banks choose their targets or, alternatively, when more frequent operations are planned, allows banks to adjust their targets more often. The key condition is that the injection or drainage of liquidity is credible and fully anticipated by the banks.

Lee (2016) points out that, although the BoE's VR system has largely succeeded in controlling rate volatility, the average money market rate has consistently been above the BoE's target. Baughman and Carapella (2019b) show that this persistent deviation of market rates from the voluntary reserve rate is mostly attributable to the endogeneity of the targets with the tolerance bands, envisaged by the BoE system. They suggest to solve the problem by providing tolerance bands that are not linked to the targets (for example, setting them on the basis of historical average values of total assets or other balance sheet items). In fact, a remuneration function that violates the condition of being additively separable can provide perverse incentives, driving money market rates away from the VR rate. In

[16] Appendix I provides analytical details on reserve systems other than minimum reserve requirements.

[17] By way of comparison, the separation condition would not be satisfied by reserve requirements, since under this system the central bank should necessarily increase the supply of reserves to reduce money market rates, autonomous factors being equal. The separation condition is instead guaranteed by a floor system without reserve requirements, where the central bank controls market rates by varying the rate of the deposited reserves. However, this is possible only if the supply of liquidity exceeds demand (see Keister, Martin and McAndrews, 2008).

particular, with a remuneration function where tolerance bands are based on the VRs, the expected market rate exceeds the target rate due to the banks' optimal targeting strategy.[18]

3.2.2 Shortcomings

The experience of the BoE shows that even this system, which in theory appears very flexible and effective, has some critical issues that are listed below.

1) In event of a crisis, it does not seem to improve the liquidity forecasts made by the central bank, even though it can rely on the preferences revealed by the banks. Indeed, crisis are typically the result of aggregate shocks and therefore individual intermediaries do not have an information advantage over the central bank. The BoE's experience at the onset of the global financial crisis suggests that banks' predetermined reserve targets turned out to be lower than their actual needs, resulting in increased money market volatility, which compelled the BoE to conduct frequent liquidity providing operations and to increase the tolerance bands around the targets.
2) It implies the operational burden for the central bank of setting the range of accepted voluntary reserve targets, which requires careful maintenance, having to be fine-tuned also according to the banks' financial structure (e.g. taking account that some institutions, such as settlement banks, have higher liquidity needs).
3) It requires adjustments with two types of unconventional measures, such as QE and negative rates. Voluntary reserves could be very difficult to manage in a situation of large excess liquidity, as an imbalance could be created between the large supply of reserves and the demand for liquidity by banks, which would find it increasingly difficult to calibrate their reserve targets. In order to prevent this from happening, the communication by the central bank is essential, as well as the possibility of allowing, in exceptional circumstances, banks to change their targets even during maintenance periods. The VR system would also require arrangements for managing negative interest rates. With negative rates and a large supply of liquidity from the central bank, it would be necessary to introduce, also in this system, a concept of excess reserves and possibly a new (negative) deposit rate at which they are remunerated.

3.3 Quota systems

3.3.1 Main features

An alternative to reserves (required or voluntary) is represented by quota-based systems. In these systems, the central bank sets for each counterparty the amount of reserves remunerated at the official rate that can be deposited and/or withdrawn from it (Target rate limited access, TARALAC). Individual deposit or funding quotas are allocated on the basis of certain characteristics of banks, such as balance sheet size or volume of transactions in the payment system. In a system with individual deposit quotas, any amount of reserves placed on deposit above the allocated quota each day by banks is remunerated at the deposit rate, which is lower than the official rate. Similarly, in a system with individual funding quotas, the use of central bank borrowing in excess of the allocated quota is paid

[18] If the width of the tolerance band was proportional to the targets that banks set themselves, they would have an incentive to set higher targets than they would otherwise have done, with the aim of increasing the width of their tolerance band to reduce the risk of being outside it.

at the marginal lending rate, which is higher than the official rate. By limiting recourse to the central bank, banks' activity on the money market is encouraged: the official rate influences market conditions and the overnight money market rate should be close to the official rate (for more theoretical details, see Appendix I). Quotas can be one-sided (limited access to only one of the two facilities) or two-sided (limited access to both facilities).

Systems based on "one-sided deposit quotas" were used by the Reserve Bank of New Zealand (RBNZ) from 2007 to 2020 and by Norges Bank from 2011 to the present.

However, defining the optimal TARALAC quota is rather complex and not obvious because there is a trade-off between the volatility of the target operating rate and money market activity. The higher the quota, the more likely it is to be sufficient to absorb shocks and the less likely it is that banks will have to resort to one of the two standing facilities at penalizing rates. The overall effect is a more stable overnight rate. If the stability of the overnight rate is the central bank's sole criterion of choice, it will be more easily pursued with a high quota; however, in this case, there will be less incentive for banks to trade on the money market. If, on the other hand, the priority is not to dry up the money market excessively, the quotas must be low or unilateral. Bindseil (2016) leads simulations showing that, under specific parameter choices, when open market operations are less frequent (each operation has to cover more days), a larger quota stabilizes the overnight rate without further penalizing money market turnover. In addition, the determination of the optimal quota level must take into account all the liquidity requirements in force in that jurisdiction, especially in the short term.

Compared to the minimum reserve requirements with mobilization, this system appears flexible for banks, as it eliminates the complexity of having to consider their fulfillment path during the maintenance period.

The RBNZ was the first central bank to introduce a quota-system and it did so in a period of positive rates (Bowman et al., 2010). It was introduced to counter the sharp decline in interbank market trading and as a response to the previous excessive hoarding of bank reserves, experienced under the RBNZ's floor system.[19]

New Zealand maintained the quota system until March 2020, when it was suspended following the implementation of a QE programme involving a very large reserve supply, which made it increasingly difficult to keep short-term rates anchored to OCR. As a result, the RBNZ decided to remunerate all deposited balances at the OCR rate and remove all tiering limits beyond which a lower remuneration rate applied (Reserve Bank of New Zealand, 2020), thereby formally introducing a floor system.

Similarly, Norges Bank has implemented a one-sided (limited access to deposit) quota-based system since October 2011, where each bank's quota is determined to be sufficient to meet daily settlement

[19] Under the quota system, banks' overnight deposits were remunerated at the reference rate (the Official Cash Rate, OCR) up to the limit set for each individual bank by the central bank ("tier"), mainly on the basis of the likely settlement needs in the case of a tail event. Balances held in excess of the limit accrued interest at a rate equal to the OCR minus 100 basis points. The relatively low rate of excess balances discouraged holding balances in excess of the limit, thus incentivizing banks with excess balances to lend them in the interbank market and to invest in liquid instruments other than central bank reserves. For more details on the evolution of the RBNZ's operational framework, see Appendix II.

needs and it is remunerated at the reference rate.[20] Norges Bank normally reviews the level of the quota allocated to each bank twice a year (Norges Bank, 2021).[21]

The Norwegian central bank maintained the quota system even after the outbreak of the pandemic crisis, unlike New Zealand, but increased its open market operations. Following the crisis, the central bank conducted several extraordinary financing operations with maturities of up to 12 months; the injected excess liquidity was drained from the banking system using daily deposits with a one-day maturity, with rates close to the policy rate.

The aforementioned central banks did not appear to face unexpected fluctuations in autonomous factors that led to large liquidity surpluses and overnight rate decreases or liquidity shortages that gave recourse to the credit facility. In any case, when these occurred, they intervened by draining or supplying reserves, on a daily basis if necessary. For the Eurosystem, where autonomous factors have shown higher volatility, a larger quota may be needed, which would then affect interbank market activity.

3.3.2 Shortcomings

The main disadvantages of the quota system are:

1) the inherent complexity of quota setting, as there is a trade-off between the precision of steering short-term market rates toward the key policy rate and money market activity;
2) the need for the central bank to be ready to intervene on a daily basis in the event of an imbalance due to unexpected autonomous factors, even if the calibration works well;
3) the inadequate functioning of the system in the presence of autonomous factors subject to frequent and unexpected fluctuations. Central banks facing high variability in autonomous factors are likely to have to calibrate very large quotas for the system to function well, resulting in negative impacts on money market trading.

3.4 Operational frameworks that do not include stabilization mechanisms based on reserves/quotas

Some central banks (Australia, Canada, New Zealand, Sweden) have adopted operational frameworks that do not provide for either reserve mechanisms or quotas, having equally succeeded in effectively controlling short-term interest rates (Sellin and Sommar, 2014).

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[20] The reserves of each individual bank above the pre-determined quota are remunerated at a penalizing rate (reserve rate, 100 bps below the policy rate), in order to incentivize banks to lend liquidity in the interbank market. At the same time, Norges Bank aims to keep total reserves in the banking system (around NOK 35 billion, with flexibility of ± NOK 5 billion) below the sum of the quota that can be remunerated at the policy rate (NOK 45 billion), so that banks can always deposit outstanding reserves in the banking system at the policy rate. Outstanding liquidity is controlled through open market operations (drainage or supply of reserves), where the interest rate is determined by auction. See Appendix II for more details.

[21] The quotas are determined on the basis of a top-down approach. First, Norges Bank determines the total quota of bank reserves remunerated at the official rate. Second, banks are divided into three groups based on data from the Norges Bank's Settlement System (NBO). The aggregate quota of each group is determined by the share of the respective groups in the total assets. All banks in a group are assigned the same quota. Banks that also settle payments for other banks are allocated an additional quota determined by their size in relation to the size of the banks for which they settle payments.

These countries have adopted a narrow and symmetrical corridor of standing facilities around the policy rate to achieve control of money market rates, with daily open market operations. Overnight overdrafts are automatically accounted for as central bank loans at the marginal lending rate.

This framework has the following criticalities: 1) a significant operational burden for the central bank due to the necessary use of daily operations; 2) in the event of substantial changes in autonomous factors, high intraday rate volatility pending the daily central bank intervention; 3) central bank intermediation might substitute market trading activity and reduce money market volume noticeably.

A reserve/quota mechanism becomes superfluous in an operational framework based on a floor system. In this case, theoretically, the central bank limits interest rate volatility by setting the deposit facility (DF) rate as the reference rate for monetary policy and injecting an amount of reserves into the system such that the liquidity supply curve intersects the demand curve at the DF rate when the demand curve is inelastic (i.e., at its flat right-hand portion). In practice, the DF rate often represents a "leaky floor", both because non-bank financial intermediaries do not have access to the DF and because leverage requirements prevent banks from arbitraging the difference between DF rate and overnight money market rate. Therefore, this system does not completely eliminate rate volatility and some central banks have been forced to introduce new instruments (for example, in September 2014 the Fed implemented the Overnight Reverse Repo Purchase, ON RRP) to provide a lower bound to money market rates (see Appendix II for more details).

The floor system is considered useful for simplifying the implementation of monetary policy and has recently been applied by many central banks, as a response to the excess liquidity injected into the system to deal with the global financial crisis first and the spread of the pandemic in more recent times. In fact, since it is not based on a reserve maintenance period to generate the flat region of the demand curve, nor on reserve requirements (either required or voluntary) to induce banks to hold liquidity, it eliminates the significant administrative burdens for both banks and central banks associated with such mechanisms (see previous paragraphs).

Moreover, even though the system has many operational advantages in stabilizing money market rates (there is no need to accurately estimate the demand for reserves or to use frequent fine-tuning operations) it also has some criticalities. First, it requires a large central bank balance sheet, with inevitable consequences for the financial risks and economic burdens associated with the remuneration of large outstanding reserves. Second, in case of high levels of excess liquidity, it leads to money market rates falling below the deposit facility rate. This may require additional instruments to control the level of rates and the need to admit generally unauthorized dealers as monetary policy counterparties (as, for example, in the United States with the ON RRP facility).

Table 1A in the Appendix summarizes the pros and cons of reserve/quota-based stabilization mechanisms comparing them with those of operational framework without such mechanisms.

4. Empirical evidence

This paragraph compares, firstly, the effectiveness of operational frameworks involving reserve/quota systems (minimum reserve requirements, voluntary reserves, quotas); subsequently, the results are compared with those reported by the operational frameworks that do not envisage such mechanisms.

The analysis uses data from the nine central banks mentioned in previous paragraphs (in addition to the ECB, the central banks of Australia, Canada, Japan, Norway, New Zealand, the United Kingdom, the United States and Sweden). The time horizon covers a 20-year period, from January 2002 to June 2022.

For each central bank, several phases have been identified which coincide with significant changes in the operational framework of monetary policy. In some cases, these changes are due to the external context, such as the outbreak of the great financial crisis or the spread of the Covid-19 pandemic.

The analysis was performed by comparing the volatilities of money market rates estimated through the GARCH model. This model takes the significant clustering in the volatility of money market rates (for example, Hamilton, 1996 and Klee et al., 2019) into account. This allows to evaluate both the persistence of volatility phenomena (i.e. how much the current estimate of volatility is influenced by its past values) and the response to innovations (shocks).[22]

Table 2 shows a summary of the evolution of operational frameworks and rate stabilization mechanisms applied by different central banks in the period 2002-2022, highlighting different levels of reserves with different colors. Specifically, reserves are classified on the basis of an econometric analysis that takes into account of: i) the probability that a central bank implements a floor system in correspondence with the different values of the reserve-to-GDP ratio; ii) the relationship between the reserve level (relative to GDP) and the spread between the money market rate and the deposit rate with the central bank. This analysis defines the lower bound for reserves under which money market rate volatility could occur.[23]

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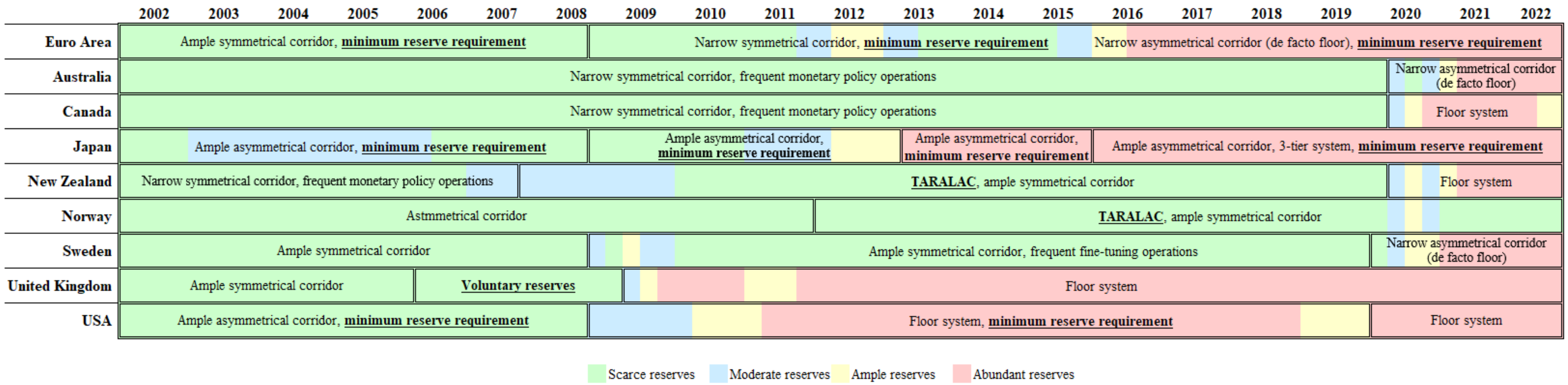
[22] GARCH (Generalized Auto-Regressive Conditional Heteroskedastic) is a statistical model used to model the variance of time series in the presence of heteroschedasticity. In a GARCH model of order (p, q), variance is a function of the values assumed by squared residuals (ε process) in previous p periods and by the variance of previous q periods. More details are presented in Appendix II.

[23] In particular, reserves are classified as: 1) abundant (reserves/GDP ratio > 9 %), situation in which the demand curve is flat and the money market rate is very close to the deposit facility rate; 2) ample (ratio between 7 and 9%), where the demand curve is slightly downward sloping; 3) moderate (ratio between 4 and 7%) where the negative slope of the curve increases and reserve changes start to induce non-negligible variations in money market rates; 4) scarce (ratio under 4%), where reserves are very close to the aggregate requirement and the demand curve has a high negative slope, leading to a strong rate reaction against small changes in reserves. For more details, see Appendix III. The proposed classification is slightly different from the one that can be found in literature (e.g. Afonso et al., 2022), in which only three categories are considered for reserves: abundant, ample and scarce.

Table 2 - Evolution of rate stabilization mechanisms in Central Banks



Note: On the thresholds used for reserves' classification see note 23 and Appendix III for details.

The performance of the various operational frameworks was evaluated by creating 3 different groups: 1) operational frameworks with minimum reserve; 2) operational frameworks with voluntary reserves; 3) operational frameworks with quotas. The results must be interpreted with due caution associated with the fact that the analysis includes countries that have money markets with different characteristics and participants, so that greater volatility could depend on structural factors.[24] The results were compared with those of central banks with frameworks without such mechanisms (central banks with "narrow corridor and daily operations", central banks with "floor"). Each group includes data from central banks that have adopted the system to which the group refers, for the period in which this occurred. Therefore, for different periods, some central banks are included in different groups. The analysis excludes periods when central banks had in place reserve requirements within *de facto* floor systems or, in any case, with at least ample reserve levels. Some systems have been adopted only by one country and for a limited period (such as voluntary reserves in the United Kingdom and reserve requirement with carry-over provision in the United States), so that any generalization of results should be treated with caution.

The following tables (3.1 and 3.2) show the results of the analysis of the daily spread between the money market rate and the monetary policy reference rate and its volatility.

In summary, with reference to the systems based on reserves/quotas, the analysis highlights the following results:

- the examined central banks were effective in pursuing the objective of keeping the overnight money market rate close to the monetary policy reference rate, albeit with differences. In a context of low reserves, the average absolute spread over the considered periods is between 2 basis points (bps) (Japan and Norway) and 8 bps (euro area and New Zealand), while in a context of moderate reserves, the euro area has the highest value of 47 bps. With regard to the volatility, it ranges from 0.02 (Norway) to 0.13 (euro area) under regimes with scarce reserves while in case of moderate reserves the highest value is again for the euro area (0.22).[25]
- the two central banks having a minimum reserve system with mobilization (ECB and Bank of Japan) present very different results. While for Japan, both the average spread and the volatility were very low regardless of the amount of outstanding reserves, for the euro area these values are much higher, particularly in the period of moderate reserves (where the spread in absolute value and volatility were respectively 47 bps and 0.22);
- for the reserve requirements system with the carry-over provision implemented in the United States, the volatility of the differential is in line with that of the euro area in the period of scarce reserves (0.07);
- in terms of spread volatility, moderate values are reported by the BoE and Norges Bank, which have adopted systems based on voluntary reserves and quota-based systems, respectively.

[24] For example, the structure of the banking system, with prevalence of small banks that are not very active in the money market, the weight of non-bank intermediaries on the money market, autonomous factors, the share of over-the-counter transactions.

[25] To deal with the 2008 financial crisis, the ECB introduced fixed rate full allotment auctions and longer-term loan programs (LTRO), allowing the overnight money market rate (EONIA) to move towards the lower limit of the corridor. To evaluate the effects of these changes on the metrics of Table 3.1 see the next sub-paragraph 4.1 ‘Robustness Check’.

Table 3.1 – Comparison of the performance of different reserve mechanisms[26]

Macro group	Group	Central Bank	Reserve Level	Average Width between Standing Facilities rates	Mean	Median	GARCH Volatility	Absolute Value Mean	Volatility/ Average policy rate
SYSTEMS WITH RESERVE/QUOTA	**Minimum reserve systems - Averaging**	Eurozone *2002-2008*	S	200	0.053	0.060	0.079	0.083	2.8%
		Eurozone *2008-2012*	M	150	-0.453	-0.553	0.219	0.469	14.8%
		Eurozone *2013-2015*	S	86	-0.155	-0.108	0.128	0.170	52.5%
		Japan *2002-2006*	M	10	0.001	0.001	0.002	0.001	Not calculable[27]
		Japan *2006-2008*	S	24	0.008	0.005	0.027	0.016	7.1%
	Minimum Reserve System - Averaging + Carry-over	United States[28] *2002-2008*	S	97	0.002	0.000	0.073	0.046	2.6%
	Voluntary reserve systems	United Kingdom *2006-2008*	S	179	0.053	0.045	0.055	0.059	1.1%
	Quota system (TARALAC)	Norway *2011-present*	S	200	-0.004	-0.010	0.024	0.016	2.7%
		New Zealand *2007-2009*	M	50	-0.119	-0.145	0.131	0.156	1.8%
		New Zealand *2009-2020*	S	50	-0.068	-0.050	0.089	0.085	3.8%
SYSTEMS WITHOUT RESERVE/QUOTA	**Systems with narrow corridor and daily operations**	Australia *2002-2020*	S	50	0.000	0.000	0.001	0.000	0.0%
		Canada *2002-2020*	S	48	-0.004	-0.003	0.008	0.007	0.5%
		New Zealand *2002-2007*	S	45	0.022	0.000	0.037	0.022	0.6%
		Sweden[29] *2002-2008*	S	147	0.116	0.100	0.048	0.119	1.6%
	Floor systems	Canada *2020-present*	Ab	25	-0.049	-0.050	0.027	0.049	7.4%
		Australia *2020-present*	Ab	36	-0.074	-0.070	0.020	0.074	11.7%
		New Zealand *2020-present*	Ab	25	-0.037	-0.030	0.045	0.044	8.6%
		United Kingdom *2009-present*	Ab	71	-0.041	-0.042	0.026	0.046	5.6%
		United States *2020- present*	Ab	26	-0.041	-0.050	0.026	0.043	12.1%
		Sweden *2020- present*	Ab	30	-0.065	-0.058	0.084	0.071	213.8%

26 The outlier values (0.5%) of the entire sample were removed.

27 It is not possible to calculate the ratio between volatility and the average policy rate as the policy rate was 0 per cent for the whole period.

28 For United States, the column of the Average width between Standing Facilities rates contains the average difference between the Primary Credit Rate and the Federal Funds Rate, as the deposits with the central banks were not remunerated (for details, see Appendix II).

29 The corridor was wide (± 75 basis points) until April 2009, was then reduced until July 2010 (± 50 basis points) and finally widened again (± 75 basis points) until 2019.

Table 3.2 – Comparison of the aggregate performance of different reserve mechanisms.

Macro-group	Group	Reserve Level	Mean	GARCH Volatility	Absolute value mean
SYSTEMS WITH RESERVE / QUOTA	**Minimum reserve systems – Averaging**	S	0.012	0.075	0.081
		M	-0.208	0.102	0.217
	Minimum reserve systems – Avg. + Carry-over	S	0.002	0.073	0.046
	Voluntary reserve systems	S	0.053	0.055	0.059
	Quota systems (TARALAC)	S	-0.035	0.055	0.049
		M	-0.119	0.131	0.156
SYSTEMS WITHOUT RESERVE/QUOTA	**Systems with narrow corridor and daily operations**	S	0.017	0.014	0.022
	Floor Systems	Ab	-0.047	0.032	0.051

Note: Tables 3.1 and 3.2 exclude the periods in which central banks had minimum reserve requirements under, *de facto*, floor systems, or, in any case, with at least ample reserve levels. In the Reserve Level column, S indicates Scarce reserves (reserves to GDP ratio value < 4%), M Moderate (ratio value between 4 and 7%), Am Ample (ratio value between 7 and 9 %) and Ab Abundant (reserves to GDP ratio value > 9%). The Average Width between Standing Facilities rates column contains the average difference between the two standing facilities (marginal lending and deposit) rates in the considered period. The Mean and Median columns show the mean and median value, calculated on daily data, of the spread between the money market rate and the policy rate. The GARCH Volatility column shows the average volatility of the spread, measured through a GARCH, in the considered period. The Absolute value mean column indicates the mean of the spread calculated on the absolute values. Finally, the Volatility / Average Policy Rate column compares the average volatility of GARCH to the average level of the policy rate, both calculated over the considered period. The daily money market rates considered are: EONIA (Euro OverNight Index Average) until October 2019 and the €STR (Euro Short-Term Rate) thereafter for the Eurosystem, Cash Rate for Australia, OMMFR (Overnight Money Market Financing Rate) for Canada, Overnight Call Rate for Japan, NIBOR (Norwegian Inter-Bank Offer Rate) until October 2011 and NOWA (Norwegian Overnight Weighted Average) thereafter for Norway, OICR (Overnight Interbank Cash Rate) for New Zealand, SONIA (Sterling Over Night Index Average) for the United Kingdom, EFFR (Effective Federal Funds Rate) for United States, STIBOR (Stockholm Interbank Offered Rate) until September 2021 and SWESTR (Swedish krona Short Term Rate) thereafter for Sweden. For more details, see Appendix II.

If we compare the results of the systems with reserves/quotas with those without them (systems with daily operations and floor systems), the second macro-group reports lower values both for the mean and for the volatility of the spread. In particular, systems with narrow corridor and daily operations, in contexts of structural liquidity deficits, record an overall difference in absolute value equal to 0.02, while for floor systems, in contexts of excess liquidity, this value is equal to 0.05. In both cases, the volatility of the spread is very low (equal to 0.01 and 0.03, respectively).[30] This latter result shows that under these systems the spread between money market rates and the policy rate has been stable and predictable, indicating an effective steering of short term rates as volatility has been kept low.

In summary, systems based on narrow corridor and daily operations and floor systems, which do not require additional stabilization mechanisms, are more effective. However, they may present disadvantages, such as: in the first case, excessive operational burdens; in the second case, comparatively higher costs and higher financial risk.

[30] For Canada and Australia, the volatility of money market rates is slightly lower under the narrow corridor system than the one observed under the floor system. The former system is very effective in stabilizing the money market rate, but implies a significant operational burden for the central bank requiring the use of daily operations.

4.1. Robustness check

In the previous paragraph, the classification of reserves is based on an econometric model that assumes constant thresholds across jurisdictions and time. As a robustness check, we estimated the model without these assumptions.[31]

Firstly, we estimated the model adding a dummy time variable to capture time effects; secondly, we tested the model allowing the coefficients to vary across jurisdictions. Both estimates confirm, on average, the previous results (see Tables 4A and 5A in Appendix III).

In addition, we used econometric analysis where the probability of a central bank implementing a floor system is related to the value of the spread between the money market rate and the rate applied to bank deposits at the central bank, instead of the value of the reserves-to-GDP ratio as previously. The estimates show a negative relation between the spread and the probability that the central bank implements a floor system: the closer the money market rate to deposit rate, the greater the probability that central banks adopt a floor system (see Tables 6A, 7A and 8A in Appendix III).

In light of these latest results, the Eurozone could be considered a *de facto* floor system already in the period 2009-2011, since it registered a low spread between EONIA and Deposit Facility Rate (DFR).[32] Considering the DFR as *de facto* policy rate instead of the main refinancing operation (MRO) rate modifies the metrics in Table 3.1. As expected, the mean, the median value of the spread between the money market rate and the reference rate as well as the mean of the spread calculated on the absolute values decreased, compared to the previous analysis, to 0.160, 0.100 and 0.160, respectively. It is also important to note that the average volatility of the spread shows a strong reduction (to 0.114, measured through a GARCH), but it increases relative to the average reference rate (to 45.4%). Even with the new metrics, however, the evaluations made in the previous paragraph remain unchanged.

5. Comparison of various stabilization systems

Each of the systems analyzed in the previous paragraphs has advantages and drawbacks that vary across different liquidity conditions. Historically, the stabilization systems analyzed in this paper were part of central banks' operational framework to ensure monetary control and to provide banks with a liquidity buffer. In particular, such systems generate a predictable minimum demand for central bank credit by the banks. These funding needs provide the central bank with a tool to adjust its stance by changing the rate applied to liquidity provision operations.

In a corridor system with scarce or no liquidity surplus, minimum reserve requirements, when accompanied with other provisions (such as averaging, carry-over or the compliance band), would maintain their role in helping to stabilize short-term rates through intertemporal smoothing of autonomous factor shocks.

However, in today's circumstances, it must be considered that there is less need to establish a structural demand for central bank reserves through minimum reserve requirements. This is because

31 See Appendix III for details.

32 See Appendix II.

there is ample liquidity demand driven by autonomous factors (such as banknotes), and most banks may wish to maintain additional reserve buffers for payment purposes.

Furthermore, the rationale for implementing minimum reserve requirements as a tool both to offer banks a liquidity buffer and to curb excessive maturity transformation activities has become less relevant. The regulatory reforms implemented after the global financial crisis have delegated the former function to the liquidity coverage ratio (LCR) and the latter to the net stable funding ratio (NSFR).

In a floor system, minimum reserve requirements would not be needed to stabilize money market rates, as the central bank can control the stance by adjusting the policy rate at which reserves are remunerated. However, even under such a system, the minimum reserve mechanism could be justified by several motives.

The central bank can consider adjusting the minimum reserve requirements ratio as an option to rapidly modify the structural amount of liquidity in the system. If, at a future date, the central bank decides to reduce the structural liquidity position, it can increase the minimum reserve requirements ratio. Nevertheless, any such decision should be carefully weighed against possible drawbacks.[33]

Furthermore, in an environment of ample excess liquidity, minimum reserve requirements could be used as a benchmark in the case of the adoption of a tiered reserve remuneration structure.[34] When tiering is aimed at mitigating the effects of negative rates on banks' net interest margins in the presence of nominal rigidity of deposit rates at the zero lower bound, the use of minimum reserve requirements (or a proxy based on bank deposits) ensures better alignment between the purpose pursued and the allocation of allowances (Boucinha et al., 2022). Similarly, minimum reserve requirements could serve as a benchmark in a reverse tiering system aimed at reducing the interest paid to banks on reserves in situations of positive interest rates and large excess liquidity. However, such a mechanism may have adverse effects, potentially leading to unintended distributional consequences within the banking sector.

In a "parsimonious" floor system, minimum reserve requirements with averaging may help to calibrate monetary policy operations (Della Valle et al., 2022).[35] Compared with the corridor system, in a "parsimonious" floor system, the central bank aims to satisfy slightly more than the precautionary demand for reserves to maintain the market rate at the floor, which is remunerated at the policy rate. The reserve supply, based on estimates of the demand for reserves and forecasts of autonomous factors, could be calibrated without a minimum reserve requirement. However, if a minimum reserve requirement is in place and is high enough - constituting a known, predetermined portion of the total reserves of the system - the central bank would encounter fewer uncertainties in determining the reserve supply needed to maintain the market rate at the floor.

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[33] See note 10.

[34] The tiered reserve remuneration structure implies a different rate of remuneration for part of a credit institution's current account holdings in excess of minimum reserve requirements. In particular, the Eurosystem adopted this system to exempt part of these holdings from the deposit facility rate (DFR) when the rate was negative (see note 6 for more details).

[35] Della Valle et al. (2022) define "parsimonious" floor system as the minimum central bank balance sheet size to implement a floor. This is different from a floor system achieved only through asset purchase programs.

Regardless of the prevailing liquidity conditions, Table 4 shows the performance of various mechanisms with reference to different aspects.

Table 4 – Pros and cons of reserve/quota systems

	Minimum reserve with averaging	**Minimum reserve with tolerance band**	**Minimum reserve with carry-over**	**Voluntary reserve with tolerance band**	**Quota systems (TARALAC)**
Liquidity forecasts accuracy *	High	Medium	Medium	Medium	Medium
Frequency of fine tuning operations	Medium	Low	Low	Low	Medium
Operational burden for banks	High	Low	Low	Medium	Low
*Independence between interest rate target and liquidity provision***	Low	Low	Low	High	High
Adaptability to the business model	Low	Low	Low	High	High

* Accuracy required in central bank liquidity estimates.

** Under the condition of independence, the equilibrium interest rate does not depend on the exact quantity of reserve balances supplied by the central bank. The interest rate target can be set according to the usual monetary policy concerns, while the quantity of reserves can be set independently.

Note: Negative characteristics are highlighted in red, neutral in yellow, and positive in green.

The minimum reserve with averaging on one hand implies: i) a high complexity to obtain an accurate liquidity forecast by the central bank, in order to correctly estimate the liquidity needed by the banking system. This drawback would be less relevant in the context of a floor system with ample excess liquidity; ii) a high operational burden for banks, because the fulfillment on average compels banks to keep track of their fulfillment path; iii) a low adaptability to the business model of the banks: the requirement is fixed according to the same formula for all banks, which takes nearly no individual peculiarity into account. On the other hand, it supports money market activity, although this would also depend on the regulatory costs of accessing the interbank market.

Compared to the mechanism with averaging, minimum reserves with tolerance band and minimum reserve with carry-over have a lower operational burden for banks and require less frequent fine-tuning operations, because the banks' requirements are more flexible and therefore they need a lower accuracy of liquidity forecasts by the central bank. As the mechanism with averaging, these two systems encourage money market activity.

Voluntary reserve with tolerance band is more flexible than the previous systems, since it allows banks to set their own requirement, while the tolerance bands lower the sensitivity of money market interest rate to liquidity shocks. However, voluntary reserves could be very difficult to manage in a situation of large excess liquidity; under such circumstances, banks could find it burdensome and increasingly difficult to calibrate their reserve targets.

Quota systems relax the need for very accurate liquidity forecasts, although quotas would need to be defined, reviewed and closely monitored by the central bank. The central bank should set the quotas in such a way to support money market activity while the volatility of short-term rates remains low. However, under this system the central bank must be ready to intervene on a daily basis in the event of an imbalance due to unexpected autonomous factors, even if the calibration of the quotas works well.

Both the system with voluntary reserves and with quotas have the advantage of being able to adapt requirements to the business model of counterparties; however, both can become burdensome for the central bank when applied to a large monetary area characterized by wide fluctuations in the autonomous factors.

6. Conclusions

This paper analyzes the Eurosystem's minimum reserve system with averaging, assessing its main advantages and disadvantages and comparing it with alternative reserve systems adopted by other central banks (such as minimum reserves with carry-over provision, voluntary reserves with compliance bands and the quota system - TARALAC).

Minimum reserve requirements generate a predictable minimum demand for central bank credit by the banks, regardless of the operational framework in which they are established. This mechanism, when accompanied with an averaging provision, is effective in a corridor system, helping to stabilize short-term rates through intertemporal smoothing of autonomous factor shocks. In a floor system, minimum reserve requirements would not be needed for this purpose, as the central bank can control the stance by adjusting the policy rate at which reserves are remunerated. However, even under a floor system, the minimum reserve mechanisms could be used to rapidly adjust the structural amount of the liquidity in the system as well as a benchmark when a tiered reserve remuneration scheme is adopted.

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APPENDIX

Table 1A – Pros and cons of reserve/quota-based stabilization mechanisms and operational framework without such mechanisms

	Pros		Cons	
	For counterparties	***For central bank***	***For counterparties***	***For central bank***
Systems with reserve/quota				
Minimum reserve with averaging		• Easy to implement • In case of liquidity deficit, effective in stabilizing rates during maintenance period • If combined with wide corridor, it supports interbank trading	• Inflexible and burdensome from the operational point of view due to the need to keep track of the fulfillment path • Based on an aggregate that does not reflect the actual liquidity needs of each bank. • It can be an inefficient tool in times of crisis	• In situations of liquidity deficit, it requires additional fine-tuning interventions at the end of the maintenance period • In case of excess liquidity, it is not strictly needed
Minimum reserve with tolerance bands	• Flexible and operationally undemanding	• In case of liquidity deficit, it eliminates volatility at the end of the maintenance period	• Based on aggregate that does not reflect the actual liquidity needs of each bank	• If the band is too wide, it reduces interbank trading • In case of excess liquidity, it is not strictly needed
Minimum reserve with carry-over	• Flexible and operationally undemanding	• In case of liquidity deficit, it eliminates volatility at the end of the maintenance period	• Based on aggregate that does not reflect the actual liquidity needs of each bank	• It complicates central bank monitoring of reserve requirement compliance • It leads to speculation about the next maintenance period's key rate decisions • In case of excess liquidity, it is not strictly needed
Voluntary reserve with tolerance bands	• Flexible • It reflects the real liquidity needs of banks • It can help to reduce the liquidity premium	• It can improve forecasts ability for central bank • Flexibility for the counterparties choice • It allows independence between interest rate target and the provision of liquidity • It supports interbank trading	• Possible difficulties in calculating reserve amounts for small banks	• Complicated to manage in the presence of QE and negative rates
Quota system (Taralac)	• Operationally undemanding	• It does not need very accurate liquidity forecasts		• Complexity of quota setting due to the trade-off between operational target control ability and interbank market activity • Possibly unsuitable in case of high volatility of autonomous factors
Systems without reserve/quota				
Daily monetary policy operations and narrow corridor	• Flexible	• Accurate control of money market rates at the end of the day	• Operationally demanding	• Operationally demanding • Possible high volatility of intraday rates pending central bank intervention
Floor	• Flexible and operationally undemanding	• It allows balance sheet to be determined independently of interest rate targets • It does not need accurate liquidity forecasts • It does not need fine tuning operations		• It needs a large balance sheet • It may request admission to the central bank deposit of operators other than banks

Appendix I – Voluntary reserve and quota systems

This appendix presents some theoretical elements about voluntary reserve and quota systems.

Voluntary reserve

In a voluntary reserve system, each bank commits in advance to a target for reserves at the central bank, while the central bank still maintains the control of the aggregate reserves by setting a range for individual targets, within which each bank must place its own target.

Baughman and Carapella (2019b) show that if the reserve remuneration function is additively separable, depending in part on the reserve target chosen by each bank (*T*) and in part on the difference between the reserves holdings and the target (*D–T*), banks will be induced to set voluntary reserve targets that bring the expected interbank market rate to equal the central bank-determined reserve rate.

If we denote by ϕ the penalizing rate that banks would be required to pay if they held reserves lower than the target, by i_E the rate that is paid on reserves in excess of the target and by i_T the rate on reserves up to the target, we obtain that at the end of a maintenance period the remuneration of the reserves held *D* with respect to a target *T* can be expressed with the following form:

$$R(D,T) = \begin{cases} i_T \times T + i_E \times (D - T) & if\ D \geq T \\ i_T \times D - \phi \times (T - D) & if\ D < T \end{cases}$$

The precondition for the central bank to encourage banks to align their reserves with the targets is the following relationship between the rates:

$$i_E < i_T < \phi$$

The remuneration function can be rewritten as $R(D,T) = i_T \times T + \widetilde{R}$, where:

$$\widetilde{R} = \begin{cases} (i_T + \phi) \times (D - T) & if\ D < T \\ i_E \times (D - T) & if\ D \geq T \end{cases}$$

This functional form is additively separable into a portion that depends on the target *T* and a portion that depends on the difference *D-T*, which makes interbank market trading choices an affine function of target reserves *T*. Baughman and Carapella (2019b) show that with this remuneration function, in equilibrium, banks will set target levels such that expected money market rates equal the target rate: $E[i_M] = i_T$.

In the case of a system with tolerance bands, reserve balance values that differ from the target but fall within the band would not imply consequences for the banks, which would in any case obtain the voluntary reserves rate as remuneration. In this case, the remuneration function taking into account the tolerance bands (of magnitude $2\delta T$) becomes:

$$(D,T) = \begin{cases} i_T \times (1+\delta) \times T + i_E \times (D - (1+\delta) \times T) & if\ D \geq (1+\delta)T \\ i_T \times D & if\ (1-\delta)T \leq D < (1+\delta)T \\ i_T \times D - \phi \times \big((1-\delta)T - D\big) & if\ D < (1-\delta)T \end{cases}$$

If the width of the tolerance band were proportional to the banks' self-determined targets, banks would have an incentive to set higher targets than they would otherwise have done in order to increase the width of their tolerance band and reduce the risk of being outside of it.

With reference to the reserve voluntary system implemented by the BoE, Lee (2016) shows that the money market rate has been consistently higher than the policy rate on average. Baughman and Carapella (2019b) demonstrate that this persistent deviation of market rates from the voluntary reserve rate is mostly attributable to the interaction (endogeneity) of the targets with the tolerance bands, provided by the BoE system. In order to solve this problem, they suggest tolerance bands that are not linked to the targets (for example, based on historical average values of total assets or other balance sheet items). A remuneration function that violates the separability condition may provide perverse incentives by moving market rates away from the rate on voluntary reserves. Specifically, with a remuneration function in which tolerance bands are proportional to the banks' self-determined targets, the expected market rate will exceed the target rate because of banks' optimal target setting strategy.

Quota system

Quota systems are based on limited access by banks to deposit and/or funding with the central bank at the official rate (Target rate limited access, TARALAC); quotas can be one-sided (limited access to only one of the two facilities) or two-sided (limited access to both facilities). Bindseil and Wurz (2008) show that in a system with deposit quotas, the daily liquidity offered by the central bank in excess of the autonomous factors should be equal to half the maximum capacity provided by the facility to ensure that TARALAC anchors the overnight rate at the policy rate. This implies that the system is symmetric: the probability that the amount of reserves in the system (in excess of the autonomous factors) is greater than the sum of the individual deposit allowances and the probability that banks are in a liquidity shortage situation are equal. In other words, the probability that full utilization of the facility is insufficient to meet banks' deposit demand must be equal to the probability that banks will use the marginal lending facility.

If both deposit and lending quotas are provided at the same time, the central bank should calibrate refinancing operations so that the ex-ante probability of the overall use of the two TARALAC facilities is equal. This implies that, assuming symmetric distributions of the autonomous factors, the ex-ante probability of the overall utilization of the two standing facilities with unrestricted access is also symmetric. An analytical proof is shown below, derived from Bindseil and Wurz (2008) and Bindseil (2016). Let us assume that the monetary policy reference rate (target rate) i_T is in the middle of the corridor determined by the two standing facilities (ϕ is the rate that is paid by banks to access the marginal lending facility and i_E, the penalizing rate of the deposit facility, where therefore $i_T - i_E = \phi - i_T$). Moreover, let us assume a quota system for both deposits and loans, where the quota (the maximum amount of liquidity that can be deposited or obtained) is Q for each of the two facilities. These quantities would have a cost or a remuneration equal to $i_Q = i_T$. Let A be the absorption of liquidity due to autonomous factors, which is given by the sum of a certain value K (the value at the beginning of the day) and a random aggregate shock ε, which is distributed, for simplicity, as a normal with mean 0 and variance σ; hence $A=K+\varepsilon$. It is also assumed that there are no reserve requirements and that the central bank injects an amount of liquidity equal to M into the system and banks are risk neutral.

In this framework, the overnight money market rate will be, at the end of the day, the weighted average of the three possible marginal rates, where the weights are represented, respectively, by the (perceived) probability that these rates are the prevailing ones at the margin.

As in Bindseil (2016), the equation for determining the overnight money market rate (i_Q) can be written as:

$$i_o = i_E \times P(\text{long}) + \mathrm{i_T} \times \mathrm{P(TARALAC)} + \phi \times \mathrm{P(short)}$$

Where *P (long)* is the perceived probability of market participants to close the day with liquidity in excess of Q quota, *P (TARALAC)* is the probability that the aggregate shock on autonomous factors is fully absorbed through TARALAC facilities; and, finally, *P (short)* is the probability of having to resort to marginal lending.

We can rewrite the interbank rate equation as:

$$i_o = i_E \times \mathrm{P(M\text{-}}(K+\varepsilon)>Q) + \mathrm{i_T} \times P(\text{-}Q < M-(K+\varepsilon) < Q) + \phi \times \mathrm{P(M\text{-}}(K+\varepsilon)<\text{-}Q)$$

For money market rates to be equal to the policy rate it is necessary that *P(long)=P(short)*, i.e. that the probability that there is excess liquidity to be deposited, at a penalizing rate, with the central bank beyond full use of the TARALAC deposit facility is equal to the probability of resorting to marginal lending, at a penalizing rate, after the full use of the TARALAC facility. Therefore, this condition can be expressed as:

$$\mathrm{P(M\text{-}}(K+\varepsilon)>Q) = \mathrm{P(M\text{-}}(K+\varepsilon)<\text{-}Q)$$

and it will be satisfied when $M = K$, under the assumption that ε is symmetrically distributed. By substituting this expression in the previous one we obtain:

$$\mathrm{P(\text{-}\varepsilon>}Q) = \mathrm{P(\text{-}\varepsilon<\text{-}}Q) \Leftrightarrow \mathrm{P(\varepsilon<\text{-}}Q) = \mathrm{P(\varepsilon>}Q)$$

Thus, for symmetric probability distributions, in the event that the central bank adopts two-sided quotas, the central bank's open market operations must inject an amount of reserves equal to the sum of the autonomous factors (at the beginning of the day). If the central bank adopts a TARALAC facility with one-sided quotas, for example with limited access to the deposit, the equation of the interbank rate becomes:

$$i_o = i_E \times \mathrm{P(M\text{-}}(K+\varepsilon)>Q) + \mathrm{i_T} \times P(0 < M-(K+\varepsilon) < Q) + \phi \times \mathrm{P(M\text{-}}(K+\varepsilon)<0)$$

In this case the condition *P (long) = P (short)* can be written as:

$$\mathrm{P(M\text{-}}(K+\varepsilon)>Q) = \mathrm{P(M\text{-}}(K+\varepsilon)<0)$$

which will be valid for any symmetric density function ε when $M = K+Q/2$. By substituting this expression into the previous one, we obtain:

$$\mathrm{P}(\frac{Q}{2} - \varepsilon > Q) = \mathrm{P}(\frac{Q}{2} - \varepsilon < 0) \Leftrightarrow \mathrm{P}(-\varepsilon > \frac{Q}{2}) = \mathrm{P}(-\varepsilon < -\frac{Q}{2}) \Leftrightarrow \mathrm{P}(\varepsilon < -\frac{Q}{2}) = \mathrm{P}(\varepsilon > \frac{Q}{2})$$

In other words, for symmetric probability distributions, if the central bank adopts a TARALAC facility with limited access to the deposit, the central bank's open market operations must inject an amount of reserves equal to the sum of the autonomous factors (at the beginning of the day) plus half of the quota (*Q/2*).

Appendix II – Review of systems adopted by central banks

This appendix analyzes the evolution of the monetary policy framework of nine central banks, over the period 2002-2022, focusing on their efficiency in terms of money market rates stabilization around the policy rate.

For each central bank, we show a figure in which the upper panel illustrates trends in the monetary policy rate, the overnight money market rate and the level of reserves deposited on accounts with the central bank (in this case the reference axis is on the right).[36] The middle panel shows the trend of the spread between the money market rate and the monetary policy reference rate; in the event that for a central bank the changes to the operational framework have led to a change in the reference rate, the trend of the new spread is also shown in the graph. Finally, the bottom panel illustrates the volatility of the spread between money market rate and monetary policy reference rate, measured by applying a GARCH (Generalised Autoregressive Conditional Heteroskedasticity) model. When it comes to capturing the volatility clustering of financial time series, GARCH models dominate.

In a GARCH model of order (*p, q*), the process ε is characterized by:

$$\varepsilon_t = \omega_t \sqrt{h_t}$$

where ω_t is an independent and identically distributed random variable, with zero mean and unit variance (white noise process), and where h_t evolves according to an ARMA process:

$$h_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_j h_{t-j}$$

h_t is the conditional variance of the process ε and is dependent upon previous q own lags and p squared error terms. In our analysis a GARCH (1,1) has been estimated: in most cases, this model is sufficient to capture the clustering of volatility in the data. The coefficient α_1 represents the response to shocks, i.e. how the conditional variance reacts to the lagged value of the squared error term (innovation); the coefficient β_1 is the proportion of how much the previously estimated value of the conditional variance transfers to the current estimate. The sum of the coefficients α_1 and β_1 represents the persistence of the process, i.e. for how long the past values influence the variance.[37]

For each central bank we identified different phases which coincide with significant changes in the operational framework of monetary policy. In some cases, these changes are due to the external context, such as the outbreak of the great financial crisis or the spread of the Covid-19 pandemic.[38] The amount of reserves deposited on accounts with the central bank, in relation to GDP, have been defined as: 1) abundant (value of the ratio of reserves to GDP > 9 percent); 2) ample (value of the

[36] Figure presents total reserves, regardless of the presence of a minimum reserves requirement.

[37] As proof of robustness, the GARCH analysis was replicated by excluding both the 0.5% and 2.5% of the smallest extreme values and the largest extreme values, respectively, focusing only on the remaining 95% and 90% of the set of observations (trimming or truncation). As an alternative, GARCH was also estimated with winsored data, in which observations with values greater or less than those of the considered percentiles are replaced with values exactly corresponding to the percentiles. This allows us to align with several empirical works in which end-of-month, end-of-quarter or end-of-year data are eliminated from the dataset, since they are influenced by window dressing phenomena.

[38] Since there was a substantial easing of monetary policy during the period under consideration, in order to analyze the development of differentials in the different phases, in addition to comparing their mean and standard deviation, we also took into account measures that combine them, such as the coefficient of variation, which is obtained as the ratio between the standard deviation and the mean in absolute value.

ratio between 7 and 9 percent); 3) moderate (ratio value between 4 and 7 percent); 4) scarce (value of the ratio of reserves to GDP < 4 percent). For more details about this classification, see Appendix III.

Eurozone

With reference to the operational framework of the Eurozone, a gradual transition from a corridor system to a *de facto* floor system has taken place in the years under review. In particular, it is possible to distinguish three phases. The reserve requirement mechanism with averaging is present in all three phases.

Phase I (2002-2008): system with wide corridor

In the first period, which runs up to October 2008, the operational framework of the Eurosystem was based on a system with a wide corridor (standing facilities at ±100 bps relative to main refinancing operations rate). As already mentioned, the minimum reserves system with averaging contributed to the stabilization of rates.

In this period, the differential with the policy rate (main refinancing operations rate) averaged 5 bps, but with a standard deviation of 0.11 percent. Considering the absolute value of the difference, the spread increases, on average, to 8 bps, due to the volatility of the rate on the last day of the maintenance period which forced the ECB to intervene with fine-tuning operations. Overall, the volatility of the spread, as measured by GARCH, was high.

Phase II (2008 – 2015): system with a narrower corridor and moderate excess liquidity

In the second phase, which followed the great financial crisis and included the sovereign debt crisis, fixed rate full allotment and longer-term loan programs were introduced (first LTRO and then TLTRO). This contributed to a situation of growing, albeit moderate, excess liquidity. The width of the corridor was reduced (standing facilities at ±50 basis points with respect to the rate of the main refinancing operations). The spread to the policy rate averaged -44 bps; the EONIA rate gradually moved towards the deposit facility rate: the spread to this rate averaged 20 bps, with a standard deviation of 0.17 percent. Volatility showed some periods characterized by sudden increases.

Phase III (2015 – 2022): ample and abundant liquidity and negative rates

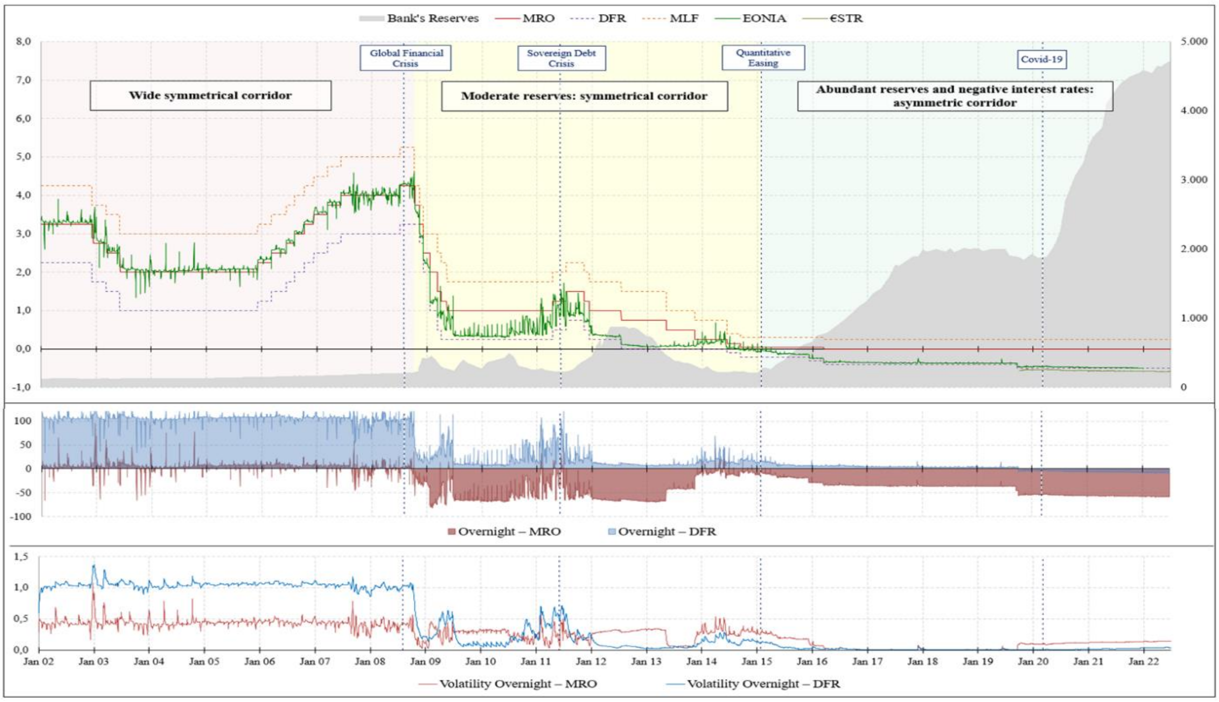
The third phase coincides with the launch of the quantitative easing programs at the beginning of 2015. From an operational point of view, this period is characterized by the significant growth in central bank reserves, the adoption of an asymmetric corridor against a zero policy rate (marginal lending at +25 bps over the main refinancing operations rate, with the deposit facility first at -40 bps and then at -50 bps) and negative money market rates.

The system became a *de facto* floor. The spread between the money market rate[39] and the deposit facility rate averaged 4.4 bps, with a very low standard deviation (0.03 percent). With the adoption of €STR starting from October 2019, the spread between the latter rate and the deposit facility rate

[39] Since October 2019, EONIA has been replaced by euro short-term rate (€STR) as the reference money market rate in the Eurozone; EONIA continued to be published until December 2021, but was calculated as €STR + 8.5 bps. In the analyses, the money market rate used is given by the EONIA until data are available (2002 - 2021), and by €STR + 8.5 bps for the subsequent period (2021 - 2022).

averaged -6 bps with a standard deviation of 0.02 percent. The negative average of the spread is due to the fact that in this period the money market is represented by transactions which also involve operators that do not access the deposit facility. Volatility is lower than that of the previous phase.

Figure 1A – Rates and level of central bank reserves in Eurozone



Australia

The framework adopted by the Reserve Bank of Australia (RBA) for the implementation of monetary policy is a corridor system focused on the key policy rate (target cash rate). The operational objective of the RBA is to maintain the overnight-unsecured interbank market rate, the cash rate,[40] at a level close to the target cash rate. To pursue this objective, the Reserve Bank sets standing facility rates and frequently conducts open market operations, both in Australian dollars and in foreign currency.

There are no reserve requirements for the banking system. Banks and other financial institutions hold settlement accounts with the RBA (called Exchange Settlement Accounts, ESAs) to settle payments and manage liquidity. The RBA does not have a target for the level of settlement balances, but instead controls the supply of liquidity to keep the cash rate close to the target.

The RBA conducts daily open market operations in order to maintain ESA account balances at an appropriate level to guarantee the smooth functioning of the money market. The daily open market operations (mainly repurchase agreement and currency swaps)[41] are performed primarily to offset the

[40] The *cash rate* is calculated as a weighted average of the interest rates at which uncollateralized overnight funds are traded in the interbank market.

[41] Open market operations are carried out at least once a week, every Wednesday. The RBA may carry out additional operations for other working days. Moreover, an additional round of open market operations can be decided every afternoon. As regards the maturity of the operations, normally, it does not exceed 28 days. In addition to the open market operations, there are also liquidity facilities, whose function is to provide liquidity to the banks following the provision of collateral for the correct functioning of the payment system (RITS). Details are given below: 1) Intraday SF Repo: interest-free intraday funding; 2) Overnight SF Repo: overnight funding, generally through the extension of the intraday maturity to the following business day. The buyback price is set at 25 bps above the key policy rate; 3)

liquidity effects of the numerous transactions between the banking system and the Australian government. It is possible to identify two phases, which differ in the symmetry of the width of the corridor and/or in the amount of liquidity injected into the banking system.

Phase I (2002 - 2020): system with narrow, symmetrical corridor

In the first period, the corridor was narrow and symmetrical: standing facilities rates were set at ± 25 bps relative to the reference rate. In November 2013, following the introduction of new provisions to ensure that financial institutions with settlement accounts with the central bank had sufficient reserves to meet their interbank payment obligations and facilitate same-day settlement (including after normal banking hours), balances held with the RBA increased (financed by using open repo transactions with the central bank, which do not have a maturity date).

The RBA has been very effective in keeping the overnight market rate close to the official rate. Deviations were rare, even during the period of financial market stress. The differential averaged 0 bps, with a very low standard deviation (amounting to 0.002 percent). The volatility of the differential between the cash rate and the target was limited and stable, during both tightening and easing periods of monetary policy. Several elements contributed to this stability, in addition to the presence of a narrow, symmetrical corridor and the high frequency of transactions, such as: i) the small number of active participants in the overnight market (15 to 20 institutions), which facilitates the search for counterparties with positions to offset; ii) market participants openly disclosed their position (short or long) on settlement balances and, by convention, generally traded overnight funds at the target cash rate; iii) the possibility for the RBA to adjust intraday liquidity, if necessary, or use moral suasion to encourage market participants to bring the overnight interbank rate back to target (Bowman et al., 2010).

Phase II (2020 - 2022): system with asymmetrical corridor and abundant excess liquidity

After the outbreak of the pandemic, the RBA adopted an asymmetric corridor system, which set the marginal lending rate and the deposit rate, respectively, 25 bps above and 15 bps below the target cash rate. From November 2020, the deposit facility rate was set at 10 bps below the target cash rate; it was, therefore, 0 percent when the target cash rate was reduced to 0.10 percent.

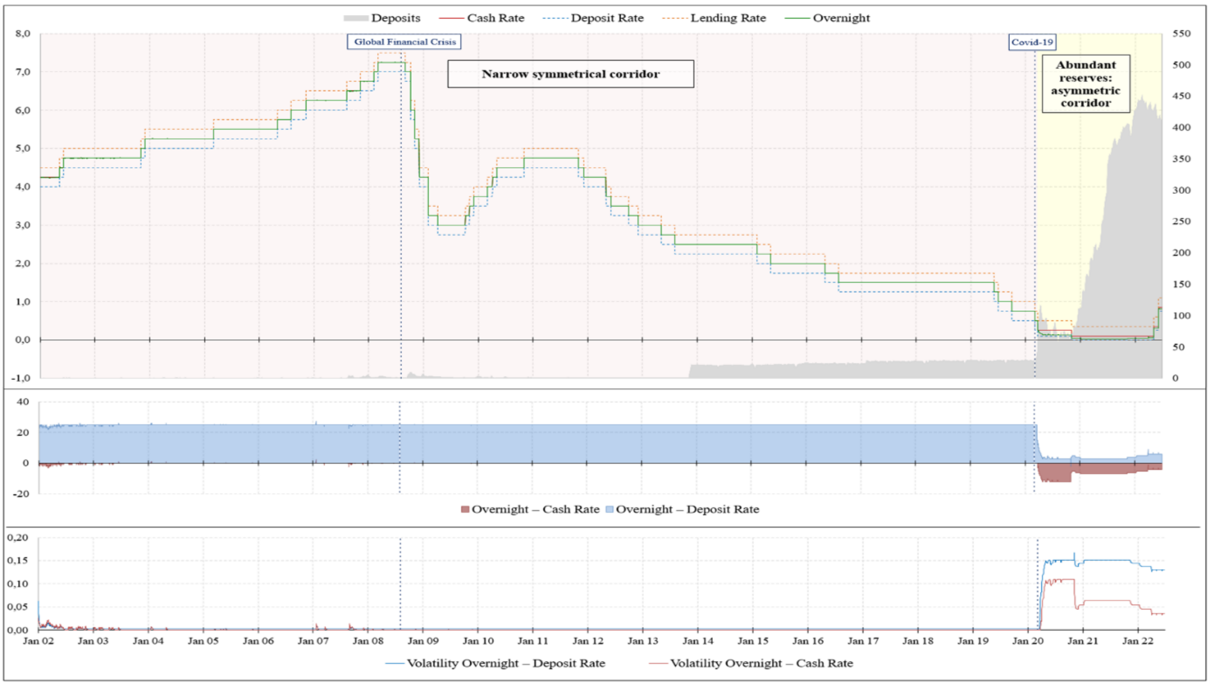
The central bank also: 1) launched a program to purchase government securities on the secondary market (which had as a target the interest rate on 3-year securities);[42] 2) launched the Term Funding Facility, i.e. 3-year loans with an interest rate equal to the target cash rate (with a disbursement window from April 2020 to June 2021 and final maturity no later than June 2024); 3) set up a swap facility with the Fed for liquidity up to 60 billion US dollars in exchange for Australian dollars. These

Open SF Repo: Repos from the Reserve Bank without a maturity date. It has the function of facilitating the liquidity buffer that banks operating in the payment system must have and assumes particular relevance for "afterhours" payments. The possibility of using this facility reduces the use of the intraday repo; 4) Term SF Repo: funding with a maturity greater than one working day up to a maximum of 30 days. This is supplemented by the Committed Liquidity Facility, targeted at certain monetary policy counterparties. This is an emergency facility linked to compliance with regulatory requirements (LCR) for the banking system. It foresees a commitment fee of 15 bps. The potential amount to be allocated is equal to the difference between the assessment of the LCR carried out by the macro-prudential supervisory authority (APRA) and the assessment of the Reserve Bank regarding the quantity of HQLA securities that the banking system can hold without jeopardizing the proper functioning of the market.

42 The initial envelope of the program was equal to 100 billion Australian dollars, subsequently increased by another 100 billion, totaling about 10 percent of GDP.

measures implied a sharp increase in central bank reserves held by the banking system. Because of the central bank's liquidity injections, the spread between the unsecured overnight money market rate and the key policy rate averaged -7 bps, with a standard deviation of 0.03 percent over the last two years. However, the volatility of the spread, as measured by the GARCH, has been sharply increasing.

Figure 2A – Rates and level of central bank reserves in Australia



Canada

The operational framework of the Bank of Canada (BoC) was based on a narrow and symmetrical corridor (except for a brief period following the global financial crisis) in the period from 2002 to 2020. Since the outbreak of the pandemic a floor system has been adopted. The Canadian operational framework does not provide for minimum reserves.

<u>Phase I (2002 – 2020): system with narrow and symmetrical corridor</u>

The operational objective of the BoC is to peg the overnight money market interest rate to the monetary policy reference rate (target for the overnight rate).[43] In the first phase, this objective was pursued in the context of a corridor system, whose bounds were the deposit rate (target rate -25 bps) and the bank rate (target rate +25 bps). When necessary, the BoC also conducted overnight open market operations at the target rate. The BoC's implementation of monetary policy is closely linked to the level of liquidity in Canada's payment system (Large Value Transfer System, LVTS). Since the inception of LVTS in 1999,[44] the BoC had set an overall target for account balances slightly above

[43] The benchmark overnight market rate is a collateralized rate. Specifically, the BoC uses two indicators as proxies for this rate. The first is the Overnight Money Market Financing Rate (OMMFR, shown in Figure 3A), which is the result of an end-of-day survey of major participants in the overnight secured market. Some counterparties in this market, such as pension funds, may not have access to the Bank of Canada's deposit facilities. The second indicator is the Canadian Overnight Repo Rate Average (or CORRA), which is a measure of the cost of overnight general collateral repo transactions using Government of Canada (GoC) bonds as collateral. During 2020, the calculation methodology was changed. The BoC calculates CORRA based on data from repo transactions traded by primary dealers and other major players in the Canadian government debt market. The difference between the two rates averaged -0.2 bps.

[44] Replaced by Lynx system in 2021.

zero (liquidity surplus) to reduce transaction costs and end-of-business day frictions for the execution of payments, making the recourse to central bank overnight lending less frequent for counterparties with deficit balances.[45]

Even though the BoC did not use the liquidity injected into the system (which translated into targets for overall account balances in the payments system) to signal policy changes, the central bank changed this aggregate to reinforce the operational target if (temporary) pressures pushed the overnight rate away from the target.

The BoC increased the liquidity surplus in mid-August 2007 in response to increased financial uncertainty and concomitant upward pressure on the overnight rate. Then it returned to a more typical target (CAD 25 million) in March 2008. In 2009, when the BoC lowered the policy rate to 0.25 percent, bringing it to the lower bound of the corridor (*de facto*, adopting a floor system), it injected CAD 3 billion surplus of liquidity to support the transition to the lower bound of the corridor. If, therefore, the use of the deposit facility was usually very limited, as it was advantageous and operationally feasible to find counterparties in the market with a liquidity shortage willing to pay the target rate, with the transition to the floor system, the amount deposited daily to the deposit facility was close to CAD 3 billion. The BoC in setting a clear target for excess reserves, rather than letting the excess fluctuate above a certain threshold, believed it would help limit uncertainty among banks. As tensions decreased, the BoC returned to using the narrow, symmetrical corridor system in 2010.

Figure 3A shows that the BoC managed to keep the overnight rate close to its target, even during the financial crisis. Over the entire period, the average spread was -0.4 bps, with a standard deviation of 0.01 percent. Volatility, as measured by GARCH, was also low. This success probably reflects the BoC's ability to keep the supply of overnight balances stable and close to zero (with the exception of the 2009 - 2010 period). The small number of participants in the interbank market and the presence of a real-time payments system also helped in generating low uncertainty about payments at the end of the day.

Phase II (2020 – 2022): floor system with abundant reserves

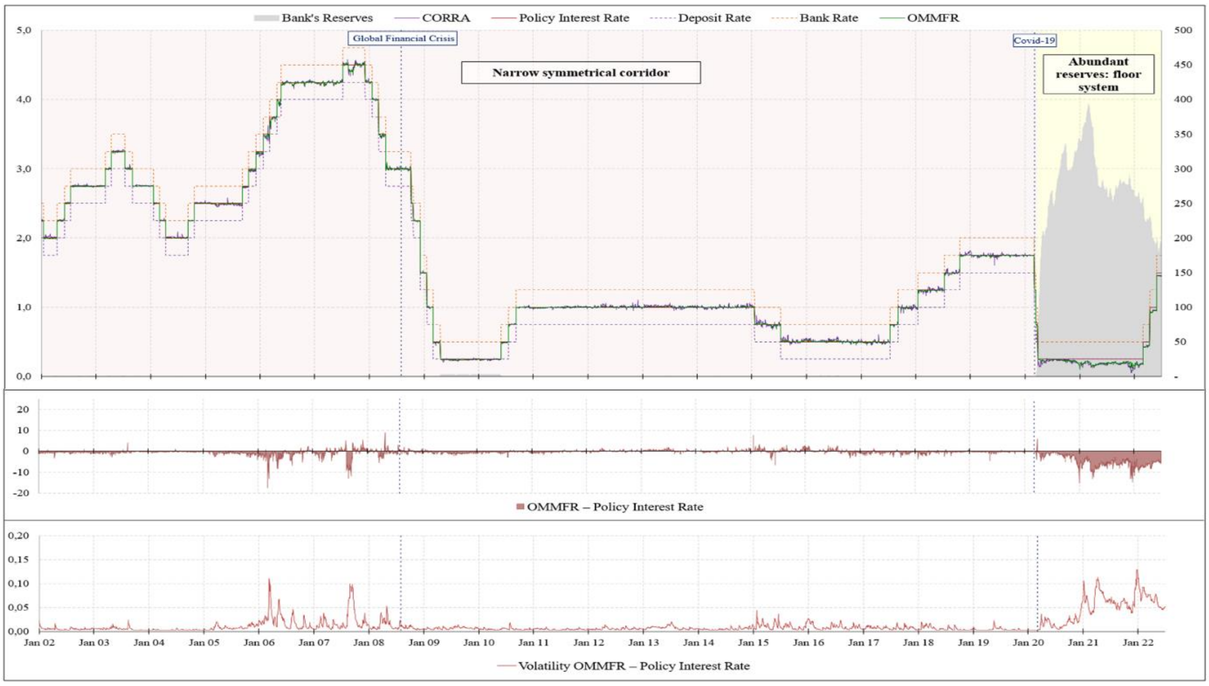
Following the outbreak of the pandemic, the BoC reduced the policy rate to 0.25 percent, bringing it in line with the deposit rate, moving back to a floor system. It also implemented a series of expansive measures as the GBPP (Government of Canada Bond Purchase Program) and medium to long-term liquidity operations (Standing Term Liquidity Facility), in order to safeguard the smooth functioning of markets.

The overnight interest rate fluctuated below the policy rate, with an average difference of -5 bps and a standard deviation of 0.03 percent. The excess liquidity held at the end of the day by financial institutions not directly participating in the payment system generated downward pressure for the

[45] For example, an increase in the target on balances, implying an increase in surplus liquidity, would have determined an incentive for banks to lend funds in the money market with consequent downward pressure on the overnight rate. Indeed, as the level of surplus liquidity (current account balances target) increases, the incentive for banks to operate in the money market is reinforced, since the liquidity surplus must otherwise be deposited overnight with the central bank at a remuneration 25 bps lower than the policy rate and thus probably lower than the overnight money market rate.

money market rate, pushing it below the deposit facility rate.[46] It increased the volatility of the spread, which was more reactive to shocks affecting the system.

Figure 3A – Rates and level of central bank reserves in Canada



Japan

The Bank of Japan's (BoJ) monetary policy operating framework over the past 20 years has been characterized by an asymmetric corridor, with the level of reserves varying over time: moderate/scarce between 2002 and 2008; scarce/moderate/ample between 2008 and 2013; abundant after 2013. The BoJ also uses the minimum reserve requirement as a monetary policy tool. Following the various monetary easing programs adopted by the BoJ, the stabilizing role of the reserve requirement has substantially lost relevance. The reserve requirement ratio has remained unchanged since 1991.

Phase I (2002 – 2008): Quantitative Easing, zero target rate and subsequent normalization

The operational target of the BoJ since 2001, with the introduction of the Quantitative Easing Policy, was to control the overall level of reserves in the banking system, in order to counterbalance negative inflation rates.[47] The operational framework was based on an asymmetric and narrow corridor system, in which the lower bound was the policy rate (monetary policy reference rate, corresponding to the remuneration of current accounts held by financial institutions with the BoJ), while the upper bound was the basic loan rate. The system was a *de facto* floor system. During the period of reserves increase (2002 - 2006), the level of the policy rate was 0%; in the subsequent normalization period (2006 - 2008), with a gradual decrease in liquidity, the policy rate was increased to 0.5 percent and the corridor was widened to 25 bps (from the initial 10 bps).

46 To correct this situation, the BoC would generally have to drain liquidity from the system, but given the emergency due to Covid, it did not choose this option.

47 The Bank of Japan has undertaken to continue this policy "until the annual rate of change in the consumer price index (CPI) is stable at or above zero per cent".

At this stage, the spread between the overnight money market rate[48] and the policy rate averaged 0.4 bps, with a standard deviation of 0.02 percent[49]. Based on GARCH, the volatility of the differential was low (particularly until early 2006), persistent, and with a relatively small response to shocks.

Phase II (2008 – 2013): asymmetric corridor and moderate liquidity

Starting from 2008, following the Global Financial Crisis, the BoJ reduced the policy rate[50] and narrowed the corridor with the basic loan rate (to +10 bps). At the same time, a new rate was introduced to remunerate reserves in excess of the minimum reserve requirement (complementary deposit facility rate), initially set at -20 bps relative to the policy rate (November 2008), later set equal to the policy rate (from December 2008). In addition, the long-term interest rate was set as a new operational target and a program to purchase long-term securities was initiated to pursue it (Asset Purchase Program, APP), leading to an increase of liquidity.

During this period, the spread between the overnight money market rate and the policy rate was on average negative and narrow (-1 bps), with a standard deviation of 0.01 percent.[51] Based on GARCH, the volatility of the differential was low, not particularly persistent and with a greater response to shocks than in the previous period.

Phase III (2013 – 2016): Quantitative Qualitative Monetary Easing and abundant liquidity

Starting from 2013, in order to bring inflation closer to target levels, the BoJ redefined the monetary policy framework by introducing the "price stability target," that is the achievement of the 2 percent inflation target as quickly as possible.[52] In addition, in April 2013 BoJ launched the Quantitative and Qualitative Monetary Easing (QQE), a massive purchase program for long-term securities, which generated a large excess of liquidity in the system.

In this period, there was a marked reduction in the coefficient of variation of both the money market rate (0.10), with an average value of the rate equal to 7 bps and a standard deviation of 0.07 percent, and the spread between the money market rate and the policy rate (0.25), with an average of -3 bps and a standard deviation of 0.01 percent. Based on the GARCH, spread volatility was low but persistent.

Phase IV (2016 – 2022): abundant liquidity, negative target rate and three-tier system

Since 2016, the BoJ, with the constant expansion of the balance sheet, which has led to abundant excess liquidity in the system, has set the policy rate at negative values (-10 bps) and the target for the Japanese 10-year government bond rate at 0 bps. In addition, BoJ implemented a tier system, in which the balance of each financial institution with the BoJ is divided into 3 brackets, remunerated respectively at a positive rate of +0.1 percent ("basic balance"), at a zero rate ("macro add-on balance") and a negative rate of -0.1 percent ("policy rate balance"). The latter rate coincides with

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[48] The overnight call rate is an unsecured rate and is calculated as the daily weighted average of the rates on transactions in the unsecured overnight market.

[49] The average value of the money market rate was equal to 15 bps; the standard deviation was low (0.22 percent) while the coefficient of variation was moderately high (1.45).

[50] First to 30 bps (November 2008), then to 10 bps (since December 2008).

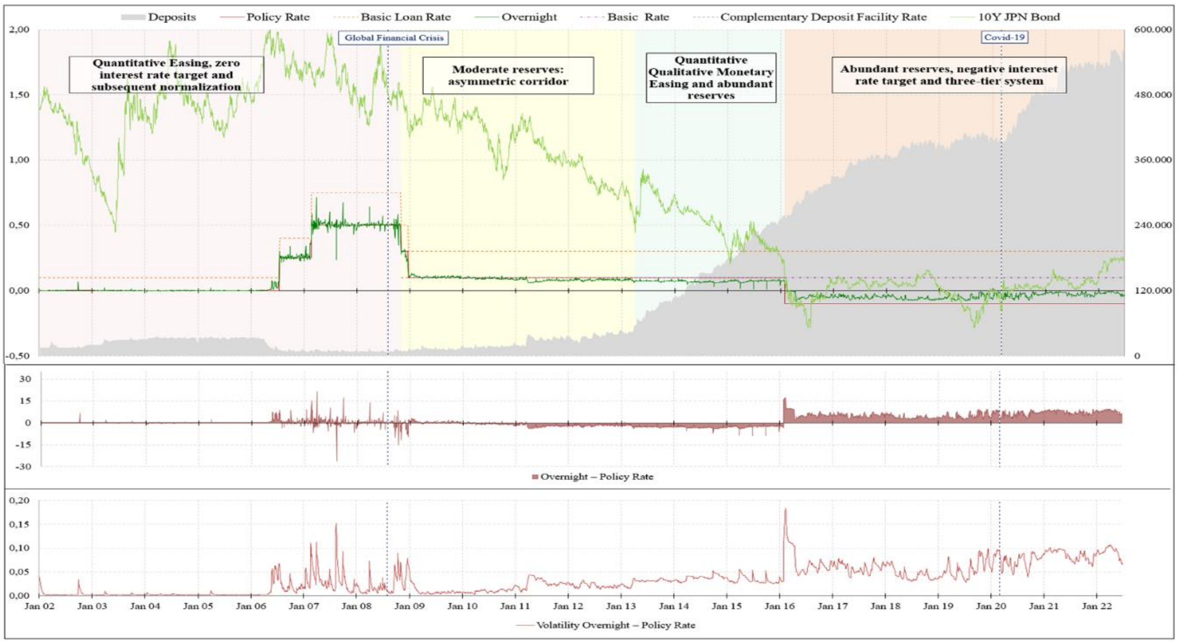
[51] The average value of the money market rate was equal to 10 bps; the standard deviation was very small (0.04 percent) as the coefficient of variation (0.38).

[52] This target replaces the previous "price stability goal" with a medium- to long-term horizon, which placed the quantitative inflation target in a positive range of 2 percent or less. The BoJ had set this target at 1 percent.

the policy rate.[53] This system aims, on the one hand, to support banks' profitability by ensuring a positive remuneration for a fixed amount, and on the other hand, to discourage excessive deposit of liquidity on the BoJ's accounts by encouraging trading in the interbank market and keeping its rate in the band between the macro add-on rate and the basic rate.

During this period, the differential between the overnight money market rate and the policy rate was, on average, +6 bps, with a standard deviation of 0.02 percent.[54] The volatility of the differential was increasing, showing a relevant reaction to shocks.

Figure 4A – Rates and level of central bank reserves in Japan



New Zealand

The Reserve Bank of New Zealand (RBNZ) was the first central bank to implement a quota-based system (called "tier"). It is possible to distinguish three phases of the operational framework: the first, prior to the adoption of the tier system, the second characterized by this system, and the third, post-pandemic, in which this system was abandoned for the floor system. During the period under review, the RBNZ's operational framework did not provide for minimum reserve requirement.

<u>Phase I (2002 – 2007): system with a narrow corridor</u>

In the first period, the RBNZ had a symmetrical and narrow corridor system, with the Official Cash Rate (OCR) as the reference rate.[55] The central bank remunerated all overnight positions on the

[53] The quotas are determined as follows: the "basic balance" quota is the average level of reserves that each institution held in the period between January 2015 and December 2015 (fixed quota); the "macro add-on balance" is calculated as the difference between the "basic balance" and the sum of the minimum reserve requirement, the amount of the special operations in response to Covid-19 and the amount of the support program to loans, multiplied by the Benchmark Ratio (determined by the BoJ on a quarterly basis); the "policy rate balance" quota is calculated on a residual basis, by subtracting the other two portions from the volume of reserves held by banks on BoJ accounts.

[54] The average value of the monetary rate was -4 bps and the standard deviation was very low (0.02 percent); the coefficient of variation was 0.54.

[55] In 1999, the RBNZ abandoned a system in which monetary policy was implemented through a target for reserves on settlement accounts in favor of a corridor system centered on the Official Cash Rate (OCR).

settlement accounts (overnight reverse repurchase facility, ORRF) at 25 bps below the OCR, while overnight-secured loans were offered on demand at 25 bps above the OCR. The central bank controlled short-term money market rate close to the reference rate through daily repo and reverse repo operations. Under this system, banks relied heavily on the intra-day liquidity provided by the RBNZ to meet their payment and settlement needs (so-called automated intra-day repurchase facility, Auto-repo). Given the important role of nonresident banks in the New Zealand banking system, the central bank also used foreign exchange swap transactions to inject liquidity into the system.

During this period, the average overnight interbank cash rate (OICR)[56] was high (6.3 percent), with a standard deviation of 0.94 percent; the coefficient of variation was small (0.15). The differential from OCR was very small: 2 bps on average, with a standard deviation of 0.06 percent. The volatility of the differential (at least until mid-2006) was low.

Despite its good ability to control the domestic money market rate (thanks to daily operations), the central bank observed several signs of stress in both the foreign exchange swap market and open market operations. These symptoms suggested that sometimes there was insufficient liquidity in the banking system or that the liquidity was inefficiently redistributed (Nield, 2006). Some examples were (i) relatively high incidence of delayed settlements; (ii) frequent use of standing facilities; (iii) underbidding in RBNZ open market operations; (iv) increased demand for government bonds to be used as collateral that led, in the face of essentially stable supply, to a surge in their prices; and (v) significant changes between the domestic overnight interbank rate and the overnight rate available in the foreign exchange swap market.

Consequently, the RBNZ decided to change its operational framework to a fully cashed-up system in 2006, which resulted in a substantial increase in the reserve supply and the progressive removal of central bank intraday liquidity. The transition to the new system was implemented from July to October 2006 and, to encourage banks to hold cash on accounts, the RBNZ switched to remunerating all overnight balances at the OCR. As a result, between October 2006 and August 2007, the RBNZ operated an asymmetric corridor, with the OCR standing at the corridor lower bound.[57] This system determined a liquidity hoarding phenomena by some banks, to which the RBNZ responded at the end of August 2007 by implementing the quota system.

Phase II (2007 – 2020): quota system with a wide and asymmetric corridor

Under the quota system, banks' overnight deposits were remunerated at the OCR up to the limit set for each individual bank by the central bank ("tier"), mainly based on likely settlement needs in a tail event.[58] Balances held in excess of the limit accrued interest at a rate equal to the OCR minus 100 bps.[59] The relatively low return on excess balances discouraged holding balances in excess of the quota, incentivizing banks with excess balances to lend in the interbank market and invest in liquid instruments other than central bank liquidity.

[56] The OICR is the average interest rate of overnight transactions (secured and unsecured) reported by domestic market price makers in a daily survey.
[57] The spread between the central bank overnight lending rate and the OCR was reduced to 50 bps.
[58] The determination of quotas was based on a liquidity algorithm that analyzed banks' balance sheets (including prudential requirements), payment flow data, and intraday liquidity use. Once the limits were assigned, each bank, if it believed they were not sufficient, could open a business case with the central bank.
[59] The spread between the central bank overnight lending rate and the OCR was reduced to 25 bps.

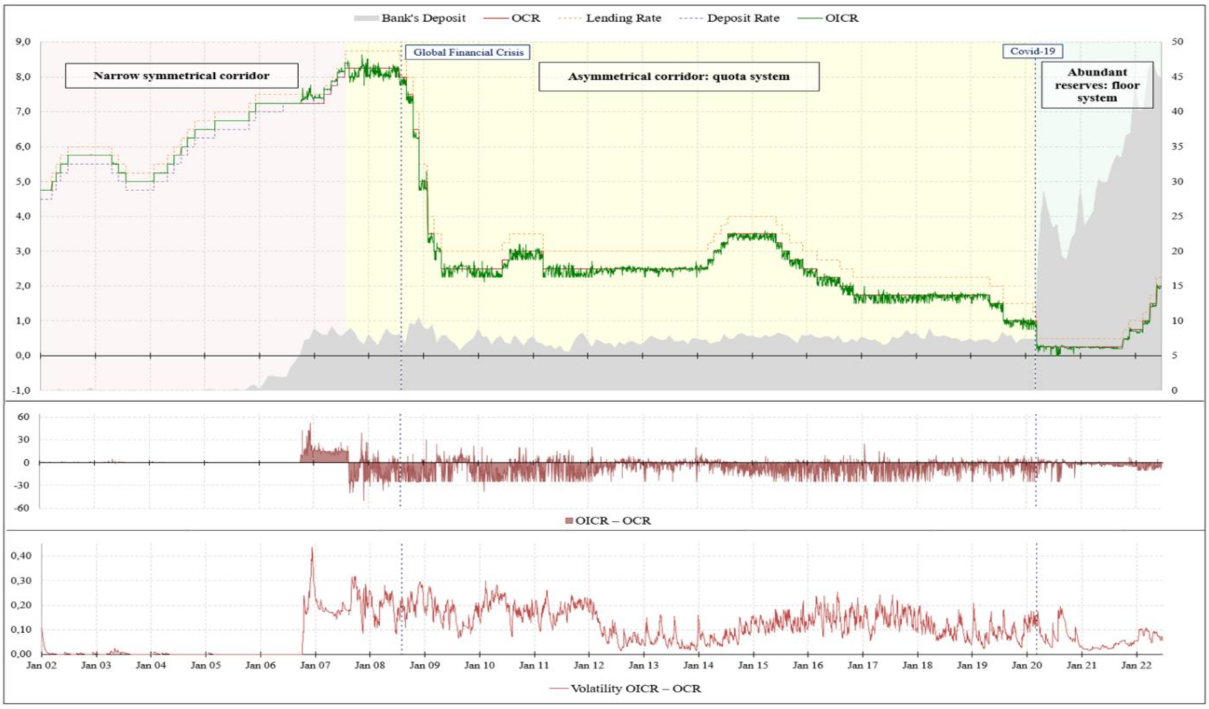
At this stage, the spread between the OICR and the OCR averaged -7.5 bps, with a standard deviation of 0.1 percent.[60] The volatility of the differential was high and persistent.

Phase III (2020 – 2022): floor system with ample/abundant liquidity

The tier-based system was adopted until March 2020, when it was suspended following the launch of a QE program (Large Scale Asset Purchases, LSAP) and targeted long-term lending operations (Funding for Lending Programme, FLP), to counter the effects of the pandemic. This resulted in a very large supply of reserves, which made it difficult to keep short-term rates anchored to the OCR. As a result, the RBNZ decided to remunerate all balances at the OCR and remove all tiering limits beyond which a lower remuneration rate was applied (Reserve Bank of New Zealand, 2020), thereby introducing a floor system.

At this stage, the money market rate anchored to the OCR[61] and the spread has narrowed to -3.7 bps, with a very low standard deviation (0.05 percent).

Figure 5A – Rates and level of central bank reserves in New Zealand



Norway

Norges Bank is one of two central banks examined (along with the RBNZ) that has implemented a one-sided (limited access to deposit) quota-based system. In the analyzed period it is possible to distinguish two phases: one before the adoption of the quota system (in October 2011) and a subsequent one. Indeed, the Norwegian central bank has maintained the quota system even after the

[60] The OICR mean was 2.94 percent with a standard deviation of 1.86 percent, implying a coefficient of variation of 0.63. The rate was persistent and unresponsive to shocks.

[61] The OICR mean was 0.49 percent with a standard deviation of 0.45 percent, implying a coefficient of variation of 0.92.

outbreak of the pandemic crisis (unlike New Zealand). There is no reserve requirement in the Norwegian system.

Phase I (2002 – 2011): system with asymmetric corridor

Prior to 2011, the operational framework of Norges Bank was based on an asymmetric corridor system. Banks received interest on all deposits with the central bank at the sight deposit rate, which is also the central bank's policy rate. The sight deposit rate was the floor for shorter-term money market rates, as banks had no incentive to lend out reserves at an interest rate lower than the rate they would receive from the central bank. Similarly, the overnight lending rate (the so-called D loan rate) represented the ceiling for short-term money market rates. In this system, the central bank ensured that there was an adequate surplus of reserves in the banking system to push overnight market rates towards the sight deposit rate. Norges Bank provided liquidity through F loans when it believed that more reserves were necessary. The interest rate on the F loans was usually a few basis points higher than the sight deposit rate.

During this period, the spread between the overnight money market rate and the sight deposit rate averaged 47 bps;[62] the standard deviation was small (0.24 percent), so that the coefficient of variation was equal to 0.51. Based on GARCH, the volatility of the differential was high, persistent and with a relatively low response to shocks.

Phase II (2011 – 2022): quota system

With the use of the asymmetric corridor system, over time Norges Bank observed that the demand at the F-loan auctions was higher than what would have been necessary for the banks to settle payments in the domestic settlement system. In particular, after the great financial crisis, when the central bank temporarily injected large amounts of liquidity into the financial system, the level of reserves rose strongly and continued to be above pre-crisis level. The central bank also noted a reduction in reserve redistribution activity in the interbank market. There were signs that the short-term money-market rate had to rise considerably before a lender would enter it.

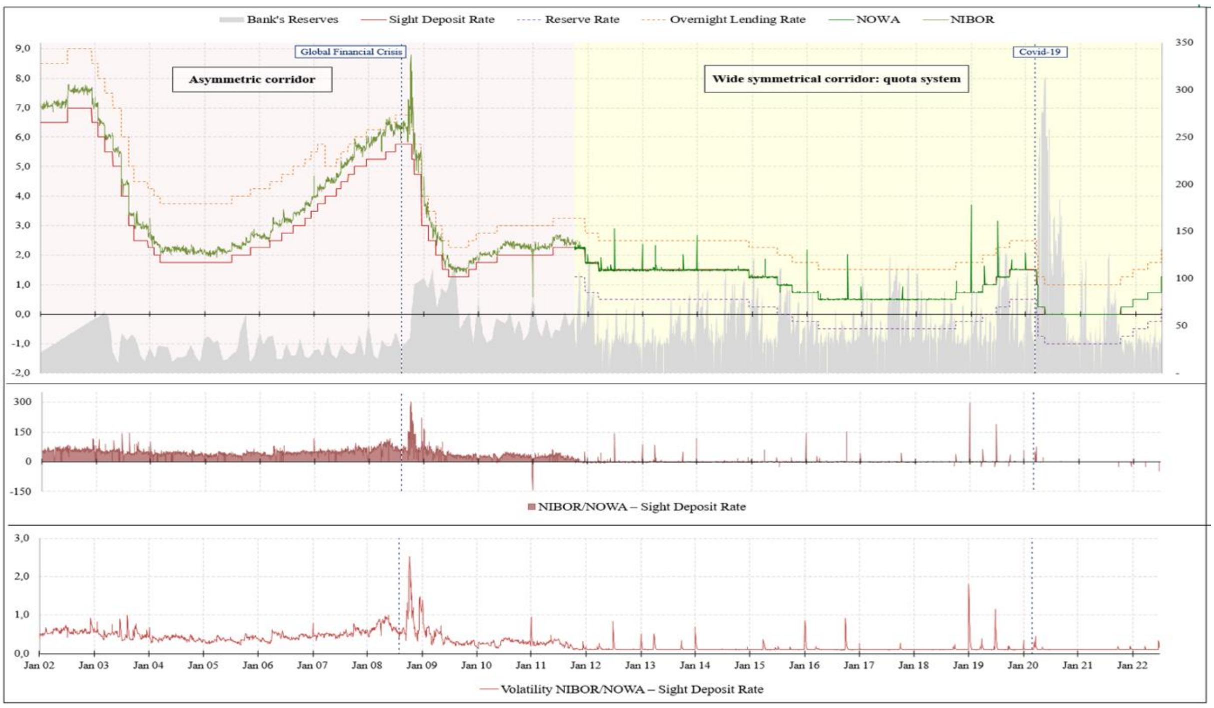
Therefore, as from October 2011, Norges Bank implemented the quota system, where each bank's "quota" is determined to be sufficient to meet daily settlement requirements and is remunerated at the reference rate. The system also foresaw a penalizing rate (reserve rate, 100 bps below the sight deposit rate) at which reserves deposited by banks above the pre-determined quota are remunerated in order to incentivize banks to lend liquidity in the interbank market.

Following the pandemic crisis, Norges Bank carried out several extraordinary refinancing operations with maturities of up to 12 months. However, it was able to maintain the quota system because the excess liquidity injected was drained from the banking system using daily deposits with a one-day maturity, with rates close to the policy rate.

[62] During the floor system period, only the Norwegian Inter-Bank Offer Rate (NIBOR) with maturity tomorrow next (data provided on the central bank's website) was available as a reference of the short-term money market rate. The central bank provides two data series: 1) nominal rates; 2) effective interest rate. This second series was used in this work. Because of the tomorrow next deadline, the series has been lagged by one day. NIBOR was based on indicative rates quoted by a group of banks active in the Norwegian market. Since the participating banks quoted, in general, wide bid-ask spreads, the actual rates at which market transactions took place were often closer to the sight deposit rate than what was apparent based on the NIBOR.

Under the quota system, the spread between the overnight money market rate (NOWA rate)[63] and the sight deposit rate averaged 0 bps; the standard deviation equal to 0.10 percent. If we exclude the observations at the end of the quarter, the differential averaged around -2 bps, with a standard deviation of 0.04 percent. Based on the GARCH, spread volatility was very low, persistent and with limited response to shocks.

Figure 6A – Rates and level of central bank reserves in Norway



Sweden

During the period under review, Riksbank has operated under a corridor system, in which there are no minimum reserves. The Riksbank uses standing facilities and open market operations to steer the short-term interbank interest rate[64] towards the target set by the central bank, the reference rate (repo rate, which from 2019 has been renamed policy rate) to indicate where the market rate should be positioned.

Before the Riksbank payment system (RIX) daily closure, banks' accounts must be balanced. If necessary, banks can borrow or deposit funds with the Riksbank overnight through the central bank's marginal lending and deposit facilities. The corridor system was supposed to ensure the liquidity needed for the proper functioning of RIX, where banks, clearing organizations, and the Swedish

[63] With the introduction of the quota-based system, Norges Bank, in cooperation with Finance Norway, began collecting rates on reserve trades by banks in the overnight market, which have since been published as the Norwegian Overnight Weighted Average (NOWA) rate. The NOWA is a weighted average of interest rates on overnight-unsecured interbank loans traded in NOK and is the first money market rate in Norway based on actual trades. The monetary rate series used in the analysis is obtained by sequentially merging NIBOR and NOWA (for October and November 2011, the transition period between the two rates, an average has been calculated between the two).

[64] The benchmark money market rate was the STIBOR until September 2021, when it was replaced by the SWESTR. While the former was a rate based on the intentions of market participants, the latter is based on rates of actual transactions.

Treasury have their accounts. Banks can have intraday credit up to the maximum amount of collateral pledged as collateral.

We have identified three phases of the operational framework, which differ in the width of the corridor, in the use of fine-tuning operations or in the liquidity injected into the system.

Phase I (2002 – 2008): system with a wide symmetrical corridor and liquidity deficit

In the first period, the corridor was wide (the standing facilities rate was set at ± 75 bps relative to the policy rate). The system had a structural liquidity deficit and the central bank used weekly one-week repo operations to provide the necessary liquidity to the banking system. During this period, the spread between the money market rate and the policy rate averaged 12 bps, with a low standard deviation (equal to 0.06 percent); the volatility of the spread was also low, at least until the end of 2007.

Phase II (2008 – 2019): system with symmetrical corridor and use of fine-tuning operations

With the outbreak of the financial crisis in October 2008, Riksbank launched a longer-term Swedish krona loan facility to ease pressure on the term funding markets. For a brief period in early October 2008, these funding pressures pushed STIBOR above the Riksbank's marginal lending rate. With the new operations, overnight balances held at Riksbank increased substantially. Subsequently, Riksbank relied frequently on daily fine-tuning operations to anchor the money market rate in the middle of the corridor. The fine-tuning rate was 10 bps below the policy rate. To drain the liquidity surplus, Riksbank also started issuing certificates, which have become a regular instrument for conducting monetary policy, with weekly issuance.

From 2015 (and up to the beginning of 2020), the policy rate was negative (with a minimum of -0.5 percent) and a securities purchase program was launched.

Over the whole period, the spread between the money market rate and the policy rate averaged 5 bps, with a fairly high standard deviation (equal to 0.13 percent). After the outbreak of the global financial crisis, the volatility of the spread has been significant; since 2013 it has decreased, except for a few spikes at the end of the year.

Phase III (2019 - 2022): system with narrow corridor and ample/abundant liquidity

From the end of 2019, Riksbank stopped conducting daily fine-tuning operations and reduced the width of the corridor, narrowing it to −/+10 bps below/above the policy rate, with the deposit facility rate effectively replacing the fine-tuning operations rate. The objective was to reduce the sensitivity of the overnight rate to the liquidity distribution in the banking system at the end of the day, to ensure that it remained pegged to the policy rate, and to automate the deposit and lending process at the end of the day, without the operational risk characterizing fine-tuning operations.

With the outbreak of the pandemic, Riksbank conducted 12-month financing operations and expanded its securities purchasing activity. As a result, there was a considerable increase in the liquidity deposited at the central bank at the end of the day. The liquidity surplus was partially drained by the increase in certificate issuances. Riksbank certificates with one-week maturity are currently offered at the policy rate.

The spread between the money market rate and the policy rate averaged -6 bps, with a standard deviation of 0.12 percent. Therefore, the money market rate moved towards the lower limit of the corridor; at irregular intervals it was a few basis points (maximum 2 bps) below the deposit facility rate. Banks seemed to have a preference for overnight reserve holdings, but this interfered with the steering of rates towards the policy rate at the middle of the corridor. The volatility of the spread was low (with the exception of one anomalous phenomenon on the last day of 2021).

Figure 7A – Rates and level of central bank reserves in Sweden

United Kingdom

During the period under review, the Bank of England (BoE) used three distinct operational frameworks for conducting monetary policy. Initially, the BoE operated with a symmetric corridor system in which banks had an incentive to hold zero reserves on their overnight balances and the central bank provided the necessary liquidity through open market operations at the reference rate. In 2006 the central bank adopted the system of voluntary reserves (VR), and then suspended it from March 2009, due to the excess liquidity provided through the launch of the quantitative easing (QE) programme. Since that date, the operating framework has been based on a floor system, in which all reserves are remunerated at the reference rate.

Phase I (2002 – 2006): system with a wide symmetrical corridor without minimum reserves

In the first period, the liquidity required by the banks was provided by very frequent open market operations (between 2 and 4 operations every day), conducted with a limited number of counterparties (less than 20 "discount houses") at the reference rate (Bank rate). Reserve balances were not remunerated and there was no minimum reserve requirement.[65] The system had had a wide

[65] Banks were required to deposit a minimum amount of cash on accounts at the BoE. This measure was known as Cash Ratio Deposits (CRDs). The liquidity was invested in government bonds with the aim of financing the BoE's institutional functions. Whitesell (2006) identifies these amounts as required reserves. However, their nature appears

symmetrical corridor (±100 bps relative to the bank rate) until 2005. It had subsequently been narrowed (±25 bps relative to the Bank rate).

The system was not particularly efficient. The volatility of the spread between the overnight money market rate (SONIA) and the Bank rate was very high and persistent: against an average of -4 bps, the standard deviation was 0.37 percent.[66]

The implementation of a corridor system usually generates a reduction in the volatility of the spread if there is unrestricted access to the standing facilities (Bindseil, 2004). In the UK, however, the availability of central bank lending at the end of the day was limited to what the BoE had foreseen would be necessary. Thus, the high volatility of the market rate relative to the policy rate could be due to BoE's forecasting errors or high market concentration, which allowed some counterparties to obtain a large share of the limited liquidity made available and therefore behave as marginal suppliers for the rest of the intermediaries (Osborne, 2016).

Phase II (2006 - 2009): voluntary reserve system

To deal with this excessive volatility, in May 2006 BoE implemented a system of voluntary reserves. If the effective reserves were positioned, as an average of the maintenance period, within the tolerance band of the voluntary reserves, they were remunerated at the Bank rate. If reserves were outside the tolerance band (above the upper limit or below the lower limit), remuneration suffered a penalty: excess reserves were remunerated at the official rate minus a spread, while banks in deficit would have to borrow from the BoE at the official rate plus the same spread, generating a sort of symmetrical corridor.

The BoE's tolerance band was limited to only ±1% around the target until September 2007. In times of market tensions, the BoE widened the band to ±60% and offered additional liquidity above banks' aggregate reserve targets through its open market operations.

These measures contributed to reduce, at least in part, the volatility of the interbank rate. Over this period, the average spread was -0.5 bps and the standard deviation was reduced to 0.20 percent. The GARCH analysis shows, especially in the initial phase of the outbreak of the financial crisis (August 2007), episodes of extreme volatility, which are also reflected in the estimate of the reaction coefficient to innovations.

Phase III (2009 - 2022): floor system

Following the bankruptcy of Lehman Brothers in September 2008, volatility in the interbank market had picked up again. Several factors had contributed to this phenomenon. Banks' demand for reserves had become broader and less predictable and banks were reluctant to resort to the Overnight Lending Facility for fear of the stigma effect. In addition to the widening of the tolerance band, the BoE increased the frequency of its liquidity operations. Between August 2008 and March 2009, the Bank rate was reduced by 4.5 percentage points (to 0.5 percent).

Following the launch of a large-scale asset purchase (QE) programme, the voluntary reserve system was replaced by a floor system, in which all available reserves on bank balances were (and are)

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different from classical required reserves, given their selected purpose and the impossibility of banks to use them in the payments system.

66 The b_1 GARCH coefficient was high, while the squared innovation coefficient (a_1) was relatively low.

remunerated at the Bank rate, without minimum reserve requirement, except for central counterparties and international central depositories. For monetary policy counterparties there are no limits (minimum and maximum) on the balance of accounts with the BoE, which are remunerated at the Bank rate. However, only in the event of a negative interest rate, the BoE envisages the possibility of maintaining a minimum balance and adopting a tiering remuneration system.

The change from a voluntary reserves system to a floor system was motivated by the fact that, in a normal situation with a stable liquidity stock, the former ensured effective control of the interest rate on the money market, but in times of stress, with strong increases in liquidity demand, it was not very efficient. The BoE system was exposed to the interaction (endogeneity) of the targets with the tolerance bands, which violated the condition of separability of the remuneration function.

The floor system, which satisfies the demand for central bank reserves at all times, made it possible to keep the interest rate on the money market anchored to the bank rate. The volatility of the difference between the two rates decreased considerably. The standard deviation was only 0.03 percent, compared to an average of -4 bps. Volatility, measured by the GARCH, was very low and significantly explained by the response to shocks. The negative average of the spread is mainly due to the fact that in this period the money market also includes entities that are not eligible for monetary policy operations (such as, for example, money market funds).

The BoE has stated that it will continue to use a variant of the current floor system to control short-term interest rates,[67] based on the following three considerations (Bank of England, 2022 and 2018a; Hauser, 2021 and 2019). First, the current framework has proven effective in keeping market rates in line with the monetary policy reference rate. Second, maintaining key elements of the current system guarantees business continuity and simplicity for both counterparties and the central bank. Third, the system would remain effective in the event of increases in the supply of reserves in the future, either due to future asset purchases or the liquidity facilities that the central bank would need to activate to deal with any shocks. The variant consists in the implementation of a "preferred minimum range of reserves (PMRR)", defined as the optimal range for the amount of reserves in the system calculated by the central bank, at the lower limit of which reserves start to become scarce.[68] This range will take into account all the buffers banks hold above their actual minimum needs to address uncertainties about potential stressed outflows, access to wholesale markets and market risks.

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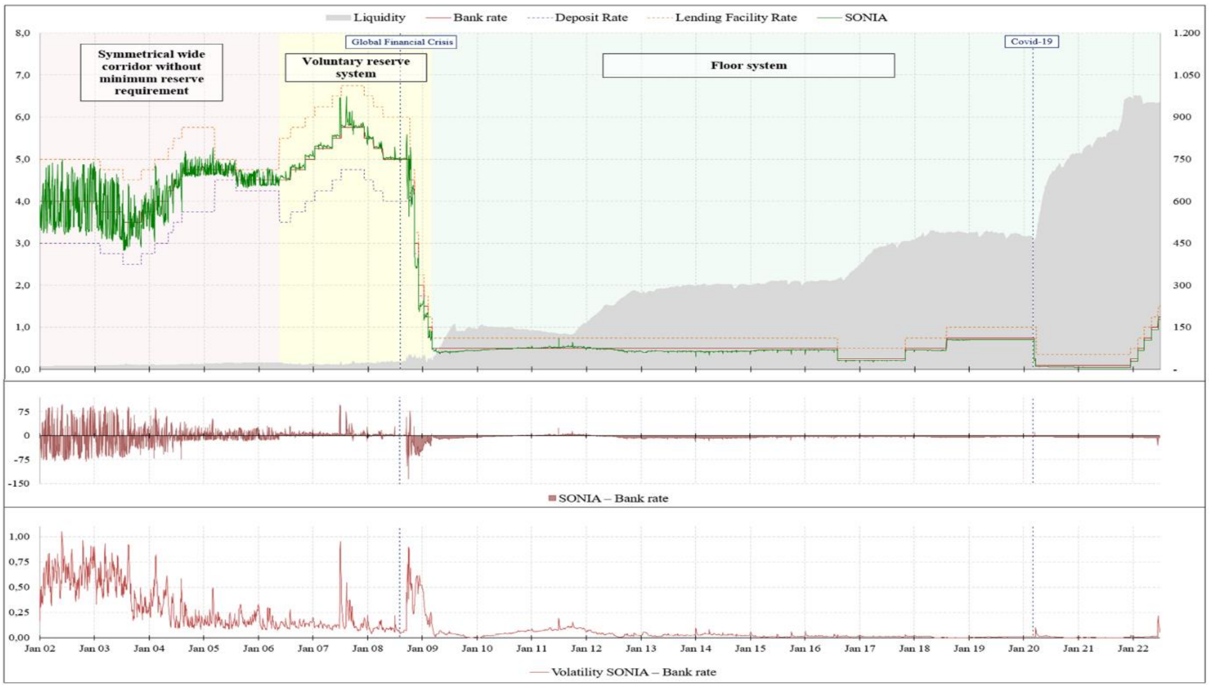
67 See https://www.bankofengland.co.uk/-/media/boe/files/monetary-policy-summary-and-minutes/2018/june-2018.pdf and https://www.bankofengland.co.uk/monetary-policy-summary-and-minutes/2022/august-2022 .

68 Since central bank reserves ensure the correct and efficient functioning of the payment system and constitute the first safeguard for unexpected liquidity shocks, the BoE, in determining the desired amount of central bank reserves, identifies two extreme situations characterized by shortage and excess reserves, thus delineating the PMRR. Within this interval, it is assumed that as reserves vary, the overnight rate will have minimal deviations from the reference rate. The BoE's framework relies on a new credit operation called the "Short-term Repo Facility", which is a 7-day open market operation, priced at the BoE's Bank rate on deposits + 0 bps (with the rate indexed to the bank rate). The framework may be considered as a zero corridor system, where reserves are remunerated daily but provided weekly with the same rate against HQLA collateral. This facility will ensure that excess liquidity remains within the fixed liquidity range, while the BoE, in parallel, pursues the reduction of its government bond portfolio. Furthermore, the BoE still has in place two standing facilities for urgent liquidity needs between the weekly operations, priced with a 25 bps spread around Bank rate.

Figure 8A – Rates and level of central bank reserves in United Kingdom



United States

The Federal Reserve (Fed)'s monetary policy operating framework has radically changed over the past 20 years. Prior to the 2008 global financial crisis, the Fed monetary policy was based on a wide asymmetric corridor system with scarce reserves, and the liquidity supply was carefully calibrated to maintain control of short-term interest rates. Subsequently, Fed implemented a floor system, where active reserve management no longer plays a role in rate control, but rather money market rates are affected by the Fed's setting of "administered" rates. Initially, reserves were ample but after the pandemic crisis they became abundant.

Phase I (2002 – 2008): system with a wide asymmetric corridor and scarce reserves

In the first period, the Federal Open Market Committee (FOMC) of the Fed communicated the monetary policy stance by announcing a target for the federal funds rate, which represented the reference rate. The Fed used open market operations (which could be daily) to make the necessary adjustments to the supply of reserves so that the money market rate (effective federal funds rate, EFFR)[69] was as close as possible to the target set by the FOMC. The monetary policy implementation system was based on an asymmetric corridor system, in which the discount rate (primary credit rate) represented the upper part of the corridor (+100 bps relative to the reference rate up to August 2017 and then +50 bps) and a zero fixed interest rate was the bottom. This is a key feature that distinguished this corridor from those implemented by many other central banks. Since the minimum rate was fixed, the width of the corridor varied with the official rate.

The Fed had reserve requirements among its instruments. A reserve ratio of 10 percent was applied to deposits (net transaction deposits). If a financial institution had deposits below $48.3 million or $7.8 million (2007 data; these thresholds varied over time) the required reserve ratio was reduced to

[69] The EFFR is calculated as the weighted median of the rates on overnight transaction between financial institutions licensed to operate in the money market.

3 percent or 0 percent, respectively. The maintenance period was generally 14 consecutive days and it was possible to carry over balances from one maintenance period to another.[70]

In this framework, banks had an incentive to hold as little reserves as possible on account balances with the Fed, as these did not accrue interest, since the Fed did not have the authority to pay interest on reserves (even minimum reserves).[71] Thus, the banking system operated with a shortage of aggregate reserves and relied on the redistribution of these through an active interbank market.

During this period, the average spread between the EFFR and the federal funds rate was 0 bps, with a standard deviation of 0.11 percent. The volatility of the spread, as measured by the GARCH, was relatively low, but increasing from August 2007.

Phase II (2008 – 2020): ample/abundant reserves and floor system

With the onset of the global financial crisis, the Fed implemented new liquidity instruments and conducted Large Scale Asset Purchases to improve conditions in financial markets and stimulate the economy. These measures generated a significant increase of reserves in the banking system. As Figure 9A shows, banking system reserves exceeded \$800 billion at the start of 2009, up from around \$10 billion in the pre-crisis period. Over the next several years, the FOMC continued to conduct asset purchases to promote a stronger economic recovery, and reserves continued to increase until the end of 2014.

With the significant increase of reserves in the banking system, it was difficult for the Fed to maintain control of rates through the previous corridor system. Small changes in the supply of reserves no longer affected the Fed funds rate. With the Fed's authorization to pay interest on reserves to banks, introduced in October 2008, the Interest Rate on Reserve Balance (IORB) became the policy rate, as it set a level below which the banks have no interest in lending. In the new system, which represented a floor system, the operational target of the Fed was to maintain the money market rate within a pre-determined range (Fed funds target range).

During this period, the spread between the EFFR and the IORB fluctuated moderately: the average was -10 bps with a standard deviation of 0.08 percent. A negative relationship can be found between

[70] Up to a maximum given by the greater between \$50,000 and 4 percent of the total requirement. The total requirement is the sum between the required reserves and the Contractual Clearing Balance (CCB). The latter supplemented the minimum reserve system with carry-over provision. The CCB was an additional amount, with respect to the mandatory requirement, that a bank (depository institution, DI) could voluntarily hold in its account at the central bank; it was remunerated in the form of credits, which could be used to pay for services that the central bank offered to banks, such as, for example, the cost of Fedwire transactions. The amount of the CCB had to be determined before the start of a maintenance period. A DI's daily average clearing balances in a given maintenance period had to be within the expected tolerance band around its requirement. The CCB system reduced the likelihood that a bank would have to resort to the Fed's overnight overdrafts. Indeed, in order to ensure the proper functioning of the payment system, the Fed allows banks to use daily overdrafts which, if not reset to zero at the end day, become overnight overdrafts. This exposure to the Fed can be risky, as it is not mandatory to collateralize this credit. Therefore, in order to discourage banks from using the overnight overdraft, the Fed applies a very high penalty rate equal to the primary credit rate + 4% for the first three days of use during the year; from the fourth onwards, 100 bps are added for each additional day of use. Sometimes, the additional requirement could be imposed by the central bank (required clearing balance, RCB), rather than being voluntary, if a DI had a history of frequent overdrafts (during the day or overnight). For more details, see M. Naber, R. Sambasivam, and M-F. Styczynski (2017).

[71] The authorization to pay interest on reserves was granted to the Fed with the Financial Services Regulatory Relief Act of 2006. This act provided that the start date of the innovation would be October 2011, then anticipated to October 2008.

the spread and the level of reserves. Volatility, as measured by GARCH, was low, at least up to early 2018. Since 2015, spikes in volatility were recorded at month-end dates.

As a consequence of the large availability of reserves, only a small fraction of money market transactions was conducted between banks (depository institutions), since none of them needed to borrow on the market to fulfill reserve requirements. The money market was dominated by other investors (such as government sponsored enterprises, GSEs, and money market funds) to get a return on their overnight cash balances. This explains the negative differential between the EFFR and the IORB, which forced the Fed to implement the Overnight Reverse Repo Purchase (ON RRP) in September 2014, a facility that became available also to non-depository institutions, with the goal of providing a lower bound on money market rates.[72] The IORB for depository institutions and the ON RRP rate for other financial institutions represent, respectively, a floor below which it is not convenient to lend funds. The spread between the two rates was on average 20 bps between September 2014 and March 2020.

Between 2017 and 2019, as the supply of reserves decreased, the spread between the EFFR and the IORB narrowed; in 2019, the EFFR exceeded the IORB for short periods.

To steer money market trading without changing the monetary policy stance (ensuring that the EFFR remains in the target range), one option available to the Fed is to implement "technical adjustments". A technical adjustment is a change in the IORB and/or the ON RRP rate that aims at improving the effectiveness of monetary policy implementation by promoting money market trading at rates within the target range, rather than changing the stance of monetary policy itself. It can also coincide with a change in the FOMC's target range.[73]

Phase III (2020 – 2022): abundant reserves and floor system

In recent years, two stress situations can be isolated: one in September 2019 with an unexpected shortage of liquidity on the repo market[74] and another in March 2020 with the outbreak of the pandemic. In both cases the tensions generated an increase in the EFFR-OIRB spread; in the first case over 20 bps with the money market rate outside the federal funds target range. The exceptional measures in response to these events, with injections of liquidity, lowered the EFFR-OIRB spread; the latter returned to being slightly negative in the period following the outbreak of the pandemic, with a liquidity level that reached its maximum peak of over $4 trillion.

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[72] Under this facility, the Fed conducts reverse repo transactions at a pre-announced bid rate set by the FOMC, offering US Treasuries held in the System Open Market Account (SOMA) portfolio. A wide range of counterparties – including money market funds and GSEs – can participate in this facility. Each counterparty may invest funds up to an assigned limit. This facility is used exclusively to drain the liquidity available on the accounts of these counterparties overnight.

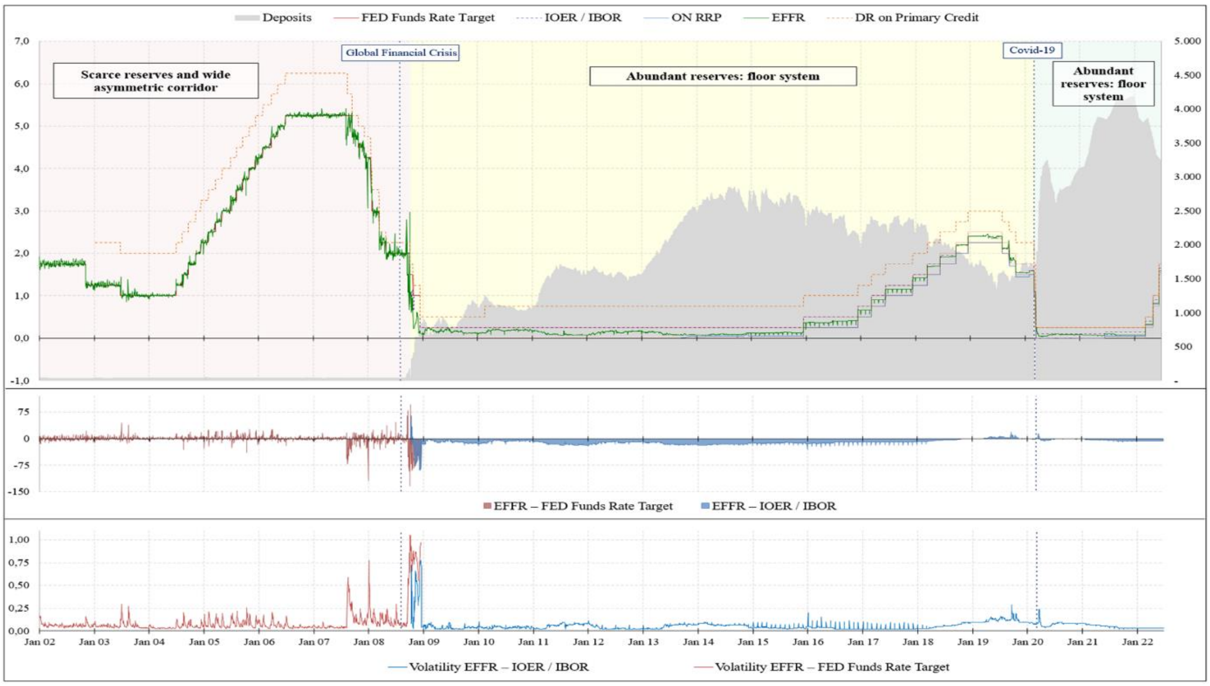
[73] A technical adjustment can occur when there is no change in the target range and the Fed adjusts the administered rates (IORB and/or ON RRP rate) to the existing target range. It can also coincide with a change in the FOMC's target range. In this case, one or both of the administered rates are changed by a different amount than the target range shift. A technical adjustment does not imply a change in the monetary policy stance. In early 2018, the IORB was set at the upper limit of the target range, as it had been since the FOMC moved to a target range in late 2008. As the supply of reserves declined in the first half of the 2018, the EFFR increased, very close to the top of the target range. With the EFFR floating just five bps from the upper limit of the target range, the Fed implemented its first technical adjustment in June 2018. The IORB was lowered to five bps below the top of the range, when the FOMC increased its target range and ON RRP rate by 25 bps, while the IORB was only increased by 20 bps. The EFFR responded quickly to IORB adjustments.

[74] For more details on the market events of September 2019, see Afonso et al. (2020a).

Following the outbreak of the pandemic, the minimum reserve requirement ratio was set to zero. To keep the money market rate in the target range, the Fed also intervened with two technical adjustments (in 2020 and 2021). As cash was traded in the market at rates close to the lower limit of the range, the IORB and ON RRP rates were raised to support trading in the Fed funds market within the range.[75]

In the most recent period, the volatility of the spread has been very low. In January 2019, the Federal Reserve announced that the implementation of long-term monetary policy would continue to be accomplished under a "large reserve" system, in which "administered" interest rates (such as the rate paid on reserves) are the main instruments and where, instead, “active” adjustments in the supply of reserves are no longer necessary to implement it.[76] With such a system, the Fed does not face the trade-off between controlling interest rates and providing liquidity to the market during times of stress (Afonso et al., 2020b; Ihrig et al., 2020).

Figure 9A – Rates and level of central bank reserves in United States



[75] In January 2020 and mid-June 2021, the IORB and ON RRP rates were increased by 5bps after the EFFR had moved within 5bps above the lower bound of the range. The 2020 and 2021 technical adjustments were effective in supporting trading in the Fed funds market at rates within the target range.

[76] See the statement “Statement Regarding Monetary Policy Implementation and Balance Sheet Normalization.” https://www.federalreserve.gov/newsevents/pressreleases/monetary20190130c.htm .

Appendix III - Analysis of the relationship between central bank reserves and money market rates

The analysis aims to investigate the relationship between:

i) central banks' decision to adopt a floor system and the reserves-to-GDP ratio (whose trend for various countries is shown in Figures 10A and 11A).[77] Additionally, it explores the link with the spread between the money market rate and the rate applied to bank deposits with the central bank;

ii) the reserves-to-GDP ratio and the spread between the money market rate and the rate applied to bank deposits with the central bank.

Figure 10A – Reserves-to-GDP ratio

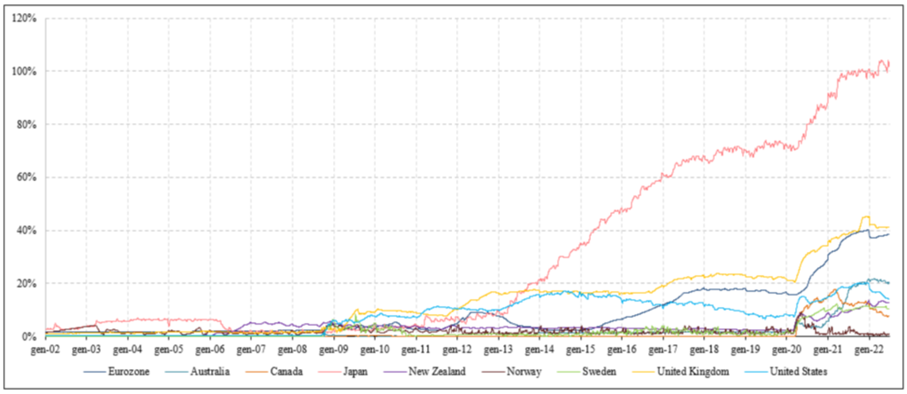
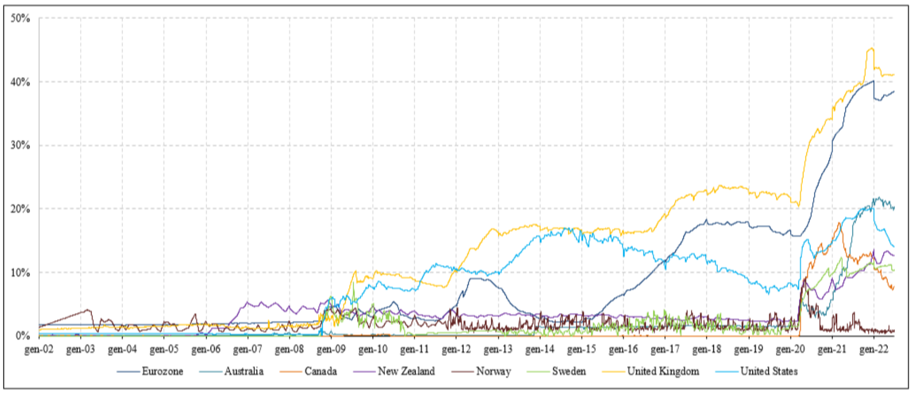


Figure 11A – Reserves-to-GDP ratio (Japan excluded)



A logistic model was estimated to identify how the ratio between reserves and GDP influences the probability that a central bank adopts a floor system. We considered a dummy variable which was equal to 1 in periods in which a central bank adopted a floor system as dependent variable.[78]

$$p\left(dummy\ floor_{i,t} = 1\right) = F\left(\alpha + \beta \times \frac{Reserves_{i,t}}{GDP_{i,t-1y}}\right)$$

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[77] The GDP at the denominator of the ratio is annual and the value at the end of the previous year was considered. Figure 11A excludes Japan to better highlight the performance of other countries.

[78] To identify floor system, we used official statements of the central banks, if any; in absence of official statements, we considered speeches/communications of the central banks' members or other central banks' documents (see table 10A for details).

where $p(dummy\ floor_{i,t} = 1)$ is the probability that the central bank of country i adopts the floor system at time *t* and F is the logistic distribution function. The estimate has a positive and significant coefficient β, which assumes a value of 0.67 (Table 2A).

Table 2A: Estimate of the logistic model with reserves on GDP ratio

	Dependent Variable
	dummy_floor_system
Reserves / GDP	0.672^{***} (0.008)
Number of observations	40,428
Log Likelihood	-11,996
Pseudo R^2	0.485
Akaike Inf. Crit.	23,995

Standard errors in parentheses: ***p<0.01, **p<0.05, *p<0.1

Therefore, it is possible to determine the probability that the central bank implements a floor system in correspondence with the different values of the reserve-to-GDP ratio. In particular, the probability is about 45% for values of the ratio equal to 4%; it increases to around 85% when the reserves-to-GDP ratio is 7%, it becomes more than 95% for values of the ratio equal to 9% (Figure 12A and Table 3A). For the central bank, when reserves-to-GDP ratio are abundant (over 9%), the floor system represents the most efficient but, at the same time, expensive operational framework.

Figure 12A - Probability that a CB adopts a floor system in relation to the level of reserves (on GDP)

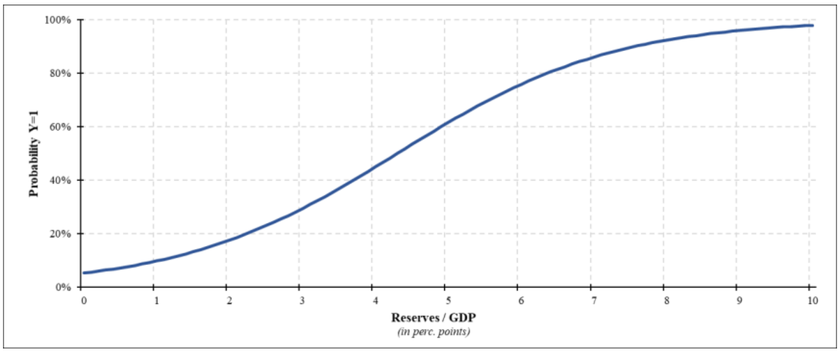


Table 3A

Riserve / PIL *(in pti perc.)*	Prob (Y=1)
0,0	5%
1,0	10%
2,0	18%
3,0	30%
4,0	45%
5,0	62%
6,0	76%
7,0	86%
8,0	92%
9,0	96%
10,0	98%
11,0	99%
12,0	99%
13,0	100%
14,0	100%
15,0	100%

In the previous analysis, the classification of reserves was based on an econometric model that assumed constant thresholds across jurisdictions and time. As a robustness check, we estimated alternative models without these assumptions.

Firstly, we added a dummy time variable to capture time effects on estimate:

$$p(dummy\ floor_{i,t} = 1) = F\left(\alpha + \beta_1 \times \frac{Reserves_{i,t}}{GDP_{i,t-1y}} + \beta_2 \times annual\ dummy_t\right)$$

Where $annual\ dummy_t$ is a dummy variable that takes different values for each year. The coefficient β_1 remains positive, equal to 0.60, and significant (Table 4A).

Table 4A: Estimate of the logistic model with reserves on GDP ratio and dummy time variable

Dependent Variable dummy_floor_system	
Reserves / GDP	0.596*** (0.007)
Number of observations	40,428
Log Likelihood	-14,291
Pseudo R^2	0.485
Akaike Inf. Crit.	25,587

Standard errors in parentheses: ***p<0.01, **p<0.05, *p<0.1

Secondly, we estimated a model that allowed to the coefficients to vary across jurisdictions:

$$p(dummy\ floor_{i,t} = 1) = F\left(\alpha_i + \beta_i \frac{Reserves_{i,t}}{GDP_{i,t-1y}}\right)$$

The coefficients are positive and significant for all jurisdictions (Table 5A).[79]

Table 5A: Estimate of the logistic model with fixed effects

Dependent Variable dummy_floor_system	
Reserves / GDP	5.828*** (1.041)
Dummy Euroarea × Reserves / GDP	-5.249*** (1.041)
Dummy Australia × Reserves / GDP	6.813*** (2.049)
Dummy Canada × Reserves / GDP	82.68*** (4.506)
Dummy New Zealand × Reserves / GDP	-2.698** (1.102)
Dummy Norway × Reserves / GDP	-5.707*** (1.041)
Dummy Sweden × Reserves / GDP	-4.687*** (1.041)
Dummy UK × Reserves / GDP	-2.851*** (1.062)
Fixed-Effect Jurisdiction	YES
Number of observations	35,936
Log Likelihood	-5,058
Pseudo R^2	0.787
Akaike Inf. Crit.	10,148

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

79 Japan was excluded from this estimate because it has adopted a *de facto* floor system during the whole period.

Both estimates confirm the previous results and allow, on average, to obtain substantially the same reserves classification thresholds previously shown.

In addition, we used econometric analysis where the probability of a central bank implementing a floor system is related to the value of the spread between the money market rate and the rate applied to bank deposits at the central bank, instead of the value of the reserves-to-GDP ratio as previously.[80] We estimated a logistic model, where the dependent variable, as before, was a dummy variable that was equal to 1 in periods in which a central bank adopted a floor system:

$$p(dummy\ floor_{i,t} = 1) = F(\alpha + \beta \times Spread_{i,t})$$

Then, we added the annual dummy variable to capture time effects:

$$p(dummy\ floor_{i,t} = 1) = F(\alpha + \beta_1 \times Spread_{i,t} + \beta_2 \times annual\ dummy_t)$$

In both models, the coefficient of the spread is negative and statistically significant (Tables 6A and 7A), meaning that the closer the money market rate to deposit rate, the greater the probability that central banks adopt a floor system.

Table 6A: Estimate of the logistic model with spread

Dependent Variable dummy_floor_system	
spread	-4.696*** (0.073)
Number of observations	45,677
Log Likelihood	-22,247
Pseudo R^2	0.275
Akaike Inf. Crit.	44,498

Standard errors in parentheses:
***p<0.01, **p<0.05, *p<0.1

Table 7A: Estimate of the logistic model with spread and dummy time variable

Dependent Variable dummy_floor_system	
spread	-4.265*** (0.066)
Number of observations	45,667
Log Likelihood	-21,632
Pseudo R^2	0.295
Akaike Inf. Crit.	43,271

Standard errors in parentheses:
***p<0.01, **p<0.05, *p<0.1

We also estimated the model allowing the coefficients to vary across jurisdictions:[81]

$$p(dummy\ floor_{i,t} = 1) = F(\alpha_i + \beta_i \times Spread_{i,t})$$

The β_i coefficients are negative, except for New Zealand (Table 8A),[82] and significant, except for Australia, confirming, on average, the previous results.

80 The deposit rates considered are: DFR (Deposit Facility Rate) for the Eurosystem, Deposit Rate for Australia, Deposit Rate for Canada, Policy Rate for Japan, OCR (Official Cash Rate) for New Zealand, Sight Deposit Rate until October 2011 and Reserve Rate thereafter for Norway, Deposit Rate for Sweden, Deposit Rate until March 2019 and Bank Rate thereafter for the United Kingdom, zero until October 2008 and IORB (Interest Rate on Reserve Balance) thereafter for United States.

81 Japan was excluded from this estimate because it has adopted a *de facto* floor system during the whole period.

82 This could depend on the fact that during the quota system period (2007-2020) the money market rate was often lower than OCR, as during the floor system period (2020-on going), and this may have impacted the estimate.

Table 8A: Estimate of the logistic model with fixed effects

Dependent Variable dummy_floor_system	
Spread	-6.417***
	(0.259)
Dummy Euroarea × Spread	-66.794***
	(3.043)
Dummy Australia × Spread	-359.285
	(4,194)
Dummy Canada × Spread	-194.137***
	(19.840)
Dummy New Zealand × Spread	7.379***
	(0.594)
Dummy Norway × Spread	-7.827***
	(0.489)
Dummy Sweden × Spread	-25.492***
	(3.076)
Dummy UK × Spread	-14.829***
	(0.982)
Fixed-Effect Jurisdiction	YES
Number of observations	40,739
Log Likelihood	-4,608
Pseudo R^2	0.820
Akaike Inf. Crit.	9,249

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

In addition, an analysis was conducted specifically for the Eurozone and the United States systems[83] to identify the relationship between the spread between the money market rate and the rate applied to banks' deposits with the central bank and the ratio of bank reserves-to-GDP. This was achieved by estimating the following non-linear polynomial function (Table 9A for the value of the estimated coefficients; Figure 13A and Figure 14A):

$$Spread_{i,t} = \beta_0 + \frac{\beta_1}{\left(1 + e^{\beta_2 \times \frac{Reserves_{i,t}}{GDP_{i,t-1y}}}\right)}$$

Table 9A: Estimate of the non-linear polynomial function

	Eurozone	**United States**
β0	3.635 ***	-10.791 ***
	(-0.086)	(-0.166)
β1	49.496 ***	506.329 ***
	(-1.496)	(-85.735)
β2	0.429 ***	0.471 ***
	(-0.014)	(-0.023)

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

[83] The time interval in this case was limited to the period 2012 - 2022. The choice is due to the fact that excessively "deep" data would refer to contexts that are probably no longer replicable.

Figure 13A – Spread and Reserves/GDP in the Eurozone

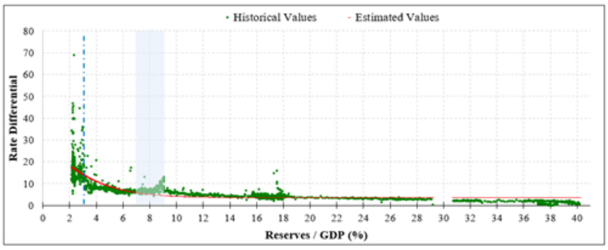
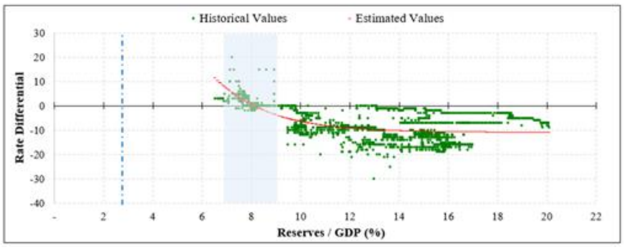


Figure 14A – Spread and Reserves/GDP in the United States



Through the joint analysis of the first and second derivatives, it is observed that, when moving from high values of the reserves-to-GDP ratio (from right to left on the x-axis), curves start to slope within the range of 7% to 9% (depicted by the blue area in Figure 15A and Figure 16A). For values below these thresholds, the spread variation shows a more pronounced reaction to the reduction of reserves.[84]

Figure 15A – First and second derivatives, Eurozone

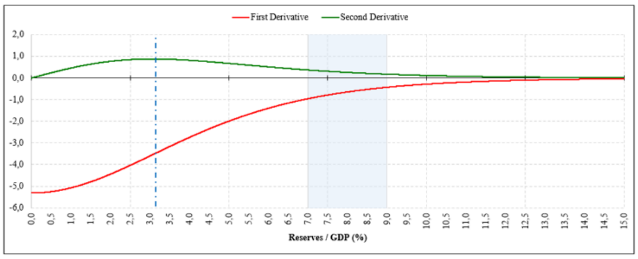
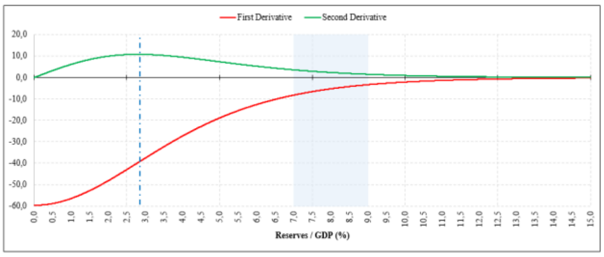


Figure 16A – First and second derivatives, USA



A reduction in reserves below this range is likely to be linked to an increase in short-term money market rates, regardless of any changes in key interest rates (see also Aberg et al., 2021). This could lead to a substantial increase in their volatility. However, it is important to approach these estimates with caution, considering that the observed relationships between variables in the past may not necessarily repeat in the future. Various structural factors, such as precautionary liquidity demand, the need for high-quality liquid assets, amount of deposits in the banking system, changes to the regulatory framework, and money market segmentation, can influence this relationship.

In the light of these analyses, reserves (in relation to GDP) can be classified as: 1) abundant (value of the ratio of reserves-to-GDP > 9%), a situation in which the demand curve is completely flat and the money market rate is around the deposit facility rate and it's very likely that a central bank will implement a floor system (probability above 95%); 2) ample (value of the ratio between 7 and 9%), where the demand curve shows a slight downward slope and the probability of a floor system is high (between 85% and 95%); 3) moderate (value of the ratio between 4 and 7%) in which the negative slope of the curve increases and changes in reserves begin to generate relevant changes in money market rates and it's likely that a central bank will implement a floor system (probability between 45% and 85%); 4) scarce (value of the ratio of reserves-to-GDP < 4%), in which reserves are close to the aggregate demand and the demand curve has a steep negative slope, which causes a strong rate variation to small changes in reserves, and the probability of a floor system is low (below 45%).

84 By observing the second derivative of the function, it is possible to identify the point of maximum slope of the curve, which is in correspondence to the value of the ratio of 3.1% for the Eurozone and 2.8% for the United States (dashed blue line in the figures).

Table 10A: Floor periods

Jurisdiction	Floor system (official or *de facto*)		Reference
	From	To	
Euroarea	02/03/2015	*On going*	https://www.ecb.europa.eu/press/key/date/2023/html/ecb.sp230302~41273ad467.en.html
Australia	20/03/2020	*On going*	https://www.rba.gov.au/education/resources/explainers/how-rba-implements-monetary-policy.html https://www.rba.gov.au/education/resources/explainers/unconventional-monetary-policy.html https://www.rba.gov.au/education/resources/in-a-nutshell/pdf/monetary-policy-implementation.pdf
Canada	23/03/2020	*On going*	https://www.bankofcanada.ca/markets/market-operations-liquidity-provision/framework-market-operations-liquidity-provision/
Japan	19/03/2001	*On going*	https://www.boj.or.jp/en/about/press/koen_2017/data/ko171019a1.pdf https://www.boj.or.jp/en/mopo/mpmdeci/mpr_2001/k010319a.htm
New Zealand	17/03/2020	*On going*	https://www.rbnz.govt.nz/hub/publications/speech/2022/speech2022-09-07
Norway	*mid-1990s*	03/10/2011	https://www.norges-bank.no/en/topics/liquidity-and-markets/The-liquidity-management-system/The-management-of-bank-reserves-The-system-in-Norway/Background-system-managing-bank-reserves/
Sweden	18/03/2020	*On going*	https://www.riksbank.se/en-gb/monetary-policy/monetary-policy-report/2020/monetary-policy-report-april-20202/ https://www.riksbank.se/globalassets/media/rapporter/ppr/fordjupningar/engelska/2020/the-riksbanks-balance-sheet-is-growing-article-in-monetary-policy-report-april-2020.pdf https://www.riksbank.se/globalassets/media/rapporter/ppr/engelska/2021/210921/monetary-policy-report-september-2021.pdf
United Kingdom	02/03/2009	*On going*	https://www.bankofengland.co.uk/-/media/boe/files/paper/2018/boe-future-balance-sheet-and-framework-for-controlling-interest-rates.pdf
United States of America	16/12/2008	*On going*	https://www.federalreserve.gov/monetarypolicy/20081006a.htm https://www.mercatus.org/macro-musings/lorie-logan-monetary-policy-operations-feds-new-standing-repo-facility-and-future https://www.newyorkfed.org/newsevents/speeches/2019/log190417 https://www.dallasfed.org/news/speeches/logan/2023/lkl231110#n9

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