Monetary Policy Implementation:

Recommendations for an Effective and Efficient Operational Framework

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Two Confessions and Some Acknowledgements

I must confess that this doctoral thesis has never been the top priority in my life. Since I started to work on it many people have asked me—and some of them many, many times—when I would eventually be a doctor. I always used to reply that I was well on track and planning to have it done in a year or two at the latest. But as life went on many unforeseen things got in the way and it was only when my wife told me that she was pregnant that I decided to really complete it as quickly as possible. Needless to say that at the time of writing these paragraphs our beloved son is already toddling around our home...

And although this doctoral thesis has never been my top priority, I must also confess that I have always been extremely interested in monetary policy and in particular in the implementation of monetary policy. That explains why through all the years I never got frustrated about this project and liked to keep on learning new facets. Indeed, I truly believe that you must have reflected about this topic for at least ten years before you are able to write a thorough doctoral thesis.

There are a number of people that I would like to thank for their continuing support and without whom I would not have succeeded. First of all, I am grateful to my supervisors Ernst Baltensperger and Antoine Martin for their advice, trust and patience. I am also grateful to many (former) colleagues at the Swiss National Bank for helpful discussions, in particular Daniel Heller, Yvan Lengwiler, Philipp Häne and Thomas Nellen. I'm particularly grateful to my family: to my wife Huyen Phan Sturm and to our son Emanuel for bringing so much love and joy to my life, to my sister Corinne Sturm Zehnder for always being there when I need her, and, of course, to my parents who have always supported and encouraged me from my earliest childhood on. And last but not least, many thanks to all of you that have continued to ask me when I would eventually complete my doctoral thesis. You may be pleased to hear that I have no intentions to write a habilitation, at least for the next few years.

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Notation

Reserve Balances

$R_{i,t}^{bod}$	Reserve balances of bank i at the beginning of day t
R_{t}^{bod}	Per capita reserve balances at the beginning of day t
$R_{i,t}^{mc}$	Reserve balances of bank i before market clearing on day t
R_{t}^{mc}	Per capita reserve balances before market clearing on day t
$R_{i,t}^{psc}$	Reserve balances of bank i after closing of the payment system on day t
R_{t}^{psc}	Per capita reserve balances after closing of the payment system on day t
$R_{i,t}^{eod}$	Reserve balances of bank i at the end of day t (i.e. after recourse to standing facilities)
R_{t}^{eod}	Per capita reserve balances at the end of day t (i.e. after recourse to standing facilities)
$B_{i,t}$	Reserves borrowed by bank i in the interbank market on day t

Reserve Requirements

$D_{i,1}$	Reserve target of bank i for the reserve maintenance period
D_1	Per capita reserve target for the reserve maintenance period
$D_{i,t}$	Reserve deficiency of bank i at the beginning of day t
D_t	Per capita reserve deficiency at the beginning of day t
λ	Allowed percentage deviation from the reserve target
T	Length of reserve maintenance period

Open Market Operations

$L_{t,t+m}^{i}$	Open market operation with bank i conducted on day t and maturing on $t+m$
$L_{t,t+m}$	Per capita open market operation conducted on day t and maturing on $t+m$
$\bar{L}_t$	Per capita open market operations maturing on day t

Interest Rates

i_t	Overnight rate on day t
i_t^*	Overnight target rate on day t
$i_{t,t+m}$	Interest rate with maturity of m days on day t
i_t^b	Borrowing rate on day t
i_t^d	Deposit rate on day t
ω	Spread between borrowing rate and deposit rate

Liquidity Shocks

$\varepsilon_{i,t}^M$	Cumulated liquidity shock to bank i in the morning on day t
$\varepsilon_{i,t}^A$	Cumulated liquidity shock to bank i in the afternoon on day t
$\upsilon_{i,t}^M$	Idiosyncratic liquidity shock to bank i in the morning on day t
$\upsilon_{i,t}^A$	Idiosyncratic liquidity shock to bank i in the afternoon on day t
$\eta_{i,t}^M$	Autonomous liquidity shock to bank i in the morning on day t
η_t^M	Per capita autonomous liquidity shock in the morning on day t
$\eta_{i,t}^A$	Autonomous liquidity shock to bank i in the afternoon on day t
η_t^A	Per capita autonomous liquidity shock in the afternoon on day t

Chapter 1

Introduction

Short-term interest rates play an essential role in the first stages of the monetary transmission channel. This is reflected by the fact that central banks' decision-making bodies typically debate and decide on the appropriate target level for the current short-term interest rate. At least *de facto*, monetary policy thus is interest rate policy. To steer short-term interest rates in the interbank money market central banks dispose of a number of monetary policy instruments, in particular reserve requirements, standing facilities and open market operations. The rules and procedures governing the use of these instruments is often referred to as the operational framework for the implementation of monetary policy.

Unfortunately, the predominant description of monetary policy implementation in the mainstream literature is subject to widespread misconceptions. The most common misconception is the proposition that monetary policy actions are (exclusively) effected through open market operations that alter some quantity such as the level of bank reserves. This view is at odds with central bank practice of influencing short-term interest rates primarily through the terms on which reserves are made available. As pointed out by Disyatat (2008), such misconceptions can have important repercussions on analyzes at the macroeconomic level. Analyzing the institutional details and mechanics of monetary policy implementation is thus not only relevant for understanding the source of central banks' power to control interest rates, but it can also cast light on macroeconomic issues such as the monetary transmission mechanism.

Considering that the implementation of monetary policy is a core task of any central bank, it might come as a surprise that academic research on how to control short-term interest rates in an effective and efficient manner is comparatively scarce. While recent years have witnessed the development of an increasing number of macroeconomic models that allow to analyze the effects of monetary (or rather: interest rate) policy and to provide guidance for policy makers, these models typically ignore the first step in the monetary transmission channel by assuming that the short-term interest rate is perfectly controlled by the central bank. Although this is a valid shortcut when focusing on the longer-term macroeconomic effects of monetary policy, the lack of interest in issues regarding the implementation of monetary policy is regrettable.

However, before doing an injustice to the guild of monetary economists, one should acknowledge that since the late 1990s research on issues surrounding the implementation of monetary policy and how it affects the functioning of money markets has gained some ground. And due to the disruptions to interbank money markets during the 2007–2009 financial turmoil and the ensuing challenges faced by many central banks in implementing monetary policy, these issues have even attracted the attention by the mass media and the general public. But despite the soaring public and academic interest, so far only a few authors have made an attempt to provide a comprehensive and normative analysis of monetary policy implementation. Indeed, as the review of related literature in Section 1.2 will reveal, most research is either purely descriptive or empirical. And the few studies with a more theoretic and normative approach typically focus only on specific aspects of monetary policy implementation. By providing a comprehensive, normative analysis of the operational framework for the implementation of monetary policy, this study thus intends to contribute to filling an important gap in monetary economics.

The remainder of this introduction is organized as follows. The next section motivates the subject, sets out the objectives and explains the general approach by which the recommendations for an effective and efficient operational framework for the implementation of monetary policy will be derived. The subsequent sections then contain a review of related literature and the outlook on the remaining chapters.

1.1 Motivation, Objectives and Approach

Having been largely ignored for many decades, monetary policy implementation has attracted more attention in the academic literature in recent years. Goodfriend (2002) mentions two factors that might explain this trend. First, although all major central banks implement monetary policy by manipulating short-term interest rates, it is striking that there remain important differences in the procedures by which interest rates are managed. Comparing the existing alternatives and exploring new operational frameworks that might fare better than the procedures currently in use would thus be of considerable interest. Second, in the late 1990s, some economists began to worry that progress in information technology and communications, and particularly technological advances in payment systems, could erode central banks' ability to control interest rates in the future and thereby render monetary policy ineffective (see Friedman 1999 or King 1999).

The starting point for this study is related to Goodfriend's first observation, the remarkable diversity in central banks' procedures for the implementation of monetary policy, which is documented in Borio's (1997) comprehensive survey on monetary policy implementation procedures in 14 industrial countries. Based on data from 1996, this survey provides an astonishing picture, both with respect to the operational targets and the operational frameworks of the reviewed central banks at that time. The operational target of all but one central bank—the Swiss National Bank—was a short-term interest rate, but the maturities of the targeted short-term interest rates varied between overnight and three months. Only three central banks officially announced their current target level, while others used the tender rate for regular open market operations, the rate of standing facilities or quantity related variables to signal the stance of monetary policy. Differences were even more pronounced regarding the operational framework, that is the rules and procedures governing the use of the central banks' instruments to control the selected operational target. For instance, eleven central banks imposed reserve requirements, but they varied substantially in terms of function, size, calculation method, remuneration or penalty schemes. All central banks provided a ceiling for interest rates by means of a standing borrowing facility, but only four also provided a floor for interest rates by offering a standing deposit facility. Furthermore, the standing facilities varied greatly in terms of pricing, access conditions or eligible collateral. Differences were probably most striking regarding the conduct of open market operations. Although all central banks made use of different types of operations, including reverse transactions such as repurchase agreements or foreign exchange swaps, outright transactions or the issuance of short-term paper, these operations exhibited remarkable differences with respect to underlying assets, maturity, frequency, pricing and settlement procedures.

Since Borio's survey, all of the reviewed central banks have revised the rules and procedures for implementing monetary policy. Some amendments were fundamental, others were more of cosmetic nature. For many European central banks this process was driven by the introduction of the euro and the establishment of the European Central Bank (ECB) and the European System of Central Banks (ESCB). Monetary integration lead to a unified framework for the implementation of monetary policy, although some minor country-specific differences regarding settlement procedures or the collateral eligible for monetary policy operations still remain. The Federal Reserve reformed its borrowing facility—the discount window—and made changes to reserve requirements as well as to some technical details of its open market operations. The Bank of Japan, in its attempt to fight deflationary pressures, temporarily introduced a quantitative target for banks' reserve balances, which could be regarded as a secondary operational target on top of the zero short-term interest rate target. The Swiss National Bank (SNB) made substantial modifications to its operating procedures when it revised its overall framework for monetary policy in 1999. Also, after a number of smaller adaptations to its procedures now and then, in 2006 the Bank of England eventually reformed its operational framework in a fundamental way. And finally, in reaction to the challenges raised by the 2007–2009 financial crisis, all major central banks had recourse to a range of extraordinary measures, at least temporarily.

By and large, over the last ten years these changes lead to some convergence of monetary policy implementation procedures across major central banks. But there remain considerable differences, which raises a number of questions. For instance, why do some central banks use the overnight rate as operational target, while others prefer a longer-term money market interest rate? Why do some central banks rely more heavily on reserve requirements than others? Why do most central banks provide a borrowing facility but only some also a deposit facility? Why do some central banks conduct open market operations very systematically, while the approach of others seems to be more *ad hoc*? Or why do some central banks prefer fixed rate tenders, while others favor variable rate tenders? This set of questions is by no means comprehensive, and going into more detail it would be possible to identify a myriad of other (often very subtle) distinctions. As suggested by Goodfriend (2002), it thus seems natural to evaluate the pros and cons of the various procedures and, eventually, to distill those features that characterize the optimal operational framework for the implementation of monetary policy. This is the purpose of the study at hand.

In principle, the quest for the optimal monetary policy implementation procedure could be set up as a constrained optimization. To begin with, one would have to specify the objective function by identifying reasonable goals that the monetary policy implementation procedure should allow to achieve. In this study, the following two policy objectives will be postulated. First, the operational framework should allow tight control of the operational target. For instance, assuming that the overnight rate is used as the operational target, actual overnight rates should be in line with the target level (at least on average) and exhibit relatively low volatility, both intraday and from day-to-day. Second, the operational framework should contribute to a proper functioning of the interbank money market, for instance by providing commercial banks sufficient incentives to effectively manage their liquidity and by fostering the development or maintenance of a liquid and competitive interbank money market. An operational framework that allows to achieve these objectives to a high degree can be considered as effective. But while effectiveness is a necessary condition, it is not sufficient, at least in a world of scarce resources. This is why the operational framework should also allow for an efficient allocation of resources by minimizing the social costs associated with the implementation of monetary policy. These social costs include not only costs borne by the central bank, but also those borne by commercial banks and even the public at large.

Having defined the arguments of the objective function as well as the relative weights of these arguments, one would then have to find the operational framework that maximizes the objective function, taking into account possible constraints. These constraints may be related to issues such as technical and operational feasibility, legal restrictions for certain types of operations, or the degree of development of financial markets in general and money markets in particular. But unfortunately, in practice the constrained optimization is doomed to failure, for it is simply too complex to be formulated in rigorous mathematical terms, let alone that it could be solved analytically. A less stringent and elegant method would consist in comparing all the theoretically feasible operational frameworks, but since monetary policy instruments can be combined in myriads of ways, this approach is also un unfeasible.

Therefore, this study will follow a different approach, which, admittedly, is less rigorous than the constrained optimization method, but yet suitable to derive an operational framework that performs well with respect to the objectives defined above. The approach can be summarized as follows. First, based on a review of the existing literature on monetary policy implementation, a thorough analysis of the functioning of the market for reserves and taking into account the experience of major central banks with their operational frameworks, we make an educated guess on how the monetary policy instruments should be specified and combined, proposing a specific operational framework. Using a dynamic general equilibrium model of the money market, which allows to analyze how commercial banks' optimal behavior and the dynamics of the equilibrium overnight rate are affected by institutional features related to the implementation of monetary policy, the performance of the proposed operational framework is then assessed in terms of the specified objectives, and compared with the performance of slightly modified frameworks. This comparison corroborates the suitability of the proposed operational framework.

Before moving on, two caveats regarding the general validity and applicability of the findings must be issued. First, given the somewhat heuristic approach described in the preceding paragraph, it is unlikely that the proposed operational framework will correspond to the globally optimal operational framework that would emerge as the result of a rigorous constrained optimization. Nonetheless, the proposed operational framework allows to achieve the postulated objectives of monetary policy implementation to a high degree. It can thus be said to be both effective and efficient. The second caveat pertains to a fundamental assumption and thus the applicability of the results. Throughout the analysis, it will be assumed that the central bank operates in an environment characterized by well developed and efficient financial markets, especially money markets. This assumption is reasonable for advanced countries, and possibly even for many emerging markets. However, the analysis and the conclusions do not necessarily hold good for central banks in countries where financial markets are in an earlier stage of development. Nor are the conclusions directly applicable to situations when the financial system is under severe stress and money markets are collapsing due to wide-spread concerns about the soundness of individual market participants, as experienced during the most acute stages of the 2007–2009 financial crisis. Bearing these caveats in mind, we now turn to a brief review of related literature.

1.2 Related Literature

Taking into account the vast amount of research on monetary policy in general, the literature focusing on the implementation of monetary policy is readily comprehensible. Probably most remarkable is the lack of textbooks providing a quick and easy introduction into both the theory and the practice of monetary policy implementation. Although most textbooks on monetary theory and policy such as Issing (2003), Mishkin (2004) or Walsh (2003) typically devote one or two chapters to issues related to the implementation of monetary policy, these reviews are usually either rather selective or quite far-off from what central banks actually do in practice. A notable exception is Bindseil (2004a), who provides not only a detailed and critical account of the history of monetary policy implementation by the Bank of England, the Federal Reserve and the Bundesbank (including its successor, the European Central Bank), but also develops a theoretical framework that allows to analyze and assess alternative operational frameworks. Other useful introductions to the subject are Allen (2004) and Gray and Talbot (2006), albeit they are theoretically less stringent.

Besides these general introductions into monetary policy implementation, the literature related to and relevant for the present study can be classified into four broad categories: (i) official information on monetary policy implementation and operational frameworks published by central banks; (ii) comparative and/or historical reviews of central banks' operational frameworks; (iii) research on interbank money markets; and finally, most closely related to the present study, (iv) research on specific aspects of the operational framework. The following review is structured along these four categories. Rather than discussing individual contributions in detail, the review aims at distilling some general observations.

Official Information by Central Banks

The most important and authoritative source of information on monetary policy implementation are central banks themselves. These days, basically all central banks provide some information on how they implement monetary policy. Relevant information may be found in official documentations or specific regulations on monetary policy instruments. Many central banks also release statistical data on the actual use of monetary policy instruments, such as the results of open market operations or the recourse on standing facilities. While some statistics may be publicly available on central banks' websites, others may be released only via financial information services such as Reuters or Bloomberg. Furthermore, in annual reports or other regular publications central banks may inform about the main developments in money markets, including their own operations.

However, as can be seen from a simple comparison of the information policy of five major central banks—the Reserve Bank of Australia (RBA), the European Central Bank (ECB), the Swiss National Bank (SNB), the Bank of England (BoE), and the Federal Reserve (Fed)[1]—, the clarity of presentation as well as the level of detail of information related to monetary policy implementation varies considerably between central banks.[2] In terms of clarity and completeness of the information provided, the ECB and the BoE stand out from the others. The ECB publishes regularly an updated version of the "General Documentation on Eurosystem Monetary Policy Instruments and

[1]For simplicity, the terms 'Federal Reserve' or 'Fed' will be used interchangeably throughout this study, without differentiating between the Federal Reserve System or individual Federal Reserve Banks.

[2]The following review summarizes the situation as of early 2007. It should be noted that during the 2007–2009 financial crisis all reviewed central banks made considerable efforts to improve the information publicly available on issues related to the implementation of monetary policy and developments in interbank money markets.

Procedures" (ECB 2006a). This document contains basically everything one needs to know about the ECB's approach to monetary policy implementation, including a detailed description of the main instruments (open market operations, reserve requirements and standing facilities), eligible counterparties and eligible assets for credit operations. Major developments in euro money markets and short-term interest rates are regularly explained in the ECB's "Monthly Bulletin", which also provides detailed statistics on the conduct of open market operations and the factors affecting the banking system's liquidity position during the reserve maintenance period. In addition, the ECB's website provides timely information on money market conditions, including the ECB's forecast of autonomous factors affecting the banking system's liquidity position.

An easily understandable overview of the BoE's operational framework is provided by Mac Gorain (2005) and by the so-called "Red Book" (Bank of England 2006). While the Red Book's audience is the interested public, more detailed information on the rules and procedures governing the various monetary policy instruments and other issues relevant for market participants are readily available in Bank of England (2005). In the "Quarterly Bulletin" the BoE further explains the main developments in sterling money markets and open market operations, although the statistical data is less comprehensive than in the case of the ECB. Market participants also benefit from detailed announcements and explanations related to the BoE's open market operations.

Getting the full picture on how monetary policy is implemented by the other three central banks is more cumbersome, mainly because there is no single document setting out the operational framework in a transparent and coherent manner. For instance, while being extremely detailed and comprehensive, relevant information on the Fed's operating procedures is scattered in various documents and regulations. For instance, rules on the calculation and maintenance of reserve requirements are contained in Regulation D of the Federal Reserve Board of Governors, while additional details and examples on how to file the respective weekly or quarterly reports can be found in the "Reserve Maintenance Manual" (Federal Reserve System 2006). Terms and conditions for having access to the Fed's discount window are governed in Regulation A of the Federal Reserve Board of Governors and various Operating Circulars. A summary of the different lending programs and links to various agreements financial institutions are required to sign in order to establish access to the Fed's discount window may also be found on a dedicated website.[3] There is also no single document providing a fully-fledged

[3] See www.frbdiscountwindow.org.

description of the various open market operations. However, on the positive side, it should be noted that the Trading Desk's annual report provides a thorough summary on developments in the federal funds market and trends in the conduct of open market operations (e.g. Federal Reserve Bank of New York Markets Group 2006). In addition, ample statistics on current open market operations are made available on the Fed's website.

In terms of clarity and coherence of published information, the RBA and the SNB perform similar to the Fed, but the level of detail is somewhat lower. Rules and procedures of the SNB's open market operations and its borrowing facility are contained in specific guidelines (SNB 2006b), while the provisions for reserve requirements may be found in the National Bank Ordinance. Information released on the conduct of open market operations is relatively scarce, as summary results of open market operations are published on a weekly basis only. Also, separate from a short section on the implementation of monetary policy in the annual report, the SNB refrains from commenting on developments in Swiss francs money markets.

RBA (2003) contains a short summary of monetary policy implementation in Australia, while specific operational notes on the RBA's website provide somewhat more detailed information on open market operations and standing facilities. The RBA also releases some statistical data regarding ongoing open market operations but, apart from a short explanation of its own operations in the annual report, it generally abstains from reviewing and commenting specific developments in money markets.

Comparative and Historical Reviews

Comparisons of central banks' operational frameworks as well as reviews of how individual central banks' procedures have evolved over time are another valuable source of information to improve our understanding of how monetary policy is implemented in practice. To my knowledge, Borio (1997) contains the most thorough comparison of alternative operating procedures. The survey comprehends a cornucopia of very detailed information on the operational targets and monetary policy instruments of 14 central banks in industrialized countries.[4] It also points out how monetary policy implementation and the strategic elements of monetary policy are connected and provides some theoretical background on banks' reserve demand and how it is related to the functioning of the interbank large-value payment system. However, the survey's most remarkable revelation is the astonishing diversity of the reviewed operating procedures.

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[4]The survey is based on BIS (1997), which includes detailed descriptions of the operational frameworks of the reviewed central banks.

An even more comprehensive but less detailed review of operational frameworks is contained in Buzeneco and Maino (2007). Their review draws on a database on monetary policy instruments maintained by the International Monetary Fund, which in 2004 contained information on central banks in 25 developed, 13 emerging, and 33 developing countries. Not surprisingly, central banks in developed and emerging countries are found to rely relatively more on market-based instruments such as open market operations and standing facilities, whereas developing countries still rely to some extent on direct instruments such as interest rate or credit ceilings, a fact that is explained by less developed money markets or institutional shortcomings. Moreover, by documenting the evolution of operational frameworks over time, the authors are able to identify a number of interesting trends. In particular, there is evidence that in developing countries the reliance on direct instruments has generally decreased, while in developed countries the instrument mix has become more diverse.

Focusing on a group of eleven smaller Western European countries, Forssbœck and Oxelheim (2007) analyze the relationship between the central bank's open market operations and the development of money markets in the 1980s and 1990s. Beyond motives and reasons for financial deregulation that are valid for the financial sector as a whole, the authors argue that central banks had additional policy motives for promoting the formation of efficient money markets. In particular, as previous monetary policy instruments such as regulations, controls and restrictions became increasingly ineffective or unavailable, central banks needed an arena in which to conduct open market operations in order to control the supply of liquidity to the banking system with more flexibility and with greater accuracy. However, they also document a significant degree of heterogeneity with respect to the development of operational frameworks and the structure of money markets, which is at least partly explained by *ad hoc* policy decisions.

A more focused comparison of the ECB and the Fed may be found in Borio (2001), Blenck et al. (2001) and Bartolini and Prati (2003), with the former two studies also including the Bank of Japan. These surveys document a number of similarities and differences in the implementation of monetary policy. The most notable similarity is the universal use of the overnight rate as the operational target, whereas the main difference is the relative weight given to individual monetary policy instruments.[5] In particular, in contrast

[5]In March 2001, the Bank of Japan replaced its traditional operating target, the uncollateralized overnight call rate, by the outstanding balance of the current accounts held by financial institutions at the Bank of Japan. However, during the whole period of monetary easing, which ended in March 2006, the Bank of Japan was committed to a zero interest rate policy. Strictly speaking, the quantitative target for outstanding balances was there-

to the other two central banks, the Eurosystem's reserve requirements are relatively high. The ECB also provides both a borrowing and a deposit facility, whereas the others only provide a borrowing facility. Reserve requirements and standing facilities thus play a more prominent role in the ECB's framework. Since these instruments effectively contribute to the smoothing of short-term interest rates, the ECB is able to follow what Bartolini and Prati (2003) call a "hands-off" approach regarding open market operations, conducting regular operations only once a week. In contrast, particularly due to the low level of reserve requirements in the U.S. the Fed's approach is more "hands-on": In order to keep the federal funds rate close to target, the banking system's liquidity needs to be fine-tuned by means of (almost) daily open market operations. And owing to large shifts in autonomous liquidity factors relative to the size of Japanese banks' balances, the Bank of Japan even conducts several operations a day.

Sellon and Weiner (1997) compare the operating procedures of the Bank of Canada, the Bank of England and the Reserve Bank of New Zealand. At that time, these central banks were implementing monetary policy without reserve requirements.[6] As a consequence, they were managing the supply of reserves rather actively by means of at least daily open market operations. In Canada, volatility of interest rates was further mitigated by a narrow interest rate corridor defined by the rates of the standing facilities.[7]

Pondering on the potential reasons for the observed heterogeneity among central banks, Blenck et al. (2001) argue that the differences reflect historical traditions rather than explicit design choices. To the extent this is the case, careful examination of how operational frameworks have evolved over time should add to our understanding of current operating procedures. In this respect, Bindseil (2004a) provides a concise account of the main stages of development of the operational frameworks of the Bank of England, the Fed and the Bundesbank, suggesting that the evolutionary path was typically far from straight-lined and often resembled a process of trial-and-error. One is left with the impression that over extended periods of time these central banks did not have a clear concept of how monetary policy should be implemented. This is probably most apparent in the examination of the Fed's long lasting seesaw regarding its operational target between 1920 and the end of the 1980s. During that period, the Fed's theoretical idea was to steer some reserve concept, which would then impact via the money multiplier broader

fore only an additional operational target. See Ito (2006) for a critical review of the Bank of Japan's experience with the zero interest rate policy and quantitative easing.

[6] The Bank of England (re-)introduced reserve requirements in 2006.

[7] A similar corridor system was adopted by the Reserve Bank of New Zealand in 1999 and the Bank of England in 2006.

monetary aggregates and, eventually, ultimate objectives such as inflation or economic growth. However, as argued by Bindseil (2004b), strictly following this so-called "reserve position doctrine" would have led to very high interest rate volatility. Therefore, with the short exception of the period from 1979 to 1982, the Fed pursued at least an implicit target for the federal funds rate, although it pretended not to do so.

Other historical reviews of the operating procedures of individual central banks are usually included in more comprehensive reviews of a central bank's history. For instance, the Fed's history is documented in Friedman and Schwartz (1963), Meulendyke (1988, 1992 and 1998) and, more recently, Meltzer (2003). However, for other central banks, it is more difficult to find independent and recent historical reviews. If available, they are either published by central banks themselves (and are therefore often not overly critical), or they are somewhat outdated. Examples falling into the first category are Deutsche Bundesbank (1995) and SNB (2007), whereas Sayers' (1976) review of the Bank of England is an example for the second category.

Research on Interbank Money Markets

Monetary policy is implemented by affecting the conditions that equilibrate supply of and demand for reserves in the interbank money market. Research on interbank money markets is thus closely related to the analysis of central banks' operational framework. Furthermore, most of the more recent research on the operational framework builds on modeling approaches that have been used in research on interbank money markets for quite some time. It is thus sensible to first discuss this strand of literature.

In the interbank money market, banks borrow and lend reserves at short maturity among each other, either on an unsecured or secured basis. Banks' demand for reserves, i.e. balances maintained on accounts with the central bank, are thus a key element of all money market models. The seminal work on banks' liquidity management is Poole (1968) who analyzes a risk-neutral bank's demand for reserves in the presence of reserve requirements and stochastic payment flows.[8] From the market's perspective, the main proposition is that if banks are required to meet reserve requirements only on average over a maintenance period lasting several days, and to the extent that reserves held on any day during the maintenance period are perfect substitutes, banks' optimizing behavior implies that the market clearing overnight rate on day t must equal the expected overnight rate on day $t+1$, and by iteration it must be equal to the overnight rate expected to pre-

[8] Various extensions of the model suggested by Poole (1968) are discussed in Baltensperger (1980) and Baltensperger and Milde (1987).

vail on the last day of the maintenance period (day T). Or more formally: $i_t = E_t\, i_{t+1} = \ldots = E_t\, i_T$, where i_t is the overnight rate on day t. According to this so-called martingale property, overnight rates are expected to remain constant and any changes in interest rates within a reserve maintenance period are not predictable. The logic behind the martingale hypothesis is straightforward: If changes of overnight rates were predictable, banks would demand more (less) reserves on days with comparatively low (high) rates, which in turn would put upward (downward) pressure on the overnight rate. By bidding up low rates and bidding down high rates any predicted differences between current and future overnight rates would be eliminated. The martingale property thus corresponds to the only sustainable equilibrium.

However, the martingale property is usually not supported by empirical evidence on overnight rates in interbank money markets. For instance, in the case of the U.S. federal funds market, it is well documented that both the level and the volatility of the federal funds rate follow predictable patterns over the two-week reserve maintenance period, which starts on a Thursday and ends two weeks later on so-called Settlement Wednesday (see e.g. Spindt and Hoffmeister 1988, Hamilton 1996, Furfine 2000 and Bartolini et al. 2001 and 2002). In particular, the federal funds rate tends to fall up through the second Friday and rises back up towards the end of the maintenance period. Moreover, while the volatility of the federal funds rate is increasing throughout the reserve maintenance period and peaks on Settlement Wednesday as suggested by the simple rational expectations model in Eagle (1995), it also exhibits additional day-of-the-week and calendar day effects. Non-martingale behavior and specific volatility patterns have also been documented for euro overnight rates (see e.g. Cassola and Morana 2003 and Würtz 2003). Furthermore, Prati et al. (2003) and Bartolini and Prati (2006) provide ample evidence for similar, though not the same, regularities in the mean and the volatility of overnight rate dynamics in other money markets.[9]

In the mid 1980s, explaining and rationalizing the deviations from the martingale property became the topic of interest of various economists. Building on the analytical framework developed by Poole (1968), many attempts were made to augment the basic reserve demand model by additional institutional features of the money market microstructure. In retrospect, two interesting developments in this strand of literature stand out. First, it is striking that until the late 1990s theoretical and empirical research was largely limited to the U.S. federal funds market, but the advent of the euro seems to

[9]The papers cited in this paragraph focus on the statistical patterns of overnight interest rates. See Furfine (1999), Demiralp et al. (2004) and Bartolini et al. (2005) for more details on the microstructure of the U.S. federal funds market and Hartmann et al. (2001) and Hartmann and Valla (2008) for the euro money market.

have spurred interest in the analysis of European money markets. Second, and more importantly, earlier contributions focused almost exclusively on the demand side of the market, whereas the supply side, i.e. the way central banks intervene in the market, was largely neglected. Indeed, while it was widely recognized that some features of the operational framework such as specific rules and procedures of reserve requirements and the configuration of standing facilities affected banks' demand for reserves—and thus eventually equilibrium interest rates—, the interaction between commercial banks' reserve management and the technicalities of the central bank's liquidity provision by means of open market operations was hardly paid attention to. Interestingly, this also changed around the turn of the century, when various economists started to integrate the central bank's liquidity management more realistically into money market models.

First generation money market models, i.e. those directing attention primarily to the demand side, typically focus on the role and impact of particular institutional features. Specific attention has been paid to market frictions such as transaction costs (Kopecky and Tucker 1993, Clouse and Dow 1999, and Bartolini et al. 2001); reserve accounting conventions such as the fact that reserve balances held before holidays or weekends count two or three days or the Fed's carry-over provisions which allow banks to carry forward small reserve deficiencies or surpluses into the next maintenance period (Spindt and Hoffmeister 1988, Griffiths and Winters 1995); payments activity in the interbank payment system (Furfine 2000); or penalties on end-of-day overdrafts (Pérez Quirós and Rodríguez Mendizábel 2006). A common implication of these institutional features is that reserves held on different days of the maintenance period are not perfectly substitutable and hence the martingale property of overnight rates may not hold. For instance, consider the impact of end-of-day overdraft penalties. Assuming that a bank targets the same end-of-day reserve balances throughout the maintenance period, the probability of incurring a (costly) end-of-day overdraft would be the same on any day, but the probability of having (costly) excess reserves would increase day by day. Moreover, once the bank has accumulated all required reserves it becomes "locked-in" for the rest of the maintenance period. In order to avoid lock-in situations, banks might target somewhat lower end-of-day reserve balances in the beginning of the maintenance period and higher balances towards the end (back-loading). Assuming a constant supply of reserves throughout the maintenance period, back-loading of reserve demand puts downward pressure on overnight rates in the early days of the maintenance period and upward pressure towards the end (Pérez Quirós and Rodríguez Mendizábel 2006).

Second generation money market models allow for a more explicit role of central bank liquidity management. In the two-period reserve management model by Nautz (1998), banks may borrow reserves in the interbank money market on either period, or from the central bank via open market operations in the second period. As of period one, the repo rate and the amount that will be allotted by the central bank in the open market operation are uncertain. As one would expect, banks increase their reserve demand in the first period if refinancing via the future open market operation is expected to be more expensive. It is more surprising, however, that the demand of risk-neutral banks is also increasing in the level of uncertainty about future refinancing conditions. This suggests that the central bank might influence current money market conditions by being more or less vague about its intentions for future open market operations.

The interaction between the central bank's supply of reserves and banks' optimizing behavior is further analyzed in a number of other papers. For instance, Bartolini et al. (2002) show how different liquidity management strategies on the part of the central bank affect the pattern of equilibrium federal funds rates within a maintenance period. Also, different patterns of interest rate volatility can be interpreted as a reflection of the confidence with which market participants view the Fed's commitment to target the federal funds rate by offsetting the impact of autonomous liquidity shocks. Moreover, Bartolini et al. (2001) demonstrate that by increasing the supply of reserves the central bank is able to dampen the upward pressure on overnight rates on high-demand days. Furthermore, assuming that the central bank's supply of reserves is such that it matches expected demand at an interest rate consistent with the current target level, Moschitz (2004) finds empirical support for a significant liquidity effect in the euro overnight market: A permanent change in reserve supply of one billion euro moves the overnight rate eight basis points into the opposite direction, although the adjustment in interest rates is rather sluggish.[10] In contrast, purely transitory supply changes have no effect at all on the overnight rate. This suggests that within the context of an operational framework that allows for reserve averaging, the liquidity effect should not be estimated on a daily frequency, but rather over the whole reserve maintenance period.[11]

[10] A change in reserve supply is considered to be permanent if it prevails until the end of the current maintenance period. Also, in order to appraise the magnitude of the estimated liquidity effect, note that the level of aggregate reserves in the considered time period was in the range of 100 to 130 billion euro.

[11] The importance of adequately taking into account the detailed institutional arrangements of monetary policy implementation when measuring the liquidity effect is further discussed in Carpenter and Demiralp (2006b and 2008).

Research on the Operational Framework

For the purposes of this study, research on specific aspects of the operational framework is the most relevant strand of literature. But although it has been rapidly growing in recent years, only a handful of studies can claim to be both normative and comprehensive—in the sense of analyzing the interplay of different monetary policy instruments—, most notably the textbooks by Bindseil (2004a) and Neyer (2007) and the papers by Bindseil and Würtz (2007), Kempa (2007) and Whitesell (2006).

Bindseil (2004a) provides probably the first and to date the most comprehensive normative analysis of the operational framework. Based on a historical review of the operational framework of major central banks, he demonstrates how the individual monetary policy instruments are closely related to each other, thereby providing evidence that the operational framework should be analyzed and assessed as a whole. Against the background of the institutional features of the ECB's operational framework, Neyer (2007) develops a model framework which allows to analyze banks' liquidity management and the interaction with central bank interventions in the money market. The framework is used to analyze specific experiences of the euro area, such as the observed episodes of under- and overbidding in the ECB's tender operations, to evaluate a number of recent changes and to propose further measures to improve the effectiveness of the ECB's operational framework. Specific attention is paid to the heterogeneity of the European banking sector and the Eurosystem's collateral framework for central bank credit operations, two issues that are of particular importance in the context of the European monetary union.

Combining interest rate corridor systems with different regimes for reserve requirements, Whitesell (2006) investigates the performance of different theoretical operational frameworks. In particular, he stresses the importance of symmetric opportunity costs in a corridor system. Kempa (2007) uses a simulation approach to compare the behavior of commercial banks and the overnight rate under different institutional setups. He is particularly interested in the impact of different central bank liquidity management strategies and alternative reserve requirement regimes on commercial banks' liquidity management and equilibrium market rates. In another interesting study, Bindseil and Würtz (2007) provide a classification of monetary policy implementation approaches, pointing out that there is a continuum of approaches, with some relying more on open market operations, and others more on standing facilities. In this respect, they also note that the distinction between some open market operations and standing facilities is not always as clear-cut as one might think. For instance, a daily fixed-rate tender with full allotment is basically the same as a standing borrowing facility.

With the exception of the literature refered to in the last two paragraphs, research on the operational framework has typically focused on individual monetary policy instruments. For instance, the purpose of reserve requirements as a means to stabilize banks' reserve demand and to increase interest-rate elasticity has been analyzed quite extensively (see e.g. Stevens 1991, Feinman 1993, and Bindseil 1997). In this respect, a number of authors have studied the consequences of the pronounced decline in U.S. reserve requirements, which set in in the early 1990s (Sellon and Weiner 1996, Clouse and Elmendorf 1997, and VanHoose and Humphrey 2001).[12] Reducing the sensitivity of banks' demand for reserves to variations in the federal funds rate, the decline in reserve requirements induced an increase in funds rate volatility. Demiralp and Farley (2005) demonstrate that in order to contain funds rate volatility, the Fed gradually increased the frequency of its open market operations and, if needed, also carried out larger transactions than before. Since the stabilizing effect of reserve averaging was (partly) lost due to banks' limited ability to substitute reserves across days of the maintenance period, the Fed had to offset shocks to banks' reserves more actively on a day-to-day basis. On a more general level, Clinton (1997) investigates the implications of a regime with zero reserve requirements, concluding that in order to ensure a determinate (potentially zero) demand for reserve balances, other features of the operational framework would have to be adopted accordingly. Similarly, Davies (1998) shows that periodic reserve requirements that allow for averaging can have a stabilizing role for overnight rates even when the level of reserve requirements is zero, provided that end-of-day overdrafts are not penalized.

Although standing facilities, and in particular borrowing facilities, have been offered by most central banks for most of the time, they have not received much attention in the academic literature. However, in recent years, the importance of standing facilities for the implementation of monetary policy seems to have been more widely recognized and a number of authors now advocate a more prominent role for this instrument in central banks' operational framework. In particular, Woodford (2000 and 2001) and Whitesell (2003) campaign for the so-called corridor or channel system, which is characterized by two standing facilities providing a symmetric corridor around the overnight target rate. Whenever the central bank adjusts the target rate, the rates of the standing facilities are shifted correspondingly. Besides providing a ceiling and a floor to market interest rates, standing facility rates have a strong influence on market interest rates throughout the maintenance

[12]The reasons for the decline in reserve requirements in the U.S. are discussed in more detail in Section 4.2.3.

period, as market participants' decisions to borrow or lend funds reflect their expectations of having recourse to either of the standing facilities. Another appealing feature of the corridor system is that banks' demand for reserves only depends on the relative position of the overnight rate within the range set by the standing facilities (but not on the absolute level of interest rates), and hence adjustments in the target rate will not shift the demand for reserves. Therefore, instead of estimating a demand curve, the central bank only needs to know banks' demand for reserves at the target rate. A symmetric corridor thus facilitates the central bank's liquidity management considerably.

The bulk of research on monetary policy instruments deals with open market operations. From a practitioners point of view, two issues are of paramount importance. First, how much liquidity should the central bank supply by means of open market operations? And second, how should open market operations be conducted? Although the first issue is more crucial than the second, it has received significantly less attention. There are a few exceptions, though. Bindseil (2000a and 2001) analyzes the interaction between the central bank and commercial banks assuming different central bank liquidity management strategies within the context of a simple money market model. Focusing on the role of autonomous liquidity factors for central bank liquidity management, he shows that publishing the central bank's forecasts of autonomous liquidity factors before open market operations are conducted is desirable as it allows commercial banks to better extract the central bank's operational intentions. However, the result hinges on the assumption that the central bank has no other means to signal its policy stance. For instance, if the central bank simply were to announce its intentions by communicating the target level of interest rates (as most central banks do these days), commercial banks would not have to extract the policy intentions from, say, the central bank's allotment decisions. On a rather general level, Bindseil et al. (2003) discuss the relationship between commercial banks' liquidity management and the central bank's management of the aggregate level of reserves available to the banking system. It is argued that in the specific context of the Eurosystem's operational framework, which is characterized by high reserve requirements that allow for averaging over a one-month period, short-term interest rates are determined exclusively by the available aggregate level of reserves relative to reserve requirements. This suggests that the ECB, in order to control short-term interest rates, may focus only on aggregate levels, but need not worry about institutional details of the interbank money market, the distribution of funds among banks or the volume of payments settled through the interbank payment system. Moreover, against the background of the general trend of increasing central bank transparency, Carpenter and Demiralp (2006a) investigate how the Fed adjusts the supply of reserves in reaction to anticipated changes in the target federal funds rate and corresponding shifts in reserve demand within a maintenance period. They present evidence that demand shifts are only partially accommodated by the Fed and, consequently, the federal funds rate tends to move in the direction of an anticipated policy change (so-called announcement effect). In line with the Fed's own explanation for incomplete accommodation (see Federal Reserve Bank of New York Markets Group 2005), they show that fully offsetting an anticipated rate increase would require to flood the market with a substantial amount of reserves before and to drain these reserves from the market after the target change becomes effective. This would leave the market with very low reserve balances for the remainder of the maintenance period, so that reserve requirements would loose their stabilizing function and funds rate volatility would soar up.

As mentioned, there seems to be more academic interest in how open market operations are or should be conducted. Generally speaking, open market operations allow central banks to auction off a specific amount of a homogenous good (reserves), with commercial banks submitting their bids for that good. The procedure thus resembles a multi-unit auction. Intuitively, in order to determine the appropriate tender procedure one would thus be inclined to apply the results of the literature on multi-unit auctions. But as pointed out by Morgan (2001), the general results on multi-unit auctions are difficult to apply to open market operations. In particular, while auction theory assumes that the auctioneer—here the central bank—either maximizes its revenue or aims at an efficient resource allocation, this is not necessarily the case in the context of open market operations.[13] Indeed, other considerations such as the ability to signal the stance of monetary policy, transparency, operational simplicity, or the perceived fairness of the auction form may also play a role in the design of the tender procedure.

Against this background, various authors have analyzed the effectiveness of different tender procedures and allotment rules, and in particular their implications on banks' bidding behavior. A main driver for these analyzes was the experience of extreme overbidding in the fixed rate tenders conducted by the ECB during the first 18 months after the introduction of the euro in January 1999.[14] For instance, Ayuso and Repullo (2003) propose a theoretical model of the tender procedures used by the ECB. Analyzing banks' bidding behavior under both fixed and variable rate tenders, they show that the equilibrium outcomes depend on the central bank's preferences. Under

[13] An auction is considered to be efficient if it puts goods into the hands of the buyers who value them most.

[14] A more thorough discussion of the ECB's experience with overbidding is provided in Section 4.2.2.

symmetric preferences, that is when the central bank values positive or negative deviations of overnight rates from the target rate the same, both auction formats have the same multiple equilibrium outcomes. However, when the central bank's loss function penalizes interbank rates below the target more heavily, fixed rate tenders have a unique equilibrium characterized by extreme overbidding. Moreover, even though variable rate tenders have in general multiple equilibria characterized by varying degrees of overbidding, they show that an equilibrium without overbidding can be obtained when the intended total allotment is preannounced by the central bank. Neyer (2003) also analyzes banks' bidding behavior and reserve management within the ECB's operational framework. She finds that in the case of fixed rate tenders, (expected) interest rate changes within the maintenance period will lead to under- and overbidding in the main refinancing operations. Similarly, in case of variable rate tenders, one should expect to observe underbidding and an extremely uneven provision of reserves when banks expect the interest rate to increase within the maintenance period. To overcome these phenomena, she suggests that refinancing operations should not hang over into the next maintenance period.

In a series of papers, Välimäki also investigates banks' bidding behavior under different tender procedures and allotment rules. Focusing on fixed rate tenders, Välimäki (2001) demonstrates how banks' optimal bidding is affected by the central bank's target—that is whether it pursues an interest rate target or a liquidity target—and the allotment rule (i.e. full or partial allotment). In Välimäki (2002a), the overbidding phenomenon is explained by the positive spread between market interest rates and the ECB's main refinancing rate, which resulted from the combination of an expected interest rate hike and the ECB's liquidity-oriented allotment decisions. Analyzing variable rate tenders in a two-day maintenance period, Välimäki (2002b) shows that the amount of liquidity demanded in the first period depends on the tender rate expected for the second period. Similarly, in a two-day maintenance period model, Bindseil (2002) analyzes the impact of various tender and allotment rules on banks' bidding behavior with and without expected rate changes. He argues that fixed rate tenders would be the adequate choice under conditions of stable interest rates, whereas the fixed rate tender tends to have some specific disadvantages relative to variable rate tenders when the market expects changes in the target rate within the maintenance period. Furthermore, Bindseil (2005) claims that observed instances of underbidding or periods of extreme overbidding can be related to central banks' inadequate liquidity management and argues for a neutral liquidity management strategy, i.e. the supply of liquidity should be such that the money market rate equals the minimum bid rate. Finally, Bindseil and Würtz (2007) discuss the pros and cons of fixed and variable rate tenders, concluding that the relative merits of the two may depend on other aspects of the operational framework.

Conclusions

What tells us the literature reviewed in this section regarding the design of an effective and efficient operational framework for the implementation of monetary policy? The short and somewhat disillusioning answer is: not too much. Indeed, the literature provides only limited guidance on how to best specify and combine the different monetary policy instruments. The main shortcoming is that the interdependence of monetary policy instruments and the performance of alternative operational frameworks are hardly ever scrutinized. Rather, research typically focuses on very specific issues which are analyzed within the context of a particular operational framework. A major flaw of this approach is that the results are not generally applicable, as they do not necessarily hold within the context of another operational framework. This is nicely illustrated by research on tender procedures for open market operations. In some circumstances, fixed rate tenders are found to be unsatisfactory since they can give rise to extreme over- or underbidding, whereas they perform reasonably well in other circumstances. This suggests that the effectiveness of individual monetary policy instruments depends at least to some extent on how other instruments are specified. Recognizing that the overall performance of an operational framework depends on a large number of often complex relationships between various features of monetary policy instruments, a more comprehensive approach thus seems to be more promising, if not indispensable.

The reviewed literature is also of little help with regard to the criteria by which the performance of alternative operational frameworks might be compared. Indeed, it remains often unclear what exactly the central bank aims to achieve by specifying the monetary policy instruments in one way or the other. But as long as the central bank's objectives are not explicitly spelled out, efforts to assess the performance of a specific operational framework or how it fares in comparison with other frameworks are to no avail.

These shortcomings notwithstanding, the reviewed literature is instructive in several respects. For instance, descriptions of how central banks implement monetary policy in practice, comparative assessments and historical reviews of central banks' operational frameworks are an indispensable source of information to enhance our understanding of monetary policy implementation. Also, research on money markets and specific aspects of the operational framework provides invaluable insights in how to address the relevant questions analytically. In this respect, the more recent money market models in which overnight interest rates are determined by the interaction between the central bank's liquidity management and commercial banks' optimizing behavior within the context of a specific operational framework are particularly useful. This modeling approach will be a key building block in the analytical part of this study.

1.3 Outline

The remainder of this study is divided into two parts. The first part considers a wide range of both theoretical and practical issues related with the implementation of monetary policy. Based on that, the second part introduces and discusses a number of recommendations for an effective and efficient operational framework.

Part I - Theoretical and Practical Considerations

Chapter 2 discusses the fundamentals of monetary policy implementation. In particular, it introduces the terminology and elaborates on the role of monetary policy implementation within the overall framework of monetary policy. In addition, this chapter reviews the pros and cons of alternative operational targets and the motivation for reserve requirements.

Chapter 3 takes a closer look at the market for reserves, which plays a pivotal role for the implementation of monetary policy. It starts with a discussion of the role of central bank money as unit of account and generally accepted means of payment, two characteristics which make it such a unique asset and from which central banks ultimately derive their ability to control short-term interest rates. Against that background, commercial banks' demand for reserves and the central bank's supply of reserves are analyzed in some detail. Moreover, Chapter 3 also introduces a modeling framework that allows to analyze the interaction between banks' demand for and the central bank's supply of reserves.

Chapter 4 reviews and discusses the practical arrangements for the implementation of monetary policy by five major central banks: the Reserve Bank of Australia, the European Central Bank, the Swiss National Bank, the Bank of England, and the Federal Reserve. While the cross-sectional comparison establishes a lot of common ground, it also reveals a number of striking differences in the way monetary policy is implemented. Moreover, this chapter also discusses the experiences with and adjustments to operational frameworks over the last decade, including the recent period of financial crisis.

Part II - Towards an Effective and Efficient Operational Framework

Chapter 5 first argues that in terms of assessing the performance of any operational framework three criteria are particularly relevant: (i) the degree to which the operational framework allows to control the overnight rate; (ii) the extent to which it contributes to a liquid and competitive interbank money market; and (iii) the social costs associated with the implementation of monetary policy. An operational framework which performs well with respect to the first two criteria is said to be effective, while one that is associated with low social costs can be considered as efficient.

Chapter 6 introduces an operational framework that performs well in terms of the above stated criteria. The main features of the proposed operational framework are condensed in 15 specific recommendations.

Chapter 7 examines the the main features of the proposed operational framework in more detail. In particular, it analyzes and discusses how the specific features of reserve requirements, standing facilities and open market operations are related to each other and why any changes to the proposed features will negatively affect the performance of the operational framework.

Finally, Chapter 8 summarizes the main conclusions.

Part I

Theoretical and Practical Considerations

Chapter 2

Fundamentals

This chapter sets the stage for the remainder of this study by introducing and discussing some fundamentals of monetary policy implementation. Section 2.1 starts by providing a definition of what is meant by 'monetary policy implementation' and familiarizing the reader with the relevant terminology. Section 2.2 reviews the role of monetary policy implementation within the overall framework of monetary policy. Essentially, it will be argued that monetary policy consists of a strategic and an operational level, with the operational target providing the nexus between the two. Focusing more closely on the pros and cons of alternative operational targets, Section 2.3 will then reveal that the overnight interest rate is the most suitable operational target. Finally, based on a review of different historical motivations for the imposition of reserve requirements, Section 2.4 will make the case that apart from their role as monetary policy instrument, there is no other convincing motivation. This implies that the rules and procedures governing reserve requirements can focus on promoting the effective and efficient implementation of monetary policy.

2.1 Terminology

Very often, the implementation of monetary policy is exclusively associated with the central bank's day-to-day operations in the money market. These so-called open market operations allow the central bank to align the supply of reserves with banks' demand for reserves such that the resulting equilibrium market interest rate is close to the central bank's target rate. For the purposes of this study, however, the focus needs to be broader. Indeed, an isolated analysis of central banks' conduct of open market operations could even prove fallacious, since to fully understand how open market operations affect market interest rates, they need to be related to the other monetary policy instruments, i.e. reserve requirements and standing facilities. Moreover, although the appropriate day-to-day use of monetary policy instruments is crucial for achieving central banks' objectives, the *ex ante* definition of the rules and procedures governing the use of these instruments is at least as important, and intellectually more interesting and challenging. For to the extent that these rules and procedures are properly defined, the effective use of the instruments on a day-to-day basis becomes straightforward.

Following Bindseil (2004a), **monetary policy implementation** thus consists of the following three elements:

(i) the selection of an operational target;

(ii) the establishment of an operational framework describing the rules and procedures of the monetary policy instruments used to control the operational target; and

(iii) the day-to-day use of monetary policy instruments.

This definition contains several key terms that will be used throughout this study: the operational target, the operational framework and the monetary policy instruments. In the remainder of this section, these terms are defined and briefly explained.[1] Defining these terms at the outset is all the more important because, unfortunately, they are not always precisely and consistently used. In particular, there is often confusion with respect to the distinction between the operational target and monetary policy instruments. For instance, in macroeconomic analysis, the short-term interest rate is often referred to as the instrument of monetary policy, whereas from the perspective of monetary policy implementation it is the operational target.

The **operational target** is an economic variable that the central bank both wants to control and—at least to a high degree—can control, with control exerted on a daily basis by the use of its monetary policy instruments. The operational target thus needs to be both reasonable and feasible. For an economic variable to be a reasonable operational target, it needs to play a key role in the monetary transmission mechanism, i.e. there should be a clear linkage between the operational target and the ultimate objectives of monetary policy. If there was no such linkage, even perfect control of the operational target would be useless and the central bank had better choose another economic variable as operational target. For an economic variable to be a feasible operational target, it needs to be controllable by the central

[1] The definitions follow Bindseil (2004a).

bank. If a specific economic variable plays an important role in the monetary transmission mechanism and is closely linked with the ultimate objectives, but the central bank is not able to exert tight control, the said economic variable is hardly a useful operational target. In practice, short-term interest rates turn out to meet both criteria rather well. This also explains why most central banks use a short-term money market interest rate as operational target, usually the overnight rate.[2] The specific target level for the short-term interest rate is typically set by the monetary policy decision-making committee for the inter-meeting period, while the central bank's implementation desk is responsible for achieving the target on a daily basis by making appropriate use of the monetary policy instruments. Moreover, it should be noted that the operational target also plays a key role in central bank communication. The announced target rate indicates the current stance of monetary policy, and hints on the future path of the target rate can shape the market's expectation regarding future policy.

A **monetary policy instrument** is a tool that the central bank makes use of to achieve the intended level of the operational target. In contrast to the latter, the central bank has perfect control over its instruments.[3] Three monetary policy instruments are widely used by central banks in developed countries: reserve requirements, open market operations and standing facilities. They are sometimes referred to as indirect or market-based monetary policy instruments. In the past (and still today in some developing and emerging countries), central banks often also relied on so-called direct or administrative controls to implement monetary policy. Typical examples of direct instruments are interest rate controls and credit ceilings which put upper limits on commercial banks' lending rates or total lending to non-banks, respectively. Besides being at odds with the principles of a market system, it is now widely recognized these kind of price or quantity restrictions entail a number of drawbacks: they imply various market distortions, inhibit competition in the banking sector and provide incentives to conceive measures to circumvent their effectiveness, and they generally lack the requisite flexibility for effective monetary policy implementation, especially when market conditions change abruptly. For all these reasons, direct instruments will be disregarded in this study.[4]

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[2] Section 2.3 will explain in more detail why the overnight rate is generally considered to be the most appropriate operational target.

[3] Note that in macroeconomic monetary policy analysis it is usually assumed that the central bank has perfect control over the short-term interest rate, hence the short-term interest rate is often referred to as the monetary policy instrument.

[4] See Allen (2004) and Buzeneca and Maino (2007) for a discussion of direct controls.

Reserve requirements impose a minimum level on banks' reserve accounts with the central bank. Banks may have to comply with reserve requirements either on a daily basis or, more often, as an average over a period of several days or weeks, the *reserve maintenance period*. In case of a reserve deficiency at the end of the reserve maintenance period, the central bank typically applies a financial penalty. Typically, a bank's reserve requirement is calculated by multiplying the reserve ratio for each category of items in the reserve base with the amount of those items on the bank's balance sheet. The *reserve base* is the sum of the eligible balance sheet items that (in particular liabilities such as transaction and sight deposits) that constitute the basis for calculating the reserve requirement of a bank. The *reserve ratio* for all eligible balance sheet items may be uniform or differentiated. There is no restriction on an individual bank's pattern of fulfillment of its reserve requirement over the maintenance period. It may spread its reserve holdings evenly over all days (neutral position), or it may hold comparatively more reserves in the beginning of the maintenance period (front-loading) or on the last days (back-loading). Required reserves may be remunerated at or below market rates, or not at all.

The purpose of reserve requirements is twofold: they increase banks' demand for reserves and, provided they allow for averaging over the reserve maintenance period, reserve requirements also increase the interest rate elasticity of reserve demand. Higher demand for reserves than in the absence of reserve requirements might be desirable for two reasons. First, it enlarges the structural liquidity deficit of the banking system vis-à-vis the central bank. In case of a structural liquidity deficit, banks regularly have to refinance themselves at the central bank, either through open market operations or at the borrowing facility. Hence, reserve requirements might be a prerequisite for other monetary policy instruments to be effective. Second, if reserve requirements are binding and thus determine the marginal demand for reserves, the demand for reserves becomes more predictable, which facilitates the central bank's liquidity management. The interest rate elasticity of reserve demand can be increased if reserve requirements provide for averaging over the reserve maintenance period. During the maintenance period, banks tend to be relatively indifferent about the amount of reserves they hold, provided that they expect the opportunity cost of holding reserves to be more or less constant over the remainder of the reserve maintenance period. Thus, if banks don't expect any changes of overnight rates, the demand for reserves would be very elastic around the level of the overnight rate expected to prevail in the future. The increased interest rate elasticity of reserve demand would help to mitigate the impact of reserve supply shocks on the overnight rate and hence contribute to a reduction of interest rate volatility.

Open market operations are monetary policy operations conducted at the initiative of the central bank. Originally, only outright purchases or sales of securities were considered as open market operations. Meanwhile, however, the term is used for any kind of operations that are initiated by the central bank with the intention to manage the supply of reserves in the money market, including in particular reverse operations such as repurchase agreements (repos) or foreign exchange swaps with limited maturity.

Normally, open market operations are conducted in the form of specific auctions.[5] The institutional details of these auctions may differ along several dimensions such as the type of auction (e.g. fixed rate tender or variable rate tender), the range of counterparties, the allotment method, the maturity and the frequency of operations, eligible collateral or settlement procedures. In a *fixed rate tender*, the interest rate is pre-announced by the central bank and banks simply submit the amount they wish to obtain at that interest rate. Alternatively, in a *variable rate tender*, banks submit interest rate/quantity pairs, i.e. they specify which amount they wish to obtain at a specific interest rate. Aggregating all bids then yields a standard downward-sloping demand curve. In both auction types, the central bank may announce the total allotment amount either in advance or, more often, after having received all bids. If aggregate bids exceed the total amount of reserves to be allotted, bids are only partially satisfied. In fixed rate tenders, the submitted bids are typically satisfied pro rata. In variable rate tenders, bids with the highest interest rate are satisfied first and subsequently bids with lower interest rates are accepted, until the total amount of reserves to be allocated is allotted.[6] If at the marginal interest rate, i.e. the lowest accepted interest rate, aggregate bids exceed the remaining amount to be allotted, the remaining amount is allotted pro rata. Moreover, for variable rate tenders, one may distinguish various sub-variants. In a Dutch auction (or uniform price auction), all successful bidders pay the same (marginal) interest rate, whereas in an American (or multiple price auction) successful bidders pay the interest rate specified in their bids. Finally, there might be a one-sided restriction to bid rates, e.g. a minimum bid rate.

Open market operations affect short-term market interest rates via two channels. The first channel is the classical *liquidity effect*. By providing more (less) reserves than banks actually demand, the central bank can put downward (upward) pressure on market interest rates. However, the extent to which such a liquidity effect exists depends on the interest rate elasticity of

[5] For simplicity, this paragraph focuses on liquidity-providing open market operations. Of course, central banks may also make use of liquidity-absorbing open market operations.

[6] This holds true for open market operations conducted as repos. In case of foreign exchange swaps, the bids with the *lowest* swap point quotations are satisfied first.

banks' reserve demand and their expectations regarding future market conditions. For instance, if reserve demand exhibits high interest rate elasticity (e.g. due to reserve requirements that allow for averaging over the maintenance period) and if banks assume that the change in reserve supply is only temporary and will be fully offset during the remainder of the reserve maintenance period, no effect on short-term interest rates is to be expected. In contrast, if the change in reserve supply is expected to prevail until the end of the reserve maintenance period, an injection (withdrawal) of reserves by means of open market operations is likely to reduce (increase) current and future short-term interest rates.

As a second channel, the central bank may exploit an *arbitrage relationship* between the conditions by which it provides reserves to market participants and market interest rates. In this respect, the policy rate, that is the interest rate at which the central bank provides (withdraws) reserves to (from) the market, plays a crucial role. Consider banks' arbitrage opportunity in case of a fixed rate tender with very short maturity, say one day. As banks can choose between refinancing themselves for one day by transacting with the central bank at the policy rate or by borrowing from other banks in the interbank market at the overnight rate, one would expect the overnight rate to be closely in line with the policy rate. If it were not, there would be an arbitrage opportunity. However, in practice, banks' arbitrage opportunity is limited by the fact that the central bank is typically not willing to lend an arbitrary amount at the policy rate. Consequently, short-term market interest rates may deviate temporarily from the policy rate. The extent to which the arbitrage channel is relevant for the determination of short-term interest rates depends on the type of open market operation. For instance, while the arbitrage relationship is typically strong for repos with short maturities, it is weaker for repos with longer maturities, and even more so for outright transactions.

By and large, open market operations thus allow the central bank to manage the level of reserves available to commercial banks. It needs to be stressed, however, that the supply of reserves is typically not perfectly controlled by central banks. Indeed, as will be explained in more detail in Section 3.3.1, there are a number of factors that might affect the level of banks' reserves that are not under direct control of the central bank's monetary policy implementation desk. To the extent that the impact of these so-called *autonomous liquidity factors* on banks' reserve balances is subject to uncertainty, these exogenous shifts in reserve supply thus may complicate the implementation of monetary policy in general and the conduct of open market operations in particular.

Standing facilities are monetary policy operations conducted at the discretion of commercial banks. Two different types of standing facilities may be distinguished, the borrowing and the deposit facility. The *borrowing facility*, sometimes also called marginal lending facility, is a liquidity-providing facility that allows banks to borrow reserves from the central bank at a pre-specified interest rate, the borrowing rate (sometimes also called marginal lending rate). Such borrowing may take place through a discount or a lombard operation. In a discount operation, the bank sells short-term securities to the central bank but receives only a fraction of the nominal value of the asset, since the nominal value of the security is discounted at the prevailing discount rate. The maturity of the loan obtained through the discount facility depends on the maturity of the discounted security. In contrast, in a lombard operation, the bank obtains collateralized credit of a standardized maturity, ordinarily overnight. The lombard credit may be granted against pledged securities or by means of overnight repos. Today, most borrowing facilities are lombard facilities. The *deposit facility* is a liquidity-absorbing facility that enables banks to deposit end-of-day excess reserves at the central bank. Excess reserves are usually deposited overnight at a pre-specified interest rate, the deposit rate. Whereas borrowing facilities have a long tradition at all major central banks, deposit facilities were introduced only recently by a number of central banks.

The borrowing rate (deposit rate) is typically above (below) the target level of the overnight rate, so that the two rates constitute a corridor around the target rate.[7] By providing an effective ceiling and a floor to interest rates the standing facilities thus contribute to limiting interest rate volatility. This is particularly relevant when the aggregate supply of reserves falls significantly short of demand or is significantly in excess of demand. In these circumstances, the possibility to have recourse to standing facilities prevents an excessive tightening or loosening of money market conditions. Moreover, the borrowing facility also serves as a safety valve for individual banks that have experienced an unexpected (temporary) shortage of reserves, for instance due to unusually large net payment outflows. In these situations, recourse to the borrowing facility allows to avoid end-of-day overdrafts on reserve accounts or to cover a shortfall in required reserves.

It has to be stressed that the impact of standing facilities on short-term interest rates typically goes much further than the definition of a fluctuation

[7] In the past, many central banks also provided borrowing facilities at below market (subsidized) rates. As these below market borrowing facilities have been abandoned in the meantime by all major central banks—and this for good reasons—, they will be disregarded in the remainder of this study, with the exception of Section 4.2.3 which includes a short discussion on the recent reform of the Federal Reserve's discount window.

margin. Indeed, even if standing facilities are not used at all from an *ex post* perspective, the borrowing and the deposit rate have a strong influence *ex ante* on the determination of interest rates at any time during a reserve maintenance period. This is due to the fact that at the end of the reserve maintenance period, the market as a whole will be either short or long of reserves and will thus have to borrow from the borrowing facility (in case of an aggregate reserve shortfall) or deposit excess reserves at the deposit facility (in case of an aggregate reserve surplus).[8] On the last day of a maintenance period lasting T days, the market clearing overnight rate, i_T, will thus correspond to the weighted average of the borrowing rate i_T^b and the deposit rate i_T^d, with the weights reflecting the probabilities of an aggregate reserve shortfall or surplus, respectively. Or more formally,

$$i_T = P_T^b \, i_T^b + P_T^d \, i_T^d, \tag{2.1}$$

where P_T^b is the probability that the market as a whole will have a reserve shortfall that needs to be covered by borrowing from the borrowing facility, P_T^d is the probability that the market as a whole will have a reserve surplus, which will be deposited at the deposit facility, and where $P_T^b + P_T^d = 1$. Moreover, provided that reserves held on any day during the maintenance period are perfect substitutes, it is possible to show that overnight rates on earlier days can be expressed as follows:

$$i_t = E_t[P_T^b \, i_T^b] + E_t[P_T^d \, i_T^d], \quad t = 1 \ldots T-1, \tag{2.2}$$

where $E_t[X_\tau]$ is the expected value of variable X at day τ as of day t, with $\tau \geq t$. Regarding relationship (2.2), two comments are in order. First, note that for a given level of reserve requirements, as of day t the probabilities of a reserve shortfall or surplus depend on the liquidity conditions over the remainder of the maintenance period. Therefore, in order to assess the probabilities of having recourse to either of the two standing facilities on the last day of the maintenance period, banks need to take into account not only current liquidity conditions in the market, but also future liquidity conditions during the remainder of the reserve maintenance period, which are affected

[8] *Aggregate recourse* to standing facilities is the result of an imbalance between the banking system's liquidity needs and the central bank's supply of reserves. In contrast, *individual recourse* to standing facilities is primarily caused by an inadequate or inefficient distribution of liquidity across banks. It is therefore possible that even when the banking system as whole has excess reserves, some banks will experience a reserve deficiency which needs to be covered by borrowing from the borrowing facility.

by both the central bank's interventions in terms of open market operations and autonomous liquidity factors. Second, it needs to be stressed that Equation (2.2) holds with equality only when reserves are perfectly substitutable across days; if substitutability is limited, e.g. due to constraints other than those imposed by reserve requirements, the relationship holds only approximately.

This last caveat notwithstanding, Equation (2.2) is a good starting point to understand the functions of the three monetary policy instruments introduced above and how they are related with each other. Essentially, reserve requirements allow to stabilize the demand for reserves by increasing the substitutability of reserves across days of the reserve maintenance period, which is a key condition for Equation (2.2) to hold (approximately). Open market operations are used to adjust the supply of reserves in the market. In Equation (2.2), the classical liquidity effect associated with open market operations is captured by the impact on the (expected) values of P_T^b and P_T^d. Finally, the rates of the standing facilities not only put a floor and a ceiling to the movement of overnight rates, but also have a strong interest rate setting function. In particular, Equation (2.2) establishes that in order to affect market interest rates, central banks do not necessarily have to change the supply of liquidity (measured by P_T^b and P_T^d), but might simply change the (expected) rates of standing facilities. Therefore, by appropriately combining the monetary policy instruments at their disposal, central banks are able to affect the conditions that equilibrate supply and demand in the interbank market for reserves, thereby exercising close control on overnight rates.

The **operational framework** of monetary policy implementation provides a description of the set of monetary policy instruments that the central bank intends to use in order to control the operational target and, particularly, includes detailed rules and procedures for the regular use of these instruments. A detailed description of monetary policy instruments and the rules and procedures governing these instruments is necessary since reserve requirements, standing facilities and open market operations can be specified and combined in many different ways. The operational framework thus provides the specific set of instruments, rules and procedures which the central bank considers as most appropriate to control the overnight rate. For instance, if the central bank intends to use repos in its regular open market operations, the operational framework should precisely lay down the rules and procedures for the conduct of repos. For instance, it needs to specify the eligible counterparties, the frequency and maturity of repos, eligible assets, the tender procedure, the allotment rule or the settlement procedures.

Establishing clear and comprehensive rules and procedures for the use of monetary policy instruments has several advantages. First, it provides guidance to the central bank's implementation desk on how to implement monetary policy on a day-to-day basis. The *ex ante* definition of rules and procedures also ensures that only a limited number of decisions has to be taken on a daily basis and that these decisions are not unnecessary complex, but rather become a matter of routine. Finally, and most importantly, one should also bear in mind that the intention of monetary policy implementation is to affect the conditions at which commercial banks trade reserves in the interbank money market. The equilibrium interest rate at which banks borrow and lend reserves in the interbank market is the result of money market participants' optimizing behavior which will be strongly influenced by their perception of the central bank's intentions and future actions. To effectively manage their reserves, banks thus need a thorough understanding of the central bank's approach to control the overnight rate. The publication of the operational framework is an effective means to enhance transparency on the central bank's intentions and its use of monetary policy instruments, allowing to reduce uncertainty on the part of banks. Therefore, at least to the extent that less uncertainty on money market conditions goes hand in hand with less interest rate volatility, increased transparency and predictability regarding the implementation of monetary policy is clearly in the central bank's interest.

It is expedient to clarify the meaning a few other terms that have been tacitly introduced in the preceding discussion and that will be used throughout this study. First, the terms *reserves* and *liquidity* will be used interchangeably as a shortcut for commercial banks' reserve balances on their accounts held with the central bank (reserve account).[9] Consequently, the *interbank market for reserves* refers to the segment of the money market in which commercial banks borrow or lend reserves held with the central bank. Finally, the notion *central bank liquidity management* is used for the central bank's day-to-day provision or absorbtion of liquidity through open market operations based on its assessment of the banking system's liquidity needs.

Before moving on, recall that monetary policy implementation consists of three elements: the selection of the operational target, the establishment of the operational framework, and the day-to-day use of monetary policy instruments. Each element calls for specific central bank decisions, but the decision on the operational framework is clearly the most challenging. Indeed, regarding the the choice of the operational target, there is no doubt that the central bank should target a short-term interest rate, preferably the overnight rate (see Section 2.3). Similarly, under the proviso that an

[9]The term *commercial bank* is used to represent any institution that may open a central bank account and participate in the payment system supported by the central bank.

appropriate operational framework has been set up, the day-to-day use of monetary policy instruments is rather straightforward. Therefore, the whole trick of monetary policy implementation is to define and set up an effective and efficient operational framework.

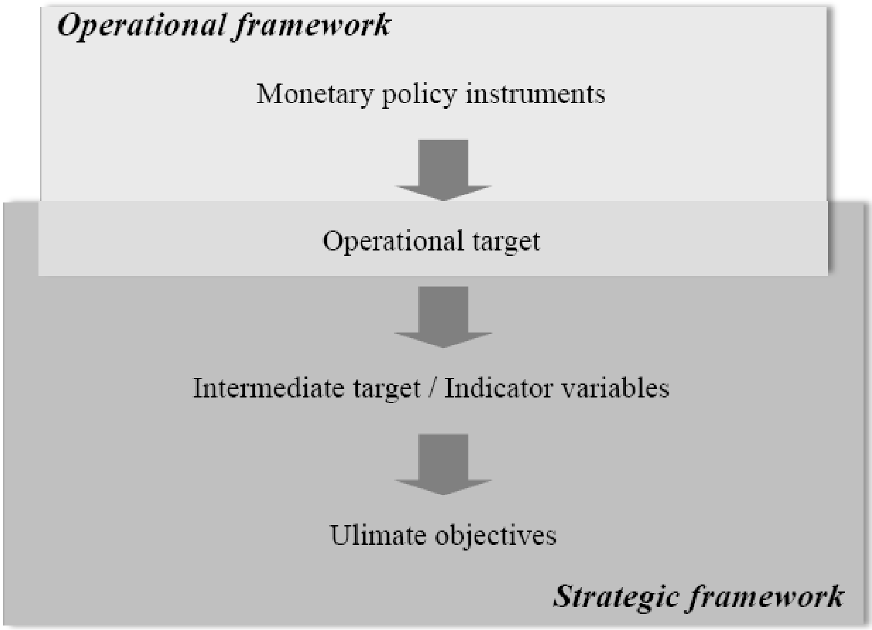
2.2 Monetary Policy Implementation within the Overall Monetary Policy Framework

Although this study focuses on the implementation of monetary policy, it should be borne in mind that monetary policy implementation is only one element within the overall framework of monetary policy. In order to explain how the implementation of monetary policy fits into the broader framework of monetary policy, and particularly how it relates to the strategic level of monetary policy, this section first recalls how monetary policy instruments and the operational target—the key variables in monetary policy implementation—relate to other variables such as intermediate targets, indicator variables or the ultimate objectives of monetary policy. Moreover, it will be argued that although the typical separation of monetary policy strategy and implementation is a useful device to facilitate monetary policy decision-making, the strategic and operational frameworks should be guided by some common underlying principles.

It is generally agreed that the ultimate objective of monetary policy is to safeguard price stability. However, the instruments at the disposal of central banks are not suited to control prices directly. They rather influence the development of prices indirectly through various channels, the transmission mechanism of monetary policy. Since the knowledge about the transmission mechanism is incomplete, there is no straightforward relationship between monetary policy instruments and the operational target on the hand—that is those variables that the central bank controls either perfectly or to a large extent—, and ultimate objectives on the other hand. In other words, monetary policy decision-makers face considerable uncertainty about the complex structure of the economy and the effects of their decisions.

In a complex and uncertain environment, reducing the complexity faced by individual decision-makers is a precondition to make well-considered decisions. In the context of monetary policy, a useful way to reduce the complexity consists in dividing the whole process from instruments to ultimate objectives into two parts that can be analyzed separately: These parts may be called monetary policy implementation and monetary policy strategy. The implementation deals with the relationship between monetary policy instruments and the operational target, whereas the strategy focuses on the relationship between the operational target, intermediate targets or indicator variables, and ultimate objectives (see Figure 2.1). One could also say that the implementation of monetary policy is concerned with money market conditions in the short-run, whereas the monetary policy strategy is concerned with macroeconomic developments in the medium- to long-run.

Figure 2.1: From Instruments to Objectives



The operational target may be considered as the fulcrum between monetary policy implementation and strategy. From the strategic (macroeconomic) perspective, the operational target is the decision variable. For instance, at the regular meetings of the central bank's monetary policy decision-making committee, decisions are made with respect to short-term interest rates, that is it is decided whether the level of short-term interest rates should be increased, cut or remain as it is. In contrast, for the implementation desk, the operational target is, as the term suggests, a target variable and the implementation officers' task is to keep the short-term interest rate at or close to the level that has been set by the decision-making committee. The separation of responsibilities between decision-making committee and implementation desk has the advantage that both may restrict their attention to a specific aspect of monetary policy. Members of the decision-making committee can focus their attention on choosing the appropriate level for the short-term interest rate, but they do not have to bother how the short-term interest rate is controlled on a day-to-day basis.[10] Similarly, the implementation officers may focus their efforts on achieving the given target, but they do not have to worry whether the current target level is appropriate from the macroeconomic perspective.

The separation between monetary policy strategy and implementation thus leads to a certain reduction of the complexity of the environment and facilitates decision-making. But the decisions that have to be taken are still challenging, especially on the strategic level. To further facilitate decision-making, central banks have developed and make use of decision-making frameworks, both for strategic decisions and for operational decisions with respect to the implementation of monetary policy.

The strategic framework or concept typically contains the following elements. First of all, it lays down the ultimate objective(s) of monetary policy. For instance, the central bank may commit itself to target an annual inflation rate of the consumer price index of 1–2%. The strategic framework also pins down the general principles, that is the strategy, of how this objective should be achieved. The principles largely reflect the central bank's model of the monetary transmission mechanism, that is how it believes that the operational target, intermediate targets (if any) and indicator variables are linked to its ultimate objectives. The strategic framework thus describes how relevant information on the the state of the economy is organized to provide a foundation for monetary policy decisions on the appropriate level of short-term interest rates. For instance, the central bank may commit itself to follow a strategy that is known as inflation forecast targeting. It will then adjust the short-term interest rate whenever the inflation forecast at a specific time horizon is not in line with the inflation target. Putting down the ultimate objectives and general principles on how to achieve these objectives in a strategic framework has the advantage that once these elements are agreed upon, they become non-negotiable, at least for a certain period of time. Although at first sight the set up of a strategic framework thus may seem to reduce the central bank's flexibility and room for manoeuvre, it is nevertheless indispensable to reduce the environment's complexity to a manageable level and to allow making well-considered decisions on the appropriate stance of monetary policy. Furthermore, especially in recent years,

[10]The widespread terminological confusion between monetary policy instruments and the operational target (see Section 2.1) is likely due to this separation of responsibilities. In macroeconomic models that focus solely on the strategic level of monetary policy, it is usually assumed that the central bank has perfect control over the short-term interest rate and, accordingly, the short-term interest rate is treated as an instrument. However, in practice, there is no perfect control and the short-term interest rate needs to be considered as an operational target.

when transparency of monetary policy and managing the public's expectations have become widely recognized as key factors for effective monetary policy, a coherent and transparent strategic framework may also facilitate communication with the public in general and allows to explain specific monetary policy decisions in particular.[11]

In the realm of monetary policy implementation, the decision-making framework is of course nothing else but the operational framework that was introduced in Section 2.1. One should note the similarity between the strategic and the operational framework. In the end, both provide rules and procedures that facilitate regular decision-making, be that on the appropriate level of the short-term interest rate or on the appropriate use of monetary policy instruments to keep the short-term interest rate in line with the target level. Moreover, both frameworks have a long-term character. They are designed to provide guidance on decision-making over an extended period of time, without being altered very frequently, at least not in a fundamental way. Setting up adequate strategic and operational frameworks for monetary policy is thus of considerable importance to any central bank.

There remains the question to what extent the two frameworks should be related to each other. One may argue that the strategic and operational decisions have not much in common and, consequently, the two frameworks may be designed independently. Indeed, the preceding discussion showed that it is not only possible but even useful to look at these issues separately. Nevertheless, one should bear in mind that in the end the operational and the strategic framework are part of the overall framework of monetary policy. Therefore, it would be desirable if the design of the operational and strategic framework reflected some common values or guiding principles. For instance, if the central bank took the view that a clear and transparent strategic framework is best suited to achieve the ultimate objectives, it would seem at odds if the operational framework was so complex and non-transparent that market participants had a hard time guessing about the central bank's intentions in the money market. Rather, it would be preferable if the operational framework was also as clear and transparent as possible. Moreover, as the design of the strategic framework is without a doubt the more challenging undertaking, the operational framework should be inspired by the strategic framework, and not the other way around.

[11]For a critical review of the theoretical literature on transparency and monetary policy see Carpenter (2004). On the role of central bank communication and expectations management see Woodford (2005).

2.3 Selection of the Operational Target

As mentioned in the last section, the operational target may be considered as the nexus between monetary policy strategy and the implementation of monetary policy. The selection of the operational target should thus strike a balance between the needs of both the longer-term macroeconomic issues of monetary policy and the central bank's day-to-day operational challenges when implementing monetary policy in the money market. From the strategic perspective, the operational target should play a significant role in the early stage of the monetary transmission mechanism; from the operational perspective, the operational target should be tightly controllable. In the following, we will show that a short-term interest rate, and in particular the overnight rate, best fits these criteria.

2.3.1 Short-Term Interest Rate versus Monetary Base

As the monopolistic supplier of the monetary base, the central bank can either control its price, that is the short-term interest rate, or its quantity. Historically, most central banks have used (or experimented with) various operational targets, but nowadays a short-term interest rate is almost universally accepted as the appropriate selection. Although there is currently broad agreement among central banks, it is nonetheless useful to recall the arguments for targeting a short-term interest rate rather than the monetary base or some of its components.

The debate on the appropriate operational target for monetary policy has a long tradition in monetary economics. The standard analysis goes back to Poole's (1970) "theory of optimal instrument choice".[12] While the theoretical frameworks to analyze this issue differ regarding their sophistication, they usually include the following elements: a representation of the main macroeconomic relationships, such as an IS-LM model; a specific objective function for the central bank including variables such as the inflation rate and the variance of output; and two or more economic disturbances such as aggregate demand shocks or shocks to money demand and money multipliers.[13] The magnitude of these shocks turns out to be crucial for the choice of the operational target, for if there were no uncertainties at all about market conditions, it would not matter whether the central bank targets an interest rate or a quantity. Targeting an interest rate or a quantity would be just two sides

[12] Note that the term 'instrument' is misleading in this context, since the analysis actually deals with the operational target.

[13] The original analysis by Poole (1970) and some of the literature that followed over the subsequent two decades is reviewed by Friedman (1990).

of the same coin. But in the presence of uncertainties, the general conclusion is that the operational target should be chosen on the basis of the relative importance of the disturbances: An interest-rate target is preferable when shocks to money demand or to money multipliers are relatively large, while monetary targeting is more attractive if the variance of aggregate demand shocks is large compared to financial sector volatility. However, as noted by Bindseil (2004a) and Disyatat (2008), the analysis underlying these results is substantially flawed due to a number of shortcomings. First, there is a mix-up of three distinct concepts, namely monetary policy instruments, the operational target, and the intermediate target of monetary policy. Second, the analysis does not distinguish between short-term and long-term interest rates nor between reserve market quantities and (broader) monetary aggregates. And third, the analysis focuses exclusively on macroeconomic shocks, thereby completely disregarding the more frequent and temporary shocks in the money market, which typically exhibit no correlation with macroeconomic disturbances. As these are rather severe objections, it follows that the standard macro-oriented analysis is not suited to make any predications regarding the appropriateness of interest rate or monetary targeting.

A more promising approach is to analyze the relative importance of interest rates and monetary aggregates in the monetary transmission mechanism. For instance, if monetary policy is deemed to work mainly through the interest rate channel, it seems natural to target a (short-term) interest rate. In contrast, if the monetary stimulus is considered to be transmitted mainly through the change in monetary aggregates and, accordingly, the central bank pursues an intermediate target for some broad monetary aggregate, one might argue that the monetary base is the obvious candidate as operational target. But even in this second case, there are good reasons why a central bank better *not* target the monetary base (see also Bindseil 2004a and 2004b). First, monetary base targeting presupposes a stable and predictable relationship between the monetary base and broader monetary aggregates. However, especially when interest rates are close to zero, the money multiplier is likely to become unstable. Second, strictly pursuing a specific target for the monetary base inevitably implies considerable volatility in short-run interest rates. This is because the demand for base money is subject to stochastic and seasonal fluctuations. At best, the high volatility in short-term rates will only affect the efficiency of the money market and impede banks' liquidity management. But there is also the risk that short-term volatility will be transmitted along the yield curve to longer term interest rates, which are relevant for economic decisions.

The third and probably most compelling reason why the central bank should avoid setting a target for the monetary base is related to the simple fact that the monetary base cannot be reasonably controlled in the short run. To see why, remember that the monetary base consists of two components: banknotes in circulation and reserves, i.e. banks' current account holdings with the central bank. The first component, banknotes in circulation, which typically represents the bulk of the monetary base, is endogenous and purely demand-driven, at least in the short run. It is hard to see how a central bank could alter the amount of banknotes in circulation in the short run, which explains why central banks have no other choice than supplying whatever amount the public demands (fully elastic supply).[14] Banks' demand for reserves, the second component, is typically determined by reserve requirements. Assuming a stable demand for banknotes in circulation, consider what would happen if the central bank decided to increase or decrease its monetary base target. To decrease the monetary base, the central bank would have to push reserves well below the level of required reserves. As a reaction, banks would simply increase their recourse to the borrowing facility, thus leaving the monetary base unaffected.[15] On the other hand, an increase in the monetary base would require the central bank to drown the market with substantial excess reserves, for instance by outright purchases of securities. With banks having more reserves than needed, this would immediately induce strong downward pressure on money market interest rates, so that the monetary stimulus due to lower interest rates is most likely much stronger and more immediate than any supposed transmission working through the increase in the monetary base. The impracticality of monetary base targeting also explains why even those central banks that have used some broader monetary aggregate as intermediate target have typically tended to manage the supply of (broad) money by way of changes in interest rates. In fact, there is no fundamental contradiction between targeting the short-term interest rate and an intermediate target for the (broad) money-supply, at least as long as the demand for (broad) money is elastic with respect to interest rates and this elasticity remains reasonably stable over time (Rich 1995).

It thus appears that a short-term interest rate remains as the only valid alternative for the operational target. This conclusion should not merely be seen as the outcome of a process of elimination, but rather the short-

[14]One might argue that the central bank could always increase banknotes in circulation by the famous helicopter drop of cash, but while this metaphor may be a useful pedagocic device to help explain money's role in the economy, it is certainly not a practical policy tool.

[15]Again, one might argue that the central bank could simply restrict recourse to the borrowing facility. But a policy that consists of squeezing the market by the imposition of reserve requirements and the concomitant undersupply of reserves would hardly contribute to a central bank's esteem.

term interest rate is simply the most obvious and appropriate candidate, and this for a number of reasons. First, given the current understanding of monetary transmission channel, it is clear that short-term interest rates play a key role in the early stages of the monetary transmission, especially in economies that benefit from highly developed and liquid financial markets. Through a number of arbitrage relationships, short-term interest rates affect longer-term interest rates, the exchange rate as well as the prices of other financial assets. From the strategic perspective of monetary policy, it is thus indisputable that short-term interest rates have much appeal as operational target. Moreover, it is theoretically intuitive and practically well demonstrated that central banks have the capacity to control short-term interest rates rather tightly. Therefore, also from the perspective of monetary policy implementation, short-term interest rates comply with the key requirement of a good operational target. In addition, compared to quantitative variables such as the monetary base, short-term interest rates are much easier to understand and interpret by the markets as well as the general public. For instance, it is fairly straightforward to assess what it means when the central bank increases its target for the short-term interest rate by say 50bp, whereas it would be much harder to appraise the implications of a decrease in the target for the monetary base by say 100 million. A short-term interest rate target thus facilitates central bank communication and, to the extent that the central bank's intentions are better understood, it enhances the central bank's transparency and may even contribute to the effectiveness of its policy. However, it should also be noted that the increased transparency might involve some reputation risk for the central bank. Indeed, as interest rates are observable in real-time, it is straightforward to judge whether the central bank is capable of achieving the announced target. If the target was permanently missed, this would call into question the central bank's ability. Moreover, any deviations between actual and targeted rates might need to be explained, since otherwise they could be interpreted by the market as signals of an implicit policy shift. To avoid these circumstances, the central bank should have in place an operational framework which allows tight control of interest rates.

2.3.2 Overnight Rate versus Other Short-Term Interest Rates

Having concluded that it is generally preferable to target a short-term interest rate, there remains the question on which maturity along the yield curve the central bank should focus. In this respect, one is confronted with an obvious trade-off between controllability, that is the degree to which a central bank might exert control over a specific interest rate, and the relevance of this interest rate in the monetary transmission channel. In general, the shorter the maturity, the better the interest rate is controllable, whereas the longer the maturity, the more the interest rate is relevant for monetary transmission.

From the strategic perspective of monetary policy, it would make sense to target the short-term interest which is most relevant for monetary transmission. Manna et al. (2001) call this interest rate the *trigger variable*. They argue that the trigger variable is likely to vary from central bank to central bank, depending on the specific economy's transmission channel and the structure of financial markets. But it is clear that relatively longer-term money market rates such as the one-month or three-month Libor are generally more relevant for monetary transmission than very short-term interest rates such as the overnight rate. Indeed, the overnight rate's relevance is confined to a rather limited set of transactions in the interbank money market, but apart from that it has no direct bearing on most economic investment or spending decisions that affect the development of output and prices in the medium- to long-term. Moreover, because macroeconomic models used in monetary policy analysis are often calibrated to quarterly data it seems natural to assume that the short-term interest rate in these models is best approximated by the three-month Libor. By and large, there is a lot that speaks in favor of the three-month Libor as trigger variable in monetary policy.

Of course, it would be very convenient if the trigger variable was at the same time also the operational target, as this would allow both policy makers and implementation officers to focus on the same short-term interest rate. But unfortunately, as will be argued in the following, the use of a longer-term money market rate as operational target can bring forth a number of undesirable side effects. Most importantly, it could lead to indeterminacies and irregularities for interest rates at the very short end of the yield curve.

To see why, note that nominal interest rates are related with each other by the expectations hypothesis of the term structure of interest rates. Basically, the expectations hypothesis states that any spot long-term interest rate may be expressed as an average of expected future short-term (e.g. overnight) interest rates. In its simplified linear form, the expectation hypothesis implies that as of day t, any nominal interest rate with maturity of T days may be written as

$$i_{t,t+T} = \frac{1}{T} \sum_{j=0}^{T-1} E_t \, i_{t+j} + \phi_{t,t+T}, \tag{2.3}$$

where i_{t+j} is the overnight rate on day $t+j$ and $\phi_{t,t+T}$ captures three components: the term premium for an interest rate with maturity T as of date t, the credit risk premium, and the liquidity risk premium.[16] For the sake of simplicity, it will be assumed in the following that this composite premium is constant. Now assume that the central bank sets a specific target for the current three-month Libor, e.g. $i^*_{t,t+90} = 3\%$, and that the three-month composite premium $\phi_{t,t+90}$ is 10bp. The fundamental problem with targeting the three-month Libor is that there are many different paths of future overnight rates that fulfil Equation (2.3). For instance, the trajectory of future overnight rates could be constant, i.e. $i_{t+j} = 2.9\%$ for $j = 0, \ldots, 89$, but the trajectory could also be decreasing, increasing, or any other combination of overnight rates for which the average expected overnight rate over the next three months is equal to 2.9%. In short, by setting a target for the three-month Libor, the path of overnight rates is not determined.

For the central bank's implementation officers, this raises the question of how to best achieve the 3% target for the current three-month Libor. Clearly, assuming that the overnight rate can be controlled very tightly, the most straightforward policy would be to keep overnight rates at a constant level of 2.9% over the next 90 days (constant overnight rate path). But this policy only works out if market participants expect the target for the three-month Libor to remain constant over the next three months. As soon as there are expected target rate changes, the implementation officers' job becomes rather tricky. For instance, assume that market participants expect the monetary policy committee to raise the target for the three-month Libor to 3.5% at the next meeting, which is scheduled to take place one month from now ($t+30$), i.e. $E_t\, i^*_{t+30,t+120} = 3.5\%$. According to the constant overnight rate path, the implementation desk would thus have to raise the level of overnight rates to 3.4% from day $t+30$ onwards. But to the extent that this increase in future overnight rates is correctly anticipated by market participants, the current three-month Libor would jump immediately to $i_{t,t+90} = \frac{1}{90}\,(30 \times 2.9\% + 60 \times 3.4\%) + 0.1\% = 3.33\%$ and then, over the next 29 days, gradually rise towards the anticipated future target level. Similarly, an expected cut in the target for the three-month Libor would induce an immediate drop in the current three-month Libor. Therefore, the constant overnight rate path, which calls for keeping the overnight rate at a level such that $i_t = i^*_{t,t+T} - \phi_{t,t+T}$, does not allow to achieve the target in case of expected target changes.

[16]Note that for simplicity the overnight rate on day t is not denoted as $i_{t,t+1}$ but as i_t throughout this study.

To make things worse, if the market expects the target to be changed, and if the implementation officers took their job of keeping the three-month Libor close to the current target serious, there would be perverse implications for the path of interest rates at the very short end of the yield curve. For instance, if the market expected an increase in the target for the three-month Libor, the implementation officers would have to bring about a temporary *decline* in current overnight rates in order to offset the effect of the expected higher future overnight rates. And similarly, if the market expected a future decrease in the targeted three-month Libor, current overnight rates would have to *rise* temporarily. The closer any expected target change comes, the more extreme these opposing movements at the very short end of the yield curve would have to be. Stabilization of the targeted three-month Libor would thus come at the cost of considerable volatility in short-term interest rates and, coming along with it, impediments to banks' liquidity management. Moreover, in periods when the market expects the general level of interest rates to increase (decrease), it would be rather challenging for the central bank to explain why it forces very short-term interest rates to decline (increase). Of course, one might argue that the central bank does not have to counteract market forces and could simply let the three-month Libor gradually adjust to the future expected target level. But this raises two other issues. First, it could then be argued that the central bank does not really stick to the announced target for the three-month Libor and the question would be why it has set a specific target in the first place. And second, persistent deviations between actual and target interest rates could damage the central bank's credibility, potentially even undermining the public's confidence in the central bank's willingness or—even worse—its ability to control interest rates.

Obviously, the preceding line of argument is valid whenever the central bank targets an interest rate with a maturity longer than overnight. But before concluding that the overnight rate is indeed the most preferable candidate for the operational target, the following three concerns need to be addressed.

First, there might be a concern that the overnight market segment is relatively illiquid or prone to collusion, especially if there are only a few important market players. In these circumstances it might seem more appealing to target a longer-term money market rate, especially if there is an active offshore market for this maturity. However, it should be recognized that market illiquidity and the potential for collusion are not purely exogenous parameters. Rather, they depend at least partially on the central bank's operational framework, and a well-designed operational framework will certainly be conducive to mitigating or even overcoming these market imperfections. To put it differently: If the overnight rate plays an important role in the central bank's monetary policy framework, this market segment will be paid more attention by market participants and hence automatically become more liquid and competitive.

Critics might also object that when targeting the overnight rate, the central bank will have insufficient leverage over the (longer-term) trigger variable, which is by definition more relevant for monetary transmission. The following considerations seem to rebut this objection. To begin with, the expectations hypothesis of the term structure suggests that the overnight rate is very closely linked with other short-term money market rates, including the trigger variable. Therefore, even when targeting the overnight rate, the central bank still has sufficient leverage over the somewhat longer-term trigger variable. Moreover, specifying and following a target for the overnight rate has a potentially beneficial side-effect: In case of expected target rate changes, movements in the trigger variable will be more gradual. For instance, to the extent that a future increase in the overnight target rate is correctly anticipated by the market, the longer-term term trigger variable will gradually move to the higher level well in advance of the actual target change. Since the trigger variable is by definition more relevant for economic decisions, gradual adjustments are preferable to discrete jumps from one day to the other. Finally, by focusing on the overnight rate and leaving longer-term money market rates determined by expectations of future monetary policy decisions, the central bank might even exploit the information revealed by movements in the trigger variable for its own purposes, as it allows to infer the market's assessment of what the central bank is most likely to do. Clearly, the validity of these arguments hinges on the assumption that the market is able to accurately forecast the central bank's decisions. But this assumption does not undermine the superiority of an operational target in terms of the overnight rate, rather it underlines the importance of conducting monetary policy in a transparent and thus largely predictable manner.

Finally, it might be argued that targeting the overnight rate is problematic if the composite premium $\phi_{t,t+T}$ is subject to significant changes over time. Indeed, consider a significant increase in the composite premium, as for instance witnessed in many money markets during the 2007–2008 financial crisis.[17] Against the backdrop of such market developments, critics might

[17] Recall that the composite premium $\phi_{t,t+T}$ captures three components: the term premium, the credit risk premium, and the liquidity risk premium. During the 2007–2008 financial crisis, the sharp increase in the spread between the interest rates on interbank term loans and overnight rates was mainly due to an increase in the credit and liquidity risk premium.

point out that the central bank should try to stabilize longer-term market rates rather than the overnight rate. While this is true, it does not imply that the overnight rate is no suitable operational target *per se*. It rather implies that *ceteris paribus* the central bank should react to such an increase in the composite premium as to other shocks that lead to a sudden tightening of monetary conditions, namely by lowering the overnight target rate. *De facto*, a central bank officially targeting a longer-term money market rate would react the same way, that is its implementation officers would have to bring about lower overnight rates in order to stabilize the longer-term money market rates near the target rate. The only difference between a central bank targeting the overnight rate and a central bank targeting a longer-term money market rate thus is that the former would have to formally announce a change in the target rate. There is thus a difference in terms of communication, but not necessarily in terms of actions.

On balance, the analysis in this section thus suggests that central banks should use the overnight rate as operational target. But it's still to be clarified whether to target the interbank overnight deposit rate for unsecured lending or the interbank overnight repo rate for secured lending. In times of normal market functioning, the spread between the interbank deposit rate and the interbank repo rate is small and fairly stable. Hence, it doesn't make much difference whether the central bank targets either or the other rate. There are, however, arguments that speak in favour of targeting the interbank repo rate. In particular, in case the central bank aims at fostering financial stability by pursuing the objective of developing the secured market segment, it might have a preference for explicitly targeting the interbank repo rate, as this would give this market segment more relevance and attention. The benefits of a deep and liquid interbank repo market become particularly apparent in times of market stress, when banks are more concerned about counterparty credit risk and the unsecured market segment is likely to dry out. In these circumstances, the deposit rate might become an unreliable indicator of banks' true borrowing costs and the spread between the interbank deposit rate and the interbank repo rate can become relatively large and more volatile. Moreover, even in normal times, targeting the interbank repo rate might be particularly sensible if the central bank's liquidity management relies strongly on short-term repos with fixed rate tenders. In this case, the central bank is able to exploit the strong arbitrage relationship between its own (fixed) tender rate and the interbank repo rate, which certainly contributes to stabilizing the interbank repo rate at or very close to the tender rate. Despite these apparent advantages of targeting the interbank overnight repo rate, one should be aware that this rate could be affected by specific developments in collateral markets. Particularly if the pool of generally acceptable collateral is small, there is a risk that short-lived but generalized shortages of collateral lead to sudden hikes in repo rates. However, in well developed financial markets with a broad range of generally acceptable high-quality collateral these risks are fairly small.

2.4 Past and Present Motivations for Reserve Requirements

Today, there are usually two reasons for the imposition of reserve requirements: they increase banks' structural demand for reserves and, provided reserve requirements allow for averaging, they also increase the interest rate elasticity of reserve demand. Both factors facilitate the control of short term interest rates and hence the implementation of monetary policy. However, it should be noted that the rationale for the imposition of reserve requirements has changed over the years, and only recently they have become to be considered as an instrument primarily facilitating the implementation of monetary policy (see e.g. Goodfriend and Hargraves 1983, Stevens 1991, Feinman 1993, Hardy 1993, Sellon and Weiner 1996, Bindseil 1997). The following brief review of the main other motivations for reserve requirements will reveal that they are generally not well founded, at least in today's context of highly developed financial markets. Therefore, when defining the rules and procedures governing reserve requirements, central banks can focus on how they best support the effective and efficient implementation of monetary policy.

2.4.1 Liquidity Provision and Financial Stability

In many countries, reserve requirements were established in the late nineteenth or the early twentieth century as an instrument of prudential banking regulation. The main motive underlying the imposition of reserve requirements was to ensure that banks have sufficient liquidity to convert deposits into currency. In principle, one would expect banks to hold sufficient liquidity voluntarily in order to avoid temporary liquidity shortfalls and costly refinancing in case of unexpected high depositor withdrawals. But to the extent that liquidity is costly and exhibits positive externalities, it is likely that the level of liquidity held on a voluntary basis is suboptimal from a system-wide perspective. If so, it is justified to impose specific liquidity requirements on financial institutions.

To assess whether reserve requirements are suited to contribute to sound liquidity management and financial stability, it is useful to distinguish whether the imposition of reserve requirements aims at safeguarding an individual bank or the banking system as a whole against unexpected withdrawals of deposits. Consider first the situation of an individual bank facing an unexpected withdrawal of deposits. To meet customers' demand, the bank needs either currency (if customers want to withdraw deposits at the counter or ATMs) or reserves (if customers want to transfer their deposits to other banks). As the bank will always be able to convert reserves into currency at the central bank (elastic supply of currency), the key issue is whether the bank has sufficient liquid assets that can be converted into reserves at very short notice. Note that assets such as government bills, short-term money market instruments and even government bonds can be readily liquidated, either by selling them outright, or by using them as collateral for interbank repos or at the central bank's borrowing facility. Therefore, to the extent that liquidity requirements are deemed to be a necessary element of banking regulation, these requirements should be based on a relatively broad concept of liquidity (i.e. reserves plus a range of other liquid assets).

Next, consider what happens if there is an outflow of liquidity from the banking system to non-banks. To the extent that the outflow is expected, it will be usually accommodated in advance by the central bank by means of open market operations. To the extent the outflow is unexpected, banks might first have to have recourse to the borrowing facility, but later on the outflow will also be accommodated by open market operations. Again, irrespective of whether banks' demand for reserves is met via open market operations or the borrowing facility, what matters is that banks have sufficient eligible collateral for these transactions. It is not, however, necessary for banks to maintain a large amount of (required) reserves as a precautionary buffer stock, particularly if the central bank accepts a wide range of collateral. By and large, it thus seems that reserve requirements *sensu stricto* are not suited to address broader liquidity concerns.

2.4.2 Fiscal Policy

Reserve requirements have also been supported for various fiscal reasons. In particular, reserve requirements may be a means to tax financial services that are otherwise difficult to tax, most notably the payment services provided by banks to their customers. Payment services are often not directly priced but cross-subsidized by below-market interest rates on customers' deposits. On the one hand, taxing these services indirectly through reserve requirements may allow to avoid that the fiscal system is biased in favor of bank intermediation. On the other hand, one might argue that most payments are only the flipside of real-economy transactions, and to the extent that these transactions are already subject to some sort of taxation, taxing payment services would cause double taxation.

From a theoretical perspective, reserve requirements may also be seen as part of an optimal taxation scheme (Bindseil 1997). From a welfare economic perspective, the question then is whether unremunerated reserve requirements constitute an optimal tax. According to the theory of optimal taxation, at the optimum, the marginal welfare costs of the last unit of tax revenue are the same for all taxes. Therefore, the question is whether the marginal welfare costs of reserve requirements, taking into account all positive and negative effects, correspond to the marginal welfare costs of other taxes? While a conclusive answer to this question is beyond the scope of this study, the ease of disintermediation and the mere threat of shifting deposits to foreign (less taxed) countries suggest that the implicit tax should be low.

In practice, the main fiscal reason for imposing reserve requirements is more trivial: They are an easy way to raise revenues needed to finance the central bank's operations. The mechanism is straightforward. Consider a permanent increase in reserve requirements. The central bank has two options to meet banks' higher demand for reserves. Either it provides these reserves by purchasing securities outright, in which case it will earn interest on these securities. Or it provides the reserves by means of revolving repo transactions, for which it will charge banks the prevailing repo rate. Obviously, the higher the level of reserve requirements and the lower their remuneration, the higher will be the central bank's revenue. But it should be recognized that from the perspective of overall economic efficiency, reserve requirements are not a (non-distorting) lump-sum tax for the banking system. Rather, they imply a number of distorting effects (Angenendt and Remsperger 1995). First of all, to the extent that reserve requirements are based on some measure of banks' liabilities such as short-term deposits, they involve distortions between reservable and non-reservable liabilities. This induces banks to develop alternative financial instruments and means of intermediating between borrowers and lenders that are not subject to reserve requirements. In turn, to protect their revenue stream, central banks need to monitor these developments and take appropriate corrective regulatory responses. Second, reserve requirements may involve distortions between financial institutions. This is particulary true if some institutions are subject to reserve requirements whereas others, which provide similar financial services, are not. But distortions may even arise between different reservable financial institutions. For instance, if banks differ with respect to their voluntary holdings of reserve balances, reserve requirements may not be equally binding (and costly) for all institutions. A third distortion may arise on an international level between financial centers. If the level of reserve requirements varies among countries, especially deposits with high cross-border mobility are likely to be shifted to those places where reserve requirements are comparatively low. Together, these distortions imply microeconomic inefficiencies in terms of resource misallocation. Of course, the extent of the distortions depends on the level and, more importantly, on the remuneration of reserve requirements. Therefore, unless the central bank has no other source of income to finance its operations and to maintain financial independence, it is difficult to justify high and non-remunerated reserve requirements on fiscal grounds.

2.4.3 Credit and Monetary Control

At certain points in time, and in certain monetary policy frameworks, reserve requirements were thought to be useful for controlling the expansion of bank credit or monetary aggregates. For instance, in the 1930s, the Federal Reserve considered reserve requirements as an essential tool to control the expansion of commercial bank credit. And even more recently, during the credit control program in the 1980s, reserve requirements on certain bank liabilities were imposed in order to curtail the growth of bank credit (Sellon and Weiner 1996). In the heyday of monetary targeting during the 1970s and 1980s, reserve requirements were typically motivated by their stabilizing effect on the money multiplier. With a constant money multiplier, so the idea, controlling the level of reserves would allow to closely control broader monetary aggregates.[18] However, for various reasons (which are beyond the scope of this study), central banks generally had to refrain from monetary targeting and now use different policy frameworks. From an operational perspective, the focus has shifted from reserve targeting to short-term interest rate targeting. Accordingly, the motivation for reserve requirements has shifted from stabilizing the money multiplier to stabilizing short-term interest rates.

For the sake of completeness one might also note that, theoretically, reserve requirements could also be used to actively manage money market liquidity. By changing either the reserve base or the reserve ratio the central bank could affect the conditions in the market for reserves and thus induce changes in short-term interest rates. For instance, holding the supply of reserves constant and assuming that reserve requirements are binding, an increase in the reserve ratio would lead to an increase in reserve demand and would thus induce an increase in market interest rates. However, there are a number of reasons why central banks better not try to actively manage the banking system's liquidity by adjusting reserve ratios (Hardy 1993). In particular, reserve requirements are relatively clumsy and don't allow fine-tuning

[18] See Goodfriend and Hargraves (1983) for a critical assessment of the Federal Reserve's experience with credit and monetary control.

of liquidity or interest rates.[19] The interest rate effects of adjustments in reserve requirements would be difficult to predict, which is problematic when targeting interest rates. Also, from a practical perspective, lags in defining the reserve base and the length of the maintenance period make frequent adjustments in the reserve ratio or the reserve base impossible. Hence, it is neither advisable nor feasible to use changes in reserve requirements to manage the banking system's liquidity or to trigger changes in money market rates.

Overall, this section has revealed that most historical motivations for reserve requirements are substantially flawed. Especially in the context of highly developed financial markets, the only convincing reason for imposing reserve requirements is their stabilizing effects on short-term interest rates. Hence, reserve requirements should be considered exclusively as an instrument facilitating the implementation of monetary policy.

[19]For instance, when the Federal Reserve lowered the reserve ratio from 12 to 10 percent in February 1992 (see also Section 4.2.3), the equivalent of USD 7.3 billion in reserves were freed up. To have the same expansionary effects, the Fed would have had to buy over USD 7 billion in government securities in open market operations, more than the Fed bought throughout the year 1991. In order to avoid such a large discrete policy effect, the Fed had to offset the impact of the decline in reserve requirements by liquidity absorbing open market operations (Hein and Stewart 2002).

Chapter 3

The Market for Reserves

Essentially, monetary policy implementation is about the central bank's control of short-term interest rates by establishing conditions in the market for reserves that are consistent with the target level for the short-term interest rate. Compared to other financial markets the market for reserves exhibits a number of peculiar features. First of all, there are two fundamentally different types of market participants: the central bank and a large number of commercial banks. Moreover, in analogy to other financial markets such as those for equities or bonds, one can distinguish between the primary and the secondary market. In the primary money market, the central bank makes use of open market operations to provide reserves to or withdraw reserves from the market, thereby altering the aggregate amount of reserves available to commercial banks. In the secondary market—which is usually referred to as the interbank money market—, reserves are borrowed or lent among commercial banks, typically for short maturities of one day up to a few weeks or months. Whereas in the primary market the central bank acts as a monopolistic supplier of reserves, determining the terms and conditions at which it provides reserves to commercial banks, the interbank market is typically very competitive and individual banks are thus best described as price takers.

In the market for reserves, central banks and commercial banks pursue different objectives. Commercial banks aim at satisfying their demand for reserves at the lowest possible cost, taking into account their need for working balances in the interbank payment system and various institutional constraints such as reserve requirements or penalties for overnight overdrafts on their reserve account. To do this, they may borrow reserves directly from the central bank in regular open market operations or via the borrowing facility, or they participate in the interbank market, where reserves can be borrowed and lent at current market interest rates.

In contrast, the central bank's main objective is to keep the interbank overnight rate close to its target level by making use of its monetary policy instruments: reserve requirements, standing facilities, and open market operations. These instruments allow the central bank to affect both the supply of reserves—e.g. by providing or absorbing reserves through open market operations and standing facilities—and banks' demand for reserves, for instance by imposing reserve requirements.

Given that the central bank is the monopoly supplier of reserves and even affects banks' demand for reserves, one might think that keeping the overnight rate at the intended level should be rather trivial. However, in practice, there are at least three reasons why this is not the case, each being attributable to a different source of uncertainty. The first uncertainty is related to banks' demand for reserves, which may vary on a day-to-day basis. From the perspective of the central bank's monetary policy implementation desk, uncertainty about the demand for reserves makes it difficult to predict the amount of reserves which needs to be supplied such that the interbank market clears at the target rate. Second, the supply of reserves is not only determined by monetary policy operations, but it is also affected by so called autonomous liquidity factors. The autonomous liquidity factors are related to transactions that affect the level of reserves but are not under control of the implementation desk, and often not even under control of any other central bank department. Consequently, to the extent that the implementation desk's forecast of autonomous liquidity factors is subject to uncertainty, actual and intended supply of reserves need not necessarily coincide. The third uncertainty is due to imperfections in the interbank money market. That is, even if reserve demand was perfectly predictable and the supply of reserves was under full control, imperfections in the interbank money market may give rise to unintended interest rate volatility. Indeed, in practice, the interbank money market may neither be perfectly competitive (e.g. if there are dominant market players) nor frictionless. In particular, trading usually involves transaction costs, irrespective of whether the transaction takes place on a bilateral basis (over-the-counter), through brokers or through multilateral electronic trading systems. For instance, a bank that needs to borrow reserves may incur search costs to find a counterparty that is willing or able to lend, especially if there are binding credit lines.

In practice, all three sources of uncertainty are relevant to understanding the market for reserves and, in particular, the behavior of market participants and the dynamics of interest rates. However, this study will focus mainly on the first two uncertainties, which are directly linked with the operational framework of monetary policy implementation and the central bank's liquidity management. There are two reasons for doing so. First, although incorporating imperfect competition and transaction costs would make the analysis more realistic, this would come at the cost of significantly higher complexity, potentially even blurring the role of institutional arrangements of monetary policy implementation. Second, and more importantly, focusing on institutional features of the operational framework rather than on market imperfections is consistent with the findings of Prati, Bartolini and Bertola (2001). Studying the day-to-day behavior of short-term interest rates in the G-7 countries as well as in the euro area, they conclude that institutional arrangements and the central bank's operational framework are the main factors determining the dynamics of the overnight rate. Besides, they find that many of the empirical features of the U.S. federal funds market, which is the most extensively researched interbank money market, are not robust to changes in the institutional environment and/or the style of central bank liquidity management. Therefore, the focus will be on the institutional arrangements that affect the demand for and the supply of reserves, whereas the microstructure of the interbank money market will be modeled rather simplistically as a perfectly competitive and frictionless call market.

But before turning our attention to the factors determining the demand and supply in the market for reserves in Sections 3.2 and 3.3, it is expedient to take a step back and reflect on two more fundamental issues. First, what is so special about central banks that they are able to control short-term interest rates in the first place? And second, given that short-term interest rates are not very important for most economic decisions, why is the control of the short-term interest rate nevertheless such a powerful tool of economic policy? As the discussion in Section 3.1 will reveal, the specific characteristics of central bank money as a unit of account and means of payment are key to answering these questions.

3.1 The Role of Central Bank Money

Again: Why are central banks able to control short-term interest rates? And why do short-term interest rates matter at all? Clearly, there are simple and straightforward answers to these questions. First of all, one might highlight the central bank's role as monopolistic supplier of reserves which enables it to set the price, that is the interest rate, for this good. Or, as stated by the Bank of England's Executive Director for Markets: "We can implement monetary policy because we are a central bank. We are a central bank essentially because we are the bankers' bank. What we have to offer is central bank money" (Tucker 2004, p. 360). Moreover, the crucial role of short-term interest rates in the monetary transmission mechanism might be explained by the expectations theory of the term structure, which states that long-term interest rates are equal to the average of expected short-term interest rates. Therefore, by controlling current short-term interest rate as well as the future path of these rates, the central bank has a leverage over longer-term interest rates, which in turn affect various other asset prices and a large number of economic decisions.

But the validity of these arguments hinges on two conditions. First, there must be some demand for central bank money or, more precisely, for reserves at the central bank, and second, a large number of contracting parties within the economy must denominate their financial obligations in the central bank's currency. Consider the consequences if either of these conditions was not fulfilled. On the one hand, if there was no demand for reserves, the mere ability to supply reserves would be irrelevant; at least *a priori* it would be unclear how the central bank could control the short-term interest rate. On the other hand, the control of a currency's short-term interest rate—and through the expectations theory also of longer-term interest rates—would be rather inconsequential if the majority of contracts between economic agents was denominated in another currency. For instance, if all residents of Switzerland suddenly preferred to contract in euro, the Swiss National Bank's leverage over Swiss francs interest rates would have no impact on the Swiss economy, as only euro interest rates would matter.

It is not difficult to verify that for the time being the two conditions are clearly fulfilled. At least in industrialized countries with developed financial markets, banks settle a large number of interbank payments in reserves held at the central bank, hence generating a positive demand for reserves. Moreover, monetary history demonstrates quite impressively economic agents' reluctance to substitute voluntarily a foreign currency for the domestic currency. In fact, currency substitution is typically observed only in situations of a severe loss of confidence in the domestic currency, resulting from episodes of very high inflation, currency devaluations and/or currency confiscations (Feige 2003). Nevertheless, some authors have raised the concern that future developments in information and communication technology, and in particular in payments technology, could erode central banks' ability to control short-term interest rates and, ultimately, render monetary policy ineffective. For instance, Friedman (1999) questions whether central banks will be able to maintain their influence over aggregate demand and inflation if the private sector's demand for base money is eroded by advances in information technology. Similarly, King (1999) proposes that central banks are likely to have much less influence in the future as new payment arrangements may come to substitute for current payment systems in which payments are settled through central bank money. These concerns have triggered a lively debate among monetary policy theorists and practitioners (see Freedman 2000, Goodhart 2000, Lahdenperä 2001, Meyer 2001, and Woodford 2000 and 2001). By and large, the conclusion is that the concerns are likely to be overstated. Even in the unlikely scenario of zero demand for central bank money central banks will retain the ability to control short-term interest rates, though the procedures by which interest rates are steered might need to be adjusted. Despite this reassuring conclusion, it is worthwhile to review Friedman's and King's concerns and the arguments that put them into perspective. In particular, it will become clear that the central bank's role in monetary policy implementation is inextricably linked to its role as bank of banks in the payment system. But to fully understand the arguments by Friedman and King it is necessary to first review some general features of payment arrangements in advanced monetary economies and the underlying factors that drive their evolution.

3.1.1 The Evolution of Payment Arrangements

In monetary economies, goods and services are exchanged against some generally accepted special good: money. But money is not only a medium of exchange or a means of payment, it also serves as a unit of account so that the value of every other good or service may be expressed in terms of a specific amount of money. The functions as means of payment and unit of account explain why the move from a barter economy to a monetary economy is accompanied by substantial efficiency gains. First, the establishment of a generally accepted means of payment eliminates the need for the coincidence of wants, thereby increasing the number of mutually beneficent exchanges. Second, the use of a common unit of account dramatically reduces the number of relative prices and enhances market transparency. Moreover, if the money is storable, it may also serve as store of value, thereby facilitating the intertemporal allocation of financial resources.

The transition from barter to a monetary exchange economy can thus be explained by economic agents' pursuit of ever more efficient ways of organizing trade (Padoa-Schioppa 2004). This process, which was enabled by the underlying forces of technological progress, competition and regulation, has affected both the means of payment and the settlement arrangements that govern how the means of payment is actually transferred. For instance, the means of payment has first evolved from early commodity monies such as salt or cowrie shells to precious metals such as gold or silver.[1] Then, only

[1]See Manning et al. (2010), Chapter 2, for a more detailed discussion on the origins of money.

about 200 years ago, commodity currencies were gradually replaced by paper currency (although initially backed by gold), which can be thought of as the starting point for the development of modern monetary systems.[2] Moreover, while only a few hundred years ago it was common that virtually all transactions were settled by means of face-to-face exchanges of money between the involved parties, today economic agents may choose from a wide range of different payment mechanisms, ranging from traditional face-to-face transfers of banknotes and coins to rather novel mechanisms such as transfers of account-based money initiated through the internet or by means of cell phones. This process of innovation in payment arrangements has not come to an end; to the contrary, technological progress—especially in information and communication technology—is extremely fast and will undoubtedly enable the introduction of ever more efficient and safer payment arrangements.

While we can only guess how future payment arrangements may look like, it is certainly useful to take stock of current payment systems.[3] Although the details of current payment systems in industrialized economies vary from country to country, they share three common features: (i) the prevalence of fiat money, (ii) the coexistence of central bank money and commercial bank money, and (iii) a layered, pyramid-like structure.

By definition, fiat money is not convertible into nor backed by any commodity that has some inherent value.[4] Nevertheless, it fulfills all functions typically associated with money: unit of account, means of payment, and store of value. Within a currency area, the unit of account is defined in terms of the central bank's liabilities. For instance, the unit of account in the United States is the US dollar, whereas in Switzerland it is the Swiss franc; both are liabilities of the respective central banks. However, money—both in the sense of means of payment and store of value—consists not only of the central bank's liabilities, i.e. central bank money in form of cash (banknotes and coins) or reserves, but also comprises so-called commercial bank money. Under this heading, one may subsume a broad range of financial assets such as sight deposits or money market deposits at commercial banks or shares held in money market mutual funds. The common element of these

[2] However, apparently the first issuer of paper money on a fiat standard was Kublai Khan in the Mongol Empire of the twelfth century. This paper money was generally accepted because Khan had the power to put to death those who didn't (Manning et al. 2010).

[3] In the following, the notion of a 'payment system' refers to the totality of payment arrangements that allow the discharge of financial obligations denominated in a specific currency.

[4] In countries with a currency board, domestic currency is fully backed by foreign currency, e.g. the US dollar. However, the foreign currency itself is fiat.

financial assets is that they provide payment services, that is they might be transferred from debtors to creditors in order to discharge financial obligations. It is important to note that the various components of the money stock share the same nominal value and are accepted as interchangeable forms of one and the same currency.

The coexistence of central bank money and commercial bank money goes hand in hand with the layered, pyramid-like structure of the payment system.[5] At the apex of the pyramid is the central bank, which provides accounts and payment services to commercial banks. A significant part of interbank transactions is typically settled in large-value payment systems operated by central banks.[6] At the same time, commercial banks provide payment services to non-banks such as firms and individuals.[7] To this end, commercial banks provide transaction accounts to non-banks and offer various retail payment systems and payment instruments that allow non-banks to discharge their financial obligations.[8] This layered structure implies that several institutions may be involved in settling a single transaction. For instance, a debtor who holds an account with Bank A may instruct his bank to transfer some money to its creditor who holds an account with Bank B. In the simplest case, both Bank A and Bank B are participants to the payment system operated by the central bank so that Bank A may simply transfer the corresponding amount to Bank B, which will then credit the creditor's account. However, if Bank B does not directly participate in the payment system but uses instead Bank C as its correspondent bank, Bank A will first make a payment to Bank C via the payment system (i.e. using central bank money), which will then credit Bank B's account (using commercial bank money). Ultimately, Bank B will then credit the creditor's account. The example thus demonstrates that "central and commercial bank money coexist in a delicate equilibrium, where they are substitutable and complementary at the same time" (Padoa-Schioppa 2004, p. 123).

The layered structure of modern payment arrangements, and in particular the role of the central bank as settlement institution for interbank payments, is closely related with the advent of fiat money and the foundation of modern central banks in the late 19th and early 20th century (Goodhart 1988,

[5]The coexistence of central bank money and commercial bank money is explored in more detail in BIS (2003).

[6]In some countries, such as Canada or Switzerland, the central bank only provides the settlement accounts while the large-value payment system is operated by a private sector company on behalf of the central bank. For a detailed overview of the functioning of large-value payment systems see BIS (2005).

[7]In recent years, an increasing number of non-financial institutions has entered the payments market by offering specific payments services to firms and individuals.

[8]For a detailed overview of retail payment systems and payment instruments see BIS (1999 and 2000).

Giannini 1995, Padoa-Schioppa 2004). Before central banks were founded, commercial banks first used to settle their mutual obligations on a bilateral basis. As the number of banks and interbank payments increased, it soon became more efficient to settle on a multilateral basis, with a central clearinghouse acting as settlement institution. In multilateral settlement arrangements, bilateral obligations are discharged by transferring the liabilities of a third party. For example, if Bank A has a claim on Bank B, the latter may discharge its obligation by means of a transfer of balances at the central clearinghouse. Bank A's initial claim on Bank B is thus simply substituted by a new claim on the clearinghouse, i.e. the liabilities of the clearinghouse provide the function of the settlement asset. While multilateral private-sector settlement arrangements were more efficient than bilateral settlement, they were also prone to crisis and financial instability. Especially the advent of fiat money increased the need for more trustworthy settlement institutions that were able to provide a safe settlement asset. In many countries, these developments led to the foundation of government-backed institutions that gradually became recognizable as modern central banks; in other countries existing banks with government support were given new responsibilities. Quite often, this process was accompanied by the replacement of various competing currencies by a single (monopoly) currency that was issued by the central bank and whose unit of account was determined in terms of the central bank's liabilities. Moreover, to foster general acceptance, specific regulations were usually imposed that declared the central bank's liabilities as legal tender.[9]

The layered structure of payment arrangements was—and still is—fostered by central banks' policies to restrict access to their accounts to banks or other regulated financial institutions. This policy allows central banks to avoid undue credit risk and is thus mainly a reflection of their own risk management which aims at protecting the balance sheet's integrity. Another reason for restricting access is related to competitive issues, as broadening access to non-banks might undermine commercial banks' role in the provision of payments services to non-banks. Alternatively, one could also support the view that the hierarchical structure reflects an efficient market arrangement, in which different institutions focus on those activities where they have a comparative advantage.

[9] Legal tender is defined as those means of payment which everyone must accept for the settlement of a monetary obligation within a currency area. However, by the freedom-of-contract principle, counterparties can agree to contract in another unit of account and/or to accept other means of payment. Hence, the role of legal tender provisions in the determination of the unit of account should not be overstated. See Buiter (2007) for a critical assessment of this so-called 'legal restrictions theory' of the determination of the unit of account.

Notwithstanding the coexistence of and the high degree of substitutability between central bank money and commercial bank money, it is important to note that in a fiat monetary system the two assets differ in a fundamental way. The acceptance of commercial bank money as means of payment or store of value is closely linked to the fact that banks promise convertibility of deposits into central bank money at fixed parity, and one needs to be aware that, at any time, there is a risk that a commercial bank cannot live up to this promise. In other words, while central bank money as well as commercial bank money exhibit the same currency-specific macroeconomic risk (loss of purchasing power due to inflation or devaluation), commercial bank money is also afflicted with a specific microeconomic risk, namely the solvency of a particular bank (Giovanoli 1993). Indeed, in the event of an insolvency, depositors do not have the possibility to sort out their claims on the insolvent bank from the estate.[10] Therefore, a deposit with a financially unsound bank is certainly not equivalent to a deposit with a AAA-rated bank; there are thus as many commercial bank monies as there are banks. This also explains why central bank money and commercial bank money are not entirely fungible. It is the absence of microeconomic credit risk which makes central bank money the safest settlement asset within the respective currency area. In conjunction with the central bank's competitive neutrality and its capacity to provide an infinite amount of liquidity when needed (i.e. in periods of distress) the safety of central bank money also explains why commercial banks generally prefer to settle especially large-value interbank payments in the books of the central bank.

The preceding description of current payment arrangements and how they have evolved over time is rather stylized and does not pay due attention to the experiences of individual countries. Nevertheless, it provides sufficient background to address the concerns raised by Friedman and King regarding future developments in payments technology and their likely impact on payment arrangements. Looking ahead, two scenarios that could adversely affect central banks' ability to implement monetary policy might be distinguished. The first is the decline and eventual disappearance of the demand for central bank money, particularly for reserves. The second scenario is the emergence of a non-monetary exchange economy in which payment arrangements differ in a much more fundamental way from today's arrangements. These scenarios are not mutually exclusive, but the second (more extreme) scenario seems to be placed in a much more distant future.

[10] In contrast, dematerialized securities held with an insolvent bank can be sorted out from the estate.

3.1.2 Monetary Policy Implementation without any Demand for Central Bank Money

Current procedures for the implementation of monetary policy depend on some positive demand for central bank money. This raises two questions which will be addressed in the following. First, how likely is it that the demand for central bank money declines and eventually disappears altogether? Second, what would a zero demand for central bank money imply for the implementation of monetary policy?

Now, one may distinguish two forms of central bank money: physical cash and account-based reserves. Not much has been said so far about physical cash, i.e. banknotes and coins issued by the central bank (or the government). The reason is that although it typically makes up by far the bigger share in the monetary base, cash is irrelevant for the implementation of monetary policy. Hence, even if those voices that predict the complete substitution of cash by new means of payment such as electronic money turn out to be right, this would leave the central bank's ability to control short-term interest rates unaffected. The only implications would be a reduction in the monetary base and a decline in seigniorage, two effects that could even be offset, at least partially, if central banks issued their own electronic money.

It is thus sufficient to restrict the analysis to the prospects of banks' demand for reserves. As will be explained in more detail in Section 3.2, this demand stems from two factors: banks' need for liquidity to settle payments in the interbank payment system and compulsory reserve requirements, with the marginal demand determined by the larger of the two. Therefore, as long as reserve requirements are in place, it is hard to see how banks' demand could be driven to zero. Surely, banks may be very innovative in order to reduce their reserve requirements, especially if reserves are not remunerated and imply significant opportunity costs. For instance, in recent years banks in the United States have substantially reduced their required reserves by the introduction of so-called sweep accounts that allow to shift customers' funds more rapidly from retail transaction accounts subject to reserve requirements to savings accounts exempt from reserve requirements (Bennett and Hilton 1997, VanHoose and Humphrey 2001). Non-bank deposits in form of transaction accounts and consequently the size of reserve requirements might also be substantially reduced by the adoption of new payment arrangements. But a decline in required reserves can be easily avoided, either by remunerating reserve requirements (which would reduce or eliminate banks' incentives to circumvent reserve requirements) or by reforming the methods used to compute reserve requirements (which would eliminate the possibility to reduce the level of required reserves). Indeed, in recent years, a growing number of central banks has started to remunerate required reserves at or close to market interest rates and some have adopted alternative computation methods that no longer relate reserve requirements to the size of banks' transaction accounts or other liabilities.

The preceding arguments notwithstanding, assume that for whatever reason reserve requirements became an ineffective instrument and banks' demand for reserves would thus solely be determined by their need to settle payments in the interbank payment system. Is it conceivable that the payments related demand for reserves shrinks to zero? To analyze this question, it is necessary to precisely define what is meant by zero demand. Two cases might be distinguished. In the first case banks continue to use central bank money as means of payment in the interbank payment system but their demand for end-of-day reserves is zero. In other words, there would only be a demand for intraday liquidity provided by the central bank. In the second case, there would be neither an intraday nor end-of-day demand for reserves since banks prefer other means of payment for settling their interbank payments. Let us consider the two cases in turn.

The first case—zero demand for end-of-day reserves—seems not overly unlikely. Indeed, in today's large-value payment systems banks' payments related demand for reserves is primarily a demand for intraday liquidity. To enhance payment system efficiency, central banks usually provide unrestricted intraday liquidity at zero interest rate, provided that intraday credits are collateralized. In the absence of reserve requirements, end-of-day balances provide no specific (payment) services and any positive end-of-day balances would only be due to unpredictable payment flows during the day. If there was no uncertainty about payment flows and the interbank market was fully efficient, each bank could target (and in fact achieve) a zero end-of-day reserve balance. Therefore, future technological developments that reduce payments uncertainty will undoubtedly lead to a decline in the demand for end-of-day reserves, and in the limit the demand will be zero.

However, during the day banks' reserve balances would still fluctuate because of outgoing and incoming payments and they would have to borrow or lend reserves in the (overnight) interbank market to adjust their end-of-day position. Provided that the operational framework for monetary policy implementation is such that the leverage over interest rates does not depend on some positive demand for end-of-day reserves, central banks could still have control over the short-term interest rate. Indeed, as will be shown in more detail in later chapters, standing facilities and open market operations would still be powerful instruments to exert close control over interest rates. Specifically, the borrowing and deposit rates would constitute a corridor within which market interest rates would fluctuate and open market operations could be used to exploit the liquidity effect. In an extreme scenario, the central bank could even fix the deposit rate and the borrowing rate at the same level. While such a measure would crowd out the overnight interbank market for reserves, it would allow to perfectly control the overnight rate.[11]

The second case to be analyzed is where banks prefer to settle their mutual obligations in another means of payment. It was mentioned before that settling payments in central bank money implies some non-negligible benefits in terms of risk reduction. A complete crowding out of the central bank payment system by a private-sector payment system which settles in an alternative means of payment issued by a private-sector institution will thus only take place if higher risks are outweighed by other benefits. Such benefits could stem from the provision of payment services at a significantly lower cost or from more practical arrangements for settling payments.

Banks' total costs of settling payments may be split into direct costs of using a payment system (e.g. fees or transaction costs that cover the resource costs for setting up and operating the payment system's technical infrastructure) and liquidity costs, i.e. opportunity costs from maintaining reserves at the central bank or the private-sector means of payment at the private-sector settlement institution. Assuming that the functionalities of the competing central bank and private-sector payment systems are the same, direct costs are likely to be independent of the operator of the payment system.[12] Therefore, banks would switch to the private-sector payment system only if liquidity costs in the central bank payment system were sufficiently higher. The costs of liquidity depend on the amount of liquidity that is needed to settle payments and the opportunity costs of liquidity. Provided that the central bank offers intraday liquidity free of interest (as most central banks do) and remunerates end-of-day reserve balances at a competitive market rate (as a few central banks already do and others could easily do), it is hard to see why liquidity costs in the central bank payment system should be higher than in a private-sector payment system. Therefore, it is unlikely that banks will switch to a private-sector payment system for cost-related reasons.

Alternatively, banks may prefer the private-sector payment system because it is more practical or provides superior functionality. For instance, the private-sector payment system could be more convenient to use, have longer operating hours, or it might offer additional features such as multi-currency

[11]To the extent that there is uncertainty about future deposit and borrowing rates, there would still be a role for longer-term money market transactions.

[12]Note that if the private-sector is deemed to be more efficient and cost-effective in the provision of payment services, the central bank could outsource the technical operation to some private-sector company while still providing the means of payment.

capability. In practice, this possibility cannot be excluded. However, there is no compelling argument why a central bank payment system should not be able to provide the same functionalities, at least if the central bank endeavors to take into account banks' preferences and to provide those services the market demands.

By and large, it is thus rather unlikely that the use of reserves as a means of payment will be completely crowded out by private-sector payment systems. Nevertheless, for the sake of completeness, assume that settlement accounts at the central banks ceased to be of any relevance for settling payments. Would this imply the end of monetary policy as we know it? Not necessarily, as even in this situation the central bank would continue to be able to control the short-term interest rate, at least provided that (i) the unit of account which is used in private contracts remains to be defined in terms of the central bank's liabilities, and (ii) the private-sector settlement institution promises convertibility of the private-sector settlement asset into central bank money at fixed parity. If these conditions are met, the central bank could control the overnight interest rate paid on the private-sector settlement asset by providing a borrowing and a deposit facility for central bank money. Indeed, if the overnight interest rate for the private-sector settlement asset fell below the level of the central bank's deposit rate, banks would convert private-sector settlement assets into central bank money and deposit these balances at the central bank. Similarly, if the overnight interest rate for the private-sector settlement asset was above the central bank's borrowing rate, banks would have recourse to the central bank's borrowing facility and convert central bank balances into the private-sector settlement asset. Therefore, even if central bank money was not used at all to settle payments, the interest rates of the standing facilities would still constitute the upper and lower bound for overnight interest rates in the market as a whole. Moreover, the two conditions are not very restrictive. For one thing, it was already mentioned that it is very unlikely that economic agents switch to using another unit of account. For the other thing, as long as the central bank's liabilities remain the unit of account, it is hard to imagine that a private-sector settlement asset not promising (and maintaining) convertibility at fixed parity would be widely accepted. As the settlement asset would be considered too risky, banks would either revert to using central bank money or start using another private-sector settlement asset which is convertible at fixed parity.

Yet, again for the sake of completeness, assume that the private-sector settlement institution would be able to establish its settlement asset as a truly fiat money, i.e. without making it convertible into central bank money or any other asset. The private-sector settlement institution would then become *de* *facto* a central bank and over time its monetary policy would determine the inflation rate and the value of its currency in terms of other currencies, i.e. the exchange rate. One could imagine competing private-sector institutions providing their own currencies so that there would be multiple price levels and a number of exchange rates. Although future technological advances will certainly reduce the costs of handling multiple currencies and prices, there is probably still a long way to go before the costs of doing so become negligible. From the perspective of monetary policy, the reemergence of such private monies is not much of a concern, as these monies would have to be managed extremely well in order to successfully compete with the central bank's currency and to be accepted by the public at large.

3.1.3 Monetary Policy Implementation in a Non-Monetary Exchange Economy

In the previous section, it was assumed that financial obligations are settled by transferring financial assets from the payor to the payee on the accounts of a settlement institution, be that the central bank or any private-sector settlement institution. However, what Friedman and King seem to have in mind when they predict the end of monetary policy is the advent of fundamentally different payment arrangements, enabled by developments in information communication and technology. Their vision is a world that resembles a non-monetary exchange economy, where financial obligations are settled in real-time by transferring wealth from one electronic account to another and a separate means of payment (money) would no longer be needed. The accounts could be either maintained in a central supercomputer or in decentralized record devices, as it is the case today for network e-money. Any financial or real asset for which there is a real-time market-clearing price could be used as settlement asset.

Such an arrangement would be highly efficient; transaction costs related to the settlement of financial obligations would be essentially zero. This vision resembles very much the neoclassical model of an exchange economy, in which goods are exchanged without the need for a generally accepted means of payment nor a unit of account to facilitate these exchanges. Indeed, in a pure exchange economy à la Arrow-Debreu there is no need for money, neither as unit of account nor as means of payment.

In this visionary world, there is also no role for monetary policy (and therefore no need for implementing monetary policy). Should we be concerned about it? Absolutely not.[13] Ultimately, the goal of monetary policy

[13] However, you might be concerned in case you are a central bank employee expecting

as we know it today is to minimize the adverse impacts of various distortions related with nominal rigidities in a monetary economy. If the economy moves towards the described frictionless pure exchange economy, monetary policy becomes meaningless, simply because the goal that it tries to achieve has already been achieved. This is as good as it gets. But since there is quite a long way to go before this vision comes true, examining monetary policy implementation in more detail is still a worthwhile undertaking.

3.2 The Demand for Reserves

Analyzing banks' demand for reserves is crucial to apprehend the functioning of the market for reserves and some of the challenges related to the implementation of monetary policy. Two demand factors are usually distinguished: working balances and reserve requirements (see e.g. Borio 1997). Working balances refer to those reserves which a bank needs to settle financial obligations in the interbank large-value payment system (LVPS), whereas reserve requirements may be considered as a constraint for a bank's liquidity management over the reserve maintenance period. Obviously, the demand stemming from reserve requirements is a demand for end-of-day reserve balances. Similarly, if the LVPS settles payments on a net basis at the end of the day (deferred net settlement or DNS), working balances are also needed exclusively at the end of the day. The effective or marginal demand for end-of-day reserve balances is then simply determined by the larger of the two demand factors.

However, over the last 10–15 years, in most countries traditional DNS systems have been superseded by real-time gross settlement (RTGS) and hybrid payment systems (Bech an Hobijn 2007). In these systems, payments are settled continuously during the day and the demand for working balances thus is a demand for intraday liquidity. Taking into consideration these technological developments, it is imperative to clearly distinguish between the demand for intraday liquidity and the demand for end-of-day reserves. Therefore, in Section 3.2.1, we will first analyze banks' demand for intraday liquidity in the context of current LVPS and how it is met by different sources of liquidity. A key finding will be that—without reserve requirements—banks will find it optimal to meet their intraday liquidity needs by intraday credits from the central bank and target zero end-of-day reserve balances. Section 3.2.2 will then analyze the demand for end-of-day reserve balances in the presence of reserve requirements.

this vision to come true before retiring.

3.2.1 The Demand for Intraday Liquidity

Settlement procedures of individual large-value payment systems (LVPS) differ in many respects.[14] Yet, current LVPS of industrialized countries have in common that payments are settled on an individual basis in real-time, thereby providing intraday finality. While this allows to reduce credit risk (and ultimately also systemic risk), it has the drawback that liquidity is needed throughout the day, giving rise to banks' demand for intraday liquidity. As the notion suggests, intraday liquidity is non-substitutable across days. In other words, if a bank needs to settle payments on a particular value day, liquidity is needed precisely on this day, and neither on the previous nor on the following day.[15] Therefore, it suffices to focus on a single day in order to analyze the demand for intraday liquidity and banks' intraday liquidity management.

A bank's intraday liquidity management seeks at settling all payments at the lowest possible cost. To get an idea of this task, it is helpful to first consider the different sources of intraday liquidity and the associated funding costs on any given day t, assuming that there are no reserve requirements and that reserves held overnight with the central bank are remunerated at the deposit rate.

- *Initial reserve balance*: The first source of intraday liquidity are balances held at the opening of the payment system. A bank's initial reserve balance, R_t^{bod}, is equal to the end-of-day balance on $t-1$. While end-of-day balances earn the deposit rate i_{t-1}^d, they could have been lent in the interbank market at the prevailing overnight rate i_{t-1}. Marginal funding costs associated with the initial reserve balance R_t^{bod} thus correspond to $i_{t-1} - i_{t-1}^d$.

- *Intraday credits*: To facilitate settlement of payments in the LVPS, central banks typically offer unrestricted intraday credits (K), either against pledged securities or by means of intraday repos. Although intraday credits are usually free of interest, they entail opportunity

[14] Bank for International Settlements (2005) provides a comprehensive overview of the design of LVPS in the G-10 countries.

[15] In fact, there is a trend that particular payments need to be settled not only at a particular value day, but at specific points in time during the day. For instance, participants to the Continuous Linked Settlement (CLS) system, a multi-currency payment system that allows to settle foreign exchange transactions on a payment-versus-payment basis, need to fund their account with CLS Bank by means of hourly payments between 7 and 12 a.m. CET. These payments are effected through the domestic RTGS systems of the CLS-eligible currencies.

costs in terms of collateral.[16] Provided the central bank accepts a wide range of collateral, the collateral cost c for an incremental unit of intraday credits is relatively small, typically a few basis points.

– *Incoming payments*: A major source of intraday liquidity in current LVPS are funds received from other banks, which can be used immediately to settle a bank's own payments. Incoming payments entail no funding costs at all.

– *Open market operations*: Banks may satisfy their intraday liquidity needs by participating in liquidity-providing open market operations, provided such operations are conducted on the particular day. Because open market operations have a maturity of at least one day, these transactions not only provide intraday liquidity but also increase banks' end-of-day reserve balances which are remunerated at the deposit rate i_t^d. Denoting the central bank's tender rate as i_t^{cb}, the marginal funding costs of open market operations are $i_t^{cb} - i_t^d$.

– *Interbank market*: Intraday liquidity needs may be satisfied by borrowing reserves overnight in the interbank money market at the prevailing overnight rate i_t. As these borrowings increase end-of-day reserve balances, the associated marginal funding costs are $i_t - i_t^d$.

Assuming that payments of total value P_t need to be settled in the LVPS, let us analyze how much intraday liquidity Λ_t banks will demand and how these liquidity needs will be funded. First note that incoming payments are the only source of intraday liquidity which entails no funding costs, so that banks are expected to recycle incoming funds as quickly as possible. Indeed, if banks were able to recycle liquidity an infinite number of times between their reserve accounts, only an arbitrarily small amount of liquidity would be required to settle P_t. The associated liquidity funding costs would then be essentially zero and the payment system's turnover ratio τ_t, defined as the ratio between P_t and Λ_t, would tend to infinity.[17] However, in practice this strategy would

[16] Martin (2004) and Martin and McAndrews (2008) argue that the central bank's provision of collateralized intraday credits at zero interest cost is part of an optimal payments policy. In particular, it improves the smooth functioning of the payment system by reducing banks' incentives to strategically delay sending payments and it guarantees that payment system participants with high liquidity needs will not bear a heavy cost. Moreover, Bhattacharya et al. (2007) argue that the zero cost policy naturally arises as an application of the Friedman rule.

[17] In practice, the amount of intraday liquidity available in the LVPS may vary during the day. Hence, Λ_t should be interpreted as a measure of the average amount of intraday liquidity available to banks on day t.

involve prohibitively high liquidity management costs, because banks would have to split their payments into (infinitely) small installments, monitor and synchronize payment flows, etc. In other words, while recycling funds as often as possible reduces intraday liquidity needs and hence funding costs, funds cannot be recycled arbitrarily often without incurring liquidity management costs. Banks will thus have to balance the costs of liquidity funding and liquidity management.

Moreover, while any LVPS needs a certain amount of intraday liquidity to run smoothly, it is evident that every bank has an incentive to free-ride on other banks' liquidity. That is, from the perspective of an individual bank, funding costs can be minimized by waiting for incoming payments from other banks. But since no bank would ever raise (costly) intraday liquidity in the first place, this strategy cannot be an equilibrium. In practice, to mitigate or even eliminate the incentives to free-ride on other banks' liquidity, many LVPS have implemented measures such as through-put guidelines, which require banks to settle a certain share of their payments obligations by a specific point in time, or time-dependent fee structures promoting early settlement of payments. In the following, it will thus be assumed that free-riding is not an issue and every bank raises intraday liquidity in proportion to its payment obligations.

It should also be noted that even if banks do not engage in any liquidity management activities, the design of current LVPS allows to achieve a turnover ratio of $\bar{\tau}_t > 1$, where $\bar{\tau}_t$ may be considered as a measure of a payment system's liquidity efficiency at a specific point in time.[18] Implicitly, $\bar{\tau}_t$ defines the minimum amount of intraday liquidity $\Lambda_t = P_t/\bar{\tau}_t$ that needs to be funded by the other four sources of liquidity. But while an individual bank may fund part or all of its intraday liquidity needs by borrowing in the interbank market, this is not possible for the market as a whole, because the interbank market only redistributes a given quantity of liquidity. Therefore, there remain only three funding sources—intraday credits, open market operations, and the initial reserve balance—and of course banks will prefer the cheapest one, which is determined by $\min[c, i_t^{cb} - i_t^d, i_{t-1} - i_{t-1}^d]$. In most situations marginal collateral costs c are lower than the spread between overnight interest rates or the tender rate and the deposit rate (i.e. $\min[\cdot] = c$) and banks will thus meet their intraday liquidity needs exclusively by means of intraday credits. Minimising funding costs thus implies $K_t = \Lambda_t = P_t/\bar{\tau}_t$.

[18] Over time, a payment system's liquidity efficiency may increase due to technological progress. For instance, in recent years, $\bar{\tau}_t$ has been raised in many LVPS by the implementation of innovative liquidity-saving mechanisms such as bilateral or multilateral offsetting.

If it refrains from active liquidity management, bank i's funding costs are thus equal to $cK_{i,t}$, with $K_{i,t} = P_{i,t}/\bar{\tau}_t$. But the need for intraday credits and thus funding costs may be reduced by liquidity management measures such as real-time monitoring of payment flows, queue management or the synchronization of incoming and outgoing payments. In particular, assume the bank has the ability to raise its individual turnover ratio $\tau_{i,t} \equiv P_{i,t}/\Lambda_{i,t}$ above $\bar{\tau}_t$ at increasing marginal liquidity management costs. The bank's liquidity management cost function $f(\tau_{i,t})$ can then be summarized as follows: $f(\tau_{i,t}) = 0$ for $\tau_{i,t} \leq \bar{\tau}_t$; $f(\tau_{i,t}) > 0$ for $\tau_{i,t} > \bar{\tau}_t$, with $\partial f/\partial\tau_{i,t} > 0$ and $\partial^2 f/\partial\tau_{i,t} > 0$. Furthermore, from the definition of $\tau_{i,t}$ it follows that $\partial f/\partial\Lambda_{i,t} < 0$. For a given value of $P_{i,t}$, liquidity management costs are thus decreasing in the quantity of intraday liquidity and they are zero if $\Lambda_{i,t} \geq P_{i,t}/\bar{\tau}_t$.

Taking into account that optimal funding of intraday liquidity needs implies $\Lambda_{i,t} = K_{i,t}$, the optimal quantity of intraday credits is then determined by minimizing the sum of collateral cost and liquidity management cost, i.e.

$$\min_{K_{i,t}} \left[cK_{i,t} + f\left(\frac{P_{i,t}}{K_{i,t}}\right)\right]. \tag{3.1}$$

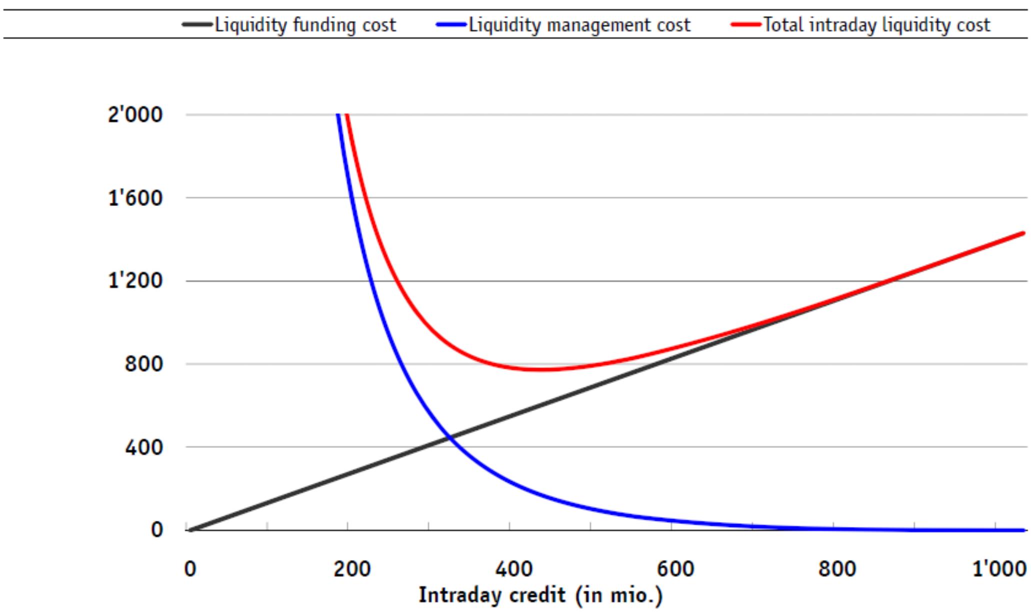
The first order condition is $c = -\partial f/\partial K_{i,t}$, which implies that the optimum is characterized by the equality of marginal collateral costs and the reduction of liquidity management costs associated with an incremental unit of intraday credits. Or, to put it differently, a bank should increase its liquidity management efforts as long as marginal liquidity management costs are outweighed by lower collateral costs for intraday credits.

The relationship between liquidity funding costs and liquidity management costs is illustrated in Figure 3.1. The functional form of the liquidity management cost function is assumed to be $f(\tau_{i,t}) = (\tau_{i,t} - \bar{\tau}_t)^2$, and the other relevant parameter values are $\bar{\tau}_t = 10$, $P_{i,t} = 10$ billion, and $c = 5$bp. Total intraday liquidity costs are then minimized by acquiring intraday credits of around 434 million.

Some additional comments are in order. First, the result that optimal intraday liquidity management implies $R^{bod}_{i,t} = R^{eod}_{i,t-1} = 0$ hinges on the assumptions that there is no uncertainty about payment obligations and that reserve requirements are zero. Under which circumstances and to what extent this result will be affected by relaxing these assumptions will be studied below. However, note that whenever $R^{bod}_{i,t} > 0$—irrespective of whether it is optimal to target a positive end-of-day reserve balance or because the bank was unable to achieve a zero end-of-day reserve balance—, the demand for intraday credits on t is simply reduced by $R^{bod}_{i,t}$. Also, should $R^{bod}_{i,t}$ be larger than $P_{i,t}/\bar{\tau}_t$, the bank's demand for intraday credits would shrink to zero. This can be easily seen by substituting $R^{bod}_{i,t} + K_{i,t}$ into the denominator of the liquidity management cost function $f(\cdot)$ in Equation (3.1).[19]

Moreover, because optimal funding requires that the demand for intraday liquidity is exclusively met by intraday credits, the sole purpose of banks' participation in the interbank market or in open market operations is to adjust end-of-day reserve balances. An important corollary of this result is that in the analysis of banks' behavior in the interbank market and in open market operations it is sufficient to focus on banks' demand for end-of-day reserve balances.

Figure 3.1: Intraday Liquidity Cost



3.2.2 The Demand for End-of-Day Reserve Balances

There are four factors explaining why banks might target positive end-of-day reserve balances. First, reserves might be needed to meet reserve requirements. Second, in case of uncertainty about payment flows, reserves might serve as a buffer against (costly) end-of-day overdrafts. Third, if reserves are remunerated, they might be held voluntarily for investment purposes. And

[19]Because $K_{i,t} \geq 0$, $R^{bod}_{i,t} \geq P_{i,t}/\bar{\tau}_t$ implies $\tau_{i,t} \leq \bar{\tau}_t$, so that $f(\cdot) = 0$. The cost function is then minimized at the corner solution $K_{i,t} = 0$.

finally, end-of-day reserve balances provide (intraday) liquidity services in the LVPS the next day.

But as shown above, holding end-of-day balances for liquidity services in the LVPS is not compatible with optimal intraday liquidity management. Moreover, even if required reserves are remunerated at or close to market interest rates, excess reserves are typically remunerated well below market rates (e.g. at the deposit rate, which provides a floor to market rates). From an investment perspective, it is thus more profitable to lend funds overnight in the interbank money market than holding excess reserves. Consequently, there remain only two pertinent reasons for targeting positive end-of-day reserve balances: reserve requirements and uncertainty about payment flows.

The seminal model to study commercial banks' reserve demand under reserve requirements and uncertainty about payments was introduced by Poole (1968). Focusing only on a single bank, the original model makes two simplifying assumptions. First, abstracting from the role of the interbank market, the interest rate at which the bank might borrow or lend reserves is assumed to be determined exogenously. Second, the (aggregate) supply of reserves is also exogenous, that is the role of the central bank's liquidity management is not explicitly modeled. Clearly, both factors will need to be endogenized in order to analyze how alternative operational frameworks affect banks' demand for reserves and the determination of equilibrium overnight rates. The following analysis of reserve demand differs from Poole's model in that it incorporates an interbank market where the overnight rate is determined as the equilibrium result of banks' borrowing and lending decisions. However, to better focus on various peculiarities of the demand side of the market the assumption that the supply of reserves is exogenous will be maintained, at least initially.

The analysis is structured in two parts. First, it will be assumed that the reserve maintenance period lasts only one day. The model is then extended to a multi-day reserve maintenance period that allows for averaging.

One-Day Reserve Maintenance Period

The model's main assumptions and the timing of events are summarized in the first subsection, the subsequent subsections then analyze the borrowing or lending decision of an individual bank and the implications for the market clearing interest rate in the interbank market.

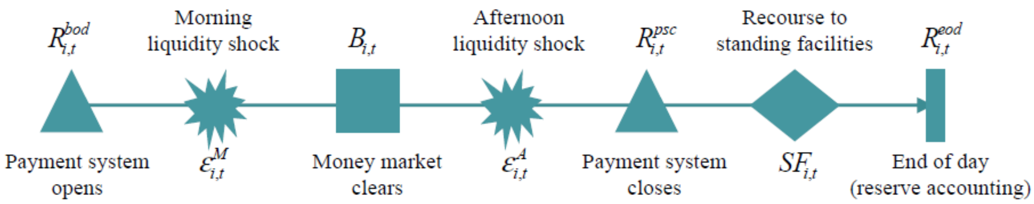
Assumptions and Timing of Events

The central bank's operational framework is characterized by reserve requirements that need to be fulfilled on a daily basis (i.e. there is no averaging), with bank i's reserve requirement on day t being denoted $D_{i,t} > 0$.[20] Moreover, the central bank provides two standing facilities, a borrowing facility at rate $i_t^b > 0$ and a deposit facility at rate $i_t^d \geq 0$, with $i_t^b > i_t^d$. Required reserves are not remunerated but any reserve deficiency is penalized at rate $i_t^p > i_t^b$.

The interbank market for reserves is a perfectly competitive, frictionless call market, where banks may borrow ($B_{i,t} > 0$) or lend ($B_{i,t} < 0$) funds between each other at the market clearing overnight rate i_t.[21] The market is populated by a set $N = \{1, 2, \ldots, n\}$ of identical, risk-neutral and profit-maximizing banks, where n is large.

In the course of the day, every bank faces two so-called cumulated liquidity shocks, $\varepsilon_{i,t}^M$ and $\varepsilon_{i,t}^A$, which both affect its reserve balance. Both shocks are normally distributed with mean zero, that is $\varepsilon_{i,t}^M \sim N(0, \sigma_{\varepsilon^M}^2)$ and $\varepsilon_{i,t}^A \sim N(0, \sigma_{\varepsilon^A}^2)$. The shocks are said to be *cumulated* since they capture the impact on the bank's reserves of both idiosyncratic and autonomous liquidity shocks.[22]

Figure 3.2: Timing of Events



As depicted in Figure 3.2, the timing of events during the day is as follows. At the beginning of the day, the payment system opens and any funds borrowed from or deposited into the standing facilities on the previous day are immediately reversed. Bank i's reserve balance at the beginning of the settlement day thus is $R_{i,t}^{bod} = R_{i,t-1}^{eod} - SF_{i,t-1}$, where $R_{i,t}^{eod}$ denotes bank i's end-of-day reserve balance and $SF_{i,t}$ is the net recourse to standing facilities on day t (see also below). In the morning, the bank then incurs the first liquidity shock, $\varepsilon_{i,t}^M$. At noon, the bank may borrow or lend reserves in the interbank money market at the prevailing equilibrium overnight rate i_t. At the same time, any funds borrowed (lent) in the interbank money market on

[20]In subsequent sections that allow for averaging of reserve requirements over a multi-day maintenance period, $D_{i,t}$ is interpreted as the reserve *deficiency* on day t, i.e. the total amount of reserves the bank needs to hold over the remainder of the maintenance period.

[21]Appendix A.1.1 discusses the rationale for these assumptions in more detail.

[22]Appendix A.1.2 elaborates on the assumptions underlying the specific modeling of payment uncertainty and liquidity shocks.

the previous day are repaid (received). In the afternoon, the second liquidity shock, $\varepsilon_{i,t}^{A}$, is realized and the payment system closes. The bank's reserve balance at that time is $R_{i,t}^{psc} = R_{i,t}^{bod} + B_{i,t} - B_{i,t-1} + \hat{\varepsilon}_{i,t}^{M} + \hat{\varepsilon}_{i,t}^{A}$, where $\hat{\varepsilon}_{i,t}^{M}$ and $\hat{\varepsilon}_{i,t}^{A}$ are the realized liquidity shocks and $B_{i,t-1}$ is predetermined. For simplicity, it will be assumed in the following that $B_{i,t-1} = 0$. Once the payment system is closed, the bank may have recourse to the standing facilities, i.e. it may borrow from the borrowing facility ($BF_{i,t} > 0$) or it may deposit (excess) reserves in the deposit facility ($DF_{i,t} > 0$), so that net recourse to standing facilities is $SF_{i,t} = BF_{i,t} - DF_{i,t}$. Bank i's end-of-day reserve balance thus is $R_{i,t}^{eod} = R_{i,t}^{psc} + SF_{i,t}$ and it is said to have met reserve requirements if $R_{i,t}^{eod} \geq D_{i,t}$.

Optimal Bank Behavior

The model's simple set-up allows us to analyze the impact of reserve requirements and payments uncertainty on banks' demand for end-of-day reserve balances and money market participation by means of a representative bank. The bank faces two decision problems. At noon, it needs to decide on the amount of reserves to be borrowed or lent in the interbank money market; and after the payment system has closed, it has to decide on the optimal use of standing facilities.

Once the payment system is closed, there is no uncertainty left so that optimal recourse to standing facilities is trivial. Three cases may be distinguished, depending on whether $R_{i,t}^{psc}$ is equal, larger or smaller than the reserve requirement:

(1) $R_{i,t}^{psc} = D_{i,t}$

The bank meets reserve requirements precisely and there is no need for having recourse to either of the standing facilities.

(2) $R_{i,t}^{psc} > D_{i,t}$

The bank has more reserves than required and it will deposit excess reserves into the deposit facility, i.e. $DF_{i,t} = R_{i,t}^{psc} - D_{i,t}$.

(3) $R_{i,t}^{psc} < D_{i,t}$

In order to avoid a reserve deficiency the bank will borrow the necessary amount from the borrowing facility, i.e. $BF_{i,t} = D_{i,t} - R_{i,t}^{psc}$.

Of course, recourse to standing facilities entails opportunity costs. For instance, excess reserves earn only the deposit rate i_t^d, which is (usually) less than what the bank could have earned by lending these funds overnight in the interbank money market. Similarly, if the bank needs to borrow from the borrowing facility in order to avoid a reserve deficiency, this is (usually) more costly than if it had borrowed these funds overnight in the interbank money market. Ex post, opportunity costs are thus equal to $DF_{i,t}(i_t - i_t^d)$ and $BF_{i,t}(i_t^b - i_t)$, respectively. The bank's challenge then is that ex ante, that is at the time of market clearing, it does not yet know the realization of the second liquidity shock; the bank thus faces uncertainty about its reserve position after the close of the payment system.

At the time of market clearing, the bank needs to decide on the amount to be borrowed or lent in the interbank money market, taking into account the direct borrowing costs (or lending revenues) as well as the impact on the reserve position after the close of the payment system and hence on the likelihood of whether it will have to use either of the two standing facilities. Obviously, the probability of ending up with excess reserves (or a reserve deficiency) is an increasing (decreasing) function of the amount borrowed in the market. Note that the reserve position after the close of the payment system can be written as $R_{i,t}^{psc} = R_{i,t}^{mc} + B_{i,t} + \varepsilon_{i,t}^A$, where $R_{i,t}^{mc} = R_{i,t}^{bod} + \hat{\varepsilon}_{i,t}^M$ is the reserve position the bank observes just before it enters the market. The probability of a reserve deficiency after the close of the payment system can thus be written as $\Pr[\varepsilon_{i,t}^A \leq D_{i,t} - R_{i,t}^{mc} - B_{i,t}]$, or alternatively as $\Gamma_{\varepsilon^A}(D_{i,t} - R_{i,t}^{mc} - B_{i,t})$, where Γ_{ε^A} denotes the cumulative distribution function of the afternoon liquidity shock. The bank's value or expected profit function thus takes the following form:

$$V_{i,t} = \max_{B_{i,t}} E_t(\Pi_{i,t}) = -i_t B_{i,t} - E_t(c_{i,t}), \tag{3.2}$$

where the first term reflects the costs (revenues) from borrowing (lending) reserves in the market and $c_{i,t}$ is the opportunity cost associated with the use of standing facilities. Note that at the time of market clearing the expected opportunity costs can be written as

$$\begin{aligned} E_t(c_{i,t}) \quad &= \quad i_t^b \int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \left(D_{i,t} - R_{i,t}^{mc} - B_{i,t} - \varepsilon_{i,t}^A\right) \psi(\varepsilon^A) \\ &- \quad i_t^d \int_{D_{i,t}-R_{i,t}^{mc}-B_{i,t}}^{\infty} \left(R_{i,t}^{mc} + B_{i,t} + \varepsilon_{i,t}^A - D_{i,t}\right) \psi(\varepsilon^A) \end{aligned}$$

where $\psi(\varepsilon^A)$ is used as a shortcut for $\gamma_{\varepsilon^A}(\varepsilon^A)\,\mathrm{d}\varepsilon^A$.

As shown in Appendix 2.1, the first order condition for profit maximization in Equation (3.2) yields

$$B_{i,t} = (D_{i,t} - R_{i,t}^{mc}) - \Gamma_{\varepsilon^A}^{-1}\left(\frac{i_t - i_t^d}{i_t^b - i_t^d}\right), \tag{3.3}$$

where Γ^{-1} is the inverse of the cumulative distribution function. For $i_t^d \leq i_t \leq i_t^b$ the argument of the function $\Gamma_{\varepsilon^A}^{-1}(\cdot)$ is in the interval $[0, 1]$ and bank i's borrowing function is thus well defined.[23]

The first term on the right hand side of Equation (3.3) reveals that optimal borrowing depends on the reserve position just before market clearing in relation to the reserve requirement. For instance, the larger the gap between the reserve requirement and the current reserve position, the more the bank will borrow in the interbank market. As a consequence, two banks that are subject to the same reserve requirement but have different reserve positions prior to market clearing—for instance because they had different initial balances or because they experienced different realizations of the morning liquidity shock—will have the same reserve positions just *after* market clearing if they borrow according to Equation (3.3). Accordingly, prior to the realization of the afternoon liquidity shock, they will have the same—optimal—probabilities of having recourse to either of the two standing facilities. The interbank market thus serves to optimally distribute available reserves among banks.

The comparative statics of Equation (3.3) reveal that, as expected, borrowing decreases with the level of the overnight rate, i.e.

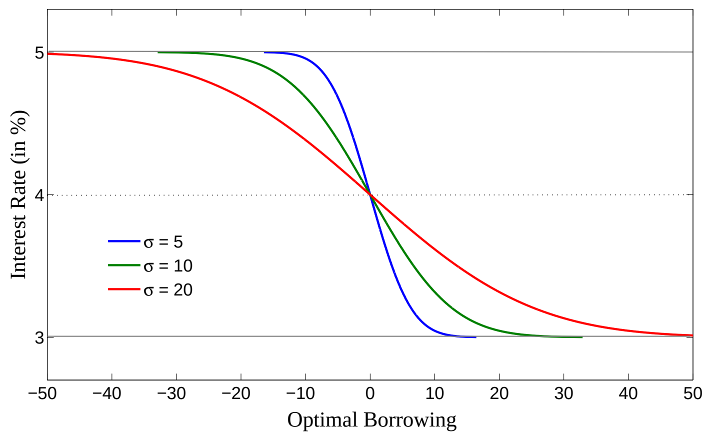
$$\frac{\partial B_{i,t}}{\partial i_t} = -\frac{\sigma_{\varepsilon^A}}{\kappa\, \varphi\left(\frac{B_{i,t}+R_{i,t}^{mc}-D_{i,t}}{\sigma_{\varepsilon^A}}\right)} < 0,$$

where $\varphi(\cdot)$ is the probability density function of a standard normal variable and $\kappa = i_t^b - i_t^d$ is the spread between the borrowing rate and the deposit rate. In particular, borrowing depends on the position of the overnight rate within the corridor defined by the two standing facilities and the degree of payment uncertainty. This is shown in Figure 3.3, where it is assumed that the deposit rate and the borrowing rate are 3% and 5% respectively and, for simplicity, $R_{i,t}^{mc} = D_{i,t}$. Whenever the overnight rate is exactly in the middle of the interest rate corridor, that is if $i_t = (i_t^b + i_t^d)/2$, optimal borrowing is zero, irrespective of the level of payment uncertainty. In other words, the bank borrows in the market that amount of reserves which is necessary to target zero end-of-day excess reserves ($E_t\left[R_{i,t}^{psc} - D_{i,t}\right] = 0$). In contrast, whenever the overnight rate is above or below the middle of the corridor, optimal borrowing depends on the degree of payment uncertainty. For instance, if the overnight rate is in the lower part of the corridor, optimal borrowing

[23] For any random variable $x \sim N(\mu_x, \sigma_x^2)$, the inverse of the cumulative distribution function, $\Gamma_x^{-1}(a)$, is well defined over the support $a \in [0, 1]$, increasing in a and $\Gamma_x^{-1}(0.5) = \mu_x$.

increases with the level of payment uncertainty. Similarly, if the overnight rate is in the upper part of the corridor, optimal lending increases with the level of payment uncertainty. To put it differently: The higher the payment uncertainty, the higher the elasticity of reserve demand.

Figure 3.3: Payment Uncertainty and Optimal Borrowing



It is also important to stress that for a given width of the interest rate corridor and a specific degree of payment uncertainty, optimal borrowing depends only on the *relative* position of the overnight rate within the corridor but not on the absolute level of either of these rates. For instance, in the example above with deposit and borrowing rates of 3% and 5% respectively, optimal borrowing at an overnight rate of say 4.5% would be exactly the same as if the standing facility rates and the overnight rate were all shifted up or down in parallel by 1%.

The Market Clearing Interest Rate

We now turn to the determination of the equilibrium overnight rate, that is the price at which supply of and demand for reserves in the interbank market coincide. In this respect, note that the model's assumptions regarding the market microstructure imply that the the market clearing interest rate is easily obtained by averaging Equation (3.3) over all banks and applying the market clearing condition $\sum_i B_{i,t} = 0$. Denoting $D_t = \frac{1}{n}\sum_i D_{i,t}$ and $R_t^{mc} = \frac{1}{n}\sum_i R_{i,t}^{mc}$ as the per capita reserve deficiency and the per capita reserve balance at the time of market clearing[24], respectively, the market clearing overnight rate is

[24]Note that we have assumed that n, the number of banks, is large but finite. If there was

$$i_t = i_t^b \, \Gamma_{\varepsilon^A} \left(D_t - R_t^{mc} \right) + i_t^d \left[1 - \Gamma_{\varepsilon^A} \left(D_t - R_t^{mc} \right) \right]. \tag{3.4}$$

The equilibrium overnight rate thus equals the weighted average of the borrowing rate and the deposit rate, with the weights corresponding to the probabilities of the representative bank having a reserve deficiency or excess reserves after the closing of the payment system, respectively. Equation (3.4) also reveals that the market clearing overnight rate lies exactly in the middle of the corridor defined by the standing facilities if and only if $R_t^{mc} = D_t$. Whenever the amount of reserves available to the banks is below the level of reserve requirements, the overnight rate tends to be in the upper part of the corridor, whereas the overnight rate tends to be in the lower part if the amount of reserves exceeds reserve requirements. In line with the classic liquidity effect, the overnight rate is thus a decreasing function of R_t^{mc}.

It is instructive to explore how the probabilities of a reserve deficiency and excess reserves—and consequently the equilibrium overnight rate—depend on the degree of payment uncertainty, which is captured by the variance of the afternoon liquidity shock. The relationship between payment uncertainty and the equilibrium interest rate is illustrated in Figure 3.4 for different values of $G_t^{mc} = R_t^{mc} - D_t$.

With the exception of the special case when $G_t^{mc} = 0$, the degree of payment uncertainty apparently affects the market clearing interest rate. For instance, for $G_t^{mc} = -20$, the red line shows how the market clearing overnight rate decreases with the degree of payment uncertainty. The explanation is as follows. On the one hand, in case of relatively low payment uncertainty, it is unlikely that the afternoon liquidity shock will turn out to be sufficiently large to lift the bank's reserve position above the level of required reserves. It is thus very likely that banks end up with a reserve deficiency (i.e. $R_{i,t}^{psc} < D_{i,t}$), which will have to be covered by borrowing from the borrowing facility. Therefore, banks are willing to borrow funds in the interbank money market even if the overnight rate they have to pay is only marginally below the central bank's borrowing rate. On the other hand, in case of relatively high payment uncertainty, the probability of realizing a liquidity shock which is sufficiently large to avoid a reserve deficiency is higher. As a consequence, banks bid less aggressively for funds and the market clearing overnight rate is closer to the middle of the corridor.[25] Vice versa, when

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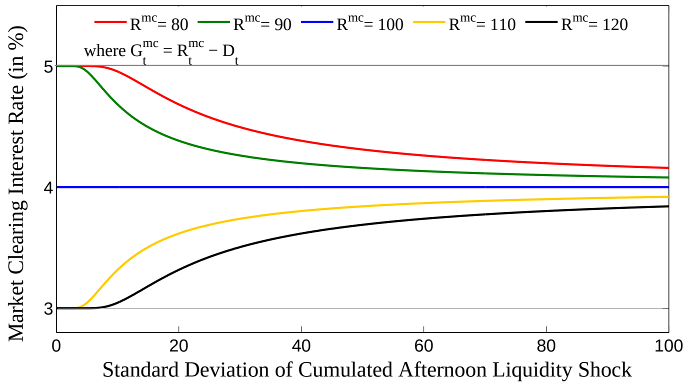
a continuum of banks with measure one, i.e. $i \in [0,1]$, the per capita reserve deficiency and the per capita reserve balance at the time of market clearing would be defined as $D_t = \int_0^1 D_{i,t} \, \mathrm{d}$ and $R_t^{mc} = \int_0^1 R_{i,t}^{mc} \, \mathrm{d}$.

[25]For instance, with $D_{i,t} = 100$ and $R_{i,t}^{mc} = 80$, a bank's probability of incurring a

Figure 3.4: Payment Uncertainty and the Market Clearing Interest Rate



R_t^{mc} is larger than required reserves (see e.g. the yellow line), high payment uncertainty implies that a reserve deficiency is more likely than in case of low payment uncertainty, and hence the market clearing overnight rate tends to be closer to the middle of the corridor. Finally, in the special case when $R_t^{mc} = D_t$ and hence $G_t^{mc} = 0$ (see the blue line), the probabilities of incurring a reserve deficiency or ending up with excess reserves are both 0.5, irrespective of whether payment uncertainty is low or high. Therefore, in this case, the market clearing overnight rate is simply $(i_t^b + i_t^d)/2$. The impact of very low and very high payment uncertainty on the market clearing overnight rate can also be summarized as follows:

$$\lim_{\sigma_{\varepsilon^A} \to 0} \Gamma_{\varepsilon^A}(D_t - R_t^{mc}) = \begin{cases} 0 & \text{for } R_t^{mc} > D_t \text{ and hence } i_t = i_t^d, \\ 0.5 & \text{for } R_t^{mc} = D_t \text{ and hence } i_t = \frac{i_t^b + i_t^d}{2}, \\ 1 & \text{for } R_t^{mc} < D_t \text{ and hence } i_t = i_t^b, \end{cases}$$

and

$$\lim_{\sigma_{\varepsilon^A} \to \infty} \Gamma_{\varepsilon^A}(D_t - R_t^{mc}) = 0.5 \text{ for } R_t^{mc} \gtreqless D_t \text{ and hence } i_t = \frac{i_t^b + i_t^d}{2}.$$

reserve deficiency after the close of the payment system is 0.977 for $\sigma_{\varepsilon^A} = 10$, whereas for $\sigma_{\varepsilon^A} = 100$ the probability is only 0.579. The associated market clearing overnight rates are 4.95% and 4.16%, respectively.

Reserve Maintenance Period with Averaging

We now turn to the more interesting case in which reserve requirements have to be complied with on average over a T-day reserve maintenance period. On every day $t = 1, 2, \ldots, T$, the bank has to decide on borrowing or lending in the interbank market. Just before market clearing on day t, the bank's situation can be summarized by two state variables: the remaining reserve deficiency, $D_{i,t}$, and the current reserve position, $R_{i,t}^{mc}$. These state variables, which can be summarized as $S_{i,t} = (D_{i,t}, R_{i,t}^{mc})$, evolve according to the following processes:

$$D_{i,t} = \max[0,\ D_{i,t-1} - R_{i,t-1}^{eod}],\ t = 2, \ldots, T, \tag{3.5}$$

and

$$R_{i,t}^{mc} = R_{i,t-1}^{mc} + \hat{\varepsilon}_{i,t-1}^{A} + \hat{\varepsilon}_{i,t}^{M}. \tag{3.6}$$

Regarding the process in (3.5), note that the total reserve requirement for the maintenance period, $D_{i,1}$, is exogenous and reserve requirements are met if $D_{i,T+1} = 0$. Also, once the deficiency is zero it remains zero for the remainder of the maintenance period. The bank is then said to be "locked-in" and any additional reserves held overnight are excess reserves. Regarding the process in (3.6), it is important to note that neither borrowing or lending in the interbank market nor the potential recourse to either of the standing facilities on day t affect the bank's reserve position at the time of market clearing on day $t + 1$. Indeed, since these transactions have overnight maturity and any funds are returned before market clearing the following day, they only affect the end-of-day reserve position on day t. The intertemporal evolution of $R_{i,t}^{mc}$ is therefore an exogenous process, driven solely by the realizations of the cumulated liquidity shocks.

In general, a bank's decisions and expected profits will not only depend on $S_{i,t}$ but also on market-wide factors, which at the time of market clearing on day t is captured by the state variables $S_t = (D_t, R_t^{mc})$, the per capita reserve deficiency and the per capita reserve position. Note that the per capita state variables evolve according to the following processes:

$$D_t = \max[0,\ D_{t-1} - R_{t-1}^{eod}],\ t = 2, \ldots, T,$$

and

$$R_t^{mc} = R_{t-1}^{mc} + \hat{\eta}_{t-1}^A + \hat{\eta}_t^M,$$

where $\hat{\eta}_{t-1}^A$ and $\hat{\eta}_t^M$ are the realized per capita autonomous liquidity shocks.[26]

The timing of events in the course of the day is the same as in the previous section (see Figure 3.2). However, banks face an additional constraint due to the fact that overnight overdrafts are not allowed. In order to avoid overdrafts, a bank will have to borrow from the borrowing facility whenever $R_{i,t}^{psc} < 0$, irrespective of whether reserve requirements have been already fulfilled or not. For simplicity, the rates for the standing facilities are assumed to be constant throughout the reserve maintenance period, so that we can simply write i^b and i^d for the the borrowing and the deposit rate, respectively.

Last Day of the Reserve Maintenance Period

On the last day of the reserve maintenance period, the analysis is very similar as in the case of a one-day reserve maintenance period. The value or expected profit function is

$$V_{i,T}(S_{i,T}, S_T) = \max_{B_{i,T}} E_T(\Pi_{i,T}) = -i_T B_{i,T} - E_T\left(c_{i,T}\right), \tag{3.7}$$

with

$$\begin{aligned} E_T(c_{i,T}) &= i^b \int_{-\infty}^{D_{i,T}-R_{i,T}^{mc}-B_{i,T}} \left(D_{i,T} - R_{i,T}^{mc} - B_{i,T} - \varepsilon_{i,T}^A\right) \psi(\varepsilon^A) \\ &- i^d \int_{D_{i,T}-R_{i,T}^{mc}-B_{i,T}}^{\infty} \left(R_{i,T}^{mc} + B_{i,T} + \varepsilon_{i,T}^A - D_{i,T}\right) \psi(\varepsilon^A). \end{aligned}$$

The first order condition then readily yields

$$B_{i,T} = B_{i,T}(S_{i,T}, S_T) = (D_{i,T} - R_{i,T}^{mc}) - \Gamma_{\varepsilon^A}^{-1}\left(\frac{i_T - i^d}{i^b - i^d}\right) \tag{3.8}$$

and the market clearing overnight rate is

$$i_T = i_T(S_T) = i^b\, \Gamma_{\varepsilon^A}\left(D_T - R_T^{mc}\right) + i^d\left[1 - \Gamma_{\varepsilon^A}\left(D_T - R_T^{mc}\right)\right]. \tag{3.9}$$

[26]Note that by definition the idiosyncratic components of cumulated liquidity shocks cancel each other out, so that the *per capita* cumulated liquidity shock is equal to the per capita autonomous liquidity shock (e.g. $\hat{\varepsilon}_{t-1}^A = \hat{\eta}_{t-1}^A$). See Appendix A.1.2 for further explanations.

The interpretation and the comparative statics of Equations (3.8) and (3.9) are the same as in the case of the one-day reserve maintenance period above. Moreover, one might ask: What is the marginal value of starting day T with an additional unit of reserves or a lower reserve deficiency? Substituting optimal borrowing from Equation (3.8) into the value function (3.7), it is easy to see that

$$\frac{\partial V_{i,T}(S_{i,T}, S_T)}{\partial R_{i,T}^{mc}} = -\frac{\partial V_{i,T}(S_{i,T}, S_T)}{\partial D_{i,T}} = i_T. \tag{3.10}$$

This result is quite intuitive: Assuming that the bank is a net lender in the market on day T, an additional unit of reserves might be loaned out in the market, earning the market interest rate i_T. Similarly, if the reserve deficiency is one unit lower, the bank might lend one unit more in the market, also earning the market interest rate i_T.

It should be stressed that these results do not depend on whether an individual bank or even the market as a whole starts day T with a positive or a zero reserve deficiency. For instance, if $D_{i,T} = 0$, it is still optimal for bank i to borrow in the market according to Equation (3.8), as doing so will minimize the expected opportunity costs of ending the day either with an overdraft or excess reserves. Also, even if $D_{i,T} = 0 \,\forall\, i$ and hence $D_T = 0$, the market clearing interest rate is still determined according to Equation (3.9). That is, even if all banks have satisfied their reserve requirement for the current maintenance period by the end of the penultimate day, the equilibrium overnight rate on day T may be well above the floor set by i^d, at least if the per capita level of reserves in the market is sufficiently low and there is a positive probability that some banks will incur an end-of-day overdraft.

Previous Days

We now turn to the analysis of banks' behavior and the implications for market clearing overnight rates on earlier days in the reserve maintenance period. In general, the value function in Bellman's equation takes the following form:

$$V_{i,t}(S_{i,t}, S_t) = \max_{B_{i,t}} E_t(\Pi_{i,t} + V_{i,t+1}), \tag{3.11}$$

where

$$\Pi_{i,t} = -i_t B_{i,t} - c_{i,t}$$

is the profit in period t and

$$\begin{aligned} E_t(c_{i,t}) &= i^b \int_{-\infty}^{-R_{i,t}^{mc}-B_{i,t}} \left(-R_{i,t}^{mc} - B_{i,t} - \varepsilon_{i,t}^A\right) \gamma_{\varepsilon^A}(\varepsilon^A)\, \mathrm{d}\varepsilon^A \\ &- i^d \int_{D_{i,t}-R_{i,t}^{mc}-B_{i,t}}^{\infty} \left(R_{i,t}^{mc} + B_{i,t} + \varepsilon_{i,t}^A - D_{i,t}\right) \gamma_{\varepsilon^A}(\varepsilon^A)\, \mathrm{d}\varepsilon^A. \end{aligned} \tag{3.12}$$

The first term in Equation (3.12) is the cost of an overdraft at the end of day t, whereas the second term reflects the cost that arises if the bank ends up with reserves in excess of its reserve deficiency. From an ex post perspective, the bank incurs an overdraft if the afternoon liquidity shock is sufficiently small (so that $R_{i,t}^{psc} < 0$), and it ends up with excess reserves if the shock is sufficiently large (so that $R_{i,t}^{psc} > D_{i,t}$). In case the realization of $\varepsilon_{i,t}^A$ falls in between, the bank will not use either of the standing facilities so that $c_{i,t} = 0$.

In the following it is necessary to differentiate whether the bank starts day t with a zero or a positive reserve deficiency. Let us first analyze the situation in which it has a zero reserve deficiency ($D_{i,t} = 0$). In this case, borrowing or lending an additional unit in the market affects only $\Pi_{i,t}$, but not $V_{i,t+1}$. Indeed, since the reserve requirement is already fulfilled (so that $D_{i,t+1} = 0$) and funds borrowed or lent on t have to be returned the next day (so that $R_{i,t+1}^{mc}$ does not depend on $B_{i,t}$), the bank's value function on $t+1$ is not affected, that is

$$\left.\frac{\partial E_t(V_{i,t+1})}{\partial B_{i,t}}\right|_{D_{i,t}=0} = 0.$$

Moreover, it is readily verified that

$$-\left.\frac{\partial E_t(c_{i,t})}{\partial B_{i,t}}\right|_{D_{i,t}=0} = i^b\, \Gamma_{\varepsilon^A}\left(-R_{i,t}^{mc} - B_{i,t}\right) + i^d\, \left[1 - \Gamma_{\varepsilon^A}\left(-R_{i,t}^{mc} - B_{i,t}\right)\right].$$

The first order condition for the maximization problem in Equation (3.11) thus yields

$$B_{i,t} = -R_{i,t}^{mc} - \Gamma_{\varepsilon^A}^{-1}\left(\frac{i_t - i^d}{i^b - i^d}\right). \tag{3.13}$$

Furthermore, if $D_{i,t} = 0\, \forall i$, the market clearing interest rate on day t is

$$i_t = i^b\, \Gamma_{\varepsilon^A}\left(-R_t^{mc}\right) + i^d\, \left[1 - \Gamma_{\varepsilon^A}\left(-R_t^{mc}\right)\right].$$

Therefore, if all banks are locked-in by the end of day $t-1$, overnight rates on the remaining days of the maintenance period depend solely on the respective per capita level of reserves on these days.

Now assume that $D_{i,t} > 0$. Contrary to the case before, the decision on $B_{i,t}$ now affects $D_{i,t+1}$ and thus the value function on $t+1$. In particular, depending on the realization of the shock $\varepsilon^A_{i,t}$, which directly affects $R^{psc}_{i,t}$, the reserve position after closing of the payment system, $V_{i,t+1}(S_{i,t+1}; S_{t+1})$ may take the following values:

$$V_{i,t+1}(\cdot) = \begin{cases} V_{i,t+1}(D_{i,t}, R^{mc}_{i,t+1}; S_{t+1}) & \text{if } R^{psc}_{i,t} < 0, \\ V_{i,t+1}(D_{i,t} - R^{psc}_{i,t}, R^{mc}_{i,t+1}; S_{t+1}) & \text{if } 0 < R^{psc}_{i,t} < D_{i,t}, \\ V_{i,t+1}(0, R^{mc}_{i,t+1}; S_{t+1}) & \text{if } R^{psc}_{i,t} > D_{i,t}. \end{cases}$$

Therefore, we may write

$$\begin{aligned} E_t\left[V_{i,t+1}(S_{i,t+1}; S_{t+1})\right] = & \textstyle\int_{-\infty}^{-R^{mc}_{i,t}-B_{i,t}} E_t\left[V_{i,t+1}(D_{i,t}, R^{mc}_{i,t+1}; S_{t+1})\right] \psi(\varepsilon^A) \\ & + \textstyle\int_{-R^{mc}_{i,t}-B_{i,t}}^{D_{i,t}-R^{mc}_{i,t}-B_{i,t}} E_t\left[V_{i,t+1}(D_{i,t} - R^{mc}_{i,t} - B_{i,t} - \varepsilon^A_{i,t}, R^{mc}_{i,t+1}; S_{t+1})\right] \psi(\varepsilon^A) \\ & + \textstyle\int_{D_{i,t}-R^{mc}_{i,t}-B_{i,t}}^{\infty} E_t\left[V_{i,t+1}(0, R^{mc}_{i,t+1}; S_{t+1})\right] \psi(\varepsilon^A) \end{aligned}$$

so that

$$\begin{aligned} \tfrac{\partial E_t[V_{i,t+1}(\cdot)]}{\partial B_{i,t}} &= \tfrac{\partial E_t[V_{i,t+1}(\cdot)])}{\partial D_{i,t+1}} \cdot \tfrac{\partial D_{i,t+1}}{\partial B_{i,t}} \\ &= -\textstyle\int_{-R^{mc}_{i,t}-B_{i,t}}^{D_{i,t}-R^{mc}_{i,t}-B_{i,t}} \tfrac{\partial E_t\left[V_{i,t+1}(D_{i,t+1}, R^{mc}_{i,t+1}; S_{t+1})\right]}{\partial D_{i,t+1}} \gamma_{\varepsilon^A}(\varepsilon^A)\, \mathrm{d}\varepsilon^A. \end{aligned}$$

The first order condition to the optimization problem in Equation (3.11) then is

$$\begin{aligned} i_t &= \phi^1_{i,t}\, i^b + \phi^3_{i,t}\, i^d \\ &- \textstyle\int_{-R^{mc}_{i,t}-B_{i,t}}^{D_{i,t}-R^{mc}_{i,t}-B_{i,t}} \tfrac{\partial E_t\left[V_{i,t+1}(D_{i,t+1}, R^{mc}_{i,t+1}; S_{t+1})\right]}{\partial D_{i,t+1}} \gamma_{\varepsilon^A}(\varepsilon^A)\, \mathrm{d}\varepsilon^A, \end{aligned} \tag{3.14}$$

where $\phi^1_{i,t} = \Gamma_{\varepsilon^A}\left(-R^{mc}_{i,t} - B_{i,t}\right)$ and $\phi^3_{i,t} = \Gamma_{\varepsilon^A}\left(R^{mc}_{i,t} + B_{i,t} - D_{i,t}\right)$ are the probabilities of incurring on day t an end-of-day overdraft or excess reserves, respectively. Regarding the third term on the right hand side, note that the integrand $-\partial E_t\left[V_{i,t+1}(\cdot)\right] / \partial D_{i,t+1}$ measures the impact of a marginally lower reserve deficiency on $t+1$ on future profits. From Equation (3.10) we already know that for $t+1 = T$, $-\partial E_t\left[V_{i,T}(\cdot)\right]/\partial D_{i,T} = E_t(i_T)$. However, for $t+1 < T$, the impact of a lower reserve deficiency is twofold. First, with probability $\phi^3_{i,t+1}$ the bank will accumulate excess reserves on $t+1$ and remain locked-in until the end of the maintenance period (i.e. $D_{i,\tau} = 0$ for $\tau \geq t+2$ and thus $-\partial E_t\left[V_{i,t+2}(\cdot)\right]/\partial D_{i,t+2} = 0$). In this case, the value of starting day $t+1$ with a marginally lower reserve deficiency is i^d. Second, in all other circumstances, the lower reserve deficiency will be carried over into the next day with the impact on future profits being captured by $-\partial E_t\left[V_{i,t+2}(\cdot)\right]/\partial D_{i,t+2}$. Therefore, the law of motion of $\partial E_t\left[V_{i,t+1}(\cdot)\right]/\partial D_{i,t+1}$ can be written as

$$\begin{aligned}
\frac{\partial E_t[V_{i,t+1}(\cdot)]}{\partial D_{i,t+1}} &= -\phi^3_{i,t+1}\, i^d \\
&+ \int_{-\infty}^{D_{i,t+1}-R^{mc}_{i,t+1}-B_{i,t+1}} \frac{\partial E_t[V_{i,t+2}(\cdot)]}{\partial D_{i,t+2}}\, \gamma_{\varepsilon^A}(\varepsilon^A)\, \mathrm{d}\varepsilon^A, \\
&\text{for } t+1 \leq T-1, \text{ and} \\
\frac{\partial E_t\left[V_{i,T}(\cdot)\right]}{\partial D_{i,T}} &= -E_t\left(i_T\right).
\end{aligned} \tag{3.15}$$

The first order condition in Equation (3.14) implicitly defines bank i's demand for reserves in the market. The intuition is straightforward: When deciding on the amount to be borrowed in the market, the bank equates the marginal cost of borrowing an additional unit of reserves, which is the current market interest rate i_t, to its marginal value. The marginal value is a weighted average of the value of an additional unit of reserves after the realization of the shock $\varepsilon^A_{i,t}$:

(1) In case the bank incurs an end-of-day overdraft, which happens with probability $\phi^1_{i,t}$, the marginal value is equal to i^b since it will have to borrow one unit of reserves less from the central bank's borrowing facility.

(2) In case the bank ends up with excess reserves, which happens with probability $\phi^3_{i,t}$, the marginal value is i^d since it will be able to deposit an additional unit of reserves in the central bank's deposit facility.

(3) In intermediate cases, which happen with probability $\phi^2_{i,t} = 1-\phi^1_{i,t}-\phi^3_{i,t}$, the bank accumulates reserves without having recourse to either of the two standing facilities. The marginal value of an additional unit of reserves is then measured by the impact of a lower reserve deficiency on future profits, captured by the expression $-\partial E_t\left[V_{i,t+1}(\cdot)\right]/\partial D_{i,t+1}$.

Unfortunately, Equation (3.14) does not allow to compute the value of a bank's optimal borrowing explicitly, nor is it possible to derive the explicit market clearing condition. Rather, in general, optimal borrowing and the market clearing condition must be derived using numerical methods. Nevertheless, a closer inspection of the first order condition allows to draw some interesting qualitative conclusions regarding both the dynamics of overnight rates and the pattern of banks' reserve demand within the maintenance period.

Intertemporal Dynamics of the Overnight Rate

First of all, note that for $t = T-1$, the first order condition (3.14) simplifies to

$$i_{T-1} = \phi^1_{i,T-1}\, i^b + \phi^3_{i,T-1}\, i^d + \phi^2_{i,T-1}\, E_{T-1}\left(i_T\right),$$

thus establishing a close link between the overnight rate on $T-1$ and the overnight rate expected to prevail on the last day of the maintenance period. In particular, provided the probabilities of both an overdraft and excess reserves on $T-1$ are negligible, it is readily verified that the overnight rate is expected to follow—at least approximately—a martingale, i.e. $E_{T-1}\left(i_T\right) \simeq i_{T-1}$. Moreover, as shown in Appendix A.2.2, by recursively substituting the law of motion in Equation (3.15) into Equation (3.14), for $t < T-1$ the first order condition can be reformulated as

$$\begin{aligned} i_t &= \phi^1_{i,t}\, i^b \\ &+ \left[\phi^3_{i,t} + \phi^2_{i,t}\phi^3_{i,t+1} + \phi^2_{i,t}\textstyle\sum_{\tau=t+2}^{T-1}\left(\phi^3_{i,\tau}\prod_{s=t+1}^{\tau-1}\left(1-\phi^3_{i,s}\right)\right)\right] i^d \qquad (3.16) \\ &+ \phi^2_{i,t}\textstyle\prod_{\tau=t+1}^{T-1}\left(1-\phi^3_{i,\tau}\right)\, E_t\left(i_T\right). \end{aligned}$$

The overnight rate on day t thus depends on: (i) $\phi^1_{i,t}$, the probability of incurring an overdraft on day t, (ii) $\phi^2_{i,t}$, the probability of not having recourse to either of the two standing facilities on day t, and (iii) $\{\phi^3_{i,\tau}\}_{\tau=t}^{T-1}$, that is the daily probabilities of becoming locked in between t and $T-1$. Again, provided the probabilities of incurring an overdraft and becoming locked-in before the last day of the maintenance period are negligibly small, Equation (3.16) reveals that $i_t \simeq E_t\left(i_T\right)$, i.e. within the reserve maintenance period the overnight rate follows approximately a martingale.

Under the martingale hypothesis, the overnight rate on day t equals the overnight rate that is expected to prevail on the last day of the maintenance period. Therefore, from Equation (3.9) it is obvious that i_t depends on the expected values of D_T and R_T^{mc}. Specifically, and as shown in Appendix A.2.3, in combination with Equation (3.9) the martingale hypothesis implies that

$$i_t \simeq E_t\left(i_T\right) = i^b\,\Phi\left(\frac{\mu_t}{\sqrt{1+\sigma_t^2}}\right) + i^d\left[1-\Phi\left(\frac{\mu_t}{\sqrt{1+\sigma_t^2}}\right)\right], \qquad (3.17)$$

where

$$\mu_t \equiv E_t\left(\frac{D_T - R_T^{mc}}{\sigma_{\varepsilon^A}}\right) = \frac{D_t-(T-t+1)R_t^{mc}}{\sigma_{\varepsilon^A}}$$

and

$$\sigma_t^2 \equiv Var_t\left(\frac{D_T - R_T^{mc}}{\sigma_{\varepsilon^A}}\right) = \frac{\sum_{j=1}^{T-t}\left[j^2\sigma^2_{\eta^M}+(j+1)^2\sigma^2_{\eta^A}\right]}{\sigma^2_{\varepsilon^A}}$$

are the expectation and the variance of the standardized per capita reserve shortfall or surplus on day T, with information as of market clearing on day t.[27] Apparently, the expected standardized reserve shortfall (or surplus) depends exclusively on the current per capita reserve balance (R_t^{mc}) and the current per capita reserve deficiency (D_t); the variance reflects the uncertainty about the effective values of R_T^{mc} and D_T, which is due to the autonomous liquidity shocks that will be realized after market clearing on day t. Clearly, the larger the variance of the individual autonomous liquidity shocks, the more uncertainty there is about the reserve shortfall (or surplus) that will prevail on day T.

Looking at a specific example allows to gain some further insights on these results, so assume that Equation (3.17) is evaluated for $t = 7$ and $T = 10$. Then, it is obvious that the overnight rate i_7 is in the upper (lower) part of the interest rate corridor, whenever there is an expected reserve shortfall (surplus); it is exactly in the middle if and only if $\mu_7 = 0$.

Moreover, to see how interest rates depend on the relative size of autonomous and cumulated liquidity shocks, assume that the variances of the autonomous liquidity shocks are equal to one ($\sigma^2_{\eta^M} = \sigma^2_{\eta^A} = 1$). It is then possible to show that if $\mu_7 > 0$ and hence $i_7 > \frac{i^b+i^d}{2}$, $\mu_7/\sqrt{1+\sigma_7^2}$—the argument in the cumulative distribution function in Equation (3.17)—is decreasing in

[27]If $\mu_t > 0$, there is an expected reserve shortfall; if $\mu_t < 0$, there is an expected reserve surplus.

$\sigma^2_{\varepsilon^A}$. This implies that for a given size of the expected reserve shortfall, an increase in $\sigma^2_{\varepsilon^A}$ will push i_7 down towards the middle of the interest rate corridor. Similarly, if $\mu_7 < 0$, an increase in $\sigma^2_{\varepsilon^A}$ will push i_7 up towards the middle of the corridor.

Finally, note that σ^2_t is a decreasing function of t, which reflects the fact that the closer one gets to the end of the maintenance period, the less uncertainty there is about the market conditions that will prevail on day T. This trivial result has a less obvious corollary, namely that the overnight rate might change from one day to the other, even though the expectation regarding the market conditions on the last day of the maintenance period remains unaltered. To see why, assume that as of day 7 there is an expected reserve shortfall ($\mu_7 > 0$) and that the realized autonomous liquidity shocks $\hat{\eta}^A_7$ and $\hat{\eta}^M_8$ are such that $\mu_8 = \mu_7$. Then, since $\sigma^2_7 > \sigma^2_8$, it follows that $\mu_7/\sqrt{1+\sigma^2_7} < \mu_8/\sqrt{1+\sigma^2_8}$ and thus $E_7(i_{10}) < E_8(i_{10})$. The intuition of this result is related to the fact that between market clearing on days 7 and 8 some uncertainty is removed. Therefore, although the size of the predicted reserve shortfall has not changed, by the time of market clearing on day 8 it has become more likely that the predicted reserve shortfall for day 10 will effectively materialize, simply because there remain fewer autonomous liquidity shocks that could turn the predicted reserve shortfall into a reserve surplus. This, in turn, is correctly captured by an increase in the overnight rate from day 7 to day 8.

The Pattern of Reserve Demand

Intuitively, the pattern of banks' reserve demand over the maintenance period is closely related with the evolution of the measures associated with the probabilities of having recourse to either of the standing facilities. To get a better understanding of this relationship, let us assume for the time being that demand for reserves is constant, in which case banks would intend to meet reserve requirements by holding the same end-of-day balances throughout the maintenance period. For instance, on the first day of the maintenance period, bank i would then choose $B_{i,1}$ such that the expected end-of-day reserve balance is $D_{i,1}/T$. As time goes on, the bank would adjust the target end-of-day balance in reaction to realized liquidity shocks, but for a given reserve deficiency $D_{i,t}$, it would simply borrow or lend the amount of reserves which is necessary to bring the target end-of-day balance in line with the average reserve deficiency, or more formally: $E_t\left(R^{psc}_{i,t}\right) = R^{mc}_{i,t} + B_{i,t} = D_{i,t}/(T-t+1)$.

With a constant demand for reserves, it follows that $E_t\left(R^{psc}_{i,t}\right) = E_t\left(R^{psc}_{i,\tau}\right)$, for $\tau = t+1, \ldots T$. Hence, as of market clearing on day t, the probability of incurring an end-of-day overdraft on any of the remaining days within the maintenance period is the same, i.e. $\phi^1_{i,t} = \phi^1_{i,\tau}$. The measure of that probability depends on the level of the target end-of-day reserve balance relative to the standard deviation of the cumulated afternoon liquidity shock. In particular, note that if $E_t\left(R_{i,t}^{psc}\right) > 3\,\sigma_{\varepsilon^A}$, then $\phi_{i,t}^1$ is essentially zero.

It is straightforward to show that the constant reserve demand allows to minimize the expected borrowing costs associated with end-of-day overdrafts over the whole maintenance period (see proof in Appendix A.2.4). But this reserve demand pattern also implies that the probability of becoming locked-in is increasing over time (i.e. $\phi_{i,t+1}^3 \geq \phi_{i,t}^3$). Indeed, at the beginning of the maintenance period, it is very unlikely that the bank ends up with excess reserves (i.e. $\phi_{i,t}^3 \simeq 0$ for $t \ll T$). But as the bank accumulates reserves over time, the remaining reserve deficiency is getting smaller and consequently, towards the end of the maintenance period, the probability of realizing a liquidity shock sufficiently large to become locked-in is getting higher. In case the reserve deficiency effectively becomes zero before the end of the maintenance period, the bank looses the ability for intertemporal optimization. Henceforth, reserve demand is determined by Equation (3.13) and the bank will either incur an end-of-day overdraft or accumulate further excess reserves, both of which is costly. Expected profits over the remainder of the maintenance period are thus lower than if the bank was not locked-in.

Clearly, the likelihood of becoming locked-in could be reduced by postponing reserve demand, that is by targeting relatively lower end-of-day reserve balances in the beginning of the maintenance period and relatively higher end-of-day reserve balances towards the end (so called back-loading). However, the incentives for back-loading are curtailed by two factors. First, as any other deviation from the constant reserve demand pattern, back-loading implies higher expected borrowing costs associated with end-of-day overdrafts. For instance, if a bank was to reduce the target end-of-day balance during the first days of the maintenance period to very low levels, the probability of being affected by a negative liquidity shock that is sufficiently large to induce an end-of-day overdraft would increase significantly. Second, to the extent that shifts in reserve demand are not perfectly accommodated by corresponding shifts in reserve supply, significant back-loading would put downward pressure on overnight rates in the beginning of the maintenance period and upward pressure towards the end; the overnight rate would thus exhibit a predictable upward trend.[28] To exploit these predictable changes in borrowing costs, banks would shift reserve demand towards the *beginning* of the maintenance periods, thereby counteracting the initial back-loading.

[28]Note that in this section, reserve supply is assumed to be an exogenous process, driven solely by autonomous liquidity shocks. As these shocks have mean zero, the supply of reserves is expected to remain constant.

Still, if back-loading led to predictable changes in overnight rates, the martingale hypothesis would clearly be rebutted. It needs to be stressed, however, that the (approximate) martingale property of overnight rates rests was established under the assumption that the probabilities of incurring an end-of-day overdraft or becoming locked-in are negligible, and if this is the case, there is no incentive for back-loading reserve demand in the first place. Now, whether it is reasonable to assume that these probabilities are negligible depends on the size of cumulated afternoon liquidity shocks in relation to the level of reserve requirements.[29] If reserve requirements are relatively low, a bank's target end-of-day balances are also low and it is thus more likely that, on any day during the maintenance period, a negative liquidity shock of given size will cause an end-of-day overdraft. Similarly, with low reserve requirements, it is more likely that a bank becomes locked-in due to a large positive liquidity shock, especially towards the end of the maintenance period when the remaining reserve deficiency is getting smaller. In contrast, when reserve requirements and thus also the target end-of-day balances are relatively high, overdrafts as well as lock-in situations occur less frequently, it at all.

Table 3.1: Reserve Requirements and Recourse to Standing Facilities

	Total Reserve Requirement ($D_{i,1}$)									
	500		1,000		2,000		3,000		4,000	
t	$\phi^1_{i,t}$	$\phi^3_{i,t}$	$\phi^1_{i,t}$	$\phi^3_{i,t}$	$\phi^1_{i,t}$	$\phi^3_{i,t}$	$\phi^1_{i,t}$	$\phi^3_{i,t}$	$\phi^1_{i,t}$	$\phi^3_{i,t}$
1	.306	.000	.158	.000	.023	.000	.001	.000	.000	.000
2	.318	.001	.162	.000	.024	.000	.001	.000	.000	.000
3	.328	.013	.167	.000	.025	.000	.001	.000	.000	.000
4	.339	.042	.172	.000	.025	.000	.002	.000	.000	.000
5	.353	.092	.179	.002	.027	.000	.002	.000	.000	.000
6	.367	.159	.187	.010	.030	.000	.002	.000	.000	.000
7	.383	.238	.197	.038	.033	.000	.003	.000	.000	.000
8	.397	.325	.215	.104	.040	.003	.004	.000	.000	.000
9	.410	.411	.240	.238	.055	.056	.008	.008	.001	.001
10	.500	.500	.499	.501	.500	.500	.499	.501	.498	.502

Notes:
$\phi^1_{i,t}$: Probability that bank i has recourse to the borrowing facility on day t.
$\phi^3_{i,t}$: Probability that bank i has recourse to the deposit facility on day t.

[29]Note that what matters is the size of a bank's *cumulated* afternoon liquidity shocks, and not the size of autonomous liquidity shocks.

The relationship between reserve requirements and the recourse to standing facilities is evident in Table 3.1, which summarizes the results of a simulation exercise. Holding the standard deviation of the cumulated afternoon liquidity shock constant at 100 and assuming that the bank has a constant demand for reserves, the probabilities of having recourse to either of the standing facilities on any day during a ten-day maintenance period were estimated for different levels of reserve requirements. 100'000 maintenance periods were simulated for each level of reserve requirement. The simulation results allow to draw a number of conclusions. First, for a given level of reserve requirements, the probability of using the deposit facility increases over time. This is because as the reserve deficiency is getting smaller, the likelihood of incurring a sufficiently large positive liquidity shock increases day by day. Second, for a given level of reserve requirements, the probability of having recourse to the borrowing facility also increases over time. Note that this is a direct consequence of the first observation: If the bank gets locked-in—which becomes more likely in the course of the maintenance period—, the target end-of-day balance is set to zero and the (conditional) probability for incurring an overdraft is .5 on all remaining days. Third, on any day other than the last day of the maintenance period, the probability of an overdraft decreases with the level of reserve requirements. For instance, if total reserve requirements are 500, on day one the bank's target balance is 50 and the associated overdraft probability is about .306. In contrast, when the total requirement is 4,000 and the day one target balance thus is 400, the probability of an end-of-day overdraft is essentially zero. Fourth, on any day other than the last day of the maintenance period, the probability of excess reserves decreases with the level of reserve requirements. For instance, on day 9, with total reserve requirements of 1,000, the bank will have excess reserves in about 23.8% of all maintenance periods, whereas when the total requirement is 3,000, the corresponding figure is only .8%. Fifth, on the last day of the maintenance period, the probabilities of having recourse to the borrowing or the deposit facility are .5, irrespective of the level of reserve requirements or whether the bank is locked-in or not. This is because the bank will target zero excess reserves, and due to the symmetric liquidity shocks the chances that it will end up with a reserve shortfall or excess reserves are fifty-fifty. Finally, and maybe most importantly, Table 3.1 shows that if the *average* daily reserve requirement exceeds the standard deviation of the cumulated afternoon liquidity shocks by a factor of three or more, the probabilities of having recourse to either of the standing facilities on days other than the last day of the maintenance period are negligible. Therefore, provided that reserve requirements are relatively high, one may conclude that, first, it is reasonable to assume that banks' demand for end-of-day balances is fairly constant over the maintenance period, and second, the martingale hypothesis provides a good approximation for the intertemporal dynamics of the overnight rate.

3.3 The Supply of Reserves

Having analyzed in detail the factors that determine banks' demand for reserves and the market clearing overnight rate in the interbank money market, we now need to take a closer look at the supply side of the market for reserves. Section 3.3.1 starts by analyzing the central bank's balance sheet, which will allow us to better understand how monetary policy operations and autonomous liquidity factors affect the level of banks' reserves with the central bank. Subsequently, Section 3.3.2 discusses some practical aspects of central banks' liquidity management and demonstrates how the money market model developed in Section 3.2.2 can be augmented by integrating the central bank's open market operations.

3.3.1 The Central Bank's Balance Sheet

As discussed in Section 3.1, the central bank's influence on monetary conditions is ultimately derived from its monopoly on the supply of central bank money and, in particular, on the supply of reserves. To understand the factors that determine the supply of reserves it is essential to understand the central bank's balance sheet.[30] Because central banks' balance sheets typically differ from each other not only in terms of numbers but also in the positions or items which are included, the detailed analysis of a particular balance sheet requires often substantial knowledge about the operations and the peculiarities of the respective central bank. Nevertheless, any central bank's balance sheet may be simplified by regrouping all items into four main categories: (i) autonomous liquidity factors, (ii) open market operations, (iii) standing facilities, and, as a residual, (iv) banks' reserves with the central bank. Table 3.2 illustrates such a stylized balance sheet.

For the implementation of monetary policy, the most important item in the balance sheet is banks' reserves with the central bank (D.1). Obviously, D.1 is affected by all monetary policy operations, i.e. open market operations and the use of standing facilities. For instance, the provision of liquidity to

[30]The relationship between central banks' balance sheets and monetary policy implementation is also reviewed in Allen (2004), Bindseil (2004a) and Borio (1997). The balance sheet of the ECB is analyzed by Bindseil and Seitz (2001), the Fed's balance sheet by Hamilton (1998) and Fullwiler (2003).

Table 3.2: Stylized Central Bank Balance Sheet

A. Autonomous liquidity factors	
A.1 Foreign assets (incl. gold)	A.4 Banknotes in circulation
A.2 Investment assets	A.5 Government deposits
A.3 Other assets	A.6 Capital and reserves
	A.7 Other liabilities
B. Open market operations	
Liquidity providing operations	*Liquidity absorbing operations*
B.1 Reverse operations	B.4 Reverse operations
B.2 Securities held outright	B.5 Issued debt certificates
B.3 Other	B.6 Other
C. Standing facilities	
C.1 Borrowing facility	C.2 Deposit facility
D. Residual	
	D.1 Banks' reserves
	– Required reserves
	– Excess reserves

the banking sector by means of a repo transaction implies a simultaneous increase in B.1 and D.1. In this respect, a useful concept to summarize all factors that influence banks' reserves and which are under the control of the central bank's implementation desk is the *net policy position* (NPP). In terms of the stylized balance sheet in Table 3.2, the NPP can be written as

$$\text{NPP} = (\text{B.1} + \text{B.2} + \text{B.3}) - (\text{B.4} + \text{B.5} + \text{B.6}) + \text{C.1} - \text{C.2}.$$

The NPP is sometimes also referred to as the banking system's liquidity position vis-à-vis the central bank. A structural liquidity deficit—which is equivalent to a positive NPP—is often regarded as desirable for the implementation of monetary policy. A structural liquidity deficit implies that commercial banks will typically have a positive demand for reserves, so that the central bank can easily stipulate the terms on which it is willing to supply reserves via open market operations. In contrast, when there is structural liquidity surplus, the marginal demand for reserves is zero or negative and the central bank needs to withdraw reserves from the market. In these circumstances, the central bank can still exert influence on monetary conditions as marginal taker of central bank money, for instance by absorbing liquidity from the market by selling securities outright or by means of reverse repos. However, since commercial banks have no obligation to buy the securities which the central bank offers or to engage in reverse repos at the proposed conditions, the central bank's influence on short-term interest rates might be less powerful as in the case when there is a liquidity shortage in the banking system. Therefore, to the extent that a central bank prefers to conduct liquidity-providing rather than liquidity-absorbing open market operations, a structural liquidity deficit is desirable because it ensures that banks need to refinance themselves regularly by borrowing from the central bank.

A straightforward way to increase the structural liquidity deficit is by establishing or increasing reserve requirements.[31] However, it should be noted that even in the case of a structural liquidity surplus the central bank may be able to conduct regular liquidity-providing short-term open market operations, provided it engages in liquidity-absorbing long-term open market operations. For instance, by issuing debt certificates with long maturity (which increases B.5) or by selling securities outright (which decreases B.2) it is possible to withdraw liquidity from the banking system for an extended period of time or even permanently, respectively. Liquidity can then be re-injected by means of regular short-term open market operations such as repos. Therefore, in practice it might be useful to distinguish between short-term and long-term operations, with short-term operations defined as all operations with a maturity of less than one or three months.

It is important to note that the level of banks' reserves is affected not only by monetary policy operations but also by so-called *autonomous liquidity factors*, which summarize the items on the central bank's balance sheet that reflect other central bank functions such as the issuance of banknotes, the management of foreign assets or the banking services provided for the treasury and other government entities. A distinguishing feature of autonomous liquidity factors thus is that they are determined neither by the central bank's implementation desk nor its counterparties for monetary policy operations. Rather, they depend on either the behavior of the public, as in the case of

[31] An increase in reserve requirements implies a one-for-one increase in banks' demand for reserves, which can then be satisfied by liquidity-injecting open market operations (simultaneous increase in D.1 and B.1 or B.2).

banknotes in circulation, or institutional arrangements that are not under control of the implementation desk, as is often the case for government deposits. The underlying transactions, however, affect banks' reserve holdings in the same way as liquidity-providing or liquidity-absorbing monetary policy operations. The *autonomous liquidity position* (ALP) may be defined as the sum of all autonomous liquidity factors, considered as an asset, i.e.

$$\text{ALP} = (\text{A.1} + \text{A.2} + \text{A.3}) - (\text{A.4} + \text{A.5} + \text{A.6} + \text{A.7}).$$

By definition of the balance sheet, the level of banks' reserves can thus be written as

$$\text{D.1} = \text{NPP} + \text{ALP}.$$

The effect of autonomous liquidity factors on reserves may be illustrated by two examples: banknotes in circulation and government deposits. Banknotes in circulation is often the largest liability on central banks' balance sheets, reflecting their function as issuer of currency. If, for example, the public's demand for banknotes increases, the public will procure itself with banknotes by withdrawing cash at commercial banks' counters or ATMs. When commercial banks' stock of vault cash falls to a critical level, they will have to exchange reserves for banknotes at the central bank in order to replenish their vaults and to satisfy their customers' demand. Central banks' supply of banknotes is usually fully elastic, that is banks' demand for banknotes is always satisfied, provided they have sufficient funds on their reserve accounts to pay for. The increase in the public's demand for banknotes thus eventually leads to a substitution of two liabilities on the central bank's balance sheet: the item banknotes in circulation (A.4) is credited and the item banks' reserves (D.1) is debited.[32] What matters for the implementation of monetary policy is that higher demand for banknotes has reduced the amount of reserves available to the banking system as a whole, although no monetary policy operations have been conducted.

The second example refers to government deposits. Central banks often provide various banking services to the government's treasury or other public agencies.[33] In particular, the government maintains an account at the central

[32]Vice versa, the transaction involves a simple asset substitution on commercial banks' balance sheets, i.e. the item banknotes increases whereas the item reserves with the central bank decreases.

[33]In some countries, commercial banks rather than the central bank provide banking services to the government.

bank which it may use for all or part of its financial transactions with the private sector. The collection of taxes provides a good example. Usually, taxable persons pay their tax liabilities by instructing their bank to transfer the due amount of money to the government. As a result, the government's account at the central bank (A.5) is credited while banks' reserves (D.1) is debited. The amount of reserves available to the banking system has thus decreased. Other regular government operations that affect the level of commercial banks' reserves are issuances and redemptions of government debt, coupon payments on government debt, payments related to the purchase of goods and services by the public sector, the payment of wages to government employees, or transfers related to social security benefits.

For many central banks, autonomous liquidity factors represent the principal source of uncertainty in the assessment of the banking system's liquidity needs. One of the main tasks of the implementation desk thus is to forecast these factors as accurately as possible.[34] Forecasts of the individual balance sheet items are made in different ways and with varying degrees of accuracy. For instance, banknotes in circulation are typically forecast by statistical methods, taking into account that the demand for banknotes exhibits different patterns and trends. In many countries, one may observe within-week patterns (demand typically rises before weekends), seasonal patterns (demand usually rises before Christmas or other national holidays and during the main summer holiday season) or a continuing upward trend reflecting economic growth. For the item government deposits, the implementation desk often needs to rely on the Ministry of Finance for the forecast. But while the Ministry of Finance has full control over (the timing) of its outgoing payments, there is often significant uncertainty both on the level and on the timing of incoming payments such as tax revenues. Forecasts of government deposits are therefore often inaccurate, even at very short horizons. Other items such as float may depend on the characteristics of the payment system and the public's spending patterns. Float is created whenever the crediting and debiting of banks' reserve accounts related to inter-bank payments do not occur simultaneously.[35] This is typically the case for cheque transactions. In the United States, where cheques are still a very popular retail payment instrument and the Federal Reserve plays an important role in cheque clearing, float is a significant source of uncertainty regarding autonomous liquidity

[34]Some central banks provide detailed account on developments of autonomous liquidity factors and their predictability. A good example is the Federal Reserve Bank of New York's annual report on domestic market operations (see e.g. Federal Reserve of New York Markets Group 2007). Bindseil and Seitz (2001) provide a descriptive as well as an econometric time series analysis of some autonomous liquidity factors of the ECB.

[35]In Table 3.2, float is included in the item A.3 (Other assets).

factors. As physical cheques often need to be delivered by airplane all over the country, float may raise in case of severe weather conditions. At times, implementation officers may thus be urged to watch the weather channel in order to improve their forecast of autonomous liquidity factors.

However, not all changes to autonomous liquidity factors come as a surprise, at least at horizons of less than a few days. For instance, if the central bank's asset managers buy or sell bonds or equities to adjust the investment portfolio or if the central bank intervenes in the foreign exchange market, these transactions typically settle with a lag of two or three days. Provided there is an efficient information flow between different central bank departments, the implementation desk is thus able to anticipate these autonomous liquidity factors and their effects on reserves very precisely, at least at short horizons. However, at longer horizons the forecasts of these items are typically also subject to substantial uncertainty.

To illustrate the magnitude to which uncertainty about autonomous liquidity factors may complicate monetary policy implementation in practice, Table 3.3 shows the daily changes of autonomous liquidity factors in the Fed's balance sheet as well as the implementation desk's daily forecast misses in 2006. These figures indicate that, on average, daily forecast misses were slightly below USD 1 billion, but the peak was higher than USD 7 billion. These absolute values should be seen against the backdrop of the level of total reserves, which in 2006 were around USD 14.7 billion (of which USD 13.1 billion required reserves and USD 1.6 billion excess reserves). On days when the impact of autonomous liquidity factors on reserves is overestimated (and hence the level of actual reserve balances falls short of the predicted value), it is thus possible that aggregate reserves fall to about half of their usual level. As the Fed's implementation desk guesstimates that the level of aggregate balances necessary to maintain a liquid federal funds market is around USD 11 billion, significant forecast misses thus have the potential to introduce an elevated risk of market illiquidity and temporary upward pressure on overnight rates (Federal Reserve Bank of New York Markets Group 2007).

In contrast to the Fed, which focuses primarily on one-day forecasts of autonomous liquidity factors, the ECB needs accurate forecasts over a one week horizon. This is because unlike the Fed, which conducts open market operations almost daily, the ECB's main refinancing operations are conducted only once per week (see also Section 4.1.5). Of course, the forecasting ability declines with the length of the forecast horizon. In the case of the ECB, the standard deviation of the one-day forecast error of autonomous liquidity factors is only EUR 700 million, but for a horizon of six business days the standard deviation of the accumulated forecast error amounts to EUR 9.2 billion; and on some occasions, the one-week forecast error exceeds EUR 25

Table 3.3: Daily Changes and Forecast Misses in the Federal Reserve's Autonomous Liquidity Factors in 2006 (in million US dollars)

	Daily Change		Daily Forecast Miss	
	Average	Maximum	Average	Maximum
Banknotes in circulation	927	3,112	186	1,281
Government deposits	585	6,945	404	7,040
Foreign RP pool*	805	5,666	176	1,106
Float	1,192	6,853	629	5,624
Net Value**	1,887	11,747	854	7,524

Source: Federal Reserve Bank of New York Markets Group (2007), Table 2.

* The foreign RP pool is an overnight repurchase agreement between the Federal Reserve System and foreign central banks and international account customers. The pool is offered to customers as an investment vehicle to help meet their cash management needs.

** Net value reflects offsetting movements and forecast misses of all autonomous liquidity factors.

billion (ECB 2006b, González-Páramo 2007). Although these figures need to be put into perspective by the high level of aggregate reserve balances of roughly EUR 170 billion, it is clear that large forecast errors have the potential to affect liquidity conditions in the money market and short-term market rates, especially towards the end of reserve maintenance periods. This is why in November 2004 the ECB has started to conduct additional fine-tuning operations on the last day of the maintenance period, with the aim to offset the potential liquidity imbalances due to forecast errors (see also Section 4.2.2).

3.3.2 Central Bank Liquidity Management

The central bank's liquidity management is a key element of monetary policy implementation. Essentially, central bank liquidity management involves the assessment of the banking system's demand for liquidity at the intended level of short-term interest rates and, based on that assessment, the provision or absorption of liquidity by means of open market operations. In this section, we will discuss some practical issues related to central bank liquidity management and augment the money market model developed in Section 3.2.2 by including the central bank's supply of reserves more explicitly. But before that, it is expedient to briefly address a more fundamental question: Why is it that central banks not only determine the price at which liquidity is provided to the market, but also the quantity? Autonomous liquidity factors play a key role in answering that question.

Rationale

For a start, one might argue that if the central bank's sole concern is the control of the overnight rate, it could simply conduct open market operations as fixed rate tenders (with the policy rate set equal to the overnight target rate) and pre-commit to allot the full amount of bids. The rationale for this so-called full allotment variant would be as follows: When bidding for reserves in the fixed rate tender, banks balance the associated cost—which is equal to the target rate—with the expected cost of borrowing reserves in the interbank market. If they bid for more (less) reserves than the market as a whole needs to balance supply and demand in the interbank market at the target rate, the overnight rate will tend to be below (above) the target rate. It would then be less costly to bid less (more) in the tender and borrow more (less) in the interbank market. Hence, in equilibrium, banks are expected to bid exactly that amount at which the costs of borrowing from the central bank and the costs of borrowing in the interbank market are equal; the expected overnight rate would thus be equal to the target rate. This raises the question why, in practice, the total allotment is determined by central banks (discretionary allotment policy).[36] The answer is that for the full allotment policy to be preferable, two conditions need to be met: First, banks must have a better forecast of autonomous liquidity factors than the central bank, and second, banks must be able to coordinate their bids. In the following, we will argue that both conditions are usually not met.

Regarding the first condition, Hayek's insight that information is dispersed among many economic agents would suggest *prima facie* that banks as a group should be able to come up with a better forecast of autonomous liquidity factors than the central bank. However, there are a number of reasons why in the case under consideration the implementation desk's forecast is most likely more accurate. First, the implementation desk has privileged (or private) information about the central bank's own financial transactions and about the government's payments, two key autonomous liquidity factors. Moreover, since adequate forecasts of autonomous liquidity factors are of greater importance to the central bank than to individual banks, one should expect that the central bank is inclined to invest more resources into forecasting these factors. Finally, even if all commercial banks had very reliable information on how they were going to be affected by autonomous liquid-

[36] The full allotment variant was applied, however, by the Bundesbank in the 1950s and by the Bank of Finland in the years preceding 1999 (Bindseil and Nyborg 2008).

ity factors individually, there is no mechanism in place that easily allows to aggregate the scattered information.

The second condition relates to the inherent coordination problem in the bidding process. Indeed, even if banks knew the amount to bid for on aggregate—irrespective of whether they come up with the better forecast of autonomous liquidity factors or the central bank publishes its own (superior) forecast ex ante—it remains unclear how they would ensure that the sum of individual bids coincides with the intended level. Altogether, it thus seems that both conditions are hardly ever met in practice and, consequently, it is preferable to have the central bank determine the amount of reserves to be supplied to the market. Otherwise, there is a high risk that banks bid for way too much or little than the market actually needs, with corresponding adverse impact on interest rate volatility. Having thus established that managing the aggregate supply of reserves is a core central bank function, the remainder of this section will examine some practical issues of central bank liquidity management by means of a numerical example.

Practical Issues

Consider a central bank that conducts regular open market operations by means of weekly repos with one week maturity. The amount of liquidity provided (or absorbed) thus affects banks' reserve balances for one week. In order to determine the size of the operation, the implementation desk needs to assess banks' demand for reserves and how supply factors will evolve over the next week. The main factor relevant for banks' demand for reserves are reserve requirements, whereas the main factors that will affect the supply of reserves are autonomous liquidity factors and repos which mature in the course of the relevant time horizon.

Assume further that the reserve maintenance period lasts 30 days, aggregate (total) reserve requirements are 3,000, banks' aggregate reserve deficiency (ARD) at the end of the 23th day is 750, and the central bank's balance sheet can be summarized as follows: ALP = −57, NPP = 150, and thus D.1 = 93. On the 24th day of the maintenance period, a Wednesday, a repo transaction matures, withdrawing 75 reserves. On the same day, the implementation desk is about to conduct the last regular repo transaction before the end of the current reserve maintenance period. The implementation desk's forecast of the autonomous liquidity position until the end of the reserve maintenance period is summarized in the second column in Table 3.4. Moreover, assuming that the maturing repo is simply rolled over, in which case the net policy position remains constant throughout the remainder of the reserve maintenance period (see third column), columns four and five show how the level of reserves and the aggregate reserve deficiency are expected to evolve. Also note that reserves held on Fridays count three times towards the fulfillment of reserve requirements and that, for simplicity, banks' recourse to standing facilities is expected to be zero.

Table 3.4: Liquidity Forecasts

Day within RMP	Expected ALP	Expected NPP	Expected reserves	Expected ARD
24 (Wed)	−60	150	90	660
25 (Thu)	−62	150	88	572
26 (Fri)	−67	150	83	323
29 (Mon)	−67	150	83	240
30 (Tue)	−64	150	86	154

Notes: RMP: reserve maintenance period. ALP: autonomous liquidity position. NPP: net policy position. ARD: aggregate reserve deficiency (at the end of the day).

Since aggregate reserve balances at the end of the 23th day are relatively low compared with the aggregate reserve deficiency, and since the (expected) decrease in the autonomous liquidity position will drain further reserves, banks are expected to terminate the reserve maintenance period with a reserve shortfall of 154.[37] Whether such a significant reserve shortfall is in line with the central bank's interest rate target depends on the overall operational framework for monetary policy implementation. For instance, assume that the operational framework is such that overnight rates stay at or near the target rate only if the expected reserve shortfall is zero. Then, given the forecast of the autonomous liquidity position, the implementation desk should seek to conduct a repo transaction of size 97 on day 24. Taking into account the maturing transaction of size 75, this transaction would inject additional 22 reserves over the remainder of the maintenance period, exactly what is needed to achieve a zero reserve shortfall.

As a matter of course, if the forecasts of autonomous liquidity factors turn out to be wrong, there will be either too few or too many reserves in the market, with corresponding impact on short-term interest rates. For instance, if over the relevant time period autonomous liquidity factors drain less reserves than anticipated, there will be a reserve surplus and short-term

[37] Of course, from an *ex post* perspective, on the last day of the maintenance period banks would use the borrowing facility in order to cover the reserve shortfall, thereby increasing the net policy position and the level of reserves in Table 3.4.

interest rates will tend to fall below the target level. This explains why central banks devote considerable resources to forecasting autonomous liquidity factors. In general, the time horizon over which autonomous liquidity factors need to be forecast will depend on various details of the operational framework such as the length of the reserve maintenance period and the frequency and maturity of regular open market operations. For instance, the appropriate forecast horizon increases with the length of the reserve maintenance period and decreases with the frequency of regular operations, with the minimum horizon being at least as long as the time period between two consecutive regular open market operations.

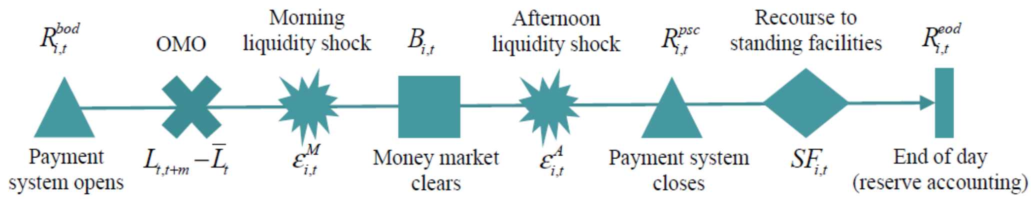
The preceding discussion highlights the crucial role of central bank liquidity management for effective monetary policy implementation. In particular, it shows that in order to maintain control of short-term interest rates the implementation desk may need to pursue a specific reserves supply path, which is typically implemented by means of adequately structured and sized open market operations. But even though the implementation desk may have a clear view of how the level of reserves should evolve, especially within a reserve maintenance period, the intended reserve supply path should not be confounded with the central bank's operational target. Rather, it merely reflects the fact that, taking all other elements of the operational framework as given, there is a straightforward inverse relationship between the level of reserves and the overnight interest rate, i.e. the central bank's true operational target. Pursuing a specific reserves supply path is thus not an end itself, but only a means to an end. Indeed, the level of reserves as such is not of great economic importance, quite contrary to the level of short-term interest rates. For instance, consider what would happen in case the level of required reserves and thus the demand for reserves were to double from one maintenance period to the other. All else equal, the implementation desk would simply increase the intended reserve supply path by a factor of two. To the extent that doing so is indispensable to maintain the overnight rate at the (unaltered) target level, the doubling of reserve balances as such has no major economic consequences, and on no account should it be considered as a relaxation of the monetary policy stance. Therefore, changes in the supply of reserves cannot and should not be interpreted independently, rather they need to be analyzed within the context of a specific operational framework.

Augmenting the Money Market Model

In the money market model developed in Section 3.2.2, the central bank's role in determining the supply of reserves was left aside. Although this allowed to better focus on some demand-side related issues, it goes without saying that any comprehensive model of the money market needs to take due account of the impact of central bank's open market operations on money market conditions and, in particular, on banks' expectation formation and their behavior. Indeed, to the extent that the operational framework allows for intertemporal arbitrage (e.g. due to averaging provisions), banks' behavior—and thus also the equilibrium overnight rate—is strongly affected by their expectations about the central bank's future operations.

In order to model explicitly the role of central banks in general and of open market operations in particular, we need to make a few assumptions and introduce some additional notation. Regarding the timing of open market operations, it seems reasonable to assume that they take place after the opening of the payment system but before realization of the morning liquidity shock (see Figure 3.5). This is in line with most central banks' practice of conducting their operations early in the morning. For convenience, but without affecting any of the results, it is further assumed that open market operations are settled without any delay and at the same time as any maturing repos.

Figure 3.5: Timing of Events



A repo transaction between the central bank and bank i conducted on day t and maturing m days later is denoted as $L^i_{t,t+m}$; the corresponding per capita repo transaction thus is $L_{t,t+m} = \frac{1}{n}\sum_i L^i_{t,t+m}$. Moreover, also on a per capita basis, the sum of all repo transactions conducted earlier but maturing on day t is denoted as $\bar{L}_t = \sum_{j=1}^{\infty} L_{t-j,t}$. The net per capita impact of open market operations on the supply of reserves on day t thus is $L_{t,t+m} - \bar{L}_t$.[38] Furthermore, all open market operations are conducted as fixed rate tenders, with $i^{omo}_{t,t+m}$ denoting the tender rate for a repo with m-day maturity.

The implementation desk is assumed to pursue a so-called *neutral allotment policy*. An allotment is said to be neutral if the allotted amount of reserves is such that the expected overnight rate equals the current overnight

[38]Note that it is assumed that the central bank does not conduct repos with different maturities on the same day. However, this does not imply that the maturity must be the same every day.

target rate $i_t^* \in [i^d, i^b]$. To the extent that different paths of reserve supply are in line with the neutral allotment policy, it is further assumed that the implementation desk has a preference for supplying reserves as smoothly as possible over the remainder of a reserve maintenance period. Finally, the implementation desk's allotment policy is assumed to be known by all banks, which is a reasonable assumption for any central bank that has published the details of its operational framework.

One-Day Reserve Maintenance Period

With a one-day reserve maintenance period, it is natural to assume that the implementation desk adjusts the supply of reserves on a daily basis by means of overnight repos. The size of the repo transaction directly affects R_t^{mc} and thus the market clearing overnight rate, which is determined according to Equation (3.4). But due to the autonomous liquidity shock in the morning, which is realized only after the central bank's open market operation, R_t^{mc} and thus also the overnight rate are stochastic in nature and cannot be perfectly controlled. The implementation desk's objective thus is to chose the (neutral) allotment $L_{t,t+1}^n$ such that the overnight rate is *expected* to trade at the target rate, i.e. $E_{t_o}(i_t) = i_t^*$, where E_{t_o} reflects that expectations are conditioned on information available at the time of conducting the open market operation on day t. As shown in Appendix A.2.5, the neutral (per capita) allotment then is

$$L_{t,t+1}^n = \bar{L}_t + D_t - R_t^{bod} - \Phi^{-1}\left(\frac{i_t^* - i^d}{i^b - i^d}\right) \sigma_{\varepsilon^A} \sqrt{1 + \frac{\sigma_{\eta^A}^2}{\sigma_{\varepsilon^A}^2}}. \tag{3.18}$$

Three observations are noteworthy. First, the higher the target rate is located within the corridor corridor defined by the two standing facilities, the less liquidity the central bank needs to supply; the neutral allotment is thus decreasing in i_t^*. Second, in case the target rate corresponds to the midpoint of the interest rate corridor, the last term on the right hand side of Equation (3.18) is zero and the implementation desk's task in determining the neutral allotment is considerably simplified. In particular, and in contrast to when i_t^* is either below or above the midpoint, the central bank does not need to know the variances of the various liquidity shocks in order to achieve—at least on average—the target overnight rate. This explains why having two standing facilities that provide a symmetric corridor around the overnight target rate is an attractive feature of an operational framework. Third, consider briefly how the neutral allotment would change if the autonomous liquidity shock η_t^M had a non-zero mean, i.e. $\eta_t^M \sim N\left(\mu_{\eta^M}, \sigma_{\eta^M}^2\right)$. In case the autonomous liquidity shock is expected drain (inject) reserves, its impact would be easily offset by a one-to-one increase increase (decrease) in the neutral allotment:

$$L_{t,t+1}^{n} = \bar{L}_t + D_t - R_t^{bod} - \mu_{\eta^M} - \Phi^{-1}\left(\frac{i_t^* - i^d}{i^b - i^d}\right)\sigma_{\varepsilon^A}\sqrt{1 + \frac{\sigma_{\eta^A}^2}{\sigma_{\varepsilon^A}^2}}.$$

Having established what the neutral allotment is, there remains the question whether the central bank is also able to implement that allotment, that is whether banks' aggregate bids in the tender are at least as high as the aggregate neutral allotment. Indeed, as will be shown in more detail in Chapter 7.3, with fixed rate tenders, this is generally the case, provided that the tender rate does not exceed the target rate, i.e. $i_{t,t+1}^{omo} \leq i_t^*$. The explanation is straightforward. Consider first the case where $i_{t,t+1}^{omo} > i_t^*$. Since the central bank will allot whatever is required to bring the expected overnight rate in line with the target rate, for any bank individually it would be profitable not to participate in the tender but to borrow later on at the lower rate in the interbank market. As a result, there will be underbidding and the implementation desk will not be able to allot the neutral amount. By comparison, when $i_{t,t+1}^{omo} < i_t^*$, there will be strong overbidding since borrowing from the central bank is cheaper than the expected interbank rate. Finally, when $i_{t,t+1}^{omo} = i_t^*$, banks are indifferent between borrowing from the central bank or in the market. However, they know that if bids fall short of $L_{t,t+1}^n$, the market rate will exceed the target rate; it is thus preferable to bid sufficiently high so that the neutral allotment can be implemented.

Reserve Maintenance Period with Averaging

To investigate central bank liquidity management in the case of reserve averaging, assume that the maintenance period lasts T days and the implementation desk conducts repo transactions with maturity of m days on a regular basis. To ease the exposition, assume further that there are no weekends or other holidays, T/m is an integer, repos are conducted on days $1, 1+m, 1+2m, \ldots, T+1-m$, and the implementation desk has a preference for a stable reserve supply path. Moreover, the overnight target rate as well as the borrowing and the deposit rate are not changed throughout the maintenance period. Then, provided that the overnight rate follows at least approximately a martingale, it can then be shown that the neutral allotment is (see Appendix A.2.6)

$$L_{t,t+m}^{n} = \bar{L}_t + \frac{D_t}{T-t+1} - R_t^{bod} - \Phi^{-1}\left(\frac{i^* - i^d}{i^b - i^d}\right)\sigma_{\varepsilon^A}\sqrt{1+\sigma_t^2}, \quad (3.19)$$

where

$$\sigma_t^2 = \sum_{j=1}^{T-t-1} j^2 \sigma_{\eta^M}^2 + \sum_{j=2}^{T-t-1} j^2 \sigma_{\eta^A}^2.$$

Again, if the target rate coincides with the midpoint of the interest rate corridor defined by the standing facilities, the last term on the right hand side of Equation (3.19) is zero and the implementation desk's neutral allotment reduces to

$$L_{t,t+m}^n = \bar{L}_t + \frac{D_t}{T-t+1} - R_t^{bod}.$$

What are the implications for the dynamics of overnight rates? First of all, note that before the last open market operation is conducted, the overnight rate is simply equal to the target rate. Indeed, as long as there is no reason to doubt that the implementation desk will allot reserves according to Equation (3.19) on $T+1-m$, the overnight rate expected to prevail on day T equals the target rate and thus, by the virtue of arbitrage, prior overnight rates should also be equal to the target rate. However, once the last open market operation has taken place, the overnight rate should reflect the impact of autonomous liquidity factor shocks on the expected reserve shortfall or surplus on the last day of the maintenance period. For instance, if there are negative shocks to autonomous liquidity factors, banks will anticipate a reserve shortfall, which will be immediately reflected by a rise in the current overnight rate. The extent of that rise in overnight rates will depend both on the size of the realized shocks and on the variance of (future) liquidity shocks. The volatility pattern of overnight rates through the maintenance period is thus quite simple: Volatility is zero throughout day $T-m$, and it starts to increase as of day $T+1-m$, reaching the peak on day T. Of course, by conducting another open market operation on day T (e.g. an overnight repo transaction), the implementation desk could further curb interest rate volatility: Overnight rates would then be flat at the target rate throughout $T-1$, and only the last day of the maintenance period would see some potential deviation of the overnight rate from the target rate.

3.4 Conclusions

This chapter has reviewed the main elements and peculiarities of the market for reserves. In particular, the discussion has focused on the factors that determine commercial banks' demand for intraday liquidity and end-of-day reserves, banks' behavior in the interbank money market and how central banks manage the supply of reserves. Moreover, this chapter has introduced an analytical framework that allows to study the link between banks' demand for and the central bank's supply of reserves and how they jointly affect the market clearing (overnight) interest rate. In the following, the main conclusions for the implementation of monetary policy in general and for the design of an effective and efficient operational framework in particular are summarized.

First, based on the analysis of modern payment arrangements and, in particular, the functioning of large-value payment systems, it is evident that banks meet their payment related demand for intraday liquidity primarily by means of (typically interest free) intraday credits. This implies that banks' participation in the interbank money market and in the central bank's open market operations is primarily motivated by their need to manage their end-of-day reserve positions.

Second, banks' demand for end-of-day reserve balances stems exclusively from reserve requirements and the uncertainty about payment flows. Moreover, the pattern of banks' intertemporal reserve demand depends crucially on various institutional features of the operational framework. In particular, important elements affecting the demand for reserves are the level of reserve requirements, whether reserve requirements allow for averaging over the reserve maintenance period, the costs associated with reserve deficiencies and end-of-day overdrafts, the conditions for borrowing (depositing) reserves from the borrowing facility (at the deposit facility), and banks' expectations regarding the central bank's supply of reserves within the reserve maintenance period.

Third, due to intertemporal arbitrage and banks' optimizing behavior, overnight interest rates within a reserve maintenance period are closely linked. In particular, the overnight rate exhibits an (approximate) martingale behavior if the probabilities of incurring an end-of-day overdraft or becoming locked-in before the last day of the maintenance period are negligible. This is the case if the level of reserve requirements is sufficiently high in relation to the daily liquidity or payment shocks faced by individual banks.

Fourth, on the supply side, autonomous liquidity factors affect the supply of reserves and hence might interfere with the central bank's liquidity management. When determining the size of open market operations needed in order to keep the overnight rate at or near the target rate, the implementation desk needs to accurately take into account the impact of autonomous liquidity factors as well as banks' demand pattern for reserves. In this respect, an important finding is that—under the assumption that banks' liquidity shocks are symmetrically distributed—the central bank's liquidity management is considerably facilitated if the overnight target rate corresponds to the midpoint of the interest rate corridor defined by the standing facilities.

Overall, the theoretical and practical considerations reviewed in this chapter thus provide various valuable hints regarding the design of an effective and efficient operational framework. The next chapter, which takes a closer look at central banks' practical arrangements for monetary policy implementation, will provide further useful indications.

Chapter 4

The Operational Framework of Major Central Banks

The preceding chapters have analyzed some fundamental issues regarding monetary policy implementation from a rather general and theoretical perspective. An in-depth analysis of how monetary policy is implemented in practice is thus the logical next step. But given that the universe of central banks is relatively large, any review of existing arrangements needs to be limited to a manageable number of central banks. As the purpose of this study is to propose an effective and efficient operational framework for central banks operating in well developed financial markets, it is clear that attention should be directed only on central banks of countries or currency areas for which this criteria is fulfilled. Moreover, the selection of central banks to be reviewed should be such that it includes to the extent possible different approaches to monetary policy implementation. For these reasons, this chapter focuses on the operational framework of the following five central banks: the Reserve Bank of Australia (RBA), the European Central Bank (ECB), the Swiss National Bank (SNB), the Bank of England (BoE), and the Federal Reserve System (Fed).

The survey proceeds in three steps, going back and forth in time. First, Section 4.1 provides a cross-sectional overview of the arrangements in place at the beginning of 2007, that is just before the financial turmoil set in. Most notably, this overview reveals some astonishing differences between the five operational frameworks. Then, recognizing that some of these differences have historical reasons, Section 4.2 goes back in time and reviews each central bank's experience with the implementation of monetary policy during the years prior to 2007, with particular emphasis on those episodes that eventually led to changes to specific operational frameworks. Finally, Section 4.3 reviews the most recent experiences and lessons learned during the financial crisis. Together, these reviews of the different arrangements and the experiences in both normal times and during times of severe market stress provide a number of valuable insights for the design of an effective and efficient operational framework. These findings are summarized in Section 4.4.

4.1 Cross-Sectional Overview

This section reviews and compares the arrangements for monetary policy implementation by the selected central banks, reflecting the situation as of early 2007. The review is structured along the main elements of the operational framework. The first subsection reviews the operational targets, the following subsections then take a closer look at the institutional details of monetary policy instruments, i.e. reserve requirements, standing facilities and open market operations.

4.1.1 Operational Targets

A short-term interest rate is used as operational target by all five central banks (see Table 4.1). This corroborates the view that *de facto* monetary policy is interest rate policy. Three central banks (RBA, BoE and the Fed) officially use the overnight rate as operational target.[1] The ECB is also understood to target the overnight rate, although it has never formally announced any operational target. However, given that the EONIA (Euro OverNight Index Average) is the only reference rate calculated in the euro area, one may conclude that at least *de facto* the overnight rate serves as the ECB's operational target. This view is supported by the first ECB's annual report, where it says that allotment decisions in open market operations were oriented towards ensuring an average interbank overnight rate close to the tender rate (ECB 1999). The only central bank not focusing on overnight rates is the SNB, which instead targets a longer-term money market interest rate, the three-month Libor in Swiss francs.

It is worth emphasizing some differences in terms of communication and signalling of the monetary policy stance. The RBA, the BoE and the Fed explicitly announce the current target for the overnight rate. For instance, after each meeting of the Federal Open Market Committee (FOMC), the Fed announces the current federal funds rate target. In contrast, the ECB's policy stance is signalled by means of official interest rates, i.e. the ECB's

[1] In some currency areas the overnight rate may be labeled differently. In particular, it is called interbank cash rate in Australia, Euro OverNight Index Average (EONIA) in the euro area, and federal funds rate in the United States.

Governing Council announces the current rates for the standing facilities and the minimum bid rate for participating in open market operations. But to the extent that the overnight rate is closely linked to the minimum bid rate, the target level for the overnight rate can be inferred straightforwardly. Finally, instead of announcing a specific target level, the SNB indicates a target range of 100bp for the three-month Libor. However, the SNB's policy statements typically specify that it intends to keep the three-month Libor near the midpoint of the target range.[2] The relatively wide target range reflects the fact that the three-month Libor is affected by interest rate expectations and, consequently, is less directly controllable than an interest rate with shorter maturity, say the overnight rate. Moreover, being the central bank of a small and very open economy, the SNB has often stressed that by the announcement of a wide target range, it has more leeway to react flexibly to exchange rate shocks without signalling an immediate change in its monetary policy stance (see e.g. Baltensperger, Hildebrand and Jordan 2007).

Usually, target rates are changed only on the occasion of scheduled monetary policy meetings. The frequency of these meetings varies from monthly (RBA, ECB and BoE) to quarterly (SNB). The Fed's FOMC meets eight times a year, i.e. roughly every six to seven weeks. However, all central banks reserve the right to adjust the target rate at any time, e.g. in reaction to market turbulence or if there is a sudden change in the perception of the overall economic situation or outlook.

For illustration purposes, Figure 4.1 illustrates the target rates and the effective money market interest rates in the five currencies under scrutiny over the last few years.[3] Even without any statistical analysis, three phenomena are visible with the naked eye. First of all, all central banks seem to have been quite successful in keeping money market interest rates close to the target level, at least on average. Second, in some currencies the volatility of market rates is apparently larger than in others. And third, for some currencies such as the pound sterling, there seem to be structural breaks in terms of money market volatility. This chapter's review of operational frameworks will contribute to understand these and other interesting phenomena.

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[2]The only exception occurred during the near zero interest rate period from March 2003 until June 2004, when the SNB temporarily reduced the target range to 75bp and intended to hold the three-month Libor in the lower part, i.e. at around 25bp.

[3]In line with the SNB's policy statements, the (inofficial) target for the CHF three-month Libor is assumed to be the midpoint of the announced target range (except for the period from 6 March 2003 until 16 June 2004, when the SNB intended to keep the CHF three-month Libor in the lower part of the target range). For the ECB, the target is assumed to be the announced policy rate (minimum bid rate).

Figure 4.1: Official Target and Money Market Interest Rates

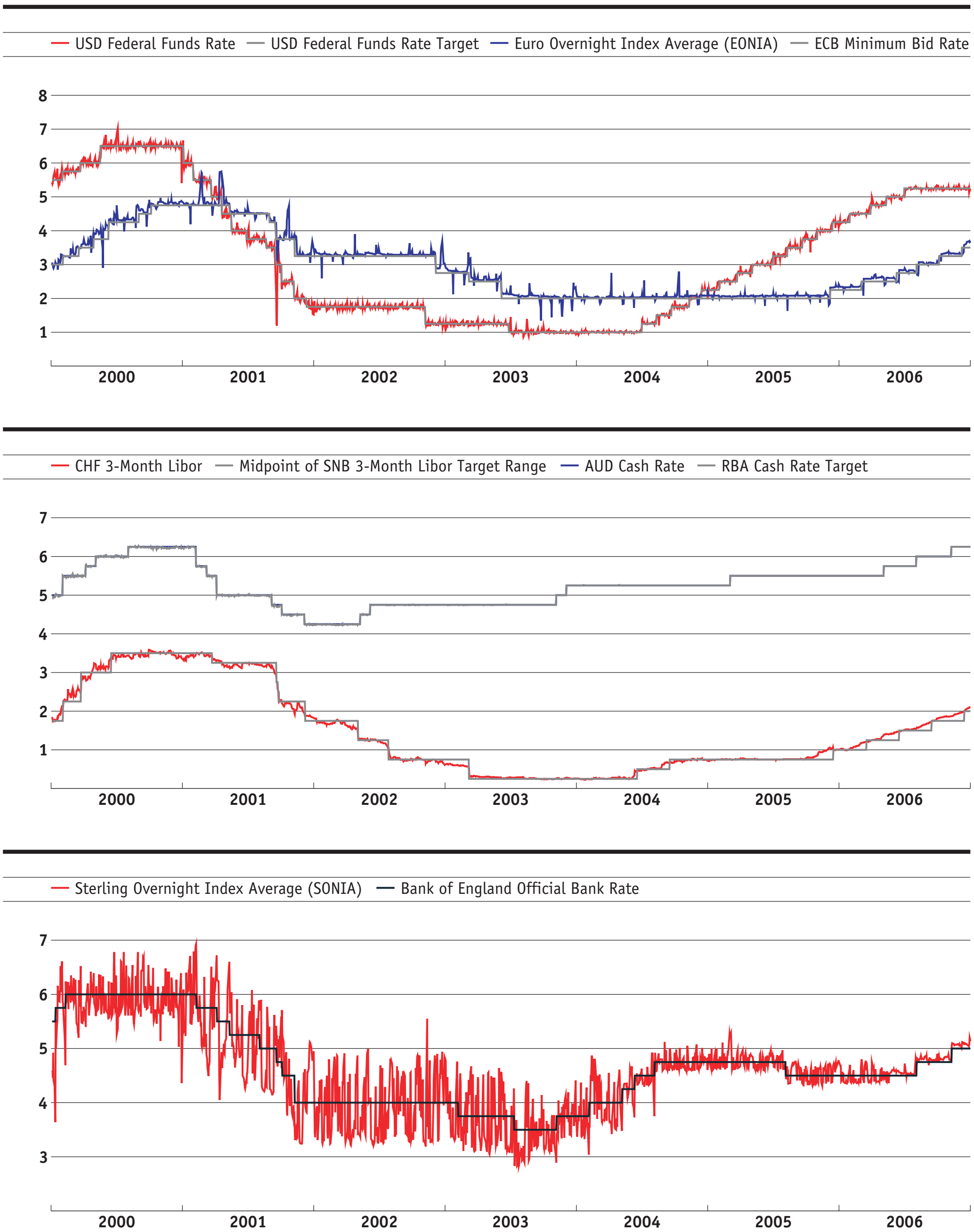


Table 4.1: Key Features of Operational Targets

	RBA	ECB	SNB	BoE	Fed
Type					
– Short-term interest rate	•	•	•	•	•
– Other					
Maturity					
– Overnight	•	•[1]		•	•
– Other			•[1]		
Precision					
– Point target	•	•[1]		•	•
– Target range			•[2]		
Communication					
– Explicit announcement	•		•[3]	•	•
– Tender rate		•			
– Standing facilities		•			
Frequency of monetary policy decisions	1m[1]	1m	3m	1m	6w

Notes:
RBA: [1]First Tuesday of every month, except in January.
ECB: [1]Not explicitly communicated.
SNB: [1]Three-month Libor. [2]Range of 100bp. [3]SNB announces in which area of the range it intends to keep the three-month Libor.

4.1.2 The Use of Monetary Policy Instruments

At the outset of the following review of the three monetary policy instruments, it is important to stress some fundamental differences in the use of these instruments by the five selected central banks. Most notably, and in contrast to the other central banks, the RBA does not impose reserve requirements (see Table 4.2). Australian banks' reserves at the RBA are thus entirely voluntary reserves or excess reserves, maintained for the sole purpose of facilitating the settlement of payments.

Moreover, there are is some disparity regarding the reliance on standing facilities. While all central banks have in place a borrowing facility, only three (RBA, ECB and BoE) also provide a facility to deposit (excess) reserves. Finally, open market operations are used by all central banks, but as the detailed analysis will show, the specific use varies from one central bank to another, particularly with respect to the frequency and maturity of operations.

Table 4.2: Use of Monetary Policy Instruments

	RBA	ECB	SNB	BoE	Fed
Reserve requirements		•	•	•	•
Standing facilities					
– Borrowing facility	•	•	•	•	•
– Deposit facility	•	•		•	
Open market operations	•	•	•	•	•

4.1.3 Reserve Requirements

Within our sample, four central banks make use of reserve requirements (ECB, SNB, BoE and Fed). However, the following comparison of the reserve requirement regimes adopted by these central banks will reveal some fine distinctions, notably in terms of the purpose of reserve requirements, the calculation and fulfillment of reserve requirements, the remuneration policy and the penalties applied in case of reserve deficiencies (see also Table 4.3).

Purpose

With respect to the rationale for the imposition of reserve requirements, all central banks emphasize that their primary purpose is to facilitate the implementation of monetary policy. Particularly acknowledged is reserve requirements' potential to create or enlarge the demand for reserves and to increase the interest rate elasticity of reserve demand. Moreover, all central banks allow reserves that are maintained (overnight) for reserve requirement purposes to be used (intraday) for the settlement of payments in the LVPS. Reserve requirements thus contribute—at least indirectly—to the smooth functioning of the LVPS by ensuring a minimum level of liquidity.

Although seigniorage would be another potential reason for imposing reserve requirements, no central bank officially refers to this function. Nevertheless, for the SNB and the Fed, which both refrain from remunerating required reserves, rasing revenue may be at least a welcome side-effect.

Table 4.3: Key Features of Reserve Requirements

	ECB	SNB	BoE	Fed
Purpose				
– Monetary policy implementation	●	●	●	●
– Settlement of payments	●	●	●	●
– Seigniorage		●		●
Method of calculation				
– Based on balance sheet	●	●	[1]	●[1]
– Reserve ratio (in %)	2	2.5	[1]	0–10
– Calculation period	end-m	end-m[1]		2w
Fulfillment				
– Averaging	●	●	●	●
– Point target	●	●		
– Flexible target			●[2]	●[2]
– Length of maintenance period	∼1m	1m	∼1m	2w
– End-day of maintenance period	var.[1]	19th	var.[3]	Wed
– Lag of maintenance period	>1m[2]	20d	2d	16d
Eligible assets				
– Reserves	●	●	●	●
– Vault cash		●		●[3]
Remuneration	●[3]		●[4]	[4]
Financial penalties	●[4]	●[2]	●[5]	●[5]

Notes:

ECB: [1]Maintenance periods end the day before monetary policy decisions become effective. [2]Balance sheet data referring to the end of a given calendar month are used to determine the reserve base for the maintenance period starting in the calendar month two months later. [3]Average rate on main refinancing operations. [4]Minimum bid rate plus 2.5%.

SNB: [1]Average of the end of the three months preceding the reserve maintenance period. [2]Average one-month Libor during the reserve maintenance period plus 3%.

BoE: [1]Reserve target is determined by banks. [2]Range of ± 1% around reserve target. [3]Maintenance periods end the day before monetary policy decisions are announced. [4]Repo rate. [5]Twice the repo rate.

Fed: [1]Banks may voluntarily commit in advance to hold additional clearing balances. [2]Allowance to carry-over a reserve deficiency or surplus of up to 4% into the next maintenance period. [3]Applied with a lag of one reserve maintenance period. [4]Voluntary clearing balances earn implicit interest in the form of earnings credits against charges for Federal Reserve priced services, such as check processing and cash shipments. [5]Primary credit rate plus 1%.

Finally, one should also mention two other potential economic functions of reserve requirements, namely prudential reasons and the control of broad money. While these functions are often mentioned in economic textbooks (see also Chapter 4.1.3), neither of them is used by the reviewed central banks to justify reserve requirements.

Method of Calculation

Traditionally, reserve requirements have been determined in relation to banks' balance sheet items, particularly (short-term) liabilities. While the ECB, the SNB and the Fed still rely on balance sheet data to establish banks' reserve requirements, this is no longer the case in the United Kingdom, where the BoE has recently moved to a regime of voluntary reserve commitments.

The ECB applies a 2% reserve ratio on deposits (overnight deposits, deposits with agreed maturity up to two years or redeemable at notice up to two years) and debt securities with agreed maturity up to two years, provided these are not vis-à-vis other institutions subject to reserve requirements. In the case of the SNB, a reserve ratio of 2.5% applies to the following balance sheet items: liabilities arising from money market paper maturing within three months; liabilities vis-à-vis banks payable on sight or maturing within three months provided these banks are not themselves subject to reserve requirements; 20 percent of all liabilities vis-à-vis customers in the form of savings or deposits; other liabilities vis-à-vis customers payable on sight or maturing within three months; and medium-term bank-issued notes maturing within three months. In the U.S., the reserve base is defined as net transaction accounts, which equal total transaction accounts (demand deposits, automatic transfer service accounts, NOW accounts, share draft accounts, telephone or pre-authorized transfer accounts, ineligible bankers acceptances, and obligations issued by affiliates maturing in seven days or less) less amounts due from other depository institutions and less cash items in the process of collection. The reserve ratio depends on the amount of net transaction accounts at the depository institution: It is 0% for net transaction accounts up to USD 8.5 million (reserve requirement exemption amount), 3% for net transaction accounts between USD 8.5–45.8 million (low reserve tranche), and 10% for net transaction accounts of more than USD 45.8 million.[4] In addition to required reserve balances, banks may contract with the Fed to hold more balances to facilitate the settlement of transactions through their accounts. These balances are called contractual clearing balances. Total

[4]The thresholds of the reserve requirement exemption amount and the low reserve tranche are adjusted on an annual basis in accordance with the provisions of Section 19(b)(11)(B) and 19(b)(2) of the Federal Reserve Act, respectively.

reserve requirements thus comprise a regulatory component (required reserve balances) and a voluntary component (contractual clearing balances).

There are also subtle differences concerning the calculation period for the reserve base. In the U.S., the reserve base is defined in terms of daily averages of reservable liabilities over a two week period ending 17 days before the start of the reserve maintenance period. By contrast, the ECB and SNB take into account end-of-month data only: In the euro area, balance sheet data referring to the end of a given calender month are used to determine the reserve base for the reserve maintenance period starting in the calendar month two months later; in Switzerland, the reserve base is defined as the average of the reservable liabilities at the end of the three months preceding the current reserve maintenance period.

In contrast to the other central banks, reserve requirements in the U.K. are not calculated in relation to specific balance sheet items. Rather, the BoE applies a system of voluntary reserve commitments, which allows banks to decide on the level of reserves they need to hold with the BoE, in the light of their view of possible shocks to payment flows and their capacity to manage their need for intraday and overnight liquidity by controlling the pattern of incoming and outgoing payments in the interbank payment system.[5] Banks have to commit to their reserve target no later than two working days before the start of the reserve maintenance period. Hence, despite all the disparities in calculating reserve requirements, the four central banks' regimes have one important element in common, namely that the calculation period precedes the reserve maintenance period (lagged reserve accounting) and, consequently, reserve requirements are known at the beginning of the reserve maintenance period.

Irrespective of the various calculation methods, from the perspective of monetary policy implementtion what matters in the end is the resulting level of reserves that banks are obliged to maintain (or voluntarily maintain in the case of banks in the U.K.). For instance, for the last reserve maintenance period in 2006, the total reserve requirement of Swiss banks was CHF 8.3 billion, whereas the corresponding value for banks in the euro area amounted to EUR 172.5 billion. Clearly, as the Swiss financial system is much smaller than the financial system of the euro area, these figures need to be qualified by some measure that serves as a proxy for the size of the financial system. Moreover, as will be shown below, a comparison of total reserve requirements can be misleading due to the fact that in some countries reserve requirements

[5]However, this decision is not completely free, as the BoE reserves the right to apply a specific minimum threshold and a ceiling. Initially, the minimum threshold was nil, while for each bank the reserve target ceiling was the higher of GBP 1 billion and 2% of the institution's deposits (excluding deposits with other banks).

may be satisfied not only by reserves but also by vault cash. Where this is possible, the effective reserve requirement—that is the level of reserves that needs to be maintained in the form of reserve balances with the central bank—is *de facto* smaller than it appears at first sight.

Fulfillment

With regard to the fulfillment of reserve requirements, the most notable feature is that all central banks allow for averaging of reserves over the reserve maintenance period. But while in the euro area and in Switzerland banks have to maintain a specific amount of reserves over the maintenance period, the regimes in the Anglo-Saxon countries allow for more flexibility. A target band of ± 1% around the reserve target applies in the U.K., while banks in the U.S. may make use of so-called carry-over provisions, which allow to carry-over a reserve deficiency or surplus of up to 4% into the next maintenance period. Moreover, contractual clearing balances are subject to a band of plus or minus the greater of USD 25,000 or two percent of the contracted level.

The reserve maintenance period as such also exhibits some disparities. In the case of the SNB and the Fed, reserve maintenance periods have a fixed length based on calendar dates: In Switzerland, it lasts one month, starting on the 20th of one month and ending on the 19th of the following month; in the U.S., it lasts two weeks, starting on a Thursday and ending on the Wednesday two weeks later. In contrast, reserve maintenance periods in the U.K. and in the euro area are aligned with monetary policy meetings: Reserve maintenance periods begin when monetary policy decisions are announced or become effective, respectively, and they last until the next meeting of the monetary policy decision-making committee is scheduled.[6] As a result, the length of reserve maintenance periods is to some extent variable.

Another remarkable distinction is related to the assets eligible to fulfill reserve requirements. Of course, balances held with the central bank (reserves) are eligible in all currency areas. But as noted above, in Switzerland and the U.S. vault cash is also accepted. As only reserves matter for the implementation of monetary policy, the eligibility of vault cash may be considered as a factor reducing the effective reserve requirement. This is particularly true for the U.S., where vault cash is applied with a lag of one reserve maintenance period, i.e. vault cash available to satisfy reserve requirements in the current reserve maintenance period is based on vault cash held during the previous reserve maintenance period. This provision ensures that

[6]Note that in terms of policy rates applied to open market operations, the BoE's monetary policy decisions become effective on the day of their announcement, whereas the ECB's decisions become effective with a one day lag.

the level of reserve balances to be held with the Fed—the effective reserve requirement—is known with certainty at the beginning of the maintenance period. In contrast, in Switzerland vault cash is applied contemporaneously. As the precise level of applicable vault cash is typically not known until the end of the maintenance period, the eligibility of vault cash introduces an element of uncertainty with regard to the level of effective reserve requirements, complicating both the banks' reserve management and the SNB's liquidity management.

Focusing on the last reserve maintenance period in 2006, Table 4.4 provides an overview of the level of reserve requirements in the four currency areas.[7] It appears that taking into account the eligibility of vault cash implies a substantial reduction in effective reserve requirements in both Switzerland and the U.S. In particular, the Fed's effective reserve requirement is less than one sixth of the total reserve requirement. In order to allow a comparison of effective reserve requirements, the absolute values are related to three alternative measures that account for the size of the respective financial system: banks' total assets, M1, and the daily turnover in the main large-value payment system. While the resulting percentage values are difficult to interpret as such, all measures lead to the same conclusion: Effective reserve requirements are clearly highest in the euro area, somewhat lower in the U.K., and significantly lower in Switzerland and the U.S. Comparing the Eurosystem's and the Fed's effective reserve requirements, the former are found to exceed the latter by a factor of 11 to 33, depending on the measure used.

Examining the level of banks' total and excess reserves is also instructive (see Table 4.4, rows 4 and 5).[8] In the euro area and in the U.K., the level of excess reserves is very small, indicating that effective reserve requirements are binding for all banks and thus the determining factor for banks' reserve demand. This seems not to be the case in Switzerland and in the U.S., where banks maintain much more reserves than needed. For instance, total reserves held by Swiss banks exceed effective reserve requirements by more than 40%. This indicates that effective reserve requirements are not sufficiently high to be binding for all Swiss banks. Indeed, an in-depth analysis of the Swiss reserve requirement data reveals that especially smaller and medium size banks maintain significant excess reserves.[9] For many of these institutions, applicable vault cash exceeds the total reserve requirement, so that the effec-

[7] The respective maintenance periods were: 7 November to 12 December for the ECB; 20 November to 19 December for the SNB; 9 November to 6 December for the BoE; and 6 to 20 December for the Fed.

[8] In Table 4.4, the definition of 'excess reserves' deviates from the standard definition, since it is calculated with respect to the effective and not the total reserve requirement.

[9] The relevant bank specific data is not publicly available.

Table 4.4: Level of Reserve Requirements

		ECB	SNB	BoE	Fed
1	Total reserve requirement[1]	172.5	8.3	17.1	38.7
2	Applied vault cash[1]	0	4.8	0	32.9
3	Effective reserve requirement[1] (1 – 2)	172.5	3.5	17.1	5.8
	– in % of banks' total assets[2]	0.66	0.11	0.33	0.06
	– in % of M1[2]	4.69	1.27	2.05	0.42
	– in % of daily turnover in LVPS[3]	8.24	1.98	7.40	0.25
4	Total reserves[1]	173.2	5.1	17.1	7.2
5	Excess reserves[1] (4 – 3)	0.7	1.6	0	1.4
	– in % of effective reserve requirements	0.41	43.59	0.01	24.98

Sources: Central bank websites.

Notes:

1 In billion of local currency.

2 As of end of 2006.

3 2006 daily averages of the main large-value payment systems settling in central bank money in each currency area, i.e. Target, SIC, CHAPS and Fedwire.

tive reserve requirement is zero. These banks hold excess reserves either to avoid end-of-day overdraft penalties or for payments purposes in the LVPS, or both. But to the extent that the demand for excess reserves is relatively unstable over time and hence difficult to predict, the assessment of the banking system's liquidity needs becomes more challenging, thus complicating the central bank's liquidity management. From the perspective of monetary policy implementation, the level of reserve requirements is therefore suboptimal.

Remuneration and Financial Penalties

In terms of remunerating required reserves, two policies can be distinguished. On the one hand, both the ECB and the BoE remunerate reserve requirements at the (average) rate of their main refinancing operations during the reserve maintenance period, thereby essentially eliminating banks' opportunity costs of holding required reserves. These two central banks also remunerate excess reserves, albeit at a lower rate (see more below on deposit facilities). On the other hand, neither required nor excess reserves are remunerated by the Fed and the SNB. In the U.S., however, voluntary clearing balances earn implicit interest in the form of earnings credits against charges for Federal Reserve priced services such as check processing and cash shipments. Moreover, in September 2006, U.S. Congress passed legislation that authorizes the Federal Reserve to pay interest on banks' reserve balances, at a rate not to exceed the general level of short-term interest rates. These changes were originally thought to become effective only in October 2011 (Federal Reserve Bank of New York Markets Group 2007, Ennis and Weinberg 2007), but during the financial crisis the authority to pay interest was accelerated by three years (see also Section 4.3).

In case of a bank's non-compliance with reserve requirements, all central banks apply financial penalties to the reserve deficiency. The ECB is entitled to charge a payment of up to 5% above the marginal lending rate or up to two times the marginal lending rate; in practice, the penalty is set 2.5% above the minimum bid rate. The penalty rate applied by the SNB is 3% above the average one-month Libor during the reserve maintenance period, and the BoE charges twice the current repo rate. In the U.S., the penalty regime is somewhat more intricate. Deficiencies in required reserve balances beyond carryover provisions are penalized at a rate 1% above the primary credit rate in effect on the first day of the calendar month in which the deficiency occurs (the primary credit rate is set 1% above the federal funds rate target, see Section 4.1.4). In addition, deficiencies in contractual clearing balances beyond the clearing band up to 20 percent of the level of contractual clearing balances are charged a penalty of 2%, and deficiencies greater than 20 percent are charged a penalty of 4%. Balances in a bank's account at the Fed are first applied to required reserve balances and subsequently used to satisfy contractual clearing balances.

In practice, however, these penalty rates are only of limited relevance, since all central banks allow financial institutions to cover potential reserve deficiencies by borrowing from the borrowing facilities. As the borrowing rates are below the penalty rates for reserve deficiencies, banks rather have recourse to the borrowing facility than incurring more costly reserve deficiencies. Therefore, non-compliance with reserve requirements occurs hardly ever, and if it does, it is typically due to a bank's miscalculation.[10]

4.1.4 Standing Facilities

As mentioned at the outset, the operational frameworks of the reviewed central banks rely on standing facilities to varying degrees. While all five central banks provide a borrowing facility, only three also provide a deposit facility

[10] In Switzerland, such miscalculation may occur due to the contemporaneous applicability of vault cash, which implies that a bank may not know the effective reserve requirement by the end of the maintenance period.

(RBA, ECB and BoE). The characteristics of these facilities are summarized in Tables 4.5 and 4.6.

Borrowing Facility

All borrowing facilities are 'above market facilities', thereby providing a ceiling to short-term (overnight) interest rates. At first sight it might seem obvious that the borrowing rate is set above market rates, as otherwise banks would refinance themselves exclusively by borrowing reserves from the central bank's facility rather than from other market participants. However, at least until very recently, a number of central banks used to provide 'below market facilities'.[11] The most prominent example of a below market facility used to be the Fed's discount window, which only as recently as 2003 was transformed into an above market facility (see also Section 4.2.3).[12]

As above market facilities, the main function of borrowing facilities is to put a ceiling on market rates. Besides that, the borrowing facilities also serve as a safety valve: Banks with temporary liquidity shortages may turn to the borrowing facility to bridge their liquidity needs. In the case of the ECB, standing facilities are also used to signal the stance of monetary policy.

Borrowing rates may be posted or floating: The borrowing rate is said to be posted if it is set as a fixed mark-up above an official interest rate such as the target overnight rate (RBA, Fed) or the minimum bid rate for regular open market operations (BoE, ECB); the borrowing rate is floating if it is set as a fixed mark-up above a market interest rate. Within our sample, the only central bank using a floating borrowing rate is the SNB, which sets the rate of its liquidity shortage financing facility in relation to the overnight rate. The mark-ups vary from 25bp (RBA) to 200bp (SNB), with the ECB and the Fed lying in between (100bp). A special case is the U.K., where the mark-up is usually 100bp, with the exception of the last day a reserve maintenance period, when it is only 25bp.

[11] Table 13 in Borio (1997) lists eight below market facilities, among others in Germany, Switzerland and the U.S. However, already at that time, some of these facilities were *de facto* deactivated.

[12] The Fed's current discount window is still somewhat special as it consists of three lending programs: primary credit, secondary credit, and seasonal credit. Only financial institutions considered to be in generally sound financial conditions qualify for primary credit, which is in practice the main borrowing facility. Financial institutions not eligible for primary credit may be granted secondary credit. Credit extended under the secondary credit program is granted at a rate above the primary credit rate. Furthermore, the Fed may extend seasonal credit for periods longer than those permitted under primary credit to assist a smaller institution in meeting regular needs for funds arising from expected patterns of movement in its deposits and loans.

The maturity of credit extensions through the borrowing facilities is typically overnight. The Fed may grant primary credits up to a few weeks, but usually banks' refinancing needs are limited to overnight. Credits are either granted by means of repo transactions or as collateralized loans. All central banks accept a wide range of collateral, including both public and private sector securities. Moreover, with the exception of the SNB, all central banks allow banks to borrow as much as they like, provided they have sufficient collateral. Swiss banks must apply in advance for a limit; eligible collateral must be held at all times in a specific custody cover account at the Swiss central securities depository.

Deposit Facility

For all three central banks providing a deposit facility, the main motivation is the same: setting a floor for short-term (overnight) interest rates. Besides that, the ECB's deposit rate has an additional role in signalling the stance of monetary policy.

In all cases, deposit rates are set at a fixed discount below official interest rates such as the target overnight rate (RBA) or the minimum bid rate for regular open market operations (BoE, ECB). For all three central banks, the deposit facility's discount is of the same magnitude as the the borrowing facility's mark-up. Together, borrowing and deposit facilities thus provide for a symmetric corridor around the target overnight rate or the minimum bid rates for regular open market operations, respectively.

Finally, one may note some minor technical differences. The ECB and the BoE require banks to actively shift any excess reserves into a dedicated (interest-earning) deposit account. In contrast, settlement balances held overnight by Australian banks automatically earn interest at the deposit rate. The RBA's interest-earning settlement balances are thus functionally equivalent to a deposit facility, albeit banks do not have to actually transfer funds into a dedicated deposit account.

Table 4.5: Key Features of Borrowing Facilities

	RBA[1]	ECB[1]	SNB[1]	BoE[1]	Fed[1]
Type					
– Above market	•	•	•	•	•
– Below market					
Purpose					
– Market ceiling	•	•	•	•	•
– Safety valve	•	•	•	•	•
– Signalling		•			
Pricing					
– Posted	•[2]	•[2]		•[2]	•[2]
– Floating			•[2]		
– Mark-up (in bp)	25	100	200	25/100[3]	100
Maturity					
– Overnight	•	•	•	•	•
– Other					•[3]
Technical form					
– Repo	•	•	•	•	
– Collateralized loan		•			•
Eligible collateral					
– Public sector securities	•	•	•	•	•
– Private sector securities	•[3]	•	•	•	•
Limits (other than collateral)			•[3]		•[4]

Notes:

RBA: [1]Overnight repurchase agreement facility. [2]Cash rate target. [3]Only bank accepted bills of exchange and negotiable certificates of deposit accepted or issues by certain eligible banks.

ECB: [1]Marginal lending facility. [2]Minimum bid rate.

SNB: [1]Liquidity shortage financing facility. [2]Repo overnight index. [3]Each counterparty must apply in advance for a limit. Once approved, the limit must be covered with eligible collateral.

BoE: [1]Borrowing facility. [2]Repo rate. [3]25bp on last day of reserve maintenance period; 100bp on all other days.

Fed: [1]Discount window, which consists of three lending programs: primary credit, secondary credit and seasonal credit. This table refers only to primary credit. [2]Federal funds rate target. [3]Overnight loans are standard, but longer-terms may be offered. [4]Only financial institutions in sound financial conditions (CAMELS rating 1 or 2) qualify for primary credits. Institutions with CAMELS rating 3 would be eligible if supplementary information suggested that they were generally sound.

Table 4.6: Key Features of Deposit Facilities

	RBA	ECB	BoE
Purpose			
– Market floor	•	•	•
– Signalling		•	
Pricing			
– Posted	•[1]	•[1]	•[1]
– Floating			
– Discount (in bp)	25	100	25/100[2]
Maturity			
– Overnight	•	•	•
– Other			
Technical form			
– Unsecured deposit		•	•
– Interest-earning settlement balances	•		

Notes:
RBA: [1]Target cash rate.
ECB: [1]Minimum bid rate.
BoE: [1]Repo rate. [2]25bp on last day of reserve maintenance period; 100bp on all other days.

4.1.5 Open Market Operations

At least in theory, there are almost no limits in how open market operations can be set up and conducted. Therefore, it should not come as a surprise that the differences of the operational frameworks are most pronounced with respect to open market operations.

Table 4.7 provides an overview of the general types of open market operations currently used by the selected central banks, both routinely and rarely (if at all).[13] It is evident that all central banks rely predominantly on repo

[13]It needs to be stressed that the focus is on operations that are conducted in order to manage the banking system's liquidity position. In addition to these monetary policy related operations, central banks may engage in market transactions in order to adjust the structure of their domestic or foreign financial assets (reserve management). Although these transactions are functionally similar to monetary policy related operations and also affect the amount of reserves held by banks, they should not be confounded with open market operations.

transactions, with maturities varying from overnight, to short-term (here defined as repos with maturity from two days up to one month) to longer-term (here defined as repos with maturity from one month up to one year). The Fed, though also mainly relying on repos for the provision of federal funds, is the only central bank that regularly conducts securities outright transactions. Also, foreign exchange swaps are still widely used by the RBA.

Table 4.7: Use of Different Open Market Operations

	RBA	ECB	SNB	BoE	Fed
Overnight repos	•	*	*	•	•
Short-term repos	•	•	•	•	•
Longer-term repos	•	•	*	•	*
Securities outright transactions	*	*	*		•
FX outright transactions			*		
FX swaps	•	*	*		
Issuance of debt certificates		*	*		
Collection of fixed term deposits		*	*		
Derivatives transactions			*		

• Routinely used
* Rarely used (if at all)

Despite the manifest preference for repos to manage the supply of reserves, central banks usually reserve the possibility to make use of other types of open market operations if deemed appropriate. A notable example is the SNB, whose guidelines on monetary policy instruments specify a wide range of open market operations, including securities outright transactions, foreign exchange outright transactions and swaps, the issuance of debt certificates, the collection of fixed term deposits, and even the possibility to create, purchase or sell derivatives on receivables, securities, precious metals or pairs of currencies. In practice, however, these alternative open market operations are hardly ever used and repo transactions are the rule. The following review thus focuses exclusively on central banks' liquidity management by means of routine repo transactions (see Table 4.8).

Although differing in many respects, it is noteworthy that the central banks' approaches to liquidity management feature two commonalities. First, all central banks apply a mix of different maturities for their routine repo transactions: all make use of overnight repos, albeit the ECB and the SNB less often than the others; all make regular use of short-term repos; and three central banks (RBA, ECB and BoE) regularly also conduct longer-term repos. The use of different maturities may be explained by the economic function of these transactions. Generally, the purpose of longer-term repos is to (partially) satisfy banks' structural or longer-term refinancing needs. Longer-term repos are thus often an alternative to outright purchases or sales of securities. As a matter of fact, the reason why the Fed does not regularly make use of longer-term repos is that it prefers to meet banks' structural refinancing needs by outright securities transactions. Short-term repos are usually geared towards gross-tuning the supply of reserves, i.e. these transactions are designed to ensure that banks have sufficient liquidity over a horizon of a few days up to two or three weeks. Finally, overnight repos, and to some extent also short-term repos with maturities of one week or less, are mainly used for fine-tuning the supply of liquidity on a day-to-day basis. However, in practice it is not always possible to clearly distinguish between basic refinancing and gross-tuning operations or between gross-tuning and fine-tuning repos. Hence, the respective indications in Table 4.8 should be interpreted with some caution.

Another common feature revealed by 4.8 is the striking preference for liquidity providing operations. Although it is straightforward to arrange liquidity absorbing repos, only the BoE stands ready to withdraw liquidity by means of overnight repos on a regular basis (see below). The other central banks might also conduct liquidity absorbing fine-tuning operations, but they do so only very rarely or by means of other instruments such as the collection of fixed term deposits. Overall, this corroborates the view that central banks generally prefer to operate in an environment where banks face a structural liquidity deficit and hence need to borrow regularly from the central bank.

Apart from these common features, individual central banks' approaches to manage the supply of liquidity by means of repo transactions are quite different, ranging from rather discretionary to very rule-based and systematic. This is most evident by focusing on the frequency and maturity of central bank operations (see Table 4.8). The RBA's approach is rather discretionary and pragmatic. Operating on a daily basis, it determines the maturity of operations on a case by case basis. As shown in Figure 4.2, maturities vary from overnight to three months, with no systematic pattern being discernable, maybe with the exception of a slight preference for one-, two-, three-, and four-week maturities. Moreover, using variable rate tenders, the amount to be allotted on a specific day may be distributed over different maturities based on the attractiveness of all bids relative to market interest rates for each maturity. This also explains why the number of operations in 2006 sums up to 992.

Table 4.8: Key Features of Routine Repo Transactions

	RBA			ECB		SNB	BoE			Fed	
	O	S	L	S	L	S	O	S	L	O	S
Purpose											
– Basic refinancing		•	•	•	•	•		•	•		
– Gross tuning		•	•	•		•		•		•	•
– Fine tuning	•			•	•		•			•	
Liquidity impact											
– Providing	•	•	•	•	•	•	•	•	•	•	•
– Absorbing	[1]	[1]	[1]	[1]			•				
Frequency											
– Periodical				w	m	d	m[1]	w	m		
– Ad hoc	•[2]	•[2]	•[2]							•[1]	•[1]
Maturity											
– Fixed				1w	3m	1w[1]	1d	1w	[2]	1d	
– Variable	•[2]	•[2]	•[2]								[2]
Tender procedure											
– Fixed rate						•	•	•			
– Variable rate	•[3]	•[3]	•[3]	•[2]	•				•[3]	•[3]	•[3]
Settlement lag	0	0	3	1	1	2	0	0	1	0	0

O: Overnight repos. S: Short-term repos. L: Long-term repos

Notes:

RBA: [1]Only occasionally. [2]Daily operations, but the maturity is determined ad hoc. Very rarely, second round operations may be undertaken in response to unexpected shocks to autonomous factors. [3]The allotment amount may be distributed over different maturities based on the attractiveness of all bids relative to market interest rates for each maturity.

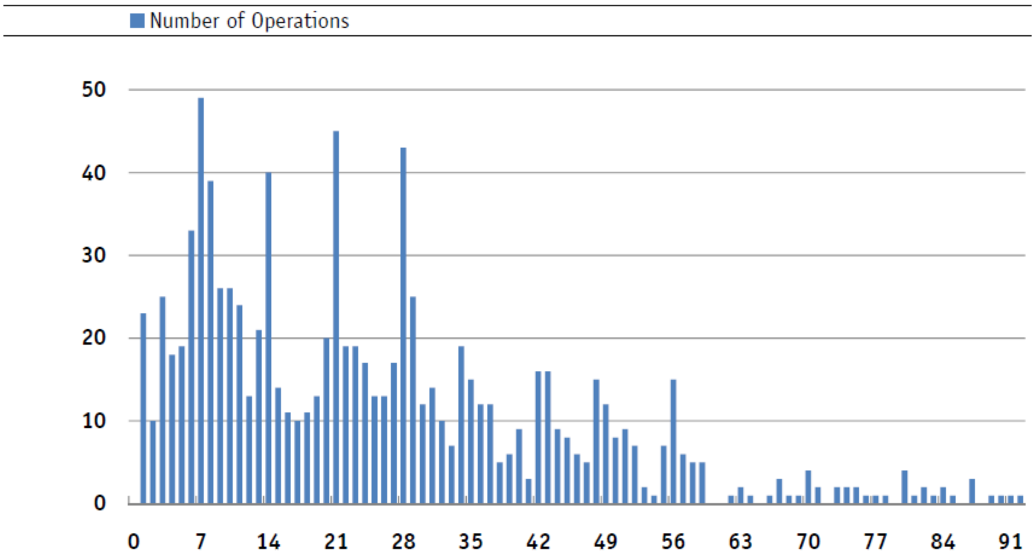
ECB: [1]Theoretically possible, but in practice never done. [2] Variable rate tender with minimum bid rate.

SNB: [1]Rarely also maturities of two or three weeks.

BoE: [1]On the last day of each reserve maintenance period. [2]3, 6, 9 and 12 months. [3]Discriminatory price auction.

Fed: [1]Almost daily. [2]2–14 days. [3]Discriminatory price auction.

Figure 4.2: Maturities of RBA's Repo Transactions in 2006



Source: Reserve Bank of Australia website

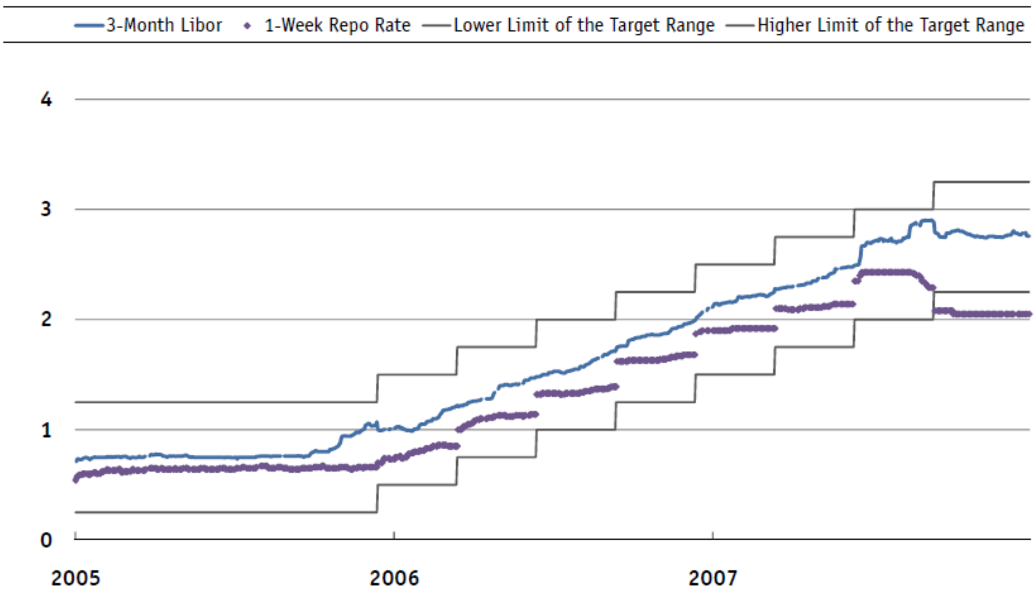
In stark contrast, the ECB's approach is very systematic and rule-based. An important part of banks' refinancing needs is satisfied by monthly repos with a fixed maturity of three months (so-called longer-term refinancing operations). Additional refinancing as well as gross- and some fine-tuning is done through weekly repos with one-week maturity (so-called main refinancing operations). Thus, whenever one repo matures, the next repo is settled, so that only one main refinancing operation is outstanding at any time. Variable rate tenders are used for both longer-term and main refinancing operations, but for the main refinancing operation a minimum bid rate applies. In addition, the ECB may also provide additional liquidity by means of fine-tuning overnight repos at the end of reserve maintenance periods (not shown in Table 4.8, see also the discussion in Section 4.2.2).

The BoE's approach exhibits many similarities with the one of the ECB. There are also monthly longer-term operations (albeit with maturities of three, six, nine and twelve months) and weekly short-term operations with one-week maturity. However, the BoE is committed to conduct an additional overnight repo on the last day of each reserve maintenance period. This transaction, which might be liquidity providing or absorbing, aims to ensure that the supply of reserves corresponds to the amount needed by the banking system to satisfy reserve requirements, thereby reducing the potential pressure on overnight rates that might be induced by a mismatch between reserve demand and supply. A fixed rate tender procedure is applied for both overnight and short-term operations, whereas longer-term repos are conducted by means of discriminatory price auctions.

The approach to liquidity management followed by the Fed and the SNB is less discretionary than the one of the RBA, but also less systematic than in the case of the ECB or the BoE. The Fed operates almost daily, with maturities typically from overnight to two weeks. For instance, in 2006, the Fed arranged repos on all but eight business days, including 203 overnight repos, 44 repos with maturities between 2 and 13 days, and weekly (every Thursday) repos with 14-days maturity. Different maturities may be offered on the same day. All operations are conducted by means of discriminatory price auctions.

The SNB conducts repo transactions almost every day, with a preference for one-week maturity. Occasionally, overnight repos or two- or three-week repos are auctioned off, too. For instance, in 2006 the SNB conducted 3 overnight, 242 one-week and 10 two-week repos. With respect to one-week repos, it is interesting to note that although the SNB relies on fixed rate tenders only, the tender rate may be altered between official changes in the target rate. Indeed, the tender rate varies quite often from one day to another by a few basis points, as depicted in Figure 4.3. This is true both in times of relatively stable market conditions (e.g. during 2005) and in times of gradual target changes (e.g. during 2006 and early 2007). As the changes in one-week repo rates are small and temporary, it is unlikely that they have a significant impact on the three month Libor. Therefore, especially in times of rather stable interest rates such as in 2005, they might be interpreted as the SNB's reaction to specific distortions in short-term money markets. Moreover, Figure 4.3 reveals that during the process of gradual interest rate increases, which started in December 2005, the tender rate was systematically increased before the target rate was officially changed. There are two mutually not excluding explanations for this behavior. First, the increase in tender rates could be interpreted as signals to the market, indicating that the SNB is likely to increase the target rate at the next monetary policy meeting. Second, the episode illustrates a practical problem when using a longer-term money market interest rate as operational target (see also Section 2.3.2). Because the target changes were widely anticipated by market participants, the three month Libor tended to trade close to the new expected rate well before the target change was eventually announced. Had the SNB kept the one-week tender rate constant at lower levels, the spread between the three month Libor and the tender rate would have increased over time. In order to lend funds at more attractive interest rates in the longer-term interbank money market, banks would have tried to borrow an increasing amount of the relatively cheap short-term funds offered by the SNB. As a consequence, the SNB would have been faced with significant overbidding in its tender operations.

Figure 4.3: SNB Tender Rates



Source: Swiss National Bank website

On a more technical note, one may also observe that the settlement lag, which measures the lag between the time the auction takes place and the time the transaction is eventually settled, varies between zero and three days (see last row in Table 4.8). For instance, the ECB's operations are settled the day after the auctions take place, so the settlement lag is one day. The ECB's weekly main refinancing operations, which are concluded on Tuesdays, are thus settled on Wednesdays and mature the following Wednesdays. For other central banks the settlement lag may depend on the maturity of the transactions, with the settlement lag being typically longer for repos with longer maturities. For instance, the SNB's overnight repos are settled on a same-day basis, whereas one-week repos have a settlement lag of two days.

More importantly, routine repo transactions of the five central banks also differ with respect to the range of eligible collateral (see Table 4.9). Some central banks may only accept government securities, while others also accept a more or less broad range of private sector securities and/or securities denominated in foreign currencies. As regards counterparties, arrangements also vary considerably. A special case is the Fed, which typically operates only with 20 large securities dealers. In contrast, the ECB's range of potential counterparties includes all the institutions that are subject to reserve requirements, although fine-tuning operations may be restricted to a subset of these institutions. It may be also noteworthy that the SNB is the only central bank which routinely deals with foreign institutions.

Table 4.9: Collateral and Counterparties for Routine Repo Transactions

	RBA	ECB	SNB	BoE	Fed
Eligible collateral					
– Government sector securities	•	•[1]	•[1]	•	•[2]
– Private sector securities	•[1]	•[1]	•[1]		
– FX denominated securities			•[3]	•[4]	
Counterparties					
– Banks[5]	•	•	•[1]	•	
– Securities firms	•			•[1]	•[6]
– Foreign institutions			•[7]		

Notes:

[1] Selected.

[2] Including agencies.

[3] Mainly euro denominated securities, but also other currencies.

[4] Euro.

[5] The precise coverage varies from country to country.

[6] Primary dealers.

[7] Provided they participate to both the Swiss Interbank Clearing (SIC) system and the Eurex repo trading platform.

Finally, central banks' policies regarding the transparency about open market operations is also of particular interest (see Table 4.10). In this respect, one may distinguish between ex ante and ex post information. Ex ante information refers to relevant data that is announced ahead of tender operations and which can be used by banks when making their bidding decisions. Ex post information refers to the release of relevant data regarding the results of tender operations.

The selected central banks have in common that they release rather detailed information on the results of tender operations. This is true both for data on relevant quantities (e.g. total bids submitted and accepted) and, where applicable, for data on relevant interest rates (e.g. high and low rates of bids submitted and weighted average or marginal rates of bids accepted).

There is, however, less conformity regarding the dissemination of information in advance of tender operations.

Table 4.10: Transparency of Operations

	RBA	ECB	SNB	BoE	Fed
Ex ante information					
– Total reserve requirement	n/a	•	•	•	•
– Residual reserve requirement	n/a	•		•	
– Forecast autonomous liquidity factors	•	•		•	
– Forecast total allotment				•	
Ex post information					
– Total bids submitted	•	•	•	•	•
– Total bids accepted	•	•	•	•	•
– Rates submitted	•	•	n/a	n/a	•
– Rates accepted	•	•	n/a	n/a	•

4.2 Experiences and Adjustments Before the Financial Crisis

Over the last decade or so, adjustments to operational frameworks of the selected central banks were the rule rather than the exception, and the future will certainly bring further modifications. Although some changes were of a rather technical nature and had only a limited impact, others were more substantial. On two occasions, central banks even undertook a complete reform of their arrangements for the implementation of monetary policy. Reviewing the selected central banks' recent experience and trying to understand why and how they have adjusted their operational frameworks is thus a worthwhile endeavor, complementing the snapshot of current arrangements taken in the preceding section.

4.2.1 Reserve Bank of Australia

In terms of interest rate control, the RBA's operational framework has been remarkably successful. This is apparent from Figure 4.4, which depicts the spread of the interbank cash rate to the target rate. While the spread was typically only a few basis points before 2002, it has become even smaller through time, and since 2002 the cash rate coincides with the target rate on almost every day. The remarkably low interest rate volatility is astonishing, particularly since the RBA's operational framework does not provide for interest rate stabilizing reserve requirements.

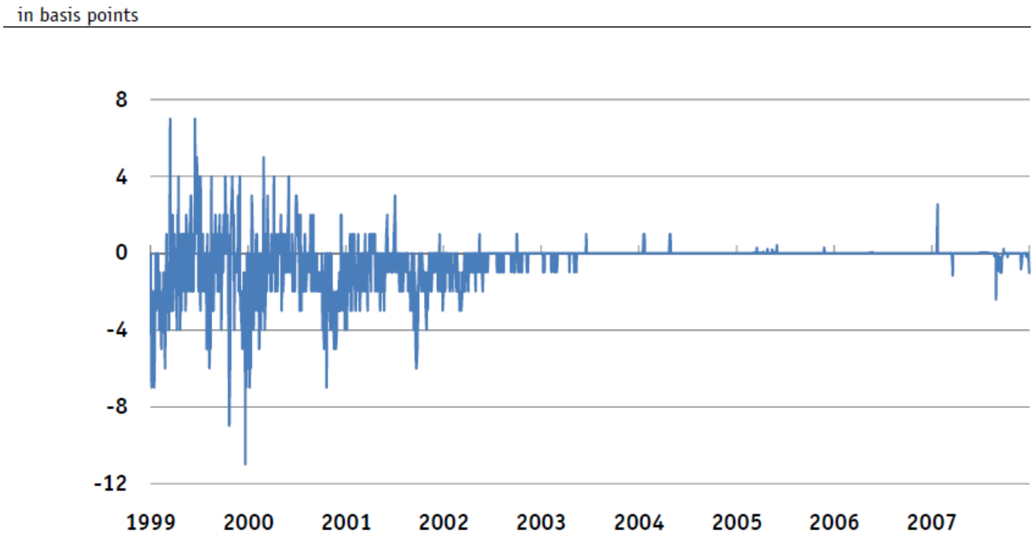
Different factors seem to contribute to the cash rate's stability.[14] The first key element in interest rate stabilization are the standing facilities that provide for a narrow interest rate corridor of ± 25bp around the target rate. Moreover, the RBA is very actively managing the banking system's liquidity by means of daily open market operations. The RBA puts a lot of resources into forecasting autonomous liquidity factors and to ensure surprises concerning daily movements in system liquidity are rare. In particular, it liaises daily with market participants in order to find out whether there is some change in the demand for settlement balances from individual institutions. These investigations are facilitated by the small number of participants holding a settlement account with the RBA (around 60 institutions). Finally, and most interestingly, it is likely that when dealing with one another financial institutions acknowledge that they are playing a multi-period game where they may be a borrower one day and a lender the next day. So even if there is an overall liquidity shortage or excess due to unexpected autonomous liquidity factors on a given day, financial institutions may simply refrain from asking (or paying) a cash rate that deviates significantly from the target rate. In the specific case of the Australian dollar money market, two arguments militate in favor of this multi-period game hypothesis. First, as the number of market participants is small, the likelihood of retaliation is comparatively higher than in other money markets; Australian banks thus may not want to exploit their peers' need to borrow or lend liquidity. Second, the RBA's active liquidity management implies that any excess or shortage of reserves is expected to be offset by the following day at the latest. No bank should thus face an excess or shortage of reserves for a sustained period.

Given the RBA's strong leverage over money market rates, it is not surprising that the operational framework has been characterized by a very high institutional stability over the last decade or so. In fact, one has to go back as far as to the early 1990s to track down the last major change. At that time, open market operations were conducted largely by outright transactions in short-dated government securities, but the RBA then started to continuously increase the share of repos at the cost of outright transactions. In 2005/06, the latter accounted for less than 2% of all open market operations.[15] As in

[14]The following explanation is based on private correspondence with John Broadbent, Head of Domestic Markets at the Reserve Bank of Australia.

[15]The RBA's financial year ends on 30 June.

Figure 4.4: Spread of AUD Cash Rate to Target Rate



Source: Reserve Bank of Australia website

many other countries, this shift was mainly motivated by the greater flexibility in terms of liquidity management provided by repos, but it also reflects the repo market's greater liquidity and the reduced supply of so-called Commonwealth Government Securities (CGS) on issue (RBA 2003).

Three other developments are noteworthy. First, reacting to the limited supply of CGS, the list of eligible securities for repos was expanded on several occasions between 1997 and 2004. The range of securities in which the RBA is prepared to deal now includes domestic bank instruments (bank bills and certificates of deposit issued by selected banks) and a broader range of foreign government and supranational paper (RBA 2003 and 2006). Second, in stark contrast to most other central banks, the use of foreign exchange swaps has reclaimed some popularity in recent years. The increasing use of foreign exchange swaps is related to the remarkable expansion of the RBA's balance sheet by more than 75 percent within four years, with the majority of this expansion owing to higher Government deposits. By buying an increased amount of foreign exchange under swap agreements the RBA replenished the funds withdrawn from the money market by the increase in Government deposits. This allowed to confine the pressure on domestic securities market that would have been incurred had the RBA simply increased the volume of its repo transactions (RBA 2006). Finally, in 2003, in an effort to enhance transparency, the RBA started to publish more information regarding its open market operations. It now releases information on the total value of open market operations, the weighted average rate, the cut-off rate and the value of all repos by maturity (RBA 2003).

4.2.2 European Central Bank

When the ECB became operational on 1 January 1999, its operational framework for monetary policy implementation succeeded the frameworks that had been previously in place at the national central banks constituting the European System of Central Banks (ESCB). Benefitting from the experiences of monetary policy implementation of its predecessors, but yet unencumbered by history and legacies of previous policies, the ECB was able to build on those elements that had proven to be effective within the euro area countries. It is therefore not surprising that by and large the ECB's operational framework has been functioning rather well.

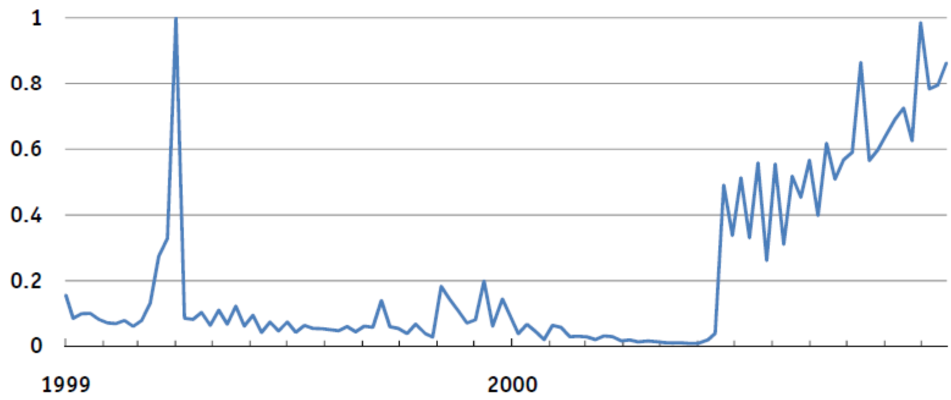
Nevertheless, over time two particular problems became apparent: extreme overbidding in the ECB's main refinancing operations and the impact of expected changes in official interest rates on counterparties' bidding behavior and current short-term interest rates. The first problem was resolved by switching from fixed rate tenders to variable rate tenders in June 2000 (ECB 2000), the second was addressed a few years later by two complementary measures: The beginning of reserve maintenance periods was aligned with the dates of the Governing Council's meetings and the maturity of the main refinancing operations was shortened from two weeks to one week (ECB 2005). Investigating these amendments and to what extent they enhanced market efficiency, is a worthwhile undertaking as it allows to demonstrate some of the practical intricacies of monetary policy implementation.

The Phenomenon of Extreme Overbidding

Initially, the ECB's weekly main refinancing operations were conducted as fixed rate tenders: The ECB announced the rate at which it was willing to lend for the maturity of two weeks and banks submitted their individual bids b_i, indicating how much liquidity they were willing to borrow at that rate. After collection of all the bids, the ECB decided on the total allotment (A). If aggregate bids $B \equiv \sum_i b_i$ were lower or equal than A, each bank's bid would be fully satisfied. In contrast, if aggregate bids exceeded the total amount to be allotted ($B > A$), banks' bids were satisfied on a pro rata basis. Thus, in general, bank i was allotted $a_i = Qb_i$, where $Q = \min(1, A/B)$ is the allotment ratio.

Figure 4.5 shows how the allotment ratio of the weekly main refinancing operations evolved from January 1999 until December 2000. From the very

Figure 4.5: Allotment Ratio in ECB Tenders



Source: European Central Bank website

beginning, the allotment ratio had been rather low, typically around 10%. The allotment ratio declined somewhat throughout most of 1999, stabilized at a higher (but still low) level towards the end of the year, but only to return quickly to a sharply declining trend during the first half of 2000. This downswing was induced by banks' ever increasing bids in tender operations. On 7 June 2000, total bids reached an all time high of nearly EUR 8.5 trillion. With the ECB allotting only EUR 75 billion, the allotment ratio was thus less than 1%.

Three different explanations have been put forward for the phenomenon of extreme overbidding: the "rate hike hypothesis", the "tight liquidity hypothesis" and the "rationing hypothesis". The rate hike hypothesis is related to the interest rate environment that prevailed at that time (ECB 2000 and Bindseil 2005). Between November 1999 and June 2000 the ECB raised the tender rate on five occasions from an initial level of 2.5% to 4.25%. These rate hikes were widely expected by market participants and it is clear that in an environment of increasing interest rate expectations banks will try to refinance themselves as much as possible before rates are increased. This is particularly true when the tender rate is expected to be raised within the current reserve maintenance period. Moreover, as the total allotment is determined by the central bank, banks anticipate that their bids will be rationed and will thus exaggerate the true demand for liquidity. Ultimately, this may give rise to the observed extreme overbidding. Reciprocally, the expectation of falling interest rates might lead to underbidding in fixed rate tenders. A situation of underbidding occurred on 7 April 1999, when demand was so low that the ECB was not able to allot the intended amount. The tender was conducted only two days before the ECB decided to cut official interest rates by 50bp, a decision that was widely expected by market participants. With the imminent expected rate cut and still more than two weeks to the end of the reserve maintenance period, banks' expected to be able to refinance themselves later on at lower rates and their bidding was very cautious.

The tight liquidity hypothesis is related to the ECB's allotment policy. Ayuso and Repullo (2003) argue that on average the ECB's supply of reserves fell short of banks' true demand. As a result, the spread between short-term market rates and the ECB's tender rate was constantly significantly above its natural level.[16] To benefit from the large spread between market rates and tender rates, banks overbid in the ECB's tender operations.

Finally, the rationing hypothesis is derived from theoretical models showing that overbidding in fixed rate tenders may occur even if interest rates are not expected to increase or if the spread between market rates and the tender rate is on average at its natural level. Reasons for overbidding may be the risk of being squeezed in the market after the tender (Nyborg and Strebulaev 2001) or the mere probability of being rationed in the tender and not receiving the full amount demanded (Ehrhart 2001).

The three conjectures are mutually not exclusive and it is likely that all have contributed their share to the observed extreme overbidding. This is corroborated by the empirical analysis of Nautz and Oechssler (2006), who conclude that none of the three theories alone can explain the overbidding phenomenon. Moreover, what is particularly striking is not the overbidding per se, but the bidding dynamics. The gradual exaggeration of reserve demand may be explained by a myopic bidding strategy where each bank simply assumes that bids of all other banks from the previous tender remain unchanged (Nautz and Oechssler 2003). Another explanation for the observed bidding dynamics is based on the assumption of increasing costs of overbidding (Bindseil 2005). Indeed, as a bank could end up with much more liquidity than it actually needs, overbidding is risky and implies two types of costs. First, since repos require collateral, it is likely that the bank would not have sufficient low-opportunity cost collateral at hand; the (excessive) bid would thus have to be covered with expensive collateral. Second, the bank may encounter difficulties in placing its surplus liquidity in the market, e.g. due to credit limits. These costs thus may explain why overbidding started at moderate levels and only gradually degenerated into extreme exaggerations.

[16]As borrowing and lending in the euro interbank market typically occur on a non-secured basis, the natural spread between short-term market rates and the ECB's repo rate reflects the opportunity cost of collateral.

Eventually, as of 28 June 2000, the ECB reacted to the extreme overbidding by replacing fixed rate tenders with variable rate tenders with a minimum bid rate. The new tender procedure brought about an immediate sharp decline in banks' bidding and, accordingly, allotment ratios rose to more normal levels. Within the context of the ECB's operational framework, the switch to variable rate tenders thus turned out to be a suitable measure to address the issue of extreme overbidding.

The Impact of Expected Rate Changes

Even so, the June 2000 amendment to tender procedures did not resolve the more general issue that, especially towards the end of a maintenance period, bidding behavior and overnight rates can be affected by expected changes in official interest rates in the current maintenance period. This issue was addressed only in March 2004 when the ECB adopted two seemingly small changes to its operational framework, one concerning the timing of the reserve maintenance period and the other the maturity of the main refinancing operations.

In the original operational framework, reserve maintenance periods lasted one month, always starting on the 24th of each month and ending on the 23rd of the following month. The weekly main refinancing operations had a two-weeks maturity. In combination, these features implied that in periods marked by plummeting interest rate expectations, banks were inclined to underbid and the total allotment fell short of the ECB's intentions. Underbidding occurred on eleven occasions, and most of these were related to expected interest rate cuts. For instance, on 7 November 2001, the minimum bid rate was 3.75% but the market expected the ECB's Governing Council to cut the minimum bid rate on 9 November 2001, and, as a matter of fact, official interest rates were slashed by 50bp.[17] It is clear that banks were not willing to refinance themselves for two weeks at the current minimum bid rate since they expected cheaper conditions on the main refinancing operations later on during the same reserve maintenance period.

Furthermore, in periods marked by expected interest rate hikes, short-term market rates as well as the marginal rate of the main refinancing operations often deviated significantly from the minimum bid rate. This is illustrated in the upper part of Figure 4.6, which shows the EONIA rate and official interest rates (fixed rate and minimum bid rate, respectively) for the period from October 1999 to December 2000. During this period,

[17] The market's expectations for rate cuts or hikes may be measured by the spread between the three month EURIBOR and the (minimum bid) tender rate. On 7 November 2001, the spread was –37 bp.

official interest rates were raised in seven steps from 2.5% to 4.75% and it is conspicuous that overnight rates usually jumped to the higher levels several days before the rate hikes were effectively announced.

Apparently, the ECB became more and more uncomfortable with these effects, not least because they could call into question its ability to tightly steer overnight rates. Therefore, to alleviate the problem, in March 2004 the ECB adopted two complementary measures. First, reserve maintenance periods were synchronized with the timing of monetary policy decisions. The beginning of each reserve maintenance period now coincides with the day after the policy meeting of the ECB's Governing Council, that is when the first main refinancing operation for which the new minimum bid rate applies is settled. The second measure was to shorten the maturity of the weekly main refinancing operations from two weeks to one week. These tenders are typically settled on Wednesdays and mature one week later, i.e. also on a Wednesday. As reserve maintenance periods also start on Wednesdays, the shortening implies that no operation conducted in one maintenance period ever hangs over into the subsequent maintenance period; banks' bidding behavior is thus no longer affected by their expectations of future monetary policy decisions. As is evident from the lower part of Figure 4.6, these measures proved to be quite effective in 2006 and early 2007, another period characterized by widely expected interest rate hikes.

In principle, the measures implemented in March 2004 could have created another problem. In the revised framework, the time interval between the day the last main refinancing operation of the maintenance period is settled and the end of the maintenance period is always six business days. Previously, time interval varied between one and six business days, so on average it was considerably shorter. To the extent that forecasting autonomous liquidity factors is more challenging for longer periods, the longer time interval might cause more serious aggregate liquidity imbalances at the end of the maintenance period and, correspondingly, higher volatility in money market interest rates. Indeed, in the months following the changes to the operational framework in March 2004, anomalous large spikes in market rates were occasionally observed on the days preceding the end of the maintenance period. In order to counteract the potentially larger liquidity imbalances, the ECB has been conducting fine-tuning operations on the last day of the maintenance period on a more regular basis since November 2004 (ECB 2006b, Jardet and Le Fol 2007).[18] In 2005 and 2006 the ECB conducted 9 and 11

[18]In case of an aggregate liquidity shortage, the ECB provides liquidity by means of an overnight repo (variable rate tender with a minimum bid rate), whereas in case of a liquidity surplus, liquidity is absorbed by the collection of fixed-term (overnight) deposits

fine-tuning operations at the end of reserve maintenance periods. By way of comparison, between January 1999 and autumn 2004, a total of only nine fine-tuning operations was conducted and—with one exception—they took place on days other than the last of the maintenance period, typically in reaction to temporary distortions in the money market. For instance, subsequent to the terrorist attacks on 11 September 2001 in the U.S., the ECB provided additional liquidity by means of fine-tuning operations on 12 and 13 September 2001.

To date, the ECB's experiences with the additional fine-tuning operations have been rather positive. In particular, the occasional large spikes in the EONIA spread on the last day of a maintenance period have been reduced significantly. Between April and October 2004, the (absolute) spread was on average 39bp, and on three occasions it exceeded 50bp. In comparison, after the introduction of regular fine-tuning operations, the average (absolute) spread fell to 9bp, and—with one exception—it never exceeded 25bp. Moreover, the fine-tuning operations also had a soothing effect on the volatility of the EONIA on prior days: The average standard deviation of daily changes in the EONIA for the six business days following the last main refinancing operation dwindled from 12 to 3.2bp (ECB 2006b).

Overall, the ECB's institutional changes unveil the interaction and interdependence of different elements of the operational framework. In particular, to tackle the perceived problem of expected rate changes the ECB had to amend specific features of both reserve requirements (the timing of the maintenance period) and open market operations (the maturity of operations). Moreover, some explanations for the observed extreme overbidding suggest that the problem was not related to the use of fixed rate tenders *per se*, but was caused by an inadequate timing of these operations (i.e. because open market operations were maturing in the next maintenance period only). Hence, the problem of extreme overbidding in fixed rate tenders could have been sorted out by other measures than switching to variable rate tenders. In particular, it is highly probable that the measures implemented in 2004 would have been suited to address the issue of extreme overbidding.

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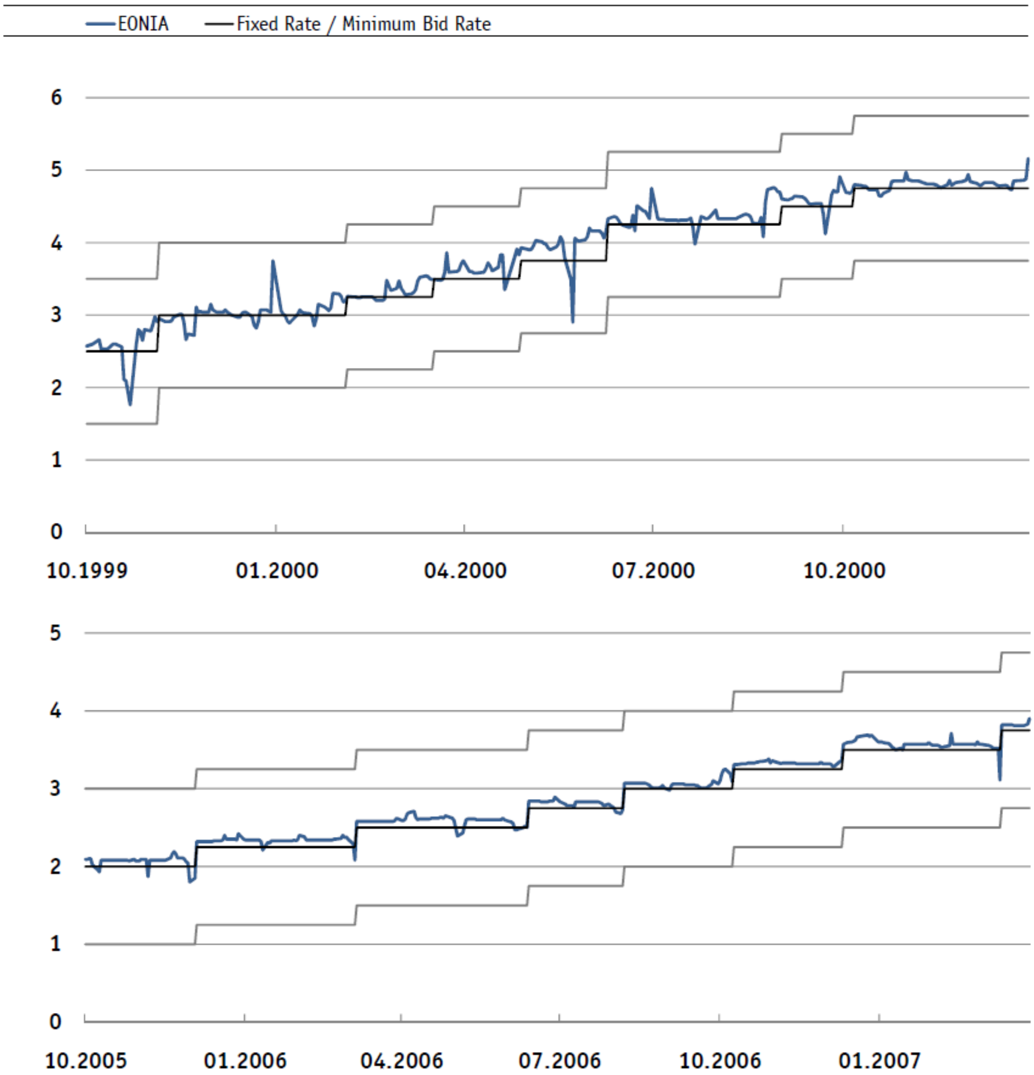
earning the minimum bid rate. Both liquidity providing and absorbing operations are conducted as quick tenders, which are executed within 90 minutes from the announcement of the operations.

Figure 4.6: EONIA and Official Interest Rates



Source: European Central Bank website

4.2.3 Federal Reserve System

The evolution of the Fed's implementation of monetary policy provides another interesting case study. Indeed, over the last years, all major elements of the Fed's operational framework have been modified at least once. The following review expounds the main changes one by one.

Operational Target

These days, even people relatively unfamiliar with monetary policy know that the federal funds rate serves as the Fed's operational target. However, this has not always been the case and it is quite instructive to review the Fed's policy in terms of operational targets over the last three decades.

From 1974 to 1979, the Fed was implicitly targeting the federal funds rate, intervening in the market whenever the federal funds rate moved out of a very narrow band. In the following decade, interest rate targeting was abandoned in favor of a quantitative reserve target. First, from 1979–1982, the Fed pursued a target for non-borrowed reserves, i.e. reserves held by banks minus borrowed reserves.[19] The adoption of this procedure caused a significant increase in the volatility of short-term interest rates. What's more, non-borrowed reserve targeting turned out to be very impractical and even confusing and was thus discarded rather quickly. Then, from 1983–1989, the Fed officially pursued a borrowed reserves target. In practice, however, the focus gradually shifted back toward attaining a specified level of the federal funds rate, a process that was largely completed by the end of the decade. But it was only in early 1994 when the Fed eventually decided to publicly announce the current federal funds rate target. Before, market participants had to infer the intended federal funds rate from the conditions at which the Fed was conducting its open market operations.

Reserve Requirements

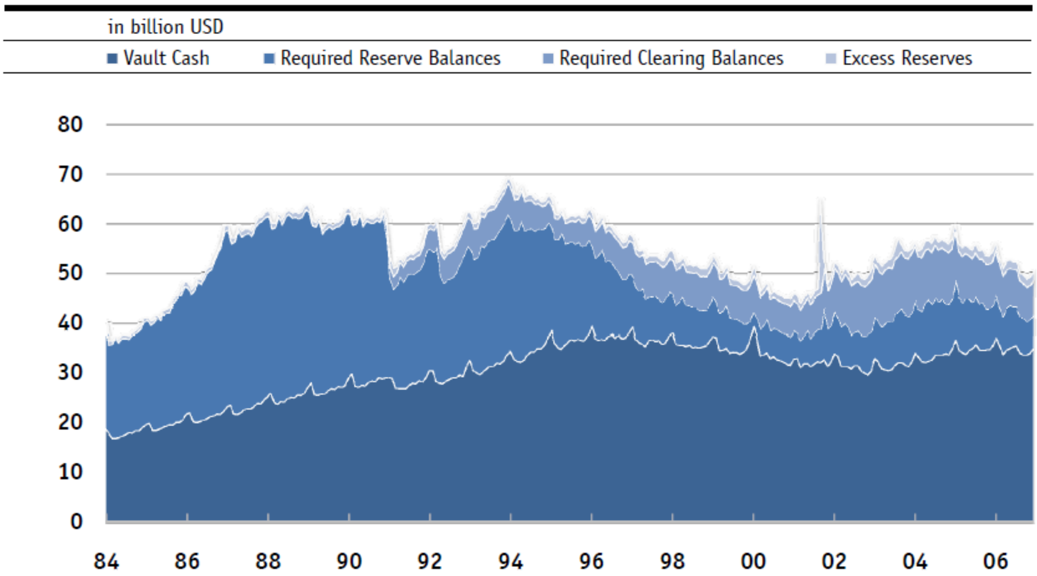
With respect to reserve requirements, two developments are noteworthy: the decline in the level of reserve requirements during the 1990s and the move from (almost) contemporaneous reserve accounting to lagged reserve accounting in 1998 (Federal Reserve System 1998).

At first, the decline in reserve requirements was the result of two cuts in reserve requirement ratios: In December 1990, the required reserve ratio on non-transaction accounts was pared from 3 percent to zero, and in April

[19] According to the Fed's terminology, non-borrowed reserves refer to reserves provided through open market operations, whereas borrowed reserves refer to banks' recourse to the discount window.

1992, the requirement on transaction deposits was trimmed from 12 percent to 10 percent. The intention of these cuts was to put banks in a better position for credit extension (Feinman 1993). As a result, required reserves fell first by roughly USD 12 billion, about one sixth of their initial level, and then by another USD 6 billion (see Figure 4.7). Taking into account the slight increase in applied vault cash, the (relative) effect on required reserve balances was more pronounced: From November 1990 to May 1992 they fell by more than a third, from USD 32 billion to USD 20 billion. In subsequent years, required reserves—and required reserve balances—dwindled further due to banks' increasing use of so-called 'sweep account' arrangements, i.e. the practice to transfer funds in customers' retail checking accounts overnight into savings accounts not subject to reserve requirements (Anderson and Rasche 2001). While depositors retain the ability to utilize their transaction accounts for making payments or withdrawals, this practice allows banks to scale down reserve requirements. As argued by Bennett and Hilton (1997), most of the decline in required reserve balances from USD 28.3 billion in December 1993 to roughly USD 10 billion in early 1997 can be attributed to the spread of sweeps. Altogether, the sharp decline in reserve requirements was thus only partially the result of the Fed's deliberate policy decision; the lion's share was attributable to banks' efforts to reduce the opportunity costs associated with non-remunerated reserves.

Figure 4.7: Components of Reserve and Account Balances at the Fed



Source: Federal Reserve Board website

Concomitant with the decline in reserve requirements many banks—especially smaller, local banks—became effectively unbound by reserve requirements, since their holdings of applicable vault cash exceeded reserve requirements (Bennett and Peristiani 2002). As banks need a certain level of reserves for payment purposes in the interbank payment system, many of these banks reacted by increasing the level of (voluntary) contractual clearing balances. As mentioned in Section 4.1.3, contractual clearing balances differ from reserve requirements in two ways: they earn implicit interest and they are hold voluntarily (although once contracted, they need to be maintained over the maintenance period). The introduction of sweep arrangements thus led to a partial substitution of unremunerated required reserve balances for remunerated required clearing balances. But the surge in contractual clearing balances was not sufficient to avoid an overall decline in the level of total requirements, i.e. the sum of required and contractual reserve balances.

The developments in the early 1990s thus provide an interesting case study as they allow to analyze the effects of the level of (total) reserve requirements on interest rate volatility. The hypothesis is that to the extent that a fall in (required) reserves makes the demand for reserves less sensitive to changes in the overnight rate, one would expect an increase in the volatility of overnight rates. Indeed, in an empirical investigation, VanHoose and Humphrey (2001) find that lower reserve balances were associated with significantly higher funds rate volatility. However, the significance is lost after March 1994, when the Fed began announcing the current federal funds rate target. The authors conclude that the explicit announcement had an alleviating effect on market uncertainty and funds rate volatility. But other factors might also have played a decisive role. For instance, it is quite likely that over time banks improved their reserve management. Moreover, as will be discussed below, in the mid 1990s, the Fed started to gradually increase the frequency of its open market operations, which allowed to offset shocks to autonomous liquidity factors more quickly.

In July 1998, the Fed switched from (almost) contemporaneous to lagged reserve accounting, a regime which is still in place today. Under the prior regime, which had been adopted in February 1984, reserve requirements were known with certainty only two days before the end of the concurrent reserve maintenance period. On previous days, both commercial banks and the Fed had to rely on estimates. Particularly in the mid 1990s, the estimation of reserve requirements became increasingly difficult, largely because of the above-mentioned implementation of retail sweep programs by many banks. By increasing uncertainty regarding the demand for reserves, the regime of contemporaneous reserve accounting complicated both the banks' and the Fed' liquidity management and was considered to be a major source of interest rate volatility.

Against the background of these practical complications, one may wonder why contemporaneous reserve accounting had been introduced in 1984 in the first place. At that time, monetary aggregates played a more prominent role in the Fed's monetary policy framework. By reducing the lag between computing and holding required reserves, the intention was to strengthen the linkage between reserves held by depository institutions and the money supply (Goodfriend 1984). But by 1984 non-borrowed reserve targeting had already been replaced by borrowed reserve targeting, and since there is no obvious link between reserve requirements and borrowed reserves, the case for introducing contemporaneous reserve accounting seems to have been rather weak from the very beginning. Be that as it may, by returning to lagged reserve accounting in 1998, the Fed pursued two objectives. By reducing uncertainty about individual reserve requirements, the new regime ought to ease banks' reserve management. And similarly, the availability of more timely and accurate information on the likely demand for reserves within the maintenance period ought to facilitate the Fed's planning of open market operations. Indeed, analyzing the effects of this policy shift, Kotomin and Winters (2007) find empirical evidence for a smoother behavior of the federal funds rate throughout the reserve maintenance period in terms of both the level and volatility. In particular, since the return to lagged reserve accounting, the well-documented spikes in the federal funds rate on the last day of the maintenance period have all but disappeared.

Standing Facilities

From a historical perspective, the reform of the discount window, which became effective on 9 January 2003, is without any doubt the biggest change to the Fed's operational framework in recent years. Ever since the Fed became operational in 1914, the discount window had been operated as a below market facility. The fact that banks were able to obtain funds at the discount window at rates consistently lower than market interest rates gave rise to a number of problems (Furfine 2003, Madigan and Nelson 2002, Peristiani 1998).[20] Most importantly, since discount window loans were offered at below-market rates, intense supervisory scrutiny and moral suasion was necessary to confine banks' use of such loans. The Fed also had to monitor that funds borrowed from the discount window were not lent in the interbank market, which would have allowed to realize arbitrage profits. These efforts proved to be quite effective and over time discount window loans fell to rather low levels. Moreover, particulary in response to the uncertainty caused by the

[20]Bindseil (2004a) provides a detailed account of the history of the discount window.

crisis of savings and loan associations and the soaring failures of commercial bank failures in the 1980s, market participants perceived that lending from the discount window would send a negative signal to the Federal Reserve, bank supervisors, and eventually the market at large. As a result, borrowing from the discount window had become so unpredictable that, by the end of 1987, the Fed was compelled to reduce its reliance on borrowed reserves as operational target. But even after the Fed's switchback to explicit federal funds rate targeting, banks' unwillingness to borrow from the discount window continued to be a concern for the following reasons. First, due to the associated stigmatization, the discount window had become rather ineffective in supporting financial markets when it was needed the most, that is during periods of financial stress. And second, volatility of the federal funds rate was higher than it would have been had the discount window properly performed its role as a marginal source of reserves for the overall banking system and as a safety valve for individual banks facing temporary liquidity shortages.

Eventually, the Fed amended the discount window by transforming it into an above-market borrowing facility. In an early evaluation of the experience with the revised facility, Furfine (2003) finds empirical evidence that borrowing from the credit facility was far lower than could have been expected given the cross-sectional variation in interest rates paid in the federal funds market. Apparently, some banks preferred to borrow in the market at rates above the Fed's borrowing rate. This suggests that—at least initially—the Fed's attempt to remove the stigma associated with borrowing form the previous discount facility was not successful. Moreover, the episode reveals that at times banks may be sluggish in adopting their behavior to a new institutional environment.

Open Market Operations

Over the last few years, the Fed's approach to conducting open market operations has been fairly stable. Nevertheless, minor changes have taken place, even though sometimes they became apparent only gradually. For example, over time the Fed increased the frequency of open market operations. While in the first half of the 1990s overnight or short-term repos were arranged on average on six out of ten days, in 2006 the Fed conducted such transactions on all but eight business days (Bartolini and Prati 2003, Federal Reserve Bank of New York Markets Group 2007). The higher frequency of short-term repos may be explained by the Fed's ambition to counter the surge in federal funds rate volatility, which was mainly due to the decline in reserve requirements in the early 1990s. This argument is corroborated by the fact that the increase in the number of operations was much more pronounced for overnight repos than for short-term and longer-term repos. Since the decline in reserve requirements implied that the Fed had to focus more closely on ensuring that total balances are sufficient to meet banks' payment-related reserve demand on a day-by-day basis, the increasing use of overnight repos is not surprising (Demiralp and Farley 2005).

Various other amendments to open market operations were predominantly of technical nature. In 1997 and again in 1999 the timing of open market operations was shifted ahead by one hour to 10.30 a.m. and then to 9.30 a.m., respectively. This allowed to allay the problems of thinness in the repo market that could limit the Fed's ability to inject the desired amount of reserves. Indeed, the Fed often found it difficult to implement large operations, in good part because the collateral needed to execute repos was not freely available (Bartolini and Prati 2006). To further alleviate this problem, in October 1999 the Fed broadened the range of eligible collateral for repos. At the same time, but in order to enhance transparency, the Fed started to disclose more information on its current open market operations by immediately releasing data on the total volume of propositions submitted, the weighted average rate of accepted propositions, the high and low rates submitted, and the cut-off rate (Federal Reserve Bank of New York Markets Group 2000). In December 2002, in an attempt to conduct open market operations in accordance with standard market practice, the Fed replaced matched sale-purchase transactions with reverse repos. While fundamentally equivalent to the former, the latter are more commonly used in financial markets.[21] Also, in September 2003, the maturity of the weekly longer term repos was reduced from 28 to 14 days, allowing the Fed to align the provision of reserves more precisely with expected movements in autonomous factors and banks' demand for reserves over the two-week reserve maintenance period (Federal Reserve Bank of New York Markets Group 2004). Finally, in 2006, the Fed rolled out a new electronic auction system for both temporary and permanent open market operations in 2006 (Federal Reserve Bank of New York Markets Group 2007). The new system allowed for improved operational processes (e.g. a shorter timeframe for submitting tenders) and faster dissemination of information on operations to the public.

In consideration of the frequent modifications, one is tempted to contend that the evolution of the Fed's operational framework bears resemblance to a process of trial and error. A more optimistic interpretation would be that the numerous amendments merely reflect the Fed's effort to attune the

[21] Matched sale-purchase transactions and reverse repos differ only in terms of their accounting treatment.

operational framework incessantly to rapidly developing financial markets. Most likely, both explanations contain a grain of truth.

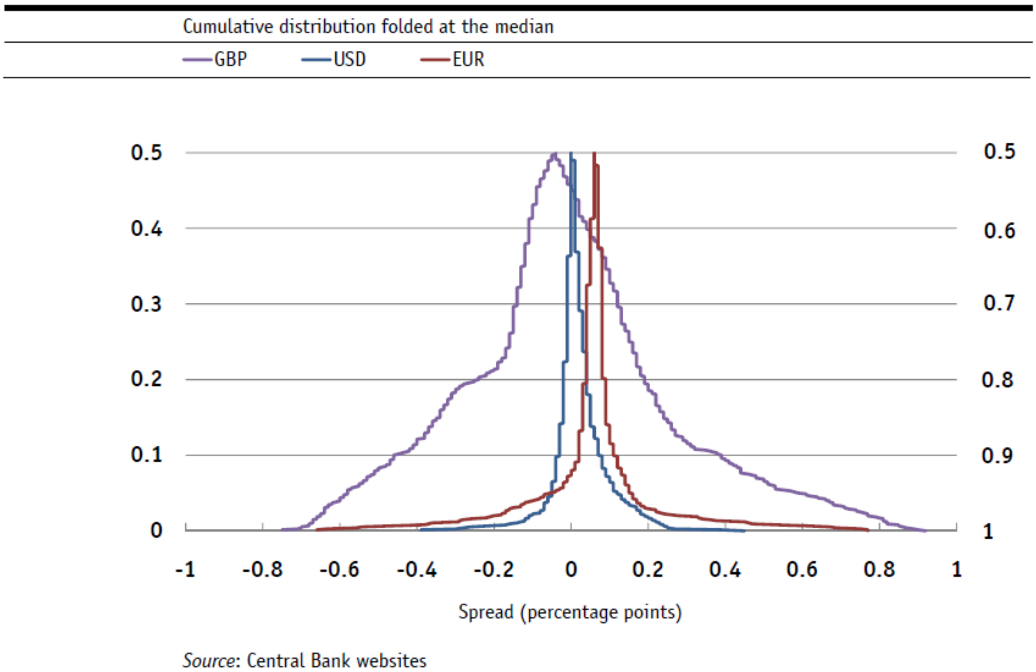
4.2.4 Bank of England

Section 4.1 provided a snapshot of the Bank of England's operational framework as of early 2007. Had the snapshot been taken one year earlier, the resulting picture would have been quite different. Indeed, the BoE's operational framework was fundamentally reformed in May 2006. Before, the implementation of monetary policy in the U.K. had been characterized by the following three features (Tucker 2004). First, as sterling settlement banks simply had to maintain non-negative balances with the BoE at the close of each business day, reserve requirements did not play any role. Second, to ensure that settlement banks were able to achieve the zero end-of-day reserves target, every day the BoE conducted at least two and sometimes even more rounds of open market operations with two-week maturity at the fixed repo rate. Third, overnight lending and deposit facilities provided for a symmetric interest rate corridor of $\pm$100bp around the repo rate.

Besides the complexity introduced by the frequent open market operations, the main problem associated with the previous framework was the high volatility of overnight interest rates—both from day to day and intraday. In the years prior to the reform, the BoE had already adopted several measures to reduce interest rate volatility and to enhance the efficiency of the sterling money market (Sellon and Weiner 1997, Tucker 2004, Vila Wetherilt 2003), albeit with limited success. In 1996, the BoE removed restrictions on participation in open market operations and various tax and regulatory impediments. In conjunction with broadening the pool of eligible collateral by including repo of gilts, this allowed for the development of a liquid gilt repo market and the gradual replacement of outright purchases or sales of eligible bank bills and sterling Treasury bills with repos. Transparency of open market operations was enhanced by dealing at the official policy rate and the announcement of more auction-related information. Furthermore, to put a ceiling on interest rates, a lending facility was established in 1998; the introduction of a deposit facility followed three years later. Together, the standing facilities provided for an interest rate corridor of $\pm$100bp, but their rate setting function was limited as access to these facilities remained reserved to a small number of settlement banks.

These measures notwithstanding, the volatility of short-term interest rates remained high by international standards, obscuring monetary policy and making sterling money markets unpredictable and unattractive. The comparatively high volatility in sterling money markets is illustrated in Figure 4.8 which depicts the folded cumulative distributions of the spread between sterling overnight rates and the BoE's policy rate as well as similar spreads for the US dollar and the Euro for the three-year period starting in January 2003.[22] The distributions are folded at the median so that cumulative probabilities for values above (below) the median are indicated by the right-hand (left-hand) scale.

Figure 4.8: Folded Cumulative Distributions of Interest Rate Spreads



Dissatisfied with the functioning of the money market, in 2004 the BoE launched the project that eventually lead to the mentioned reform of its operational framework (Clews 2005). To recall, the key elements of the revised operational framework, which became effective in May 2006, are:

– the alignment of reserve maintenance periods with the timing of monetary policy decisions,

– voluntary reserve requirements, which allow banks to set their own reserves target for each reserve maintenance period,

[22]For the US dollar, the spread is defined as the difference between the federal funds rate and the federal funds rate target; for the euro, the spread is defined as the difference between EONIA and the ECB's minimum bid rate.

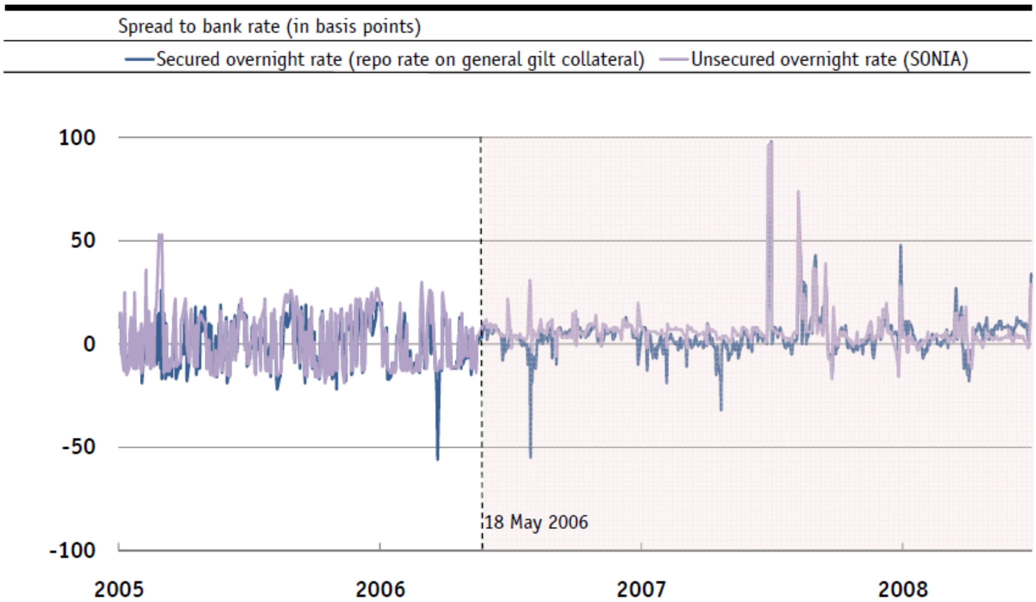
– remuneration of reserves at the BoE's official repo rate, provided reserves are within a range of ± 1% around the reserve target,

– standing facilities that provide for a symmetric interest rate corridor around the official repo rate, with the width of the corridor being 50 basis points on the last day of the maintenance period and 200 basis points on other days,

– the conduct of open market operations each week and on the last day of the reserve maintenance period, in order to ensure that the supply of reserves is as close as possible to the level that will enable banks to meet their reserve targets.

Since its introduction, the BoE's experience with the revised operational framework has been fairly good. In particular, three aspects are worth highlighting. First, the new framework allowed to significantly curb volatility in sterling short-term interest rates, especially before the financial turmoil set in (see Figure 4.9).

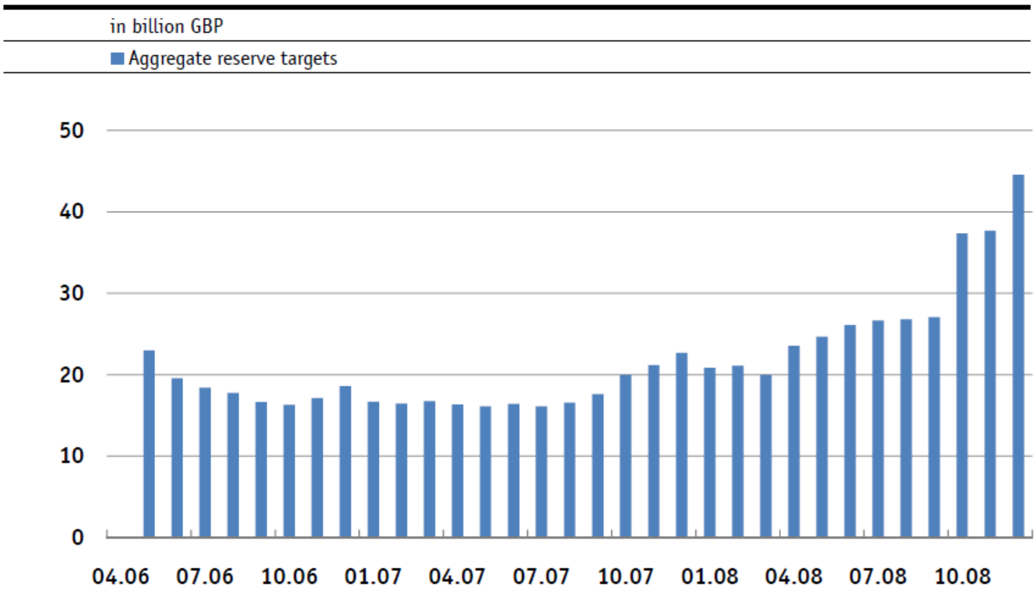
Figure 4.9: Spread of GBP Overnight Interest Rates to Bank Rate



Source: Bank of England website

Second, the increase in interest rate volatility towards the end of reserve maintenance periods, which is typical for most reserve requirement regimes that allow for averaging, is not discernible in the data for sterling overnight rates. From May 2006 to September 2008, that is during the first 28 reserve maintenance periods after the introduction of the new operational framework, the absolute spread of the overnight rate to the official target rate on the last day of the reserve maintenance period was on average only 3 basis points and at most 11 basis points. This is likely attributable to the reserve target range, which increases interest rate elasticity of reserve demand on the last days of a reserve maintenance period. Furthermore, Figure 4.10 indicates that banks made effective use of their ability to freely determine their reserves targets. In particular, when faced with heightened uncertainty about potential liquidity outflows during the financial crisis, banks have raised their reserve targets and hence their precautionary balances.

Figure 4.10: Aggregate Reserve Targets of UK Banks



Source: Bank of England website

4.2.5 Swiss National Bank

The SNB provides an interesting case study to illustrate the nexus between the strategic and the operational level of monetary policy (see discussion in Section 2.2). In particular, it exemplifies how changes to the strategic framework are reflected in the operational framework.

On the strategic level of monetary policy, the SNB had been one of the most prominent advocates of monetary targeting for many years. In particular, between 1980 and 1999 the SNB pursued an intermediate target defined in terms of the seasonally adjusted monetary base; until 1990 the SNB set annual growth targets, in 1991 it shifted to a medium-term targeting strategy (Rich 2007). During that period, reserves held by banks on their accounts with the SNB (giro deposits) served as the operational target. To steer the level of giro deposits, the SNB relied mainly on weekly foreign exchange swaps which had maturities of typically one to six months. As of 1998, foreign exchange swaps were gradually replaced by repos.

Over time, two problems associated with the SNB's monetary policy framework became apparent. First, especially in the second half of the 1990s, the monetary base became more and more distorted, loosing its significance as a leading indicator for future inflation. As a consequence, the SNB paid increasing attention to other indicators such as economic conditions, the exchange rate and, particularly, M3. The second problem was related to the operational target. The SNB was aware that strictly following the target set for giro deposits would have resulted in high short-term interest rate volatility. Therefore, in practice, the SNB followed a hybrid approach, allowing deviations from the path set for giro deposits in order to avoid excessive interest rate volatility and to limit deviations of short-term market interest rates from an implicit interest rate target.[23]

Becoming increasingly dissatisfied, the SNB eventually adopted a new monetary policy framework as of the beginning of 2000 (Swiss National Bank 2000). The new framework is based on three elements. The first pillar is the explicit definition of price stability, which is considered to be achieved with an annual inflation rate of less than 2% measured by the consumer price index. The second pillar is a medium-term inflation forecast which serves as the basis for monetary policy adjustments. Finally, the third element is the reliance on the three-month Libor as operational target for day-to-day monetary policy implementation.

The most significant modification to the operational framework thus consisted in the replacement of a quantity based operational target (giro deposits) with an explicit interest rate target (three-month Libor). Moreover, the SNB entirely abandoned the use of foreign exchange swaps; ever since regular open market operations have been conducted exclusively in the form of repos. Also, for the sake of completeness, one might mention that the SNB decided not to fix the discount rate any longer. However, *de facto* the SNB had stopped carrying out discount operations already back in 1993.

[23]Note that since September 1993, the SNB's economic staff had to prepare internal guidelines on the path of interest rates considered to be consistent with the Governing Board's planned course of actions. These guidelines were used for managing the banking system's liquidity (Rich 2007).

Since the reform in 2000, the operational framework was amended twice. In January 2005, a new regulation on reserve requirements succeeded the previous cash liquidity provisions (Swiss National Bank 2005). Amendments related to both eligible assets and the definition of liabilities subject to reserve requirements. Eligible assets were confined to include giro deposits, banknotes and coins in circulation; before, also credit balances at Postfinance—the financial arm of Swiss Post—and credit balances at one of the clearing centers recognized by the Swiss Federal Banking Commission were eligible. It remains unclear, however, why eligibility was not restricted to giro deposits only. Indeed, pursuant to article 17 paragraph 21 of the National Bank Act and the explanatory notes, the (sole) purpose of reserve requirements' is to facilitate the functioning of the money market and the implementation of monetary policy by ensuring a stable demand for reserves and limiting interest rate volatility (Swiss Federal Council 2002). The eligibility of banknotes and coins is thus clearly inconsistent with the stated purpose of reserve requirements.

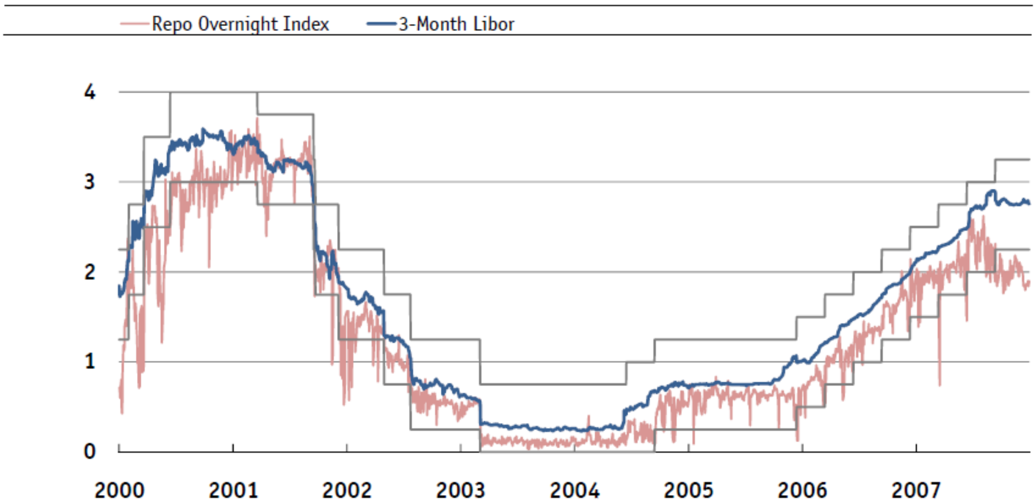
During 2005, traditional Lombard loans were phased out and replaced by special-rate repos (Swiss National Bank 2006a).[24] With the introduction of special-rate repos, the pool of eligible collateral for having recourse to the standing facility was broadened and harmonized with all other monetary policy operations. Moreover, operational procedures were standardized and now allow for more efficient collateral management.

Within our sample of selected central banks, the SNB is the only one using a longer-term money market rate as operational target. In this respect, two questions are of particular interest. First, to what extent was the SNB able to effectively control the three-month Libor? And second, what were the implications for shorter term money market interest rates, particularly the overnight rate? Figure 4.11 reveals that the SNB managed to keep the three-month Libor within the defined target range of 100bp at any point in time. Especially during times of stable interest rates, such as in 2005, the three-month Libor traded very closely to the intended (inofficial) target level. However, in line with the expectations theory of the term structure, in times of interest rates hikes or cuts, the three-month Libor tended to move to the anticipated future target level well in advance of official monetary policy decisions. Regarding the short end of the yield curve, Figure 4.11 indicates that overnight rates—here measured by the repo overnight index—exhibit rather high volatility. Besides the fact that the SNB is not particularly

[24]As marginal lending facilities, Lombard loans and special-rate repos perform the same economic function. However, they differ regarding practical arrangements. While Lombard loans are advances against pre-pledged collateral, the execution and settlement arrangements for special-rate repos are similar to regular repo transactions.

focusing on overnight rates, this is most likely due to institutional features of Swiss reserve requirements (generally low level with many banks fulfilling reserve requirements by vault cash only), which complicate the forecast of banks' demand for reserves on a day-to-day basis. Accordingly, temporary shocks to either the demand or the supply of reserves are directly translated into overnight rates.

Figure 4.11: CHF Interest Rates



Source: Swiss National Bank website

Quite contrary to the Bank of England, the SNB does not seem to be overly worried about the high volatility of short-term interest rates, at any rate it has never officially raised such concerns nor has it actively tried to do something about it. Nevertheless, the potential problems associated with high short-term interest rate volatility are similar for the Swiss franc as for the pound sterling. In particular, it complicates commercial banks' reserve management and may prevent potential market participants from market entrance in the first place.

4.3 Experiences and Adjustments During the Financial Crisis

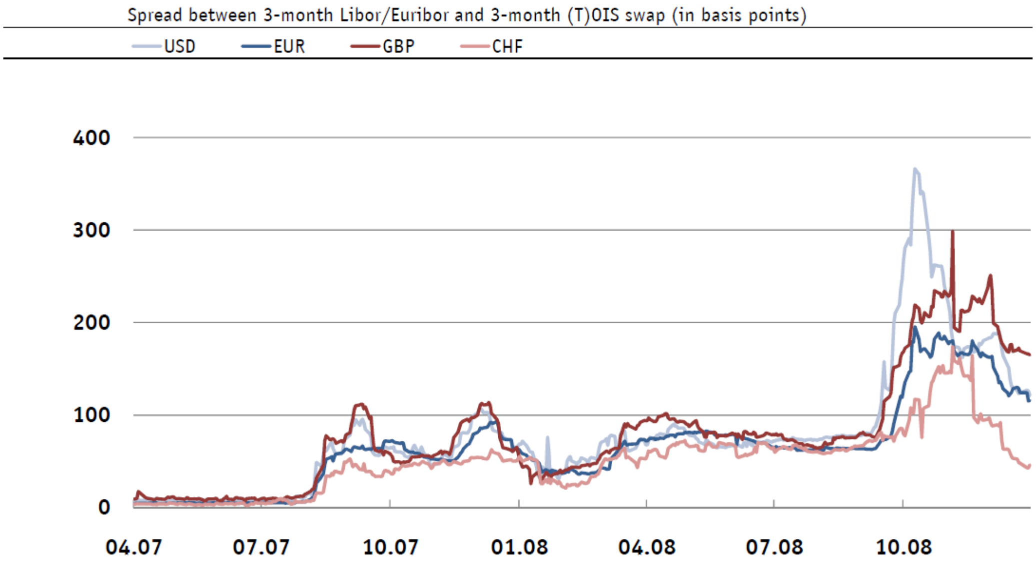
In the course of 2007, the global financial system came increasingly under stress. Originating in the US subprime mortgage market, the crisis unfolded like shock waves, quickly affecting many other market segments. While some developments, such as the drying out of the asset-backed commercial paper market, increased banks' uncertainty about their future funding needs, other developments, such as the wide-spread write-downs and losses due to the repricing of mortgage-backed securities and other assets, led to mounting concerns about counterparty credit risk as well as banks' ability to meet potentially higher funding needs in a timely fashion and at a reasonable cost. As a result, many market participants started to hoard liquidity and cut back on lending to each other, with devastating effects on market liquidity in money markets, especially in the United States and in Europe. As of August 2007, the liquidity tensions in money markets started to hamper the implementation of monetary policy and called for responses by central banks.[25]

Although the tensions were palpable in all segments of the money market, they were most severe for longer maturities, such as the one-month or three-month segments. Evidence for these tensions in term markets is provided by the spread between the Libor and corresponding overnight index swap (OIS) rates. For instance, the three-month Libor-OIS spread measures the difference between what is charged for a three-month (uncollateralized) loan in the London interbank market and the average of expected overnight rates over the term of a three-month swap. This spread, which mainly reflects the credit and liquidity premium on unsecured money market transactions, can be considered as an indicator of the health of the (term) money market. As can be seen from Figure 4.12, (term) money markets experienced four waves of tension: the first in September 2007, the second around the end of 2007, the third in March 2008, and the fourth in the wake of the mid-September 2008 failure of Lehman Brothers. While the Libor-OIS spreads used to hover around a few basis points before August 2007, they reached peak levels of more than 100 basis points for some currencies during the first three waves, and even significantly higher peaks during the fourth and hitherto most acute wave.

In reaction to the financial crisis and its impact on the real economy, major central banks responded by introducing a number of unconventional measures, which fall into three broad categories: (i) the provision of liquidity to banks on extraordinary terms to alleviate pressures in the interbank money market; (ii) intervention in selected credit markets to support secondary market liquidity and/or credit supply; and (iii) outright asset purchases aimed

[25]For a detailed analysis of the origins and the key characteristics of the 2007-2009 financial turmoil see, for instance, the Overview section of the September 2007 and subsequent issues of the *BIS Quarterly Review*. Moreover, see Brunnermeier (2009) for a discussion of the mechanisms that explain why market liquidity—which was at a historically high level just before the onset of the financial turmoil—can evaporate so quickly.

Figure 4.12: Risk Premium in Money Markets



Source: Bloomberg

at easing monetary conditions beyond what could be achieved by policy rate cuts. The remainder of this Section focuses on the first category, which has the closest link to the implementation of monetary policy.

From the perspective of monetary policy implementation, the financial market turbulences entailed two fundamental challenges for central banks (Borio and Nelson 2008). The first consisted in implementing the given policy stance (i.e. keeping overnight rates near the policy targets), whereas the second challenge was to promote more orderly conditions in term interbank money markets.[26]

The measures taken by major central banks to deal with these challenges during the first year of the financial crisis are described and explained in detail in CGFS (2008) and Borio and Nelson (2008) and summarized in Table 4.11.[27] Interestingly, all key elements of the operational framework were adjusted by at least one of the five central banks included in our survey. The most visible adjustments were related to the conduct of open market

[26]From a broader monetary policy perspective, another challenge was the decision whether—and if yes to what extent—to adjust the monetary policy stance in reaction to (a) the deteriorating macroeconomic outlook triggered by the financial turmoil and (b) the increased stress in the financial system. However, this issue is beyond the scope of this study.

[27]Annex 1 of CGFS (2008) provides a particularly useful chronology of central banks' actions.

operations. In particular, all central banks engaged in both exceptional fine-tuning and exceptional long-term operations. While the long-term operations usually intended to alleviate tensions in term markets (e.g. by reducing banks' funding uncertainty), the (short-term) fine-tuning operations typically aimed at removing imbalances in the overnight segment and overcoming frictions in the distribution of reserves. These operations were exceptional in the sense that they were either outside the regular schedule (both in terms of frequency and maturity) or in significantly larger than usual amounts.

Table 4.11: Measures Taken in Response to the Financial Turmoil

	RBA	ECB	SNB	BoE	Fed
Exceptional fine-tuning operations	•	•	•	•	•
Exceptional long-term operations	•	•	•	•	•
Front-loading of reserves		•	•		
Changes to tender procedure		•	•		
New instruments to drain liquidity	•		•	•	
Changes to reserve requirements				•	•
Changes to standing facilities	•	•	•	•	•
Broadening of eligible collateral	•	•	[1]	•	•
Broadening of counterparties				•[2]	•
Introducing/increasing securities lending				•	•

Source: Central banks.

Notes:

[1] The broadening on 1 October 2007 was not linked to the financial turmoil.

[2] Only for four special auctions of term funding, for which there were no bids.

While all surveyed central banks faced similar (yet in their extent different) challenges, their measures taken in response to the market turmoil varied considerably, partly reflecting the pre-crisis differences in their operational frameworks. As the US financial system was undoubtedly hit hardest by the financial turmoil, it is not surprising that the list of measures taken by the Fed is longer than the list of any other central bank. Indeed, as the crisis unfolded, the Fed implemented a series of measures to improve market liquidity and market functioning in the US dollar money market. In particular, besides the mentioned exceptional fine-tuning and long-term operations, the Fed introduced a number of new credit and liquidity facilities. In December 2007, the Fed introduced the Term Auction Facility (TAF), which provided for biweekly auctions of one-month loans against discount window collateral to a very wide range of banks.[28] Later in March 2008, with the intention of encouraging the smooth functioning of repo markets, the Fed introduced two new facilities for primary dealers, the Term Securities Lending Facility (TSLF) and the Primary Dealer Credit Facility (PDCF). The TSLF allowed primary dealers to borrow US treasury securities for up to 28 days against certain agency-guaranteed and other high-quality private mortgage-backed securities. The PDCF offered primary dealers overnight discount window loans against certain investment grade debts securities as well as collateral for regular open market operations.[29] Eventually, at the summit of the crisis after the failure of Lehman Brothers, the Fed introduced another range of facilities, with the intention to facilitate access to funding liquidity for particular market participants. These facilities included three commercial paper facilities—the Commercial Paper Funding Facility (CPFF), the Asset-Backed Commercial Paper Money Market Mutual Fund Lending Facility (AMLF), and the Money Market Investor Funding Facility (MMIFF)—and the Term Asset-Backed Securities Loan Facility (TALF).[30] Most of these facilities expired in the late 2009 or early 2010.

In addition, the Fed also modified the terms of the discount window, both by extending the term for borrowing from overnight to 30 days (with the possibility for renewal) and by reducing the premium on the primary credit or discount rate in two steps from 100 to 25 basis points. Also, in October 2008, the Fed started to pay interest on both required and excess reserves. Initially, the interest rate paid on required reserve balances equaled the average targeted federal funds rate over each reserve maintenance period less 10 basis points, and the interest rate on excess reserves was set at the lowest targeted federal funds rate for each reserve maintenance period less 75 basis points. But when the federal funds rate target was lowered and funds rate started to trade close to zero, these spreads were also reduced to zero, meaning that the rate paid on required and excess reserves would generally be at the current target rate.[31] By and large, these measures have altered—temporarily—several dimensions of the Fed's liquidity provision: they have

[28]The range of collateral eligible for discount window loans is much broader than for the Fed's regular open market operations. For more details on the TAF see Armantier, Krieger and McAndrews (2008).

[29]Note that prior to the introduction of the PDCF the Fed had not extended discount window loans to non-depository institutions since the 1930s.

[30]See Federal Reserve Bank of New York Markets Group (2009) for a short description of these facilities.

[31]The Financial Services Regulatory Relief Act of 2006 originally authorized the Fed to begin paying interest on reserve balances beginning 1 October 2011, but the Emergency Economic Stabilization Act of 2008 allowed the Fed to accelerate the effective date by three years.

lengthened the duration of access to liquidity, they have broadened the types of eligible collateral, they have expanded the range of eligible counterparties for some activities, and they have reduced the cost of borrowing from the Fed relative to market rates.

Both the ECB and the SNB adjusted the pattern of reserve supply within individual maintenance periods, systematically providing relatively more liquidity at the beginning and withdrawing liquidity towards the end of the maintenance period. This front-loading was intended to reduce banks' concerns about their ability to meet reserve requirements. Moreover, in view of the dysfunctional nature of the interbank markets at the peak of the crisis, these two central banks also altered the tender procedure for their refinancing operations. In mid-October 2008, the ECB switched back to fixed rate tenders and decided to (at least temporarily) increase its intermediation role by satisfying 100% of counterparties' bids in both the main and the longer-term refinancing operations. Similarly, the SNB also adopted a full allotment policy at the end of October 2008. Furthermore, in October 2008, the ECB decided to reduce the width of the corridor formed by the two standing facilities from 200 to 100 basis points. Similarly, the SNB reduced the mark-up of the liquidity-shortage financing facility from 200 to 50 basis points as of January 2009. In addition, the SNB started to issue its own bills, which allows it to easily drain larger amounts of liquidity from the market in case of need.

In the United Kingdom, the BoE provided more flexibility to banks' reserve management by increasing the ceiling on reserve targets and broadening the band around these targets, while at the same time the banks took the opportunity offered by the voluntary reserve requirement regime to set higher targets for their reserve balances. As the crisis unfolded, in April 2008 the BoE introduced the Special Liquidity Scheme, enabling banks to swap some mortgage-backed and other securities for UK Treasury bills, and later on, after the Lehman bankruptcy, it established the Discount Window Facility, from which banks are able to borrow gilts against a wide range of collateral. Moreover, also in October 2008, the BoE altered the terms for access to standing facilities by reducing the interest rate corridor from 200 to 50 basis points and by limiting the disclosure of the use of the standing facilities. The second measure is intended to remove the stigma in using the facilities. Finally, the Bank of England also started to issue its own short-term bills to drain large quantities of reserves from the market.

Down under, the RBA also made a number of changes to its operating procedures (Debelle 2008). First of all, as a reaction to banks' higher demand for precautionary settlement balances, the RBA allowed these balances to significantly increase. While banks' settlement balances had hovered around

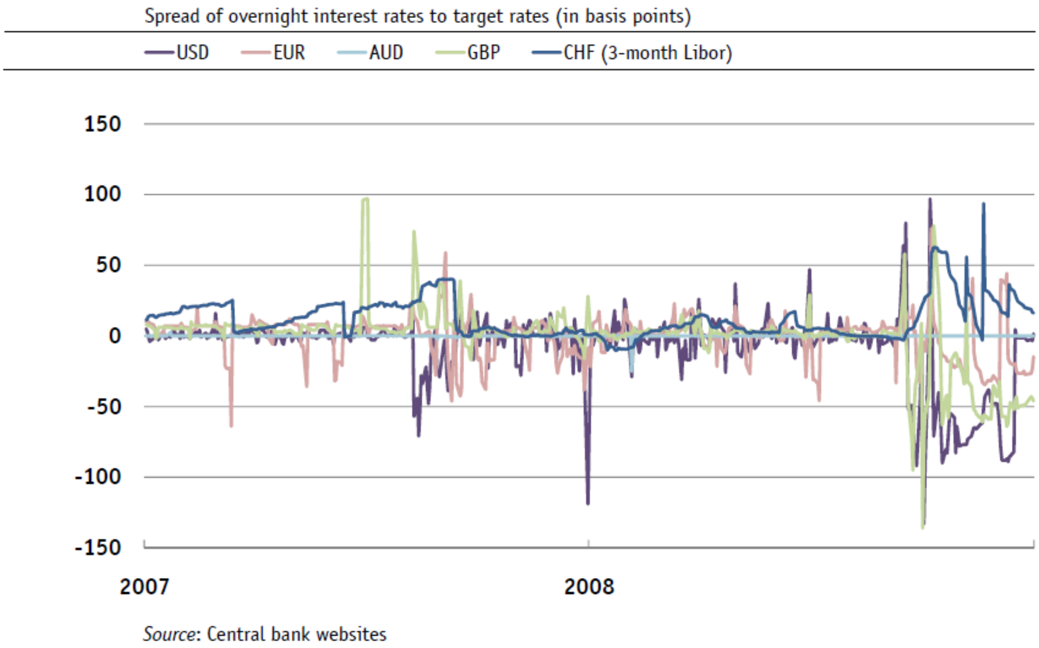
AUD 750 million for a number of years prior to the onset of the financial crisis, these balances surged to roughly AUD 5 billion during the first three waves of tension, and they peaked at AUD 10 billion in September and Ocotober 2008. Also, in an effort to provide greater certainty of term funding to financial institutions, the RBA increased the average maturity of its repo transactions. While these measures allowed to alleviate some pressure in term funding markets, the significant and unprecedented increase in settlement balances raised concerns about potential disruptions to the functioning of the short-term interbank market and downward pressures on the cash rate. To relieve this tension in the overnight cash market, in September 2008 the RBA introduced a new term deposit facility, which allows institutions to move some of the funds that otherwise would have sat in their (overnight) settlement accounts to a longer maturity of either 7 or 14 days. In other words, the RBA lent out the money long-term (to support term markets), and at the same time it stood ready to take it back at a shorter-term (to avoid disruptions to the cash market).

Despite the fact that during the financial turmoil some central banks entered new territory by doing things they had never done before, the arguably most notable measure was the intensified cooperation between central banks. In particular, on 12 December 2007 the Fed announced to put in place a US dollar swap line with the ECB and the SNB, which allowed these central banks to provide US dollar funding to their domestic counterparties on several occasions, thereby alleviating the specific US dollar funding shortages faced by some non-US institutions. With the intensification and spread of US dollar shortages after the failure of Lehman Brothers, the Fed's swap lines grew in number from 2 to 14, and the previously existing maximum limits for the SNB, ECB, BoE and Bank of Japan were lifted in mid-October 2008 to allow them to conduct full-allotment US dollar operations at fixed rates. Moreover, ECB and SNB established similar swap-lines with other central banks to facilitate the distribution of euros and Swiss francs, respectively.

Against the backdrop of all these adjustments to the operational frameworks, it needs to be assessed whether they were effective in terms keeping overnight rates near the policy targets and promoting more orderly conditions in term interbank money markets. Overall, the results are mixed. The adjustments were certainly effective in terms of stabilizing market rates near target rates, as is evident from Figure 4.13. Although at the outset of the crisis the volatility of market rates was for some currencies higher than normal, central banks seem to have regained control relatively quickly, at least until Lehman's failure.

It is more difficult, however, to make the case that the measures also affected the term markets such as the one- or three-month segments as in-

Figure 4.13: Interest Rate Control During the Financial Turmoil



tended, simply because observable spreads such as the three-month Libor-OIS spread contain two major components—the credit risk premium and the liquidity risk premium.[32] While both anecdotal evidence and preliminary empirical studies such as Michaud and Upper (2008) suggest that the observed increase in risk premia in the interbank money market since August 2007 was due to both credit and liquidity factors, it is most likely that central banks' measures were at least to some extent successful in terms of mitigating the liquidity premium.[33] This view is corroborated by preliminary findings on the effects of the Fed's TAF (McAndrews, Sarkar and Wang 2008). In other words, without central banks' forceful interventions the tensions in (term) money markets would have been even more severe.

On a more critical note, however, one should point out two worrying developments. First, some of the measures taken by central banks led to rapid and strong growth in central banks' balance sheets. At least in those

[32]For the sake of completeness, one should also refer to the term premium as a third component. However, in money market rates the term premium is generally believed to be small and not much affected by the financial turmoil.

[33]Note that all the central bank measures discussed in this section are geared to reduce the liquidity risk premium, whereas there is not much central banks can do to affect the credit risk premium (with the exception of bailing out failing institutions, but that would be the topic for another study).

situations where this can be traced back to central banks providing reserves against more risky assets or standing ready to swap liquid or high-quality assets against illiquid, more risky or difficult to value assets, this went hand in hand with a worsening risk profile of central banks' balance sheets. Although the long-term implications of these expanded and more risky balance sheets are not yet fully understood, it appears that restoring the integrity of central banks' balance sheets must be given high priority once the crisis has receded.

Second, against the backdrop of dysfunctional interbank markets, central banks have increasingly taken over the role of private markets by directly intermediating between financial institutions. While in most cases this was a necessary short-term measure to prevent the collapse of individual institutions or even the financial system as a whole, there is a risk that increased central bank intermediation may weaken banks' incentives to resume their intermediation function in the medium- or long-term. Indeed, as long as it is possible to borrow large or even unlimited amounts from the central bank at rates close to the target rate, there is no incentive for banks to try to raise funds from the market. Similarly, by allowing banks to deposit (excess) reserve balances at near-zero opportunity cost with the central bank, there is no incentive to lend out these funds to other market participants. Unless central banks define a clear exit strategy, these emergency measures thus have the potential to perpetuate the dysfunction of the interbank money market.

4.4 Conclusions

This chapter has reviewed the operational framework of five major central banks. The bulk of this review has focused on the characteristics of and the experiences with the operational frameworks during periods of regular money market conditions. Against the backdrop of the recent tensions and disruptions in major money markets, this emphasis may seem inappropriate. But it should not be forgotten that for most of the time financial markets perform rather efficiently, which is particularly true for money markets. And since sooner or later the perfect storm will subside and money markets will gradually return to normality, it would not be advisable to ignore the lessons that can be learned from calmer periods. This is why the following conclusions are primarily drawn from Sections 4.1 and 4.2. But before turning to these conclusions, let us briefly consider the main lessons from central banks' actions during the crisis.

In this respect, the most obvious lesson is that during times of significant stress in the financial system, central banks will do whatever is needed to calm the situation and to prevent money markets from collapsing, no matter whether the requisite measures to do so are in line with their previous convictions and procedures. Clearly, many of the adjustments discussed in Section 4.3 were only temporary. Nevertheless, it is important that the operational framework for monetary policy implementation in normal times provides sufficient flexibility in order to be able to quickly react in case of need and to take appropriate measures without undue delay. For instance, during the crisis it became evident that some central banks' capacity to drain liquidity by means of regular open market operations was limited by the existing size and composition of their balance sheet. New instruments, such as the issuance of non-monetary (short-term) liabilities, thus had to be introduced at short notice. Similarly, collateral swaps or the provision of liquidity in a foreign currency may not be an integral part of a central bank's arsenal in normal times, but the operational framework should nonetheless provide for the adoption of such measures when needed.

Turning to the lessons from the pre-crisis era, the two main conclusions that emerge from the review in this chapter can be summarized as follows: First, the different elements of an operational framework are strongly intertwined and interdependent. And second, despite the fact that there is a lot of common ground between central banks' approaches to monetary policy implementation, there persists considerable heterogeneity regarding the detailed operational frameworks.

The review in this chapter has forcefully demonstrated that the different elements of an operational framework are strongly intertwined and interdependent. Whether a particular feature makes sense thus often depends on the context and the configuration of other elements. By way of example, the assessment of the pros and cons of alternative tender procedures to auction off liquidity might lead to different conclusions, depending on whether the maturity of open market operations is aligned with the timing of monetary policy decisions or not. If the policy rate is expected to be cut or raised before the current operation's maturity date, fixed rate tenders can give rise to undesirable consequences such as underbidding or extreme overbidding; otherwise, fixed rate tenders might work perfectly fine and, compared to variable rate tenders, they offer advantages in terms of simplicity, transparency and signalling. It thus follows that one should refrain from focusing the analysis on one or two isolated elements; the alleged conclusions could easily prove fallacious in a different context. Moreover, before altering a specific operational framework, one should bear in mind that changing one particular element—be that the length of the reserve maintenance period, the frequency of open market operations, or the mark-up of the borrowing facility—might have unintended repercussions for the functioning of the operational framework as a whole, potentially necessitating further changes to other elements.

For instance, a significant reduction in reserve requirements might only be expedient if accompanied by more frequent open market operations, as otherwise the increase in interest rate elasticity of reserve demand could lead to unintended volatility of day-to-day overnight rates. Altogether, this suggests that the design of a properly functioning operational framework is a challenging and delicate undertaking. And those who are responsible for the operational framework are well-advised to take into account as many theoretical considerations and practical experiences as possible.

This chapter has also documented a certain degree of conformity in central banks' operational frameworks. Generally speaking, the common denominator is that monetary policy is implemented through a combination of market-oriented instruments, which—by affecting the supply and demand in the market for reserves—are geared to controlling short-term interest rates, typically the overnight rate. In terms of liquidity management, all central banks aim at offsetting the impact of autonomous liquidity factors and to provide whatever amount of reserves is needed to balance the market at the target overnight rate. The generally preferred instrument for adjusting the supply of reserve are short-term repos. Further consensus refers to the universal provision of a borrowing facility, which acts both as an insurance to temporary liquidity shortages and as ceiling for overnight rates.

Moreover, comparing current arrangements with the situation ten years ago allows to discern a number of trends. Regarding the relative importance attached to the different monetary policy instruments, many central banks now seem to rely more heavily on standing facilities, both for signalling the stance of monetary policy and for limiting money market volatility (the latter is particularly relevant where standing facilities provide caps and floors to money market rates). Furthermore, among those central banks that rely on reserve requirements, there is a tendency to reduce or even eliminate associated opportunity costs by remunerating required reserves. Indeed, while the ECB has been remunerating required reserves ever since its inception in 1999, the Bank of England and the Federal Reserve started to do so more recently. Another development suited to reduce banks' (opportunity) costs is the significant expansion in terms of collateral eligible for open market operations. Finally, there is a certain trend towards more transparency and improved communication. In particular, most central banks nowadays are much clearer on what their operational target is and how they intend to achieve it. They also provide their counterparties with more relevant data or information, e.g. on their own liquidity forecasts, reserve maintenance, excess reserves or the results of tender operations. Besides higher standards for central bank accountability, the enhanced transparency reflects the insight that managing the market's expectation is crucial for ensuring orderly conditions in the interbank money market and for effective stabilization of short-term interest rates at or near the target level. It needs to be stressed, however, that full transparency about operations is not necessarily optimal. Especially in times of market stress, disclosure of sensitive information such as the recourse on standing facilities or even the provision of emergency liquidity assistance to a particular bank can be more harmful than useful. This explains why some central banks have become more cautious regarding the immediate publication of such data during the financial crisis.

Notwithstanding the aforementioned common ground and general trends, central banks' institutional arrangements of monetary policy implementation continue to exhibit considerable differences. Of course, a certain degree of heterogeneity is not surprising per se. On the contrary, given the countless possibilities how monetary policy instruments can be specified and combined, it would be a sheer coincidence if two central banks followed identical procedures. What is amazing, however, is that operational frameworks differ from each other in vital points. In particular, it seems that the effectiveness of individual monetary policy instruments is appraised quite differently. For some central banks, such as the ECB or the Bank of England, standing facilities and reserve requirements play a prominent role, whereas for others this is less the case. For instance, while non-existing in Australia, reserve requirements' effectiveness is significantly retrenched in both Switzerland and the U.S., partly because the level of reserve requirements is too low to be binding for all banks, partly because vault cash is eligible for meeting reserve requirements. With respect to open market operations, differences are less apparent at first sight, but the detailed examination of how central banks manage the banking system's liquidity reveals a broad spectrum of approaches. On the one hand, the ECB's and the Bank of England's liquidity management is very systematic and rule-based, with frequencies, maturities and conditions of open market operations being determined and announced well in advance. On the other hand, the Reserve Bank of Australia's operations are subject to much more discretion. The enumeration of such differences could be easily extended.

Which factors might explain the observed heterogeneity? To begin with, one might argue that the differences in operational frameworks are a mere reflection of the respective financial systems' particularities. But although it is undisputed that the financial systems and in particular the money markets of the reviewed currencies have their peculiarities, this argument is not very convincing. Indeed, the causality runs rather the other way round, i.e. it is more likely that the money market's peculiarities reflect the way monetary policy is implemented. The pound sterling money market provides a good example underpinning this hypothesis. Before the Bank of England's reform in 2006, the U.K. money market was dominated by a few market participants and characterized by very high volatility in short-term interest rates. Once the new operational framework became effective, the functioning of the money market improved rapidly.

Another reason for some of the observed heterogeneity could be related to varying degrees of institutional inertia in the reviewed currency areas. Institutional inertia is high if, for whatever reason, the central bank's ability to implement major amendments or reforms is limited. In that case, amendments to the operational framework will be only gradual; to implement major changes or even comprehensive reforms, it would take much more dissatisfaction with the current situation than in the case of low institutional inertia. The Federal Reserve provides a good example for this kind of institutional inertia. For instance, even though the inexpedience of the former below-market discount window had been widely recognized for decades, it was displaced only in 2003 by a more typical above-market borrowing facility.

Yet another explanation might be that central banks have spent relatively little resources on research related to the implementation of monetary policy. This conjecture is supported by the non-existence of a general framework that would allow to analyze in detail the advantages and disadvantages of alternative operational frameworks. Indeed, as already mentioned in Section 1.1, the development of a normative theory on monetary policy implementation is still in its infancy. The second part of this study thus shall contribute to filling this gap by establishing specific recommendations for an effective and efficient operational framework.

Part II

Towards an Effective and Efficient Operational Framework

Chapter 5

Objectives and Principles

The remarkable heterogeneity of central banks' operational frameworks documented in the previous chapter raises the question whether there is an 'optimal' operational framework. But as discussed in Section 1.1, the rigorous derivation of an optimal operational framework is condemned to failure for various theoretical and practical reasons. The ambition of this study is thus more humble: to come up with an operational framework that is both effective and efficient. But before presenting and discussing such an operational framework in the subsequent chapters, this chapter will clarify what is meant by 'effective' and 'efficient'.

In terms of effectiveness, it will be argued that monetary policy implementation should pursue two main policy objectives: tight control of the operational target (i.e. the overnight rate) and a liquid and competitive interbank money market. An operational framework is said to be effective if it permits to achieve these policy objectives to a high degree. Moreover, the operational framework should also allow for an efficient resource allocation. From a welfare perspective, the most appropriate criterion to measure efficiency are social costs caused by the operational framework. That is, the lower the social costs attributed to an operational framework, the more efficient it is. Effectiveness and efficiency are thus translated into three—to a large extent measurable—concrete policy objectives: (i) tight control of the overnight rate, (ii) a liquid and competitive interbank money market, and (iii) low social costs.

In the following, Section 5.1 will discuss the three policy objectives in more detail. Moreover, Section 5.2 will argue that in order to achieve these policy objectives, an operational framework should adhere to a number of principles. These principles will guide the central bank in designing the operational framework, particularly as they allow to narrow down the set of potential frameworks.

5.1 Policy Objectives

In recent years, most central banks have paid increasing attention to being transparent about the ultimate objectives of monetary policy. This is particularly true for those central banks that are committed to inflation targeting or some variant of it, such as inflation forecast targeting. The definition and the public announcement of the objectives—e.g. in form of a target inflation rate—are considered to be essential for two reasons. First, transparency about the objectives of monetary policy is a prerequisite for adequate central bank accountability, an aspect that has gained in importance due to central banks' increasing independence. Second, and more importantly, by announcing the (inflation) target, central banks intend to anchor the public's expectations and to enhance the effectiveness of monetary policy.

There is less transparency, however, about the objectives central banks pursue with respect to the implementation of monetary policy. Of course, most central banks announce a specific target level for the operational target. But besides that, it is less clear which—if any—other objectives central banks might pursue. An exception is the Bank of England, who has publicly announced four specific objectives (Bank of England 2006): (i) Overnight rates should be in line with the Bank's official rate and short-term market interest rates should exhibit very limited day-to-day or intraday volatility; (ii) an efficient, safe and flexible framework for banking system liquidity management; (iii) a simple, straightforward and transparent operational framework, and (iv) competitive and fair sterling money markets. Another exception is the ECB, whose objectives may be summarized as follows: (i) influencing money market interest rates; and (ii) ensuring the proper functioning of the money market. Besides that, the ECB mentions that the operational framework is designed in accordance with a number of guiding principles, such as operational efficiency, equal treatment and harmonization, decentralized implementation, simplicity, transparency, continuity, safety and cost efficiency.[1]

Some of these objectives, such as those related to the control of interest rates and the proper functioning of the money market, are straightforward and will be taken up below as well. Moreover, it seems that the ECB's distinction between policy objectives and guiding principles has some merit. For instance, it remains unclear why transparency should be an objective of monetary policy implementation. As in the case of the strategic framework of monetary policy, transparency is only a means to an end, rather than an end in itself. Therefore, in the following, a clear distinction will be made

[1]Interestingly, the objectives and guiding principles are stated only on the ECB's website, but they are not included in the otherwise very detailed general documentation on the Eurosystem's monetary policy instruments and procedures (ECB 2006a).

between actual policy objectives on the one hand, and guiding principles that are conducive to achieving these objectives on the other hand.

5.1.1 Tight Control of the Overnight Rate

The ability to influence short-term interest rate with high precision is at the heart of monetary policy implementation. Nobody would thus challenge that tight control of the overnight rate (which is assumed to be the operational target) is the most important objective of monetary policy implementation. But what does tight control really mean? First of all, it requires that the mean overnight rate equals the target rate, that is any deviations of effective rates from the target rate must cancel each other over time. Moreover, besides the mean, the volatility of overnight rates also needs to be taken into account. Indeed, even if the mean overnight rate is equal to the target rate, effective overnight rates might temporarily deviate more or less significantly from the target rate. The lower the frequency and the magnitude of these deviations, the tighter is the control of interest rates. Therefore, in practice, the extent of interest rate control can be measured by two simple statistics: the mean and the volatility of overnight rates.

In order to reinforce the importance of tight interest rate control, consider the detrimental effects of persistent deviations from the target rate and excessive interest rate volatility, respectively. First of all, persistent deviations of overnight rates from the announced target are likely to raise doubts in the market and the economy as a whole about both the effective and the intended monetary policy stance. As a consequence, the market's expectations on future target rate changes might change, with unintentional immediate effects on longer-term interest rates. Moreover, if the mean overnight rate were consistently above or below the target rate, this spread would be transmitted along the yield curve into longer-term interest rates. Monetary policy would then be either more expansive or more restrictive than intended by policy makers. Also, persistent deviations from the announced target would undermine the market's belief in the central bank's ability to steer short-term interest rates. The associated loss of reputation might even impair the central bank's credibility in other domains.

While low or moderate volatility in overnight and other short-term interest rates might not be much of a concern, it is beyond doubt that excessive volatility can have rather harmful consequences. To begin with, as the central bank is considered to be responsible for ensuring orderly market conditions in short-term money markets, it might face a reputation problem if volatility in money market interest rates is inordinately high. Furthermore, excessive volatility in overnight rates might deter some financial institutions from active participation in the interbank money market. In particular, if lucrative participation in a money market characterized by high interest rate volatility seems to require special expertise and therefore a disproportionate commitment of market intelligence, smaller and foreign institutions with comparatively lower trading volumes might refrain from participation at all. By the same token, high volatility and unpredictability in overnight rates might reduce the incentives for market-making in this market segment, resulting in less liquid overnight markets and temporary frictions in the market-wide distribution of liquidity. In turn, this would increase banks' funding risks and liquidity management costs. Moreover, the development of related market segments such as the overnight indexed swap (OIS) market might also be impeded.

Perhaps the most serious concern is that excessive volatility in overnight or other short-term money market interest rates could be transmitted along the yield curve, causing excessive volatility in longer-term interest ratesd and other financial assets. By influencing spending and investment decisions, this could have distorting effects on real economic activity (Sellon and Weiner 1997). However, empirical evidence on the extent of volatility transmission along the yield curve is inconclusive. For instance, while the transmission of volatility into longer-term interest rates has been rejected for the U.K. (Vila Wetherilt 2003), it has been confirmed for euro interest rates, at least for shorter maturities (Cassola and Morana 2003, Durré and Nardelli 2006).

Finally, it needs to be stressed that even though the ability to influence short-term interest rates with high precision is the most important objective of monetary policy implementation, it is not the only one. In fact, if it were, establishing an effective operational framework would be straightforward: The central bank could easily peg the interest rate at the target level by (i) providing a borrowing and a deposit facility, (ii) setting the borrowing rate and the deposit rate equal to the target rate, and (iii) announcing that commercial banks are permitted to borrow or to deposit an unlimited amount of reserves at these facilities. However, in practice, such an operational framework has never been used, the reason being that a zero interest rate corridor would completely crowd out the interbank money market. Indeed, no bank with a reserve surplus would ever be able to lend funds at an interest rate higher than the overnight target rate, and similarly no bank with a reserve shortfall would ever be able to borrow funds at an interest rate lower than the overnight target rate. Instead of searching for other banks with opposing funding needs, banks would simply rely on the central bank's standing facilities for borrowing (depositing) needed (surplus) funds. Trading would cease and the interbank market collapse. In the next section, it will be shown that a complete breakdown of the interbank money market would have a number of serious consequences. Preserving and promoting a well-functioning interbank money market is thus the second objective of monetary policy implementation.

5.1.2 Liquid and Competitive Money Markets

The vital role of money markets for the financial system becomes most evident in times when they cease functioning. In this respect, the experience with the severe disruptions to major money markets during the 2007–2008 financial crisis should be sufficient to explain why—to the extent possible—the operational framework for the implementation of monetary policy should contribute to liquid and competitive interbank money markets and underpin incentives for banks to manage liquidity risk prudently. This notwithstanding, let us briefly explore what it actually means to have a competitive and liquid interbank money market, and why the central bank should have a keen interest in the proper functioning of this market.

The interbank money market can be said to be liquid and competitive if it permits banks to easily borrow or lend an arbitrary amount of funds at fair and predictable prices (i.e. interest rates) and at low transaction costs. A well-functioning money market thus allows offsetting short-term liquidity needs or surpluses, no matter whether these liquidity imbalances result from a bank's deliberate position taking or from customers' stochastic payment flows. High trading volumes, low bid-ask spreads, and a moderate level of interest rate volatility are typical features of liquid and competitive money markets. Clearly, a large number of market participants, the presence of several market makers, the absence of dominant market players and a high degree of transparency are conducive to a liquid, competitive and thus well-functioning interbank money market.

A liquid and competitive short-term money market provides several advantages. First of all, contributing to the efficient distribution of funds between market participants, it prevents the central bank from becoming any bank's lender of first resort. Indeed, if borrowing from other (liquidity abundant) banks is not possible or at least severely inhibited by market frictions, banks with short-term liquidity needs have no alternative to falling back on the central bank, either by borrowing more in open market operations or from standing facilities. In the presence of an illiquid interbank money market, the central bank thus can't help providing liquidity to banks with short-term funding needs either way; otherwise these banks would run into serious liquidity problems or, by desperately seeking funds in the dried-out market, they would bid up overnight rates to levels not in line with the central bank's target rate. Also, as banks' short-term liquidity imbalances can be rather large, the need for additional liquidity provision by means of open market operations or via standing facilities would be significant. The associated expansion of the central bank's balance sheet would raise either of the following concerns: On the one hand, if additional short-term lending is not or not adequately collateralized, the central bank could be exposed to excessive credit risk vis-à-vis its counterparties, especially if they are perceived to be financially unsound. On the other hand, if lending is adequately collateralized, the mere size of banks' incremental collateral requirements could severely strain the market for collateral, with unintended consequences for the pricing of financial assets. Both concerns are resolved if the interbank money market is sufficiently liquid. In that case, the central bank only has to worry about providing the adequate aggregate amount of liquidity, while the interbank market will ensure that these funds are efficiently distributed between financial institutions.

Market discipline is another reason why central banks should have a keen interest in liquid and competitive interbank money markets. As argued by Rochet and Tirole (1996), by generating incentives for lending banks to screen and monitor borrowing banks, interbank exposures may contribute to prudent market behavior and reduce the risk of bank failures and financial instability. Therefore, to the extent that banks are provided with proper incentives to identify the risks of other banks, they can perform a complementary task to banking supervisors and rating agencies.[2] Regulators then may rely on market signals to identify those banks which the market perceives as comparatively risky. Even more, as banks anticipate that they will face pricing effects and quantity rationing in the interbank money market if they are perceived to be too risky by their peers, they have an incentive to reduce their riskiness in the first place. A well-functioning interbank money market thus may contribute to a generally sound banking system, which, in turn, is a precondition for effective transmission of monetary policy.

Last but not least, a liquid and competitive interbank money market goes usually hand in hand with a low level of interest rate volatility and is thus instrumental to achieving the central bank's primary policy objective: tight control of interest rates. As a matter of fact, both objectives—tight interest rate control and a well-functioning money market—are mutually reinforcing: If interest rate control is tight, the interbank market should become more liquid and competitive; and in turn, if the interbank market is liquid and competitive, it is easier to exert tight interest rate control.

[2]Empirical evidence supporting the market discipline hypothesis in the U.S. federal funds market is documented by Furfine (2001) and King (2008), and for central and eastern European interbank markets by Dinger and von Hagen (2008).

5.1.3 Low Social Costs

With tight control of the overnight rate and a well-functioning interbank money market being the two main policy objectives of monetary policy implementation, the adequacy of any operational framework should be assessed by the extent to which it allows achieving these goals. However, it is quite likely that many different operational frameworks permit to achieve these objectives to the same or at least a similar degree. In order to discriminate between these frameworks, it is useful to pay attention to another factor: the efficient allocation of resources. In the present context, an operational framework is said to be efficient if—for a given degree of achievement of the two main policy objectives—it causes the lowest social costs. Thus, if two or more operational frameworks perform similarly well in terms of their effectiveness, efficiency considerations call for choosing the framework that causes the lowest social costs.

The implementation of monetary policy occasions a wide range of costs. Some of these costs are borne by the central bank, others by commercial banks or even the public at large. For instance, the technical infrastructure needed for monetary policy implementation is a major expense factor. It includes the development, investment, maintenance and ongoing operating costs of different systems or platforms, such as the trading or auctioning system for open market operations and the post-trading market infrastructures for settling payments and securities transactions.[3] Another important cost factor is related to human resources. For the central bank, forecasting autonomous liquidity factors and conducting open market operations requires staff in both the front-office and the back-office. Similar cost issues arise for commercial banks' liquidity management, which requires staff for liquidity analysis and planning, market intelligence, trading and settlement of transactions with the central bank and in the interbank money market.[4] Moreover, the implementation of monetary policy may also imply less tangible social costs, such as allocative inefficiencies due to distortions induced by the rules and procedures of the operational framework. For instance, the non-remuneration of reserve requirements might imply suboptimal portfolio allocation or induce banks to invest in (socially wasteful) measures to reduce

[3]The post-trading market infrastructures are typically used also for other purposes, but a certain share of their total cost is attributable to the implementation of monetary policy. To what extent these costs are borne by the central bank or commercial banks (e.g. in form of transaction fees) may depend on the specific circumstances.

[4]Banks do not *have* to invest resources in liquidity management. However, they face a trade-off between investing resources into liquidity management on the one hand, and the costs associated with suboptimal end-of-day liquidity positions or unsettled transactions on the other hand (Bindseil and Nyborg 2008).

the level of required reserves.[5] Moreover, the central bank's outright holdings of securities or its collateral policy might have distorting effects on the relative prices of financial assets.

Clearly, these costs depend on how monetary policy is implemented. For instance, the higher the frequency of open market operations, the higher the labor costs for both the central bank and commercial banks. Also, the resources that commercial banks will have to spend on market intelligence will likely depend on the central bank's tender procedure for open market operations. In particular, bidding in variable rate tenders is more demanding and requires more expertise and knowledge about current and future market conditions than bidding in fixed rate tenders.[6] Moreover, the degree of transparency on central bank liquidity management will likely affect the resources banks spend on forecasting future central bank actions. The more opaque the central bank's procedures, the more banks will have to spend on analyzing and interpreting the central bank's actions, on reading messages in say the allotment decisions, and on anticipating future operations. Furthermore, the degree of complexity of the rules and procedures governing reserve requirements will have a corresponding impact on the cost of computing required reserves and banks' activities to circumvent reserve requirements.

There are also important intertemporal trade-offs, particulary between investment costs and ongoing operating costs. For instance, setting up infrastructures that allow for standardized and highly automated trading and post-trading processes causes significant investments, but once established, efficient infrastructures will imply less manual interventions and thus lower ongoing operational costs and risks. Whether these investments ultimately pay off will depend on a range of factors, such as the size of the financial system and the relative factor costs. Finally, one might mention that even minor modifications such as changes to the auction format for open market operations or new rules for computing reserve requirements need to be understood, assessed and implemented by many market participants. Any change to an operational framework is thus likely to cause considerable learning and adaptation costs, both for the central bank and, more importantly, for a large number of commercial banks.

Although the preceding enumeration of different cost factors is by no means comprehensive, it suggests that measuring total social costs associ-

[5] Note that the interest foregone on banks' non-remunerated reserves accrues as profit to the central bank and thus involves no direct social costs.

[6] In variable rate tenders, less informed banks run the risk of either bidding too low an interest rate (in which case they will not be allocated any funds and they might have to borrow at higher costs in the interbank market) or bidding too high an interest rate (in which case they will pay too much for the allotted amount).

ated with a specific operational framework is a formidable task. Therefore, instead of measuring the costs induced by an operational framework directly, we will follow an indirect approach and postulate a number of guiding principles. The idea is that any operational framework that adheres to these principles will cause relatively low social costs. Moreover, as will be argued, complying with these principles also contributes to achieving the two other policy objectives. A welcome side effect of postulating these principles thus is that they allow to narrow down the set of contemplable operational frameworks.

5.2 Guiding Principles

This section postulates a number of guiding principles, adherence to which will be conducive to achieving the policy objectives set out above. As argued below, the operational framework should be characterized by a high degree of simplicity, transparency and neutrality, and from an intertemporal perspective, it should exhibit a high degree of continuity. In addition, the infrastructure used for the implementation of monetary policy should provide for a high degree of operational reliability and security.

Simplicity

First and foremost, the operational framework should be simple and straightforward. The rules and procedures governing the use of monetary policy instruments should dispense with any unnecessary complexities, as they would only raise the social costs associated with the implementation of monetary policy in some way or the other. Simplicity—at least to the extent possible—is thus a precondition for the efficient allocation of resources and, as further demonstrated below, also contributes to the achievement of the other policy objectives.

Transparency

The rules and procedures of the operational framework as well as the central bank's actual use of monetary policy instruments should be transparent, both ex ante and ex post. Ex ante transparency requires the central bank to disclose its policy objectives (e.g. tight interest rate control, liquid and competitive money markets, and low social costs) and to explain how the design of the operational framework contributes to achieving these objectives. Moreover, the definition of largely rule-based (rather than discretionary) procedures and the timely release of any information that might facilitate commercial banks' liquidity management are suited to heighten ex ante transparency. In addition, ex post transparency requires the timely disclosure of any relevant information on central bank operations and the achievement of policy objectives (accountability).

In conjunction with simplicity, a high degree of transparency fosters market participants' ability to understand the working of the operational framework and to anticipate as well as comprehend the central bank's operations. By eliminating undue uncertainty on the part of commercial banks, simplicity and transparency are thus conducive to achieving all three policy objectives.

Neutrality

The operational framework should be neutral in the sense that the rules and procedures (i) minimize distorting effects on relative prices of financial assets and the longer-term yield curve (market neutrality) and (ii) ensure equitable treatment of all market participants (competitive neutrality).

Market distortions may result from the central bank's portfolio choices, the specification of open market operations or the collateral policy. For instance, relative prices of financial assets might be affected by the central bank's outright holdings of specific securities and, in particular, by outright purchases or sales of securities in the primary or secondary market. To the extent that the central bank has a choice of satisfying banks' structural liquidity needs by means of outright holdings or reverse operations, it seems that reverse operations are preferable for two reasons. First, because ownership of the underlying assets is not affected in reverse operations, the price of a security will be less distorted than if the security were bought or sold outright. Moreover, in outright transactions, the central bank would have to make a decision on the maturity of the instrument purchased or sold, thereby potentially affecting the yield curve at that maturity. However, especially in cases where the banking system's structural liquidity deficit is large and increasing over time (e.g. due to an increase in the public's demand for currency), it is difficult to provide liquidity exclusively by means of repo transactions, as the size of these transactions would have to increase perpetually. Most likely, the central bank will then find it more convenient to provide a significant amount of liquidity via outright holdings of securities. In this case, to minimize the impact on prices and liquidity of financial assets, the central bank should strive to hold a well diversified portfolio of liquid securities with varying maturities.[7]

[7]One should also note that to the extent that the slope of the yield curve is positive, providing liquidity by means of outright holdings of longer-term securities generates, on average, higher revenues than providing liquidity by means of short-term repos.

Another channel through which securities prices might be affected is the central bank's collateral policy. Indeed, it is quite likely that there is a premium on securities eligible for central bank operations, or to put it differently, that non-eligible securities trade at a discount. Such distorting effects are minimized if a relatively wide range of collateral is accepted and if the riskiness of the different types of collateral is reflected by the application of adequate haircuts.

As for competitive neutrality, it is obvious that some market participants are placed at a disadvantage in case the central bank decided to deal only with certain counterparties or in case the collateral policy were biased in favor of a particular group of banks. The specification of open market operations and the collateral policy thus seem to be crucial in ensuring competitive neutrality. In particular, in terms of open market operations, competitive neutrality would call for tender-based reverse operations, with a relatively simple auction form (e.g. fixed rate tender) and the admission of all interested parties. Moreover, accepting a wide range of eligible collateral should also contribute to minimize any distortions between different types of banks and to promote a level playing field.

Continuity

As mentioned in Section 5.1, even minor changes to the operational framework have the potential to cause significant adaptation and learning costs, both for the central bank and all commercial banks. Moreover, any modification to the rules and procedures could adversely affect the effectiveness of monetary policy implementation, at least transitionally. This is because it usually takes some time to fully apprehend the impact of changes to the operational framework. To keep the social costs at bay as well as to avoid unnecessary uncertainty about the working of the operational framework, the central bank should thus strive for a high degree of continuity in the manner it implements monetary policy.

As a matter of course, this principle should not be abused as an excuse for sticking longer than necessary to a conspicuously flawed operational framework. Rather, it implies that the operational framework should be carefully designed in the first place, so as to minimize the need for future amendments. And in case amendments become necessary nonetheless, they should be implemented only after thorough examination of their potential implications.

Operational Reliability and Security

While the preceding four guiding principles bear on the rules and procedures governing the instruments of monetary policy, the last principle refers to the business processes and the underlying information and communication technology (ICT) used to implement monetary policy. For obvious reasons, the relevant business processes and the critical ICT have to be operationally reliable and secure. For instance, the implementation of monetary policy would be severely hampered if relevant business processes such as open market operations could not be conducted or settled as planned, e.g. due to technical issues with the underlying technical infrastructure, a failure of the communication network or the lack of qualified staff. Also, there must be not the slightest doubt about the confidentiality and integrity of any data exchanged between the central bank and commercial banks.

Let alone for efficiency reasons, the use of standardized and automated processes is instrumental to achieving a high degree of operational reliability and security. Of course, one might object that the reliance on automated processes and thus the smooth functioning of the underlying ICT leads to an increase in operational risk. However, it should be noted that automated processes are less error-prone than manual processes and interventions and, moreover, operational risks can be mitigated and controlled by the implementation of appropriate measures (e.g. redundant infrastructure or periodically tested back-up and contingency procedures).

In practice, central banks should pay due attention to all guiding principles. However, for the purposes of this study, which aims at proposing an effective and efficient operational framework, the first three principles—simplicity, transparency and neutrality—are the most relevant. The fourth principle—continuity—is particularly important from an intertemporal perspective, which is beyond the scope of this study. And as mentioned, the last principle—operational reliability and security—is not directly related to the operational framework as such, but refers to the underlying technical infrastructure and the relevant business processes.

Chapter 6

The Recommended Operational Framework

The preceding chapter has postulated three main policy objectives associated with monetary policy implementation, i.e. tight control of the overnight rate, liquid and competitive money markets, and low social costs. In addition, it was contended that in order to achieve these objectives the operational framework for the implementation of monetary policy should adhere to a number of guiding principles. In particular, the operational framework should be simple, transparent and neutral. The detailed description of the objectives and guiding principles is an important step towards a normative analysis of monetary policy implementation, as establishing a common understanding on what monetary policy implementation should achieve (and what it should not achieve) is a precondition for assessing the pros and cons of currently applied operational frameworks, for their further development and for devising alternative (potentially preferable) operational frameworks.

The main purpose of this study is to propose an effective and efficient operational framework, i.e. one that performs well in terms of the stated policy objectives. In this respect, the first part of this study provides a wealth of useful insights on how individual monetary policy instruments should be specified and how they should fit together. Based on these findings, the key elements of such an operational framework are sketched in Section 6.1. Section 6.2 then provides an initial assessment of the proposed operational framework against the policy objectives. The rationale for many of the specific recommendations will then be further studied in Chapter 7.

6.1 Overview

The core elements of the proposed operational framework are summarized by 15 recommendations. While most of these recommendations govern the rules and procedures for the three monetary policy instruments, i.e. reserve requirements, standing facilities, and open market operations, the last three recommendations are of a more general nature and relevant for several (or all) instruments. In addition, it needs to be stressed that the recommended operational framework takes for granted that the central bank's operational target is set in terms of a specific target for the overnight rate (see Section 2.3).

Reserve Requirements

R-1 Averaging. Reserve requirements allow for averaging over the reserve maintenance period.

R-2 Timing of reserve maintenance periods. Reserve maintenance periods are aligned with the timing of monetary policy decisions such that (regular) changes in the overnight target rate become effective on the first day of a new reserve maintenance period.

R-3 Reserve target range. Prior to the beginning of a reserve maintenance period, the central bank sets for each bank the reserve target and a symmetric range around the reserve target. Reserve targets are sufficiently high and the reserve target range is sufficiently wide to absorb the impact of shocks to banks' liquidity and autonomous liquidity factors.

R-4 Remuneration. Required reserves are remunerated at the level of the central bank's average tender rate for short-term repos over the current reserve maintenance period. Any excess reserves are remunerated at the deposit rate, while any reserve shortfalls must be covered by borrowing from the borrowing facility.

Standing Facilities

R-5 Borrowing facility. The central bank provides a borrowing facility, which allows banks to borrow reserves overnight at their discretion at the prevailing borrowing rate against eligible collateral. Borrowed reserves are applied to required reserves.

R-6 Deposit facility. The central bank provides a deposit facility, which allows banks to deposit reserves overnight at their discretion at the prevailing deposit rate. Deposited reserves are not applied to required reserves.

R-7 Symmetric interest rate corridor. The borrowing rate and the deposit rate provide for a symmetric interest rate corridor around the overnight target rate. The width of the corridor is set such that it strikes the appropriate balance between the objectives of tight control of the overnight rate (which calls for a relatively narrow corridor) and liquid and competitive money markets (which calls for a relatively wide corridor).

Open Market Operations

R-8 Liquidity Management Strategy. The central bank undertakes to provide the amount of liquidity the banking system needs to comply with aggregate reserve targets over the reserve maintenance period. Within the reserve maintenance period, the central bank aims at smoothing the day-to-day provision of liquidity.

R-9 Regular operations. The central bank provides or absorbs liquidity primarily by means of the following regular open market operations:

– long-term repos for basic refinancing, conducted monthly with maturity of three or six months;

– short-term repos for managing liquidity within the reserve maintenance period, conducted weekly with maturity of one week (the maturity of the last short-term repo within a reserve maintenance period may need to be adjusted in order to ensure that the repo matures on the first day of the next reserve maintenance period);

– overnight repos for liquidity fine-tuning, conducted on the last day of the reserve maintenance period.

R-10 Occasional operations. The central bank may conduct the following open market operations as needed:

– securities outright transactions to accommodate permanent changes in autonomous liquidity factors;

– overnight or short-term repos to offset major unanticipated temporary changes in autonomous liquidity factors on any day within the reserve maintenance period.

R-11 Exceptional operations. To deal with exceptional circumstances, the central bank disposes of arrangements that allow to drain large quantities of reserves (e.g. by issuing non-monetary liabilities), to conduct collateral swaps and to provide liquidity in the most important foreign currencies.

R-12 Tender procedures. The central bank conducts short-term and overnight repos as fixed rate tenders, with the tender rate set equal to the current overnight target rate. The central bank conducts long-term repos as variable rate tenders (uniform price auctions without minimum bid rate). In both tender procedures the central bank pre-announces the total intended allotment. In the event of overbidding, liquidity is allotted on a pro-rata basis, with a maximum allotment ratio applying for any bidder.

Miscellaneous

R-13 Scope. All participants to the interbank large-value payment system are subject to reserve requirements, have access to the standing facilities, and are eligible counterparties for open market operations.

R-14 Collateral Framework. The central bank accepts a wide range of collateral and applies risk-based valuation haircuts.

R-15 Documentation. The central bank publishes a general documentation on the operational framework, explaining in detail the rules and procedures governing the use of the relevant monetary policy instruments, both in normal and exceptional circumstances.

6.2 Appraisal

The rationale for as well as further considerations regarding the specific recommendations outlined above will be discussed in Chapter 7. However, before going into the details, a more general discussion of the proposed framework is warranted. To this end, this section first shows how the key elements of the recommended operational framework can be captured in a modified version of the money market model developed in Chapter 3. Based on that model and further considerations, it will then be established that the recommended operational framework allows to achieve the stated policy objectives to a very high degree.

6.2.1 Modeling

In Chapter 3, a rather general model of the money market has been introduced that allows to study the interaction of banks' demand for reserves and the central bank's supply of reserves. In particular, it was shown how banks' demand for reserves in the interbank money market and, by implication, the market clearing overnight rate are affected by various institutional features of the operational framework, such as the specific configuration of reserve requirements, standing facilities, and banks' expectation regarding the terms and conditions of the central bank's open market operations within the reserve maintenance period. In terms of the notation introduced in Chapter 3, the specific features of the recommended operational framework can be summarized as follows.

First, regarding reserve requirements, note that reserve maintenance periods are aligned with the timing of monetary policy decisions. This implies that the length of the reserve maintenance period, measured as the number of days $t = 1, \ldots, T$, may vary. For instance, if the monetary policy committee meets monthly on the second Wednesday, the implication would be that the reserve maintenance period may last 28 or 35 days. More importantly, the recommended operational framework provides for a symmetric range around the reserve target. Denoting bank i's reserve target at the beginning of the reserve maintenance period as $D_{i,1}$, the reserve target range can then be written as $[(1-\lambda)D_{i,1}, (1+\lambda)D_{i,1}]$, where λ is the allowed percentage deviation from the reserve target.[1] The bank complies with reserve requirements if the accumulated end-of-day reserve balances over the reserve maintenance period fall within that range. In that case, the accumulated reserve balances are remunerated at the average tender rate for short-term repos, which equals the current overnight target rate i^*. In case the accumulated reserve balances fall short of $(1-\lambda)D_{i,1}$, the bank needs to borrow the shortfall from the borrowing facility; in case accumulated reserves exceed $(1+\lambda)D_{i,1}$, excess reserves can be deposited at the deposit facility.

Second, in terms of standing facilities, the symmetric interest rate corridor around the current overnight target rate implies that the borrowing rate and the deposit rate can be written as $i_t^b = i_t^* + \omega/2$ and $i_t^d = i_t^* - \omega/2$, respectively, where ω is the width of the interest rate corridor. Moreover, since the analysis is restricted to one maintenance period and the overnight target rate is (typically) not changed within reserve maintenance periods, we may simply write i^*, i^b and i^d.

Third, with respect to open market operations, the central bank's liquidity management strategy calls for providing the market with sufficient reserves to comply with the aggregate reserve target and to smooth the day-to-day provision of liquidity as much as possible. Ideally, the path of per capita end-of-day reserve balances would thus be $R_1^{eod} = R_2^{eod} = \ldots = R_T^{eod} = D_1/T$.

[1] Similarly, the per capita reserve target and the per capita reserve target range are D_1 and $[(1-\lambda)D_1, (1+\lambda)D_1]$, respectively.

Assuming that the shocks to autonomous liquidity factors have mean zero and that there is no long-term repo maturing during the current reserve maintenance period, the regular weekly short-term repos have the following optimal allotments. The first one-week repo, to be conducted on the very first day of the reserve maintenance period, should have a per capita allotment of $L_{1,8} = \bar{L}_1 + D_1/T - R_1^{bod}$. With this allotment, the expected end-of-day reserve balances throughout the first week of the reserve maintenance period are D_1/T. Of course, to the extent that the realized shocks to autonomous liquidity factors are non-zero, the actual end-of-day reserve balances will deviate from the optimal path. By the beginning of the second week, the remaining per capita reserve deficiency is D_8 and, ideally, the per capita end-of-day reserve balances over the remainder of the reserve maintenance period would now be $R_8^{eod} = \ldots = R_T^{eod} = D_8/(T-7)$. The required allotment then is $L_{8,15} = \bar{L}_8 + D_8/(T-7) - R_8^{bod}$, and so on for the remaining weekly repos. Eventually, on the last day of the reserve maintenance period, the remaining per capita reserve deficiency is D_T and the optimal allotment of the fine-tuning overnight repo is $L_{T,T+1} = D_T - R_T^{bod}$.

6.2.2 Assessment Against the Policy Objectives

Objective 1: Tight Control of the Overnight Rate

First and foremost, the recommended operational framework needs to be assessed against the extent to which it allows to control the operational target, which is defined as a specific target for the interbank overnight repo rate. The money market model developed in Chapter 3, which captures both banks' demand for reserves in the interbank money market and the central bank's attempts to manage the aggregate supply of reserves by means of open market operations, is well suited to carry out this assessment. As in Chapter 3, equilibrium overnight rates in the interbank money market (which are derived from banks' optimal borrowing decisions) and the central bank's optimal allotment decisions in open market operations can be calculated by means of backward induction.

From a bank's perspective, the value of an additional unit of reserves at the end of the reserve maintenance period is i^d (in case of excess reserves), i^b (in case of a reserve shortfall), or i^* (in case the accumulated reserve balances are within the reserve target range). Correspondingly, at the time of market clearing on day T, i.e. before the cumulated afternoon liquidity shock is realized, any bank's demand for reserves depends on its assessment of the probabilities of incurring excess reserves, a reserve shortfall, or being within the reserve target range. The probabilities attached to these three states depend on the bank's remaining reserve deficiency $D_{i,T}$, its reserve position before market clearing $R_{i,T}^{mc}$, and the variance of the cumulated afternoon liquidity shock $\varepsilon_{i,T}^{A}$.

Assuming that at the beginning of day T each bank's level of accumulated reserves lies below the lower bound of the reserve target range (i.e. $D_{i,T} > \lambda D_{i,1}, \forall i$), the market clearing interest rate is

$$\begin{aligned} i_T &= \Gamma_{\varepsilon^A}\left(D_T - \lambda D_1 - R_T^{mc}\right) i^b \\ &+ \left[1 - \Gamma_{\varepsilon^A}\left(D_T + \lambda D_1 - R_T^{mc}\right)\right] i^d \\ &+ \left[\Gamma_{\varepsilon^A}\left(D_T + \lambda D_1 - R_T^{mc}\right) - \Gamma_{\varepsilon^A}\left(D_T - \lambda D_1 - R_T^{mc}\right)\right] i^*, \end{aligned} \tag{6.1}$$

where D_T is the per capita reserve deficiency at the beginning of day T. The market clearing overnight rate i_T thus is a weighted average of the three possible values of an additional unit of reserves, with the weights reflecting the probabilities of ending the reserve maintenance period with accumulated reserves that (i) fall short of the lower bound of the reserve target range (ii) exceed the upper bound of the reserve target range, and (iii) lie within the reserve target range.

By the same logic, on the penultimate day of the reserve maintenance period, the market clearing interest rate is a weighted average of the borrowing rate, the deposit rate, and the interest rate expected to prevail on the last day of the reserve maintenance period, with the weights reflecting the probabilities of (i) being overdrawn at the end of the day, (ii) exceeding the upper bound of the reserve target range, and (iii) avoiding both standing facilities. More formally, the overnight rate on $T-1$ thus is:

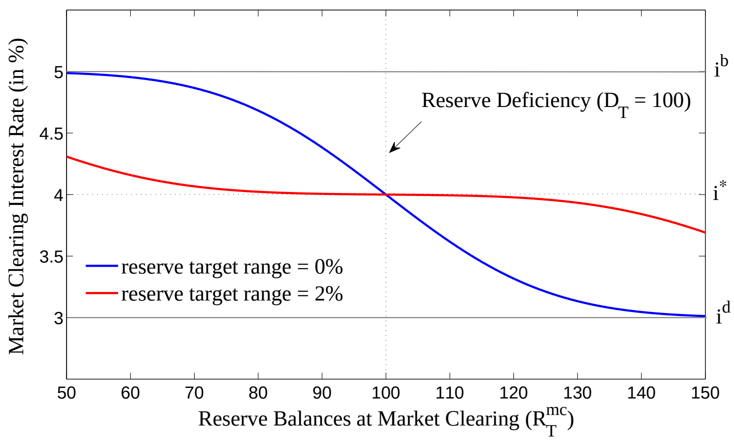
$$\begin{aligned} i_{T-1} &= \Gamma_{\varepsilon^A}\left(-R_{T-1}^{mc}\right) i^b + \left[1 - \Gamma_{\varepsilon^A}\left(D_{T-1} + \lambda D_1 - R_{T-1}^{mc}\right)\right] i^d \\ &+ \left[\Gamma_{\varepsilon^A}\left(D_{T-1} + \lambda D_1 - R_{T-1}^{mc}\right) - \Gamma_{\varepsilon^A}\left(-R_{T-1}^{mc}\right)\right] E_{T-1}(i_T). \end{aligned} \tag{6.2}$$

What can we say about the measure of the respective probabilities and hence the market clearing rate $T-1$? First, note that if the reserve targets are sufficiently high compared to the size of banks' liquidity shocks as recommended in recommendation R-3, the demand for end-of-day reserve balances over the reserve maintenance period is fairly constant (see the discussion in Section 3.2.2). Moreover, R-8 calls for a fairly smooth supply of reserves during the reserve maintenance period. If these conditions are met, the probability that banks are being forced into either of the standing facilities on the penultimate day is close to zero, and hence $i_{T-1} \approx E_{T-1}(i_T)$. By implication, the same holds true for the previous days, so that the martingale property holds approximately, i.e.

$$i_t \approx E_t(i_T), \text{ for } t = 1, \ldots, T-1. \tag{6.3}$$

In order to maintain overnight rates at or near the target rate throughout the reserve maintenance period, it is imperative that the (expected) market clearing overnight rate on day T equals the target rate. Equation (6.1) reveals that i_T is equal or very close to i^* whenever the term $|D_T - R_T^{mc}|$ is small. If the per capita reserve balances at the time of market clearing R_T^{mc} exceed (fall short of) the remaining per capita reserve deficiency D_T, i_T tends to be below (above) the target rate i^*. However, as shown in Figure 6.1, the interest rate effects of such deviations are mitigated by the reserve target range.

Figure 6.1: Market Clearing Overnight Rate on the Last Day of the Reserve Maintenance Period



The underlying assumptions in Figure 6.1 are as follows: the reserve maintenance period lasts 28 days; the per capita reserve target is $D_1 = 2,800$; the remaining per capita reserve deficiency at the beginning of day T is $D_T = 100$; and the standard deviation of the cumulated afternoon liquidity shock is $\sigma_{\varepsilon^A} = 20$. Moreover, the reserve target range is either zero (blue line) or 2% of the per capita reserve target (red line). The effect of the reserve target range is striking: In case the per capita reserve balances at the time of market clearing deviate from the remaining reserve deficiency, the impact on the overnight rate is significantly smaller than without reserve target range. Establishing a reserve target range as recommended in R-3 is thus an effective device to mitigate or even avoid the usual spikes in overnight rates at the end of reserve maintenance periods.

Besides the reserve target range, a number of other features of the recommended operational framework play an essential part in contributing to tight interest rate control. To facilitate the discussion of these features and how they are related to each other, it is useful to distinguish between demand and supply factors.

Regarding the factors that affect the demand for (end-of-day) reserve balances, the first key element are sufficiently high reserve requirements (R-3). In combination with the averaging provision (R-1) high reserve requirements increase the interest rate elasticity of reserve demand and reduce the probabilities of having recourse to either of the standing facilities throughout the reserve maintenance period. The remuneration of required reserves at the current target rate (R-4) and the symmetric interest rate corridor established by the standing facilities (R-7) imply symmetric opportunity costs of reserve deficiencies and excess reserves. As a result of this symmetry, it is optimal for banks to target the mid-point of their reserve target range, i.e. the reserve target. Moreover, the timing of the reserve maintenance period (R-2) is such that expected future target rate changes do not affect banks' reserve demand pattern within the reserve maintenance period. Together, all these features then imply that the martingale property holds. Finally, on the last day of the reserve maintenance period, the reserve target range (R-3) provides banks with some flexibility in complying with reserve requirements and reduces the probability of having recourse to either of the standing facilities. This increases the interest rate elasticity of reserve demand and reduces or even eliminates the typical end-of-maintenance-period spikes in overnight rates.

On the supply side, the central bank's liquidity management strategy, in particular the commitment to undertake within the current reserve maintenance period those open market operations that are required for banks to be able to comply with reserve requirements (R-8), has a stabilizing effect on banks' interest rate expectations and, due to the martingale property, on overnight rates throughout the reserve maintenance period. As banks anticipate that shocks to autonomous liquidity factors will be offset by the next regular open market operation at the latest, temporary small deviations from the smooth supply of reserves do not translate into corresponding interest rate movements. And the impact of larger shocks to autonomous liquidity factors can be offset immediately by means of occasional fine-tuning operations (R-10). Moreover, the regular fine-tuning operation on the last day of the reserve maintenance period (R-9) allows to ensure that the aggregate supply of reserves over the reserve maintenance period is as close as possible to the aggregate reserve target. Furthermore, the terms on which the central bank makes reserves available play a crucial role in anchoring overnight rates at or near the target rate. In particular, the tender procedure used for regular and occasional short-term and overnight repos contributes to anchoring overnight interest rates at the current target rate (R-12). Providing liquidity to the market by means of fixed rate tenders at the current target rate provides not only a clear signal on the central bank's intention to keep interbank rates at or close to the target rate, but it also allows to exploit the arbitrage relationship between the tender rate and market interest rates. Finally, the recommended operational framework exhibits various features that support central bank liquidity management. In particular, the assessment of the banking system's liquidity needs is facilitated by the fact that all participants to the interbank large-value payment system are subject to high and binding reserve requirements (R-3 and R-13) and by the symmetric interest rate corridor (R-7). These features entail that aggregate demand for reserves is well anchored at the aggregate reserve target, irrespective of the level of interest rates or the variance of liquidity shocks. Moreover, the predictability of autonomous liquidity factors is facilitated by applying reserve requirements to all participants to the interbank large-value payment system.

The interaction of all these features allows to anchor the overnight rate at the current target rate. The recommended operational framework thus allows the central bank to exert very tight control of overnight rates.

Objective 2: Liquid and Competitive Money Markets

Even though reserve requirements are fairly high and the reserve target range provides additional insurance against unintended reserve shortfalls or excess reserves, the recommended operational framework encourages banks to actively manage their end-of-day reserve balances throughout the reserve maintenance period. In particular, note that the central bank's liquidity management aims only at offsetting the impact of shocks to autonomous liquidity factors, whereas banks are also subject to idiosyncratic liquidity shocks. As noticed in Section 3.2.2, with relatively high reserve requirements and overnight rates following (at least approximately) a martingale process, banks' cost-minimizing strategy is to target a constant level of end-of-day reserve balances throughout the reserve maintenance period. This strategy requires to actively offset the impact of idiosyncratic liquidity shocks on a day-to-day basis, with corresponding positive effects on money market liquidity: Banks having experienced an unexpected inflow of liquidity will try to lend these funds to other banks in the interbank market, while banks confronted with an unexpected outflow of funds will undertake to borrow these funds. The interbank money market thus performs a crucial role in redistributing reserves from liquidity-abundant to liquidity-scarce banks, for the benefit of both.

There are a number of other features that favor liquid and competitive money markets. In particular, the rules and procedures of the operational framework are fairly simple and highly transparent. These characteristics, which are further supported by a detailed documentation (R-15), directly contribute to fair and predictable market conditions, thereby ensuring broad market participation. Fair competition is also promoted by granting all banks access to the central bank's open market operations and standing facilities (R-13). This ensures that no bank is (fully) dependent on the provision of liquidity by other banks. Moreover, potential market cornering by one or a few larger banks is prohibited (or at least severely impeded) by setting a maximum allotment for individual bidders in open market operations (R-12).

All in all, it can thus be concluded that the recommended operational framework is suited for ensuring liquid and competitive money markets.

Objective 3: Low Social Costs

It is more difficult to assess the social costs associated with the recommended operational framework. However, as argued in Section 5.1.3, instead of measuring social costs directly (which would be a formidable task), they can be gauged indirectly by means of the guiding principles set out in Section 5.2.

A first indication regarding the good performance in terms of social costs is given by the high degree of simplicity and transparency of the recommended operational framework. Indeed, the rules and procedures governing the use of the monetary policy instruments are straightforward, well attuned to each other, and limited to what is needed for effective monetary policy implementation. By keeping the operational framework as simple and transparent as possible, direct resource costs (both for the central bank and for commercial banks) are kept to a minimum. Above all, the operational framework ensures that liquidity management is made as simple and transparent as possible, both for the central bank and commercial banks, thereby avoiding unnecessary liquidity management costs and risks. From the central bank's perspective, the assessment of banks' demand for reserves is facilitated by the relatively high reserve requirements (R-8) and the symmetric interest rate corridor (R-7), which ensure that the demand for reserves is fairly stable throughout the reserve maintenance period and neither affected by the general level of interest rates nor by the uncertainty about liquidity shocks. From the banks' perspective, liquidity management is tremendously facilitated by the central bank's commitment to provide the amount of liquidity needed to comply with aggregate reserve targets and to smooth the supply of liquidity within the reserve maintenance period. This commitment implies that banks do not have to engage in socially wasteful guessing about any hidden signals in the central bank's open market operations, nor do they have to estimate the impact of shocks to autonomous liquidity factors, as they will be offset by the end of the reserve maintenance period at the latest.

The recommended operational framework also exhibits a number of features that allow to minimize the resource costs associated with potential distortions. This is probably most visible regarding the rules and procedures governing reserve requirements, where potential distortions are minimized by remunerating required reserves at the current tender rate for short-term repos (R-4). In combination with the acceptance of a wide range of collateral (R-14), this policy basically reduces banks' opportunity costs of complying with reserve requirements to zero, thereby eliminating the socially wasteful efforts to circumvent reserve requirements. Moreover, the principle of market neutrality is upheld by accepting a broad range of collateral and applying risk-based haircuts (R-14). And potential competitive distortions are minimized by granting broad access to all central bank operations (R-13) at equal conditions.

Altogether, the recommended operational framework thus performs rather well in terms of social costs, in particular when compared to most of the arrangements currently in place.

Chapter 7

Discussion

The preceding chapter has sketched the main features of a particular operational framework and argued that this framework is both effective and efficient, in the sense that it allows to achieve the identified policy objectives—tight control of the overnight rate, liquid and competitive money markets, and low social costs—to a high degree. This chapter examines some of the main features of the proposed operational framework in more detail.

By subjecting the operational operational framework to critical scrutiny, we pursue several objectives. First, the detailed discussion should contribute to apprehend the rationale underlying the individual recommendations and to understand how they are related to each other. At the same time, this will enhance the comprehension of how the recommended operational framework works as a whole. Moreover, the discussion intends to substantiate the contended benefits of the recommended operational framework in comparison with other frameworks.

As it is impossible to compare the proposed operational framework with all other potentially feasible frameworks, the analysis is confined to a comparison with fairly similar other frameworks. That is, the performance of the recommended operational framework is compared to the performance of alternative frameworks that differ from the recommended framework only with respect to certain features. If altering a particular feature impairs the performance, the recommended operational framework is preferable. This approach is suitable to analyze a wide range of issues, including why reserve requirements should be relatively high and what relatively high means; why it makes sense to allow for a reserve target range and to align the timing of the reserve maintenance period with monetary policy decisions; why standing facilities should provide for a symmetric interest rate corridor; or why short-term repos should be conducted as fixed-rate tenders.

The discussion is structured along the three monetary policy instruments. Reserve requirements are analyzed in Section 7.1, standing facilities in Section 7.2, and open market operations in Section 7.3.

7.1 Reserve Requirements

Provided they are suitably specified, reserve requirements contribute to the effective and efficient implementation of monetary policy. In particular, by ensuring and stabilizing the demand for reserve balances and by increasing the interest rate elasticity of reserve demand, they contribute to lower interest rate volatility. Section 6.1 included four particular recommendations regarding the specification of reserve requirements, namely on averaging (R-1), on the timing of reserve maintenance periods (R-2), on the reserve target range (R-3), and on remuneration (R-4). Below, these recommendations are discussed in more detail. Before that, however, the next subsection takes up an often ignored yet fundamental issue, namely the scope of application of reserve requirements (see also recommendation R-13 in Section 6.1).

7.1.1 Scope of Application

Who should be subject to reserve requirements in the first place? This obviously depends on the purpose of reserve requirements. As discussed in Section 2.4, the motivation for reserve requirements has changed over time. For instance, originally, reserve requirements were seen primarily as an instrument of prudential banking regulation, and the purpose of reserve requirements was to ensure that banks maintain sufficient liquidity to convert customers' deposits into currency. Hence, at that time, it made sense to impose reserve requirements on all deposit-taking institutions and to determine the level of required reserves in relation to their (short-term) liabilities.

Today, it is widely acknowledged that the sole purpose of reserve requirements is to facilitate the implementation of monetary policy. In particular, to the extent that the demand for central bank reserve balances is subject to fluctuation and difficult to predict, (binding) reserve requirements contribute to stabilizing the demand for reserves, thereby improving the central bank's forecast of aggregate demand and facilitating liquidity management. This implies that, ideally, all institutions which maintain an account with the central bank should be subject to reserve requirements, irrespective of whether they are deposit-taking institutions or not, or whether they are located domestically or abroad. The reasoning is obvious: If all these institutions were subject to binding reserve requirements, and if all these institutions had an incentive to achieve their reserve targets with high precision—as is the case under the recommended operational framework—, this would, first of all, facilitate the central bank's assessment of aggregate reserve demand. Moreover, compared to a situation where only deposit-taking institutions are subject to reserve requirements, there would also be less payment flows between reservable and non-reservable institutions, and hence potentially smaller shocks to autonomous liquidity factors. To the extent that shocks to autonomous liquidity factors have the potential to affect the supply of reserves and thus money market conditions, any measures that limit their size are conducive to monetary policy implementation.

In practice, it can be difficult to subject all institutions which maintain an account with the central bank to reserve requirements. This is particularly true for institutions such as foreign central banks, international or supranational organizations, and government agencies, for which many central banks provide accounts and at least some payment services. However, it is certainly possible to impose reserve requirements on all private-sector institutions participating in the large-value payment system, e.g. by stipulating compliance with reserve requirements as a condition for granting access to the large-value payment system.

The main benefit of subjecting as many reserve account holders as possible to (binding) reserve requirements lies in reducing the size of the shocks to autonomous liquidity factors. In terms of the money market model, this benefit can be exemplified by considering the last day of the maintenance period. On that day, in the morning, the central bank observes the level of reserve balances R_T^{bod} and the remaining reserve deficiency D_T, and it knows that the market interest rate will be determined according to Equation (6.1), i.e.

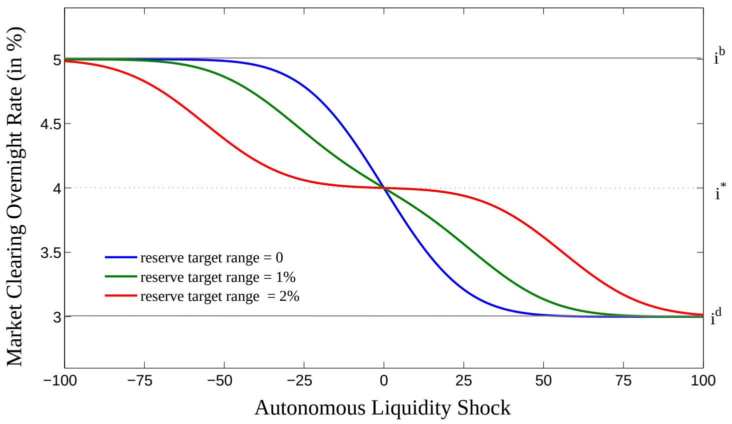
$$\begin{aligned} i_T &= \Gamma_{\varepsilon^A}\left(D_T - \lambda D_1 - R_T^{mc}\right) i^b \\ &+ \left[1 - \Gamma_{\varepsilon^A}\left(D_T + \lambda D_1 - R_T^{mc}\right)\right] i^d \\ &+ \left[\Gamma_{\varepsilon^A}\left(D_T + \lambda D_1 - R_T^{mc}\right) - \Gamma_{\varepsilon^A}\left(D_T - \lambda D_1 - R_T^{mc}\right)\right] i^*. \end{aligned} \tag{7.1}$$

At the time the central bank needs to decide on the size of the fine-tuning overnight repo $L_{T,T+1}$, $R_T^{mc} = R_T^{bod} + L_{T,T+1} + \eta_T^M$ is a random variable with mean $R_T^{bod} + L_{T,T+1}$ and variance $\tilde{\sigma}^2_{\eta^M}$ (see Appendix A.1.2). In order to maximize the probability that the (expected) overnight rate i_T will equal the target rate i^*, the central bank should set $L_{T,T+1}$ such that $E_T(R_T^{mc}) = D_T$, which implies $L_{T,T+1} = D_T - R_T^{bod}$. In that case, $D_T - R_T^{mc} = -\eta_T^M$, and once the autonomous liquidity shock in the morning has been realized, the equilibrium overnight rate i_T will be

$$
\begin{aligned}
i_T &= \Gamma_{\varepsilon^A}\left(-\lambda D_1 - \hat{\eta}_T^M\right) i^b \\
&+ \left[1 - \Gamma_{\varepsilon^A}\left(\lambda D_1 - \hat{\eta}_T^M\right)\right] i^d \\
&+ \left[\Gamma_{\varepsilon^A}\left(\lambda D_1 - \hat{\eta}_T^M\right) - \Gamma_{\varepsilon^A}\left(-\lambda D_1 - \hat{\eta}_T^M\right)\right] i^*.
\end{aligned} \tag{7.2}
$$

The impact of the realized autonomous liquidity shock $\hat{\eta}_T^M$ on i_T is shown in Figure 7.1, where the underlying assumptions are $T = 28$, $D_1 = 2,800$, $\sigma_{\varepsilon^A} = 20$, $i^b = 5\%$, $i^d = 3\%$, and λ is either 0, 1 or 2 percent.

Figure 7.1: Impact of Autonomous Liquidity Shocks on the Market Clearing Overnight Rate on Day T



As one would expect, negative shocks, which drain reserves from the market, will push the overnight rate towards the borrowing rate i^b, whereas positive shocks, which add reserves to the market, will push the overnight rate towards the deposit rate i^d. However, for a given size of $\hat{\eta}_T^M$, these effects are decreasing in λ. That is, the larger the reserve target range, the smaller is the impact of autonomous liquidity shocks on the market clearing overnight rate. We will come back to this point in Section 7.1.4. What matters here is that smaller autonomous liquidity shocks allow more effective interest rate control. Therefore, taking measures that reduce their size—such as subjecting as many reserve account holders to reserve requirements—enhances the performance of the operational framework.[1]

[1] Of course, all institutions subject to reserve requirements must be able to manage their reserves. This is why these institutions should also be given access to the standing facilities and be eligible for open market operations (see recommendation R-13).

Because the shocks to autonomous liquidity factors have the potential to interfere with central bank liquidity management, they matter not only on the last day of the reserve maintenance period but also before. Indeed, the larger the shocks to autonomous liquidity factors, the more difficult it is for the central bank to smooth the day-to-day provision of liquidity within the reserve maintenance period (see R-8). If the shocks are large relative to the daily average required level of reserves (measured by D_1/T), the smooth provision of reserves throughout the reserve maintenance period might necessitate either an increase in the frequency of regular short-term repos or the frequent conduct of occasional overnight or short-term repos to offset the impact of these shocks. Therefore, also from this perspective, reducing the size of the shocks to autonomous liquidity factors is beneficial.

7.1.2 Averaging

In order to increase the elasticity of reserve demand and hence to unfold their full potential as a monetary policy instrument, reserve requirements should allow for averaging over a reserve maintenance period. The benefits of reserve averaging become apparent by comparing the recommended operational framework with a similar operational framework, which differs only with respect to one element, namely that the reserve maintenance period is shortened to one day. In terms of the analysis within the context of the money market model, this means setting $T = 1$. Each day could then be considered as the last day of the reserve maintenance period and, consequently, each day the overnight interest rate would be determined according to Equation (7.1).

A one-day reserve maintenance period affects the performance of the operational framework as follows. First, if the central bank were to refrain from daily fine-tuning overnight repos and conduct only the regular weekly short-term repos, the shocks to autonomous liquidity factors between these operations would directly affect overnight rates (because there is no possibility that these shocks will be offset later on in the current reserve maintenance period). In contrast, in the case of averaging over a multi-day reserve maintenance period, these shocks have a very limited impact on current overnight rates (if any impact at all), as banks rightly expect that the shocks will be offset later on by the central bank's open market operations.

Moreover, even if the central bank were to conduct daily fine-tuning overnight repos, there would be an increase in interest rate volatility, unless the reserve target range is extremely wide. But too wide a reserve target range might have a detrimental impact on the liquidity of the money market, as banks would have little incentives to adjust their reserve positions by trading in the interbank money market (see Section 7.1.4). And as the conduct of open market operations is not free of cost (both for the central bank and its counterparties), daily overnight repos would cause higher social costs than in the recommended operational framework. Without an averaging provision the operational framework thus performs worse with respect to each of the three policy objectives. Recommendation R-1 thus is uncontested.

7.1.3 Timing of Reserve Maintenance Periods

The review of major central banks' practical experiences with their operational frameworks in Chapter 4 has shown that the precise timing of reserve maintenance periods matters. The reason is straightforward. If the reserve maintenance period is longer than one day (which is unavoidable to benefit from averaging), commercial banks will try to exploit any arbitrage opportunities within the reserve maintenance period. If banks expect overnight rates to be higher (lower) later on during the reserve maintenance period, they will want to front-load (back-load) their reserve holdings and adjust their borrowing or lending in the interbank money market accordingly. Such arbitrage is important to establish the martingale property of overnight rates.

At the same time, the exploitation of expected target rate changes raises some issues in terms of banks' bidding behavior in the central bank's open market operations. If banks expect to obtain funds from the central bank at a lower price later on during the same reserve maintenance period, they will refrain from bidding today (underbidding). And vice versa, if banks expect to receive funds from the central bank only at a higher price later on during the same maintenance period, they will try to borrow as much as possible today (overbidding). Both situations are undesirable. On the one hand, in case of underbidding, banks will find themselves short of reserves, which might give rise to tensions in the interbank money market and hence might necessitate additional fine-tuning operations. On the other hand, in case of (extreme) overbidding, the allocation of funds to individual bidders can be rather arbitrary. Some banks (those who bid most aggressively because they expected others to do the same) may end up being allocated way too many funds, while other banks (those who bid according to their true demand) may receive much less than what they actually need. Of course, such imbalances can be offset by redistributing reserves in the interbank money market, but in case some banks find it difficult to borrow or lend large amounts, these imbalances can cause tensions in the money market.

The detrimental effects of expected target rate changes on banks' bidding behavior are easily avoided by three complementary measures. The first measure is to align the end of reserve maintenance periods with the timing of monetary policy decisions (see recommendation R-2). As monetary policy decisions are typically taken and communicated on scheduled and publicly announced dates, it is straightforward to determine the reserve maintenance periods such that they expire right before potential target rate changes become effective. The second measure is to ensure that regular short-term open market operations mature before the potential target rate change becomes effective (i.e. before or at the first day of the next maintenance period, see R-9). And finally, the third measure is to set the tender rate in regular short-term operations equal to the current target rate (see R-12).

Two further comments on the timing of reserve maintenance periods are appropriate. First, regarding the appropriate length of maintenance periods, the interval between scheduled monetary policy decisions provides an upper bound to the length of the reserve maintenance period. For instance, if monetary policy decisions are taken every four weeks, it is not possible to have longer reserve maintenance periods. It is, however, feasible to have more than one reserve maintenance period between two scheduled meetings. Although the benefits of averaging would speak in favor of having longer rather than shorter reserve maintenance periods, having two or more reserve maintenance periods between two scheduled monetary policy meetings may make sense if this interval is fairly long, say if monetary policy decisions are taken on a quarterly basis only.

Second, even though central banks take their monetary policy decisions usually on scheduled dates, they do not (and should not) commit to never change the target rate between these dates. Therefore, one might argue that the issues arising from expected target changes within reserve maintenance periods cannot be fully eliminated by aligning reserve maintenance periods with the timing of regular monetary policy decisions. But this argument can be easily rebutted. First, most central banks' monetary policy committees meet quite often, typically once a month. Even in times of heightened uncertainty about economic developments there are thus frequent opportunities to adjust the stance of monetary policy if deemed necessary. The need for changing the target rate between scheduled monetary policy meetings should thus be very limited. Moreover, should the need to change the target rate before the next scheduled meeting arise nonetheless, it is typically due to a major shock, which was (by definition) not foreseeable, neither by the central bank nor by market participants. By way of example, after the 2001 terrorist attacks on the World Trade Center in New York a number of central banks slashed their target rates without waiting for the next scheduled policy meeting. As these (unscheduled) target rate changes had not been anticipated, they did not affect market participants' bidding behavior in the open market operations preceding the terrorist attacks. It follows that recommendation R-2 is an indispensable feature of an effective and efficient operational framework.

7.1.4 Reserve Target and Reserve Target Range

This section addresses two issues, the appropriate level for a bank's reserve target and the appropriate size of the target range around banks' reserve targets. In the money market model, the first is captured by $D_{i,1}$ and the latter by the parameter λ.

Reserve Target

The specification of reserve requirements is critical for their effectiveness and efficiency as a monetary policy instrument. The level of reserve requirements—here measured by a bank's reserve target $D_{i,1}$—is an important dimension of this specification.

On the one hand, too low reserve requirements would compromise their effectiveness in terms of stabilizing the demand for reserves, which in turn would complicate the implementation desk's assessment of the banking system's liquidity needs on a day-to-day basis. Also, low reserve requirements—and hence low reserve balances—would imply that banks experiencing sufficiently large liquidity shocks would have to rely frequently on either of the standing facilities.

On the other hand, too high reserve requirements can cause distortions and inefficiencies. For instance, even if reserve requirements are remunerated, distortions may arise if in order to comply with reserve requirements banks need to deviate significantly from their optimal portfolio allocation, e.g. if they have to hold more central bank eligible collateral than they would otherwise. Therefore, even though reserve requirements need to be sufficiently high to support the effective implementation of monetary policy, they should not be unduly high.

To determine the appropriate level of reserve requirements, one needs to be clear about their purpose. From the perspective of the implementation desk, reserve requirements should contribute to a stable and predictable reserve demand throughout the reserve maintenance period. Ideally, banks should be inclined to hold the same amount of end-of-day reserves on any day. That is, there should be no incentive for either front-loading or back-loading reserve demand within the maintenance period. In this case, forecasting banks' demand for reserves is straightforward and the implementation desk only has to make sure that the supply of reserves matches the demand. Moreover, under these circumstances, the overnight rate exhibits the martingale property. Then, if banks expect the overnight rate to be equal to the target rate on the last day of the maintenance period, the equilibrium overnight rate on previous days should also be equal to the target rate.

What does this imply for the appropriate level of reserve targets? As discussed at the end of Section 3.2.2, in order to ensure that banks' demand for end-of-day reserve balances is fairly constant throughout the reserve maintenance period, reserve requirements need to be high enough to absorb the impact of potential liquidity shocks. As the impact of liquidity shocks experienced before market clearing can be offset in the interbank money market on the same day, the only shock that matters in this context is a bank's cumulated liquidity shock in the afternoon ($\varepsilon_{i,t}^{A}$). If the distribution of these shocks is known, it is straightforward to determine the level of the reserve target $D_{i,1}$ such that the probability that the bank will have to have recourse to either of the two standing facilities on any day is extremely low. For instance, assuming normally distributed liquidity shocks, setting $D_{i,1}/T \geq 4\sigma_{\varepsilon^A}$ is sufficient to avoid any incentives for front- or back-loading reserve demand (see Table 3.1). The appropriate level for a bank's reserve target is thus linked to the standard deviation of the bank's cumulated liquidity shock in the afternoon and the length of the maintenance period.

Having established the appropriate theoretical level of reserve requirements, there remains the practical issue of implemention. Today, in most countries reserve requirements are still computed based on banks' (short-term) liabilities, a remnant from the times when reserve requirements served other purposes (see the discussion in Section 2.4). However, it is unlikely that this practice is suited to establish appropriate reserve targets in the sense of the discussion above. Alternatives are thus needed, and some approaches are discussed in the following.

Ideally, the central bank would have the possibility to set each bank's reserve target based on the empirical data of the bank's liquidity shocks. If adequate data is not available, it could rely on proxy measures, such as a bank's turnover in the large-value payment system. This proxy works if a bank's turnover and the size of its liquidity shocks are positively correlated. Banks' reserve targets could then be set as a fraction of their turnover in the large-value payment system.

Another possibility consists in having reserve targets determined by the banks themselves. Indeed, since reserve requirements are remunerated and do not impose any significant opportunity costs, it is in a bank's own interest to set the reserve target sufficiently high so that reserve requirements can perform their role as shock absorber, facilitate liquidity management and prevent it from having recourse to costly standing facilities.

The two proposals might also be combined. The central bank could determine the minimum reserve target based on empirical data on banks' liquidity shocks or banks' turnover in the payment system, while banks retain the possibility to set higher reserve targets if they believe that the one determined by the central bank is not sufficiently high. Of course, there may be other approaches to establish banks' reserve targets. But since the method as such does not really matter, in the following, it will simply be assumed that reserve targets are appropriate, without further specifying the approach in detail.

Reserve Target Range

As shown in Section 6.2.2, establishing a reserve target range allows to mitigate or even avoid the usual spikes in overnight rates at the end of reserve maintenance periods. Without a reserve target range, such spikes arise whenever the central bank's forecast of autonomous liquidity factors deviates from the actual realization. In the model, these deviations are captured by the autonomous liquidity shock in the morning (η_T^M).

From Equation (6.1) and Figure 6.1 it is also evident that the larger the target range (i.e. the larger the parameter λ), the higher is the interest rate elasticity on day T. In other words, the red curve becomes flatter and the impact of an autonomous liquidity shock of given size on the market clearing overnight rate i_T becomes smaller.

This would speak in favor of setting the target range as wide as possible. However, too wide a target range is likely to have a detrimental effect on the liquidity of the interbank money market. To see why, assume that $T = 28$, $D_{i,1} = 2,800$, $\sigma_{\varepsilon^A} = 20$ and λ can be either zero or 3%. Now consider a bank that has started the last day of the reserve maintenance period with a reserve deficiency of $D_{i,T} = 100$ and, just before market clearing, has a reserve balance of $R_{i,T}^{mc} = 80$. If there is no target range ($\lambda = 0$), the bank should borrow 20 in the market so that the expected end-of-day position equals the reserve deficiency, in which case the expected cost of having access to the standing facilities at the end of the day are minimized. But if $\lambda = .03$, there is much less incentive for the bank to offset the imbalance between $D_{i,T}$ and $R_{i,T}^{mc}$, as it is very likely that the reserve position at the end of the day, $R_{i,T}^{eod} = R_{i,T}^{mc} + \varepsilon_{i,T}^A$, will be sufficient to comply with reserve requirements. Indeed, note that in general the bank complies with reserve requirements as long as $D_{i,T+1} \in [-\lambda D_{i,1}; \lambda D_{i,1}]$, where $D_{i,T+1} = D_{i,T} - R_{i,T}^{eod}$. In the particular numerical example, it complies with reserve requirements if $D_{i,T+1} \in [-84; 84]$, or alternatively, if $R_{i,T}^{eod} \in [16; 184]$. In other words, as long as $\varepsilon_{i,T}^A$ turns out to be in the interval $[-64; 104]$, the bank will meet reserve requirements and will not have to use either of the two standing facilities. For the assumed standard deviation of $\varepsilon^A_{i,T}$ this is very likely to be the case and hence there is no need for the bank to borrow in the market.

One might object that even though the probability of not complying with reserve requirements is very low in the above example, it is not zero and hence borrowing in the money market the amount necessary so that the bank expects to meet the reserve target as closely as possible still provides a marginal benefit. This is true in the context of the money market model, which for simplicity abstracts from any transaction costs. However, to the extent that in practice any borrowing or lending activities in the money market imply some form of transaction costs, there will be situations where these transaction costs outweigh the benefits from participating in the money market. As a result, the interbank money market would become less liquid. Too wide a reserve target range would thus compromise the objective of liquid money markets.

When determining the reserve target range—that is setting the parameter λ in the money market model—one thus needs to strike the right balance between the contribution to effective interest rate control and the impact on money market liquidity. In practice, the appropriate λ is a function of the variance of the autonomous liquidity shock in the morning ($\tilde{\sigma}^2_{\eta^M}$), the variance of the cumulated liquidity shock in the afternoon ($\sigma^2_{\eta^A}$), and transaction costs. In particular, λ should be increasing in $\tilde{\sigma}^2_{\eta^M}$ and $\sigma^2_{\eta^A}$, but decreasing in transaction costs.

7.1.5 Remuneration

The remuneration of reserve requirements, and the consequences if a bank does not comply with them, is another factor affecting the effectiveness and efficiency of monetary policy implementation. In terms of efficiency, it is widely acknowledged that in order to minimize the potential distortions associated with reserve requirements—and hence to minimize the social costs associated with the implementation of monetary policy—, opportunity costs of required reserves should be eliminated.

In the recommended operational framework required reserves are remunerated at the level of the central bank's average tender rate for short-term repos over the current reserve maintenance period. At the same time, the average tender rate for short-term repos is equal to the target overnight rate i^*, at least as long as the central bank does not change the target rate within the reserve maintenance period. In that case, the recommended remuneration policy eliminates basically any opportunity costs associated with reserve requirements. This is because for the banks as a group, the central bank is the only source of reserves, and these reserves are provided to the banks primarily by means of short-term repos. In the recommended operational framework, the cost of borrowing these reserves is equal to the (fixed) tender rate, which in turn equals the target rate. By remunerating required reserves at the tender rate, banks are fully reimbursed for the costs associated with borrowing reserves from the central bank and opportunity costs are thus eliminated.

Closely related is the question of what happens if a bank does not comply with reserve requirements. In the recommended operational framework, a bank complies with reserve requirements if the sum of end-of-day reserve balances over the reserve maintenance period is within the reserve target range, or alternatively, if at the end of the reserve maintenance period the bank's reserve deficiency is such that $D_{i,T+1} \in [-\lambda D_{i,1}; \lambda D_{i,1}]$. If the bank's accumulated reserve balances fall short of the lower bound of the reserve target range ($D_{i,T+1} < -\lambda D_{i,1}$), the bank will have to borrow the reserve deficiency at the borrowing facility at rate i^b. And if accumulated reserve balances are larger than the upper bound of the reserve target range ($D_{i,T+1} > \lambda D_{i,1}$), the bank will have to deposit excess reserves in the deposit facility, earning the deposit rate i^d.

The crucial point of this arrangement is that reserve shortfalls and excess reserves have the same opportunity costs. This is because the remuneration of any reserves that fall within the reserve target range is equal to the target rate i^* and the standing facilities provide for a symmetric corridor around i^*, so that we can write $i^d = i^* - \omega/2$ and $i^b = i^* + \omega/2$. The opportunity cost of excess reserves or of a reserve shortfall thus is $\omega/2$. Given that the reserve target range is symmetric around the reserve target, the symmetry of opportunity cost implies that each bank has the incentive to achieve the reserve target as closely as possible, as this maximizes the probability that it will end the reserve maintenance period within the reserve target range (and thus does not have to incur any opportunity cost related to the access to standing facilities). To put it differently: On the last day of the reserve maintenance period, a bank should borrow or lend in the market the amount necessary such that $E(R_{i,T}^{eod}) = D_{i,T}$ and hence $E(D_{i,T+1}) = 0$. In turn, this implies that the implementation desk's fine-tuning overnight repo transaction should be such that $E(D_{T+1}) = 0$.

7.2 Standing Facilities

Standing facilities that provide for a symmetric interest rate corridor around the overnight target rate are a crucial element of the recommended operational framework. This section first recalls the rationale of this arrangement and then discusses the pros and cons of having a larger or smaller spread between the two standing facility rates.

7.2.1 Symmetric Interest Rate Corridor

The main advantage of having a symmetric interest rate corridor around the overnight target rate is straightforward: It tremendously facilitates the central bank's liquidity management. As revealed on many occasions throughout this study, this is because a symmetric interest rate corridor makes banks' demand for reserves very predictable, especially if the level of reserve requirements is sufficiently high. Most notably, with a symmetric interest rate corridor, the demand for reserves does not depend on the general level of interest rates. Hence, an increase or decrease in the overnight target rate (and accordingly in the standing facility rates) does not affect banks' demand for reserves. Rather, since opportunity costs of reserve shortfalls and excess reserves are the same, banks' demand for reserves is well-anchored at the level of the reserve target.

The benefit of a symmetric interest rate corridor is most evident on the last day of the reserve maintenance period. Assuming for simplicity that the reserve target range is zero, recall from Equation (3.19) that the implementation desk's neutral allotment for the overnight fine-tuning operation on day T is

$$L^n_{T,T+1} = \overline{L}_T + D_T - R^{bod}_T - \Phi^{-1}\left(\frac{i^* - i^d}{i^b - i^d}\right)\sigma_{\varepsilon^A}. \tag{7.3}$$

In case of a symmetric interest rate corridor, it follows that $\Phi^{-1}\left(\frac{i^*-i^d}{i^b-i^d}\right) = 0$, so that the last term on the right hand side of Equation (7.3) disappears. The neutral allotment then is simply $L^n_{T,T+1} = \overline{L}_T + D_T - R^{bod}_T$, which can be easily implemented.

In contrast, assume a non-symmetric interest rate corridor. This is the case if, for instance, there is no deposit facility, which is equivalent to setting $i^d = 0$. The neutral allotment on day T then is

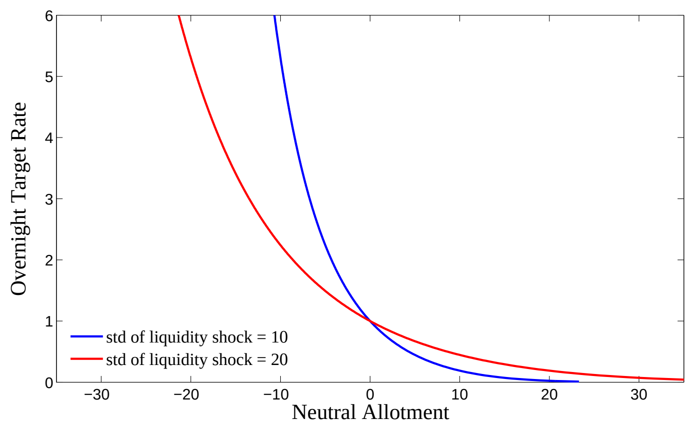
$$L^n_{T,T+1} = \overline{L}_T + D_T - R^{bod}_T - \Phi^{-1}\left(\frac{i^*}{i^b}\right)\sigma_{\varepsilon^A}. \tag{7.4}$$

The last term on the right hand side of Equation (7.4) disappears only if $i^b = 2\,i^*$. If the borrowing rate is set as a fixed markup over the overnight target rate, this will be the case only by chance. In all other situations, the last term will not disappear and complicate the implementation desk's fine-tuning operation, as the precise distribution of the cumulated liquidity shock in the afternoon needs to be known to implement the neutral allotment. Moreover, even if the precise distribution were known, it is apparent that the neutral allotment would depend on the general level of interest rates. To see this, write $i^b = i^* + \omega/2$ so that the neutral allotment becomes

$$L^n_{T,T+1} = \overline{L}_T + D_T - R^{bod}_T - \Phi^{-1}\left(\frac{i^*}{i^* + \omega/2}\right)\sigma_{\varepsilon^A}. \tag{7.5}$$

Setting $\omega/2 = 1\%$ and assuming for simplicity that $\overline{L}_T + D_T - R^{bod}_T = 0$, Figure 7.2 shows, for two different values of σ_{ε^A}, how the neutral allotment varies with the level of the overnight target rate.

Figure 7.2: Neutral Allotment with Non-Symmetric Interest Rate Corridor



In this example, the implementation desk will have to inject (absorb) reserves, whenever i^* is smaller (higher) than 1%. For instance, if the target rate were equal to 3%, the neutral allotment would be $L^n_{T,T+1} = -6.7$ (for $\sigma_{\varepsilon^A} = 10$) or $L^n_{T,T+1} = -13.5$ (for $\sigma_{\varepsilon^A} = 20$), respectively. Moreover, only in the special case where $i^* = 1\%$, in which case there would be a symmetric interest rate corridor, the neutral allotment would not depend on the variance of the cumulated liquidity shock in the afternoon.

7.2.2 The Width of the Interest Rate Corridor

Having established that a symmetric interest rate corridor is undeniably a desirable feature of the recommended operational framework, the spread between the standing facility rates remains to be determined. As will become clear from the following discussion, the decision on the spread will have to trade-off two of the policy objectives set out in Section 5.1. On the one hand, tight interest-rate control would speak in favor of having a very narrow interest rate corridor. On the other, money market liquidity will benefit from a large spread between the borrowing and the deposit rate.

The first part of this trade-off is straightforward. The two standing facilities provide a natural corridor for interbank money market overnight rates. No bank would ever pay more than the borrowing rate, and no bank would ever accept less than the deposit rate. The smaller the width between the two standing facility rates, the smaller thus is the range of feasible interest rates in the interbank money market. In the extreme case, when the spread is zero and the borrowing and the deposit rate coincide with the overnight target rate, banks would never transact with each other at any other rate than the target rate and there would be perfect interest rate control.

However, in case there is a zero spread between the standing facility rates, it remains unclear why banks should transact with each other in the first place. Rather than borrowing reserves from or lending reserves to other banks, any bank could simply use the standing facilities to adjust its reserve position as needed at the end of the day. This is because the opportunity costs of having recourse to these facilities would be zero (note that the opportunity cost for a bank having recourse to the borrowing facility is the difference between i^b and the overnight interest rate it would have paid earlier on in the interbank money market; similarly, the opportunity cost for using the deposit facility is the difference between the overnight interest rate it would have been paid in the interbank money market and i^d). The extreme example of a zero interest rate corridor thus reveals that money market liquidity is affected by the width of the interest rate corridor. The smaller the width, the lesser banks' incentives to actively manage their reserve positions, as the opportunity costs of having recourse to the standing facilities decrease.[2]

As a zero spread inevitably leads to a dysfunctional money market, it cannot be optimal. But how wide does the interest rate corridor have to

[2] Allen (2007) discusses a related issue associated with too narrow an interest rate corridor. If banks are confident that their cash flow management can be carried out relatively cheaply by transacting with the central bank, they will reduce their efforts in forecasting their own cash flows, which is likely to be unconducive to prudent (liquidity) risk management.

be to ensure a liquid money market? In the context of the money market model, which abstracts from transaction costs, even a very small spread would be sufficient to provide banks sufficient incentives to actively manage their reserve positions in the interbank money market. In practice, however, the existence of transaction costs implies that opportunity costs of having recourse to the standing facilities need to be sufficiently large to ensure a liquid money market. It is thus likely that a liquid money market can only be established if the interest rate corridor is sufficiently wide. But paradoxically, at the same time, a liquid money market is likely to reduce transaction costs, in which case a rather narrow interest rate corridor would provide sufficient incentives for banks to actively manage their positions in the interbank money market. The optimal width of the interest rate corridor thus remains largely an empirical question and it might not necessarily be the same across different money markets.

To get a better feeling for what the appropriate spread in absolute terms might be, assume that each interbank money market transaction involves fixed transactions costs of 50. Further, assume that on day T a bank enters the market with a reserve position that is 5 million short of its preferred position and that it could borrow this amount in the market at the current overnight target rate i^*. Does it pay off to borrow 5 million in the money market? Or should the bank rather sit and wait and cover the (expected) shortfall at the borrowing facility at rate $i^b = i^* + \omega/2$? In the first case, the cost of borrowing in the market is $C_1 = 50 + \frac{5{,}000{,}000 \cdot i^*}{100 \cdot 360}$. In the second case, the (expected) cost of borrowing from the borrowing facility is $C_2 = \frac{5{,}000{,}000 \cdot (i^* + \omega/2)}{100 \cdot 360}$. Some simple arithmetic then reveals that $C_2 > C_1$ for $\omega >$ 72 bp. Therefore, only if the interest rate corridor is sufficiently wide—in the example it would have to be more than 72 bp—the bank would fare better by borrowing in the market.

7.3 Open Market Operations

Regarding the central bank's open market operations, it is useful to distinguish two issues. First, the liquidity management strategy, which determines the amount and pattern of liquidity to be provided to the banking system. And second, the type of operations used for the provision of liquidity. This section focuses first on the recommended liquidity management strategy and then discusses how this strategy can be implemented by a combination of regular repo transactions with different maturities. Finally, this section also provides the rationale for occasional and exceptional other transactions.

7.3.1 Liquidity Management Strategy

According to recommendation R-8, the central bank's liquidity management strategy consists of two pillars. First, the central bank should undertake to provide the amount of liquidity the banking system needs to comply with aggregate reserve targets over the reserve maintenance period. And second, within the reserve maintenance period, the central bank should aim at smoothing the day-to-day provision of liquidity.

The rationale for this strategy is straightforward from the inspection of Equations (6.1) and (6.2). On the last day of the maintenance period, the first element of the strategy implies that the central bank commits to set $L_{T,T+1} = D_T - R_T^{bod}$, in which case the banks' probabilities of having recourse to either of the standing facilities are the same and hence the expected market clearing overnight rate as of the time when the open market operation takes place is i^*. If the central bank were to provide more (less) liquidity, this would increase (decrease) the probability of having recourse to the deposit (borrowing) facility, pushing the expected overnight rate above (below) the target rate. Also, note that simply implementing $L_{T,T+1} = D_T - R_T^{bod}$ is not sufficient. Rather, the central bank needs to commit to do so *ex ante*, as only this commitment ensures that on previous days market participants expect that i_T will equal the target rate.

The second element—smoothing the day-to-day provision of liquidity—contributes to avoiding situations where banks expect that they will have to use either of the standing facilities on previous days, as would be the case if at the end of the day they incurred an overdraft or experienced excess reserves. While a sufficiently high level of reserve requirements serves as a buffer to absorb the impact of ordinary shocks to autonomous liquidity factors, these situations could nevertheless arise in the case of very large shocks to autonomous liquidity factors that are not offset by the central bank sufficiently quickly. It does not mean, however, that all ordinary autonomous liquidity shocks must be offset on a daily basis and, typically, it will be sufficient to offset liquidity imbalances on a weekly basis.

7.3.2 Regular Operations

The liquidity management strategy described above can be implemented in many different ways. Recommendation R-9 suggests to rely on a specific combination of regular long-term, short-term and overnight repos. Other relevant operational factors relate to the tender procedure (recommendation R-12), the counterparties eligible for open market operations (recommendation R-13), and the collateral framework (recommendation R-14).

Type

Using repo transactions as regular open market operations provides a number of advantages (CGFS 1999, Bindseil and Würtz 2007). First and foremost, repos allow to manage liquidity in a flexible and precise manner, as their main features (amount, maturity, frequency, tender procedure) can be tailored according to liquidity conditions. In particular, repos not only allow to provide liquidity, but also to withdraw liquidity from the market, either by not renewing all or some fraction of maturing repos (provided the maturity structure is tailored to do so), or by conducting reverse repos.[3] In addition, repos carry low credit risk, have no or very limited impact on the prices of underlying securities (at least in the case of general collateral repos with relatively short maturity), and utilize established markets accessible to a broad range of financial institutions.

Structure

The suggested structure of regular operations distinguishes between long-term, short-term and overnight repos. These repos serve different functions.

The fine-tuning overnight repo on the last day of the reserve maintenance period aims at bringing in line the supply of liquidity with the amount of liquidity needed by the banking system to comply with reserve requirements. As mentioned before, in order to maximize the probability that the (expected) overnight rate i_T will equal the target rate i^*, the size of this repo transaction is $L_{T,T+1} = D_T - R_T^{bod}$. This operation can be either liquidity providing or liquidity absorbing. While the size of this transaction might be small, its importance cannot be underestimated, as the *ex ante* commitment to offset any liquidity imbalance before the end of the reserve maintenance period exerts a very strong influence on banks' interest rate expectations and contributes significantly to keep the overnight rate at or very near the target rate throughout the reserve maintenance period.

The bulk of liquidity needed by the banking system is provided by means of short-term and longer-term repos, but the two have different functions. On the one hand, three- or six-months repos are useful to provide a certain amount of liquidity on a longer-term basis (basic refinancing). The advantage of longer-term repos is mainly operational: Instead of rolling over all the liquidity by more frequent short-term repos, the same effect in terms

[3]Note, however, that reverse repos may not be suitable to withdraw large amounts of liquidity, as the central bank may be collateral constrained. It is thus recommended that the central bank has at its disposal other liquidity-absorbing instruments that can be used in exceptional circumstances.

of liquidity provision can be achieved by less frequent longer-term repos. Depending on the arrangements in place for clearing and settling repo transactions, this can also reduce settlement risks (CPSS 2010). On the other hand, a certain amount of liquidity needs to be provided by means of regular short-term repos, as they provide more flexibility to react to short-term liquidity imbalances. There is, however, no general rule to determine how much liquidity should be provided by long-term and short-term repos, respectively. Depending on the circumstances, some central banks will find it preferable to provide a relatively large share of liquidity by means of long-term repos, whereas other will provide the bulk of liquidity by means of short-term repos.

The appropriate frequency and maturity of short-term repos depends on various factors, including the timing and length of the reserve maintenance period, the level of reserve requirements, the variance of the shocks to autonomous liquidity factors, and the transactions costs (for both the central bank and banks) associated with the conduct of open market operations. Most importantly, the frequency-maturity structure must ensure that short-term repos do not span over the end of the maintenance period (which is linked to the timing of monetary policy decisions), which could cause over- or underbidding in the event of expected target rate changes. Moreover, as short-term repos should allow to offset any liquidity imbalances due to ordinary shocks to autonomous liquidity factors, it follows that—in order to ensure a sufficiently smooth supply of liquidity throughout the reserve maintenance period—short-term repos must be conducted frequently if the level of reserve requirements is low or if the variance of shocks to autonomous liquidity factors is high. In the context of the recommended operational framework, where reserve requirements are relatively high compared to the size of liquidity shocks, it seems that weekly repos with a maturity of one week strike the right balance between the need to be able to react quickly to liquidity imbalances (which would call for frequent operations) and the intention to minimize transaction costs (which would call for less frequent operations). Assuming that the reserve maintenance period lasts four weeks, the central bank would thus conduct each week one short-term repo with maturity of seven days, with the last one maturing on the first day of the next reserve maintenance period.

Tender Procedure

Whether it is preferable to use fixed rate or variable rate tenders cannot be generally stated, as they both have advantages and disadvantages (Bindseil and Würtz 2007). The prime advantage of fixed rate tenders is that they provide a strong signal on the monetary policy stance and can be considered as an implicit pre-commitment to keep the overnight rate near the tender rate. Fixed rate tenders also seem to be logically more consistent with the concept of interest rate steering, especially if the tender rate is set equal to the target rate. Moreover, bidding in fixed rate tenders is simpler than in variable rate tenders, which reduces the risk of putting less sophisticated bidders at a disadvantage. However, a major drawback of fixed rate tenders is that they can give rise to underbidding or extreme overbidding in the event that market participants expect the target rate to be changed before the repo matures.

Variable rate tenders are usually seen as a more efficient allocation mechanism, as banks can express their relative preferences for funds in their bids. However, to the extent that there exists an efficient interbank market, achieving an efficient allocation of reserves does not seem to be a major concern in central banks' open market operations. Moreover, the phenomena of under- and overbidding are less likely in variable rate tenders, although underbidding would still be possible if a minimum bid rate applies. A major drawback of variable rate tenders is that the variations in the (marginal) bid rate can be misinterpreted as a policy signal by the central bank. This is particularly the case if the allotment volume is not pre-announced, in which case it will be unclear to the market whether the central bank, when deciding on the allotment, cares about the resulting interest rate.

While both fixed and variable rate tenders thus have their merits, it seems that in the context of the recommended operational framework regular short-term as well as the fine-tuning overnight repos are better conducted as fixed rate tenders (see recommendation R-12). This is because the main concern with fixed rate tenders—the underbidding or extreme overbidding—is avoided by the specific frequency-maturity structure, which ensures that short-term repos never span into the next reserve maintenance period. Moreover, to further reduce the incentives for extreme overbidding (which could be related to the attempt of cornering the market), the central bank may set a maximum allotment ratio for any bidder. In the event of overbidding, which will likely occur to some extent nonetheless, reserves will simply be allotted on a pro-rata basis.

Fixed rate tenders are not advisable, however, for longer-term repos, where banks' bidding behavior will be affected inevitably by expected target rate changes. This is why these operations should be conducted as variable rate tenders (without minimum bid rate). To avoid any confusion and to ensure that all market participants understand that the resulting marginal rate does not reflect any policy signal by the central bank but rather banks' own interest rate expectations, the central bank should take appropriate measures such as pre-announcing the intended allotment. Moreover, for reasons of equal treatment of banks the variable rate tender should be conducted as uniform price auction.

Eligible Counterparties

The operational framework also needs to specify the range of counterparties the central bank is willing to transact with. According to recommendation R-13, all institutions that participate to the large-value payment system and are subject to reserve requirements should be eligible counterparties for open market operations. This is because these institutions must be able to actively manage their reserves, and access to the central bank's open market operations is crucial to that end.

Having a broad range of eligible counterparties has other benefits, too. In particular, from a liquidity risk management perspective, the broader the range of counterparties with access to open market operations (including standing facilities), the broader the provision of funding liquidity risk insurance to the banking system as a whole. Even in the interbank market, banks might be more willing to transact with counterparties that have access to the central bank than with counterparties that don't. Providing access to a broad range of counterparties can thus be beneficial to liquidity in the interbank market.

Collateral Framework

Economically, repos are loans secured by collateral. A central bank's collateral framework describes the type of collateral it is willing to accept and how this collateral will be valued. The primary function of the collateral is to protect the central bank against financial losses in the event of a counterparty's default. In theory, the principal objective of ensuring a very high degree of protection against financial losses could be achieved in two ways: (i) either by only accepting assets with a very low credit, market and liquidity risk; or (ii) by accepting a wider range of collateral, with varying degrees of credit, market and liquidity risk, but applying sufficiently high valuation haircuts (Cheun et al. 2009). In practice, a central bank's collateral framework will also reflect a number of other factors, including any legal restrictions imposed by the central bank's statute (although these statutes are not carved in stone and can be amended in case of need), the legal certainty about the transfer of the collateral to the central bank and the central bank's ability to liquidate the assets in case of a counterparty default, the outstanding volume of certain assets, the availability of information on the pricing and credit quality of the assets, or the costs involved with the transfer of collateral (Bindseil and Papadia 2006). All these factors suggest that the specification of a comprehensive collateral framework is a formidable task and hence out of the scope of this study. This notwithstanding, it seems that two elements are particularly crucial: the acceptance of a broad range of collateral and the application of risk-based haircuts (see recommendation R-14).

The central bank's decision to accept a certain asset as collateral can increase this asset's liquidity and raise its value in the secondary market relative to non-eligible assets. By accepting a relatively broad range of collateral the central bank can thus minimize distorting effects on relative prices in financial markets (market neutrality). At the same time, a broad range of eligible collateral would generally increase the level of banks' liquidity insurance, facilitate banks' collateral management as well as reduce banks' potential opportunity costs associated with the collateral they hold to participate in open market operations. It should be noted that the range of eligible collateral can be broadened in many dimensions, e.g. in terms of type of assets (debt securities, equities, bank loans, etc.), type of issuer/debtor (central government, other government entities, corporates, banks, supranational institutions, etc.), issuer residence (domestic, foreign), credit standards for issuer or asset, or the denomination currency (domestic, foreign).

While accepting a broad range of collateral clearly has some benefits, it can also increase the risks to the central bank. To mitigate these risks to an acceptable level, but also for the sake of preserving market neutrality, the relative riskiness of different collateral must be reflected by the application of appropriate valuation haircuts.[4] Failing that, banks would have an incentive to collateralize repo transactions with the central bank with the least attractive assets, i.e. typically those assets that are deemed to be the most risky or that cannot be used for other purposes. This race to the bottom can be prevented by the application of appropriate valuation haircuts, which will typically take into account the asset's price volatility and the prospective liquidation time, but may also reflect different degrees of credit quality.[5] In theory, the haircuts should be set such that distortions are minimized and banks are indifferent regarding the assets they provide as collateral. It needs to be acknowledged, however, that in practice this can be very challenging and the collateral framework will need to strike a balance between precision and simplicity.

[4]Other typical risk mitigation measures are margin calls (which are triggered if the collateral value, after the application of the haircut, falls below a certain trigger level) and the imposition of limits on the use of collateral from certain issuers or on the use of certain types of collateral.

[5]Alternatively, to protect against credit risk, the central bank may set a minimum credit quality threshold.

7.3.3 Occasional and Exceptional Operations

Most of the time, the regular open market operations described above will be sufficient to manage liquidity efficiently and effectively. However, the operational framework should provide enough flexibility to deal adequately with unusual situations. Depending on the likelihood of such situations, one may distinguish between occasional and exceptional operations.

Occasional operations are operations the central bank will probably conduct several times a year, but the timing of which cannot be scheduled (see recommendation R-10). Typical examples are ad hoc overnight or short-term repos to offset major unanticipated temporary changes in autonomous liquidity factors, which, if not offset immediately, could affect the smooth supply of reserves within the reserve maintenance period and hence market interest rates. Moreover, there might be the need from time to time to accommodate permanent changes in autonomous liquidity factors. For instance, in the event of a permanent increase in the level of currency in circulation (which reduces the level of reserves banks hold with the central bank accordingly), there will be a permanent decrease in the banking system's autonomous liquidity position. In principle, this could be accommodated by a corresponding permanent increase in the size of regular short-term or long-term repos. However, it might be preferable to keep the size of regular operations roughly constant and to accommodate such a permanent shift by purchasing securities outright in the market and keeping them on the central bank's balance sheet until maturity. Hence, the operational framework also needs to specify the instruments the central bank will use to accommodate permanent changes in autonomous liquidity factors. While these transactions are not directly related to the implementation of monetary policy, they should nevertheless be considered as part of a central bank's operational framework.

Exceptional operations are operations the central bank will probably not have to conduct for several years but only in very rare and extreme circumstances (see recommendation R-11). As a matter of fact, the 2007-2009 financial crisis has demonstrated that circumstances can arise in which central banks need to engage in transactions that they usually would not do. While it is in the nature of exceptional circumstances that they cannot be foreseen, it seems that as a precautionary measure central banks should be prepared—both contractually and operationally—to implement at least a number of exceptional operations in case of need. At a minimum, arrangements should be in place that allow, within a reasonable time period, to drain large quantities of reserves (which might not be possible by reverse repos alone), to conduct collateral swaps and to provide liquidity in the most important foreign currencies. Obviously, at least the last operation would typically require the coordination and cooperation between central banks.

Chapter 8

Concluding Remarks

Today, most central banks use a short-term interest rate, usually the overnight rate, as operational target to implement monetary policy. To steer the overnight rate towards the target level, central banks typically make use of three monetary policy instruments: reserve requirements, standing facilities and open market operations. The rules and procedures governing the use of these instruments are often referred to as the operational framework of monetary policy implementation.

While at first sight major central banks' operational frameworks exhibit a number of similarities, a closer inspection reveals considerable heterogeneity in the institutional arrangements used for the implementation of monetary policy. Most notably, significant differences exist regarding the relative importance and the specification of the three commonly used monetary policy instruments. Moreover, central banks' practical experience with their operational frameworks provides evidence that even minor differences in the specification of individual monetary policy instruments and how they interact with each other can affect the effectiveness of monetary policy implementation. Therefore, there arises the question whether some operational frameworks are preferable to others, and ultimately, whether there is an optimal operational framework.

Against that background, it is surprising that the normative analysis of monetary policy implementation is in the early stages of development. There is, in particular, no comprehensive analytical framework to assess the performance of alternative operational frameworks. The aim of this study was to contribute to filling this gap and, hopefully, to sensitize both central bank practitioners and interested academics for the relevance of this topic.

The three most important general conclusions from this study may be summarized as follows:

(i) A clear definition of the objectives a central bank pursues in implementing monetary policy is a prerequisite for any normative analysis of the operational framework. In this respect, this study has postulated three criteria for assessing the performance of an operational framework. First and foremost, the operational framework should provide the central bank the ability to control the overnight rate with high precision. Second, the operational framework should contribute to a liquid and competitive interbank money market. And third, the operational framework should minimize the social costs associated with the implementation of monetary policy.

(ii) An appropriate model of the money market is indispensable for a comprehensive normative analysis of the operational framework. In this respect, the money market model developed and used for the purposes of this study exhibits two crucial features. First, the model allows to analyze the impact of different institutional arrangements for the implementation of monetary policy on banks' behavior in the interbank money market and the market clearing overnight rate. Second, reflecting the importance of payments in the interbank large-value payment system as a major source of uncertainty in banks' liquidity management, the model explicitly distinguishes between the impact of banks' idiosyncratic liquidity shocks and shocks to autonomous liquidity factors, a distinction often missing in other money market models.

(iii) The different elements of an operational framework are strongly intertwined and interdependent. Consequently, the operational framework needs to be looked at in a comprehensive manner. Some features or specifications may make sense in the context of a particular framework, but not in another. For instance, it is not possible to generally conclude whether open market operations should be conducted as fixed rate tenders or as variable rate tenders, as the relative advantages and disadvantages of the two tender procedures depend on a range of other institutional features.

More specifically, this study has strived to outline a stylized operational framework that allows to achieve the three aforementioned objectives to a high degree. Although the applied method does not allow to derive the optimal operational framework, it is fair to say that the proposed operational framework provides a solid basis for the effective and efficient implementation of monetary policy. In this regard, the following rules and procedures governing the use of monetary policy instruments have been found to be critical. First, reserve requirements should be sufficiently high in relation to the size of liquidity shocks and provide for a symmetric target range around bank-specific reserve targets. Moreover, reserve requirements should be remunerated and the reserve maintenance period be aligned with the timing of monetary policy decisions. Second, standing facilities should provide for a symmetric interest rate corridor around the overnight target rate, with the width of the corridor being set such that it strikes the right balance between the objectives of tight interest rate control and a liquid and competitive money market. Third, the central bank should commit to provide the amount of liquidity needed for the banking system to comply with reserve requirements and make use of a combination of regular long-term and short-term repos, added by a fine-tuning overnight repo at the end of each reserve maintenance period. While the long-term repos should be conducted as variable rate tenders, the regular short-term repos should be conducted as fixed rate tenders and mature before the next monetary policy decision.

Finally, it is worth reiterating the benefits of a transparent operational framework. Making publicly available the rules and procedures governing the individual monetary policy instruments and how they are related with each other in a simple and coherent manner will foster market participants' understanding of the central bank's operational decisions and actions, contributing to a more predictable and hence more effective implementation of monetary policy. Moreover, the recent financial crisis has forcefully demonstrated that in times of severe market stress central banks may be forced to take unconventional measures, that is measures they would not adopt in normal times. The operational framework should thus also provide sufficient guidance on how the central bank intends to deal with exceptional circumstances.

Appendix A

Technical Appendix

A.1 Modeling Assumptions

A number of modeling assumptions made in the analytical parts of this study are motivated below. These assumptions concern mainly the modeling of the interbank market for reserves as a perfectly competitive and frictionless call market and the specific modeling of payment uncertainty.

A.1.1 The Interbank Market for Reserves

Throughout the analysis, the interbank market for reserves is assumed to be a perfectly competitive and frictionless call market. This assumption is clearly at odds with what one observes in practice. Indeed, interbank money markets are typically not perfectly competitive, particularly if there are dominant market participants. Moreover, trading usually involves frictions in terms of transaction costs, irrespective of whether trading takes place on a bilateral basis (over-the-counter), through brokers or through multilateral electronic trading systems. For instance, a bank that needs to borrow reserves may incur search costs to find a counterparty that is willing or able to lend reserves, especially if there are binding credit lines. And finally, the microstructure of the market for reserves is usually characterized by continuous trading, with banks borrowing or lending reserves at any time during the day.

So why do we abstract from these issues? The answer is straightforward: In order to focus on the relationship between the central bank's operational framework for monetary policy implementation and the behavior of commercial banks in the market for reserves, the relationship between banks—that is: their interaction in the interbank market—has to be modeled in a relatively simple way. Incorporating market frictions such as transaction costs or imperfect competition into an environment that allows for continuous trading would certainly bring the model closer to reality, but not only would this come at the cost of significantly higher analytical complexity, it would also blur the vision on the role of institutional arrangements of monetary policy implementation. Moreover, focusing on institutional features of the operational framework rather than on market frictions is consistent with the findings by Prati, Bartolini and Bertola (2001). Studying the day-to-day behavior of short-term interest rates in the G-7 countries as well as in the euro area, these authors conclude that institutional arrangements and the central bank's operational framework are the main factors shaping the dynamics of the overnight rate. Besides, they find that many of the empirical features of the U.S. federal funds market, which is the most extensively researched interbank money market, are not robust to changes in the institutional environment and/or the style of central bank liquidity management. Furthermore, a continuous trading model would be particularly useful if we were interested in studying the intraday behavior of the overnight rate. However, from the perspective of monetary policy implementation, the intraday dynamics of interest rates are not a major concern, at least as long as on average interest rates are close to the central bank's target rate and intraday volatility is not excessively high. Overall, these considerations support our approach of modeling the interbank market in a rather simple way.

When the interbank market is modeled as a call market, it is important to make a reasonable assumption on the timing of market clearing. Indeed, in conjunction with the degree of payment uncertainty, the timing assumption affects the precision by which banks are able to achieve their target for end-of-day reserve balances. For example, if the market clears shortly before the closing of the payment system, the remaining payment uncertainty, which is captured in the model by the variance of the cumulated liquidity shock in the afternoon, is relatively low and, consequently, banks will be able to achieve their desired end-of-day reserve balance rather precisely by borrowing or lending the necessary amount of reserves in the interbank market. By contrast, if market clearing takes place early in the day, there is a substantial amount of post-trading payment uncertainty, which implies that actual end-of-day reserve balances might be considerably above or below target. Empirical evidence on intraday trading activity in (continuous) overnight money markets indicates that significant trading takes place both in the morning and in the afternoon, with lower activity around midday. For instance, in the U.S. federal funds market trading volume as well as trading intensity are high in the morning between 8:30 and 10 a.m. they dip from the late morning through mid-afternoon, and they peak late in the afternoon

(Bartolini et al. 2005). In the Italian electronic broker market MID[1], trading volumes in the overnight market segment show a similar two-hump shaped pattern, with trading activity highest in the morning from 9–11 a.m. and in the afternoon from 3–5 p.m. (Hartmann, Manna and Manzanares 2001). In other euro area countries, quoting frequencies, which are likely to be closely correlated with trading volumes, exhibit a similar pattern. High market activity in the morning may be explained by market participants' reaction to news accumulated overnight, whereas high trading activity in the late afternoon is most likely a reflection of banks' desire to adjust their reserve balances prior to the closing of the payment system (Angelini 2000).[2] The empirical results thus indicate that when the interbank market is modeled as a call market, the timing should be such that it implies substantial payment uncertainty both before and after market clearing.

A.1.2 Payment Uncertainty

In practice, banks face substantial uncertainty with respect to their payment flows, with the degree of uncertainty depending on the type of payments. On the one hand, some payments are perfectly predictable because the underlying transactions were concluded one or more days in advance. An instructive example are securities transactions which are typically settled with a lag of three days, that is if securities are bought or sold on day t, the delivery of securities in the securities settlement system and the settlement of the cash leg in the large-value payment system (LVPS) take place only on day $t+3$. Similarly, foreign exchange (spot) transactions are typically settled on a $t+2$ basis. Therefore, payments related to securities or foreign exchange transactions can be anticipated almost perfectly. But even for these transactions, there remains some uncertainty, especially with respect to incoming payments, as a bank can never be sure that its counterparty will discharge its obligations in time. On the other hand, there are payments that cannot be predicted at all. Pertinent examples are incoming payments on behalf of a bank's customers, or payments that are initiated by a bank's own customers on settlement day only. Yet another source of uncertainty are operational

[1]The Italian electronic broker market MID (Market for Interbank Deposits) covers virtually the entire domestic overnight deposit market in Italy. Participants include a large number of Italian banks and a few foreign banks. When the respective offered and bid rates and quantities match, transactions between members are clinched automatically. See Hartmann, Manna and Manzanares (2001) for more details on MID.

[2]The observed pattern of trading activity is also consistent with the following explanation: Activity is high in the morning since traders have just arrived in the office and are raring to go, it is low around noon since traders have gone for lunch, and it peaks again in the afternoon since traders need to justify their outrageous salaries.

disruptions occurring either at the core of the payment system or at the level of individual payment system participants. For instance, participants might be unable to make payments due to internal hard- or software failures or due to a loss of connectivity to the LVPS. As a consequence, payments may not settle as expected, especially if operational disruptions occur late in the day. On the whole, a bank hence does not know *ex ante* the value of payments that needs to be settled, and it faces even more uncertainty regarding the value of incoming payments.

Since payments are settled in the LVPS throughout the day on a continuous basis, an individual bank's payment uncertainty may be modeled as a sequence of many payment or liquidity shocks, i.e. $\{\varepsilon_{i,t}^{j}\}_{j=1}^{K}$, where $\varepsilon_{i,t}^{j}$ represents an unexpected inflow ($\varepsilon_{i,t}^{j} > 0$) or outflow ($\varepsilon_{i,t}^{j} < 0$) of funds on bank i's reserve account. For simplicity, assume that these payment shocks are normally distributed white noise shocks, that is they are independently and identically distributed with mean zero and variance σ_{ε}^{2}. Throughout the day, one liquidity shock after the other is realized and eventually, by the closing of the payment system, any remaining uncertainty on the cumulated impact of these shocks on the bank's end-of-day reserve position will have been removed.

It is important to clearly distinguish between two types of liquidity shocks: idiosyncratic and autonomous liquidity shocks. *Idiosyncratic liquidity shocks* refer to unexpected payments between two banks (or anticipated payments between two banks that fail to settle, for instance due to operational problems). Any idiosyncratic liquidity shock implies a redistribution of reserves between banks, without affecting the aggregate quantity of reserves available to the banking system as a whole. By contrast, *autonomous liquidity shocks* refer to unexpected payments between a bank and any non-bank participant to the LVPS (in particular the central bank or the treasury). The distinguishing feature of autonomous liquidity shocks thus is that they alter the amount of reserves to the banking system as a whole.[3]

For an individual bank's reserve demand it makes no different whether a liquidity shock is of one type or the other. For instance, in case of an unexpected outflow of funds, a bank will generally try to offset the induced change in its reserve position by borrowing more in the interbank market for reserves, irrespective of whether the outflow was due to an idiosyncratic or an autonomous liquidity shock. However, to the extent that the quantity of reserves available to the banking system affects the market clearing interest rate, differentiating between the two types of payment shocks is es-

[3]Autonomous liquidity shocks are thus closely related to the concept of autonomous liquidity factors which is discussed in more detail in Section 3.3.

sential to understand the link between uncertainty on payment flows and the dynamics of interest rates. In terms of the model, this differentiation is easily achieved by assigning each element of $\{\varepsilon_{i,t}^j\}_{j=1}^K$ to one of two separate sequences, $\{\upsilon_{i,t}^j\}_{j=1}^L$ and $\{\eta_{i,t}^j\}_{j=1}^P$, where $\upsilon_{i,t}^j$ and $\eta_{i,t}^j$ are the idiosyncratic and autonomous liquidity shocks of bank i, respectively, and $L+P=K$. Supposing that market clearing takes place between the realization of $\upsilon_{i,t}^l$ and $\upsilon_{i,t}^{l+1}$ and $\eta_{i,t}^p$ and $\eta_{i,t}^{p+1}$, respectively, it is then possible to define the following liquidity shocks:

1. *Idiosyncratic liquidity shock in the morning*:
   - $\upsilon_{i,t}^M \equiv \sum_{j=1}^l \upsilon_{i,t}^j$, where $\upsilon_{i,t}^M \sim N\left(0, \sigma_{\upsilon^M}^2\right)$ and $\sigma_{\upsilon^M}^2 = l\sigma_{\upsilon^j}^2$.
   - $\upsilon_t^M \equiv \frac{1}{n}\sum_{i=1}^n \upsilon_{i,t}^M = 0$.
2. *Autonomous liquidity shock in the morning*:
   - $\eta_{i,t}^M \equiv \sum_{j=1}^p \eta_{i,t}^j$, where $\eta_{i,t}^M \sim N\left(0, \sigma_{\eta^M}^2\right)$ and $\sigma_{\eta^M}^2 = p\sigma_{\eta^j}^2$.
   - $\eta_t^M \equiv \frac{1}{n}\sum_{i=1}^n \eta_{i,t}^M$, where $\eta_t^M \sim N\left(0, \tilde{\sigma}_{\eta^M}^2\right)$ and $\tilde{\sigma}_{\eta^M}^2 = \sigma_{\eta^M}^2/n$.
3. *Cumulated liquidity shock in the morning*:
   - $\varepsilon_{i,t}^M \equiv \eta_{i,t}^M + \upsilon_{i,t}^M$, where $\varepsilon_{i,t}^M \sim N\left(0, \sigma_{\varepsilon^M}^2\right)$ and $\sigma_{\varepsilon^M}^2 = \sigma_{\eta^M}^2 + \sigma_{\upsilon^M}^2$.
   - $\varepsilon_t^M \equiv \frac{1}{n}\sum_{i=1}^n \varepsilon_{i,t}^M = \eta_t^M$.
4. *Idiosyncratic liquidity shock in the afternoon*:
   - $\upsilon_{i,t}^A \equiv \sum_{j=l+1}^L \upsilon_{i,t}^j$, where $\upsilon_{i,t}^A \sim N\left(0, \sigma_{\upsilon^A}^2\right)$ and $\sigma_{\upsilon^A}^2 = (L-l)\sigma_{\upsilon^j}^2$.
   - $\upsilon_t^A \equiv \frac{1}{n}\sum_{i=1}^n \upsilon_{i,t}^A = 0$.
5. *Autonomous liquidity shock in the afternoon*:
   - $\eta_{i,t}^A \equiv \sum_{j=p+1}^P \eta_{i,t}^j$, where $\eta_{i,t}^A \sim N\left(0, \sigma_{\eta^A}^2\right)$ and $\sigma_{\eta^A}^2 = (P-p)\sigma_{\eta^j}^2$.
   - $\eta_t^A \equiv \frac{1}{n}\sum_{i=1}^n \eta_{i,t}^A$, where $\eta_t^A \sim N\left(0, \tilde{\sigma}_{\eta^A}^2\right)$, and $\tilde{\sigma}_{\eta^A}^2 = \sigma_{\eta^A}^2/n$.
6. *Cumulated liquidity shock in the afternoon*:
   - $\varepsilon_{i,t}^A \equiv \eta_{i,t}^A + \upsilon_{i,t}^A$, where $\varepsilon_{i,t}^A \sim N\left(0, \sigma_{\varepsilon^A}^2\right)$ and $\sigma_{\varepsilon^A}^2 = \sigma_{\eta^A}^2 + \sigma_{\upsilon^A}^2$.
   - $\varepsilon_t^A \equiv \frac{1}{n}\sum_{i=1}^n \varepsilon_{i,t}^A = \eta_t^A$.

As these liquidity shocks show up in many places in this study, a few additional comments are in order. First, note that the idiosyncratic liquidity shock in the morning (afternoon) simply adds up all the individual underlying idiosyncratic liquidity shocks before (after) market clearing. Similarly, the autonomous liquidity shock in the morning (afternoon) adds up all the individual underlying autonomous liquidity shocks before (after) market clearing. Also, since the underlying shocks $\{\varepsilon_{i,t}^j\}_{j=1}^K$ are independently distributed, $\upsilon_{i,t}^M, \upsilon_{i,t}^A, \eta_{i,t}^M$ and $\eta_{i,t}^A$ are mutually independent.

Moreover, the summation of idiosyncratic liquidity shocks over all banks is necessarily zero, because by definition any idiosyncratic liquidity shock to bank i is compensated by an idiosyncratic liquidity shock with opposite sign to bank $j \neq i$.[4] In contrast, summing up the autonomous liquidity shocks typically yields a non-zero value. Ex post, the realizations of η_t^M and η_t^A, that is the average or per capita autonomous liquidity shocks, thus may be positive or negative, and, as a consequence, so are the per capita cumulated liquidity shocks ε_t^M and ε_t^A.

A.2 Derivations

A.2.1 Equation (3.3)

Bank i's profit maximization problem is

$$\begin{aligned} \max_{B_{i,t}} E_t(\Pi_{i,t}) &= -i_t B_{i,t} \\ &- i_t^b \int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \left(D_{i,t} - R_{i,t}^{mc} - B_{i,t} - \varepsilon_{i,t}^A\right) \psi(\varepsilon^A) \\ &+ i_t^d \int_{D_{i,t}-R_{i,t}^{mc}-B_{i,t}}^{\infty} \left(R_{i,t}^{mc} + B_{i,t} + \varepsilon_{i,t}^A - D_{i,t}\right) \psi(\varepsilon^A) \end{aligned} \tag{A.1}$$

where $\psi(\varepsilon^A)$ serves as a shortcut for $\gamma_{\varepsilon^A}(\varepsilon^A)\,\mathrm{d}\varepsilon^A$. Integrating by parts, the integral in the second term of (A.1) can be written as

$$\begin{aligned} &\int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \left(D_{i,t} - R_{i,t}^{mc} - B_{i,t} - \varepsilon_{i,t}^A\right) \psi(\varepsilon^A) \\ = \; &\Gamma_{\varepsilon^A}(\varepsilon_{i,t}^A) \left(D_{i,t} - R_{i,t}^{mc} - B_{i,t} - \varepsilon_{i,t}^A\right) \Big|_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \\ + \; &\int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \Gamma_{\varepsilon^A}(\varepsilon_{i,t}^A)\,\mathrm{d}\varepsilon_{i,t}^A \end{aligned} \tag{A.2}$$

where the first term on the right hand side is equal to zero. Similarly, the integral in the third term of (A.1) can be reformulated as

[4] Note that the term *idiosyncratic* is therefore somewhat misleading.

$$\begin{array}{rl} & \int_{D_{i,t}-R_{i,t}^{mc}-B_{i,t}}^{\infty} \left(R_{i,t}^{mc} + B_{i,t} + \varepsilon_{i,t}^{A} - D_{i,t}\right) \psi(\varepsilon^{A}) \\ = & \int_{-\infty}^{\infty} \left(R_{i,t}^{mc} + B_{i,t} + \varepsilon_{i,t}^{A} - D_{i,t}\right) \psi(\varepsilon^{A}) \\ - & \int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \left(R_{i,t}^{mc} + B_{i,t} - D_{i,t} + \varepsilon_{i,t}^{A}\right) \psi(\varepsilon^{A}) \\ = & R_{i,t}^{mc} + B_{i,t} - D_{i,t} + \int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \Gamma_{\varepsilon^{A}}(\varepsilon_{i,t}^{A})\, \mathrm{d}\varepsilon_{i,t}^{A}. \end{array} \tag{A.3}$$

Substituting these terms into (A.1), the profit maximization problem becomes

$$\begin{array}{rcl} \max_{B_{i,t}} E_t(\Pi_{i,t}) & = & i_t^d(R_{i,t}^{mc} - D_{i,t}) - (i_t - i_t^d)B_{i,t} \\ & - & (i_t^b - i_t^d) \int_{-\infty}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \Gamma_{\varepsilon^{A}}(\varepsilon_{i,t}^{A})\, \mathrm{d}\varepsilon_{i,t}^{A}. \end{array} \tag{A.4}$$

The first order condition for the profit maximization problem in (A.4) then yields

$$\Gamma_{\varepsilon^{A}}(D_{i,t} - R_{i,t}^{mc} - B_{i,t}) = \frac{i_t - i_t^d}{i_t^b - i_t^d}, \tag{A.5}$$

which implies that expected profits are maximized when borrowing is

$$B_{i,t} = D_{i,t} - R_{i,t}^{mc} - \Gamma_{\varepsilon^{A}}^{-1}\left(\frac{i_t - i_t^d}{i_t^b - i_t^d}\right). \tag{A.6}$$

A.2.2 Equation (3.16)

Note that if $\varepsilon_{i,t}^{A} < (D_{i,t} - R_{i,t}^{mc} - B_{i,t})$, then $\partial E_t\left[V_{i,t+1}(\cdot)\right]/\partial D_{i,t+1}$ does not depend on $\varepsilon_{i,t}^{A}$ and hence

$$\int_{-R_{i,t}^{mc}-B_{i,t}}^{D_{i,t}-R_{i,t}^{mc}-B_{i,t}} \frac{\partial E_t\left[V_{i,t+1}(\cdot)\right]}{\partial D_{i,t+1}} \gamma_{\varepsilon^{A}}(\varepsilon^{A})\, \mathrm{d}\varepsilon^{A} = \phi_{i,t}^{2} \frac{\partial E_t\left[V_{i,t+1}(\cdot)\right]}{\partial D_{i,t+1}}, \tag{A.7}$$

where $\phi_{i,t}^{2}$ is the probability of not using the standing facilities on t. Moreover, the law of motion in Equation (3.15) is

$$\frac{\partial E_t\left[V_{i,t+1}(\cdot)\right]}{\partial D_{i,t+1}} = -\phi_{i,t+1}^{3}\, i^d + \int_{-\infty}^{D_{i,t+1}-R_{i,t+1}^{mc}-B_{i,t+1}} \frac{\partial E_t\left[V_{i,t+2}(\cdot)\right]}{\partial D_{i,t+2}} \gamma_{\varepsilon^{A}}(\varepsilon^{A})\, \mathrm{d}\varepsilon^{A}.$$

Denoting for convenience $Q_{i,\tau} = D_{i,\tau} - R^{mc}_{i,\tau} - B_{i,\tau}$ and $\psi = \gamma_{\varepsilon^A}(\varepsilon^A)\,\mathrm{d}\varepsilon^A$, recursive substitution of $\partial E_t\left[V_{i,\tau}(\cdot)\right]/\partial D_{i,\tau}$ for $\tau = t+2,\ldots,T$ yields

$$\begin{aligned}
\tfrac{\partial E_t[V_{i,t+1}(\cdot)]}{\partial D_{i,t+1}} &= -\phi^3_{i,t+1}\, i^d + \textstyle\int_{-\infty}^{Q_{i,t+1}} \tfrac{\partial E_t[V_{i,t+2}(\cdot)]}{\partial D_{i,t+2}}\,\psi \\
&= -\phi^3_{i,t+1}\, i^d + \textstyle\int_{-\infty}^{Q_{i,t+1}} \left[-\phi^3_{i,t+2}\, i^d + \int_{-\infty}^{Q_{i,t+2}} \tfrac{\partial E_t[V_{i,t+3}(\cdot)]}{\partial D_{i,t+3}}\,\psi\right]\psi \\
&= \ldots \\
&= -\phi^3_{i,t+1}\, i^d - (1-\phi^3_{i,t+1})\phi^3_{i,t+2}\, i^d \\
&- (1-\phi^3_{i,t+1})(1-\phi^3_{i,t+2})\phi^3_{i,t+3}\, i^d \\
&- \ldots - (1-\phi^3_{i,t+1})\ldots(1-\phi^3_{i,T-2})\phi^3_{i,T-1}\, i^d \\
&+ \textstyle\int_{-\infty}^{Q_{i,t+1}} \int_{-\infty}^{Q_{i,t+2}} \cdots \int_{-\infty}^{Q_{i,T-1}} \tfrac{\partial E_t\left[V_{i,T}(\cdot)\right]}{\partial D_{i,T}}\,\psi\cdots\psi
\end{aligned}$$

Since $-E_t\left[\partial V_{i,T}\right]/\partial D_{i,T} = E_t\left[i_T\right]$ the last term simplifies to $-(1-\phi^3_{i,t+1})\cdots(1-\phi^3_{i,T-1})E_t\left[i_T\right]$. Summarizing we obtain

$$\begin{aligned}
-\tfrac{\partial E_t[V_{i,t+1}(\cdot)]}{\partial D_{i,t+1}} &= \left[\phi^3_{i,t+1} + \textstyle\sum_{\tau=t+2}^{T-1}\left(\phi^3_{i,\tau}\prod_{s=t+1}^{\tau-1}\left(1-\phi^3_{i,s}\right)\right)\right] i^d \\
&+ \textstyle\prod_{\tau=t+1}^{T-1}(1-\phi^3_{i,\tau})E_t\left[i_T\right].
\end{aligned}$$

Equation (3.16) then follows straightforwardly.

A.2.3 Equation (3.17)

The derivation of Equation (3.17) proceeds in three steps. First note that Equation (3.9) can be reformulated as

$$i_T = i^b\,\Phi\left(\frac{D_T - R^{mc}_T}{\sigma_{\varepsilon^A}}\right) + i^d\left[1 - \Phi\left(\frac{D_T - R^{mc}_T}{\sigma_{\varepsilon^A}}\right)\right], \tag{A.8}$$

that D_T and R^{mc}_T can be written as

$$D_T = D_t - (T-t)R^{mc}_t - (T-t)\eta^A_t - \sum_{j=1}^{T-t-1}(T-t-j)(\eta^M_{t+j} + \eta^A_{t+j}) \tag{A.9}$$

and

$$R_T^{mc} = R_t^{mc} + \sum_{j=1}^{T-t} \left(\eta_{t+j}^M + \eta_{t+j-1}^A \right), \tag{A.10}$$

so that we have

$$\begin{aligned} D_T - R_T^{mc} &= D_t - (T-t+1)R_t^{mc} \\ &- \textstyle\sum_{j=0}^{T-t-1} (T-t+1-j)\eta_{t+j}^A - \sum_{j=1}^{T-t} (T-t+1-j)\eta_{t+j}^M. \end{aligned}$$

Accordingly, at the time of market clearing on day t, $X_t = \frac{D_T - R_T^{mc}}{\sigma_{\varepsilon^A}}$ can be interpreted as a normally distributed random variable with mean

$$\mu_t = \frac{D_t - (T-t+1)R_t^{mc}}{\sigma_{\varepsilon^A}} \tag{A.11}$$

and variance

$$\sigma_t^2 = \frac{\sum_{j=1}^{T-t} \left[j^2 \sigma_{\eta^M}^2 + (j+1)^2 \sigma_{\eta^A}^2 \right]}{\sigma_{\varepsilon^A}^2}. \tag{A.12}$$

Second, because the cumulative distribution function $\Phi(\cdot)$ is a non-linear function Jensen's inequality implies that $E(\Phi(X)) \neq \Phi(E(X))$. However, one can show that if $X \sim N(\mu, \sigma^2)$ and $Y \sim (0,1)$, with X and Y independent, then

$$E(\Phi(X)) \equiv E(\Pr[Y \leq X]) = \Phi\left(\frac{\mu}{\sqrt{1+\sigma^2}} \right). \tag{A.13}$$

Third, applying Equation (A.13) to the martingale hypothesis $i_t \simeq E_t(i_T)$, and using the results in Equations (A.11) and (A.12), Equation (3.17) follows immediately.

A.2.4 Minimizing Expected Borrowing Costs

Lemma 1. *Assume bank i's intertemporal reserve demand over the maintenance period with length $T \geq 2$ is characterized by targeting a constant level of end-of-day balances, that is, on any day t it chooses $B_{i,t}$ such that $E_t\left[R_{i,t}^{psc}\right] = D_{i,t}/(T-t+1)$. The expected total borrowing costs over the remainder of the reserve maintenance period, $E_t\left[TBC_{i,t}\right]$, are then smaller than for any other pattern of intertemporal reserve demand that satisfies $D_{i,T+1} = 0$.*

In the following, we prove Lemma 1 for $t = 1$, but the generalization to subsequent days in the reserve maintenance period is straightforward. To start with, note that the constant reserve demand pattern implies that $E_1\left[R^{psc}_{i,\tau}\right] = (1/T)D_{i,1}$ for $\tau = 1 \ldots T$. As of the beginning of the maintenance period, the expected borrowing costs on day τ are thus

$$\begin{aligned} E_1\left[BC_{i,\tau}\right] &= -\,i^b \int_{-\infty}^{-(1/T)D_{i,1}} \left((1/T)D_{i,1} + \varepsilon^A_{i,\tau}\right) \gamma_{\varepsilon^A}(\varepsilon^A)\,\mathrm{d}\varepsilon^A \\ &= i^b \int_{-\infty}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,\tau})\,\mathrm{d}\varepsilon^A \end{aligned}$$

and expected total borrowing costs over the whole maintenance period are thus

$$E_1\left[TBC_{i,1}\right] = T\,i^b \int_{-\infty}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,\tau})\,\mathrm{d}\varepsilon^A. \tag{A.14}$$

Consider now the consequence of a slight deviation from the constant reserve demand pattern. In particular, assume that the bank targets a marginally lower end-of-day balance on day l and a marginally higher end-of-day balance on day h, that is $E_1\left[R^{psc}_{i,l}\right] = (1/T)D_{i,1} - \Delta$, $E_1\left[R^{psc}_{i,h}\right] = (1/T)D_{i,1} + \Delta$, and $E_1\left[R^{psc}_{i,\tau}\right] = (1/T)D_{i,1}$ for $\tau \neq (l,h)$. Expected borrowing costs are then:

$$\begin{aligned} E_1\left[BC_{i,l}\right] &= i^b \int_{-\infty}^{-(1/T)D_{i,1}+\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,l})\,\mathrm{d}\varepsilon^A, \\ E_1\left[BC_{i,h}\right] &= i^b \int_{-\infty}^{-(1/T)D_{i,1}-\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,h})\,\mathrm{d}\varepsilon^A, \\ E_1\left[BC_{i,\tau}\right] &= i^b \int_{-\infty}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,\tau})\,\mathrm{d}\varepsilon^A \quad \text{for } \tau \neq (l,h). \end{aligned}$$

Now note that

$$\begin{aligned} \int_{-\infty}^{-(1/T)D_{i,1}+\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,l})\,\mathrm{d}\varepsilon^A &= \int_{-\infty}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,l})\,\mathrm{d}\varepsilon^A \\ &+ \int_{-(1/T)D_{i,1}}^{-(1/T)D_{i,1}+\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,l})\,\mathrm{d}\varepsilon^A \end{aligned}$$

and

$$\begin{aligned} \int_{-\infty}^{-(1/T)D_{i,1}-\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,h})\,\mathrm{d}\varepsilon^A &= \int_{-\infty}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,h})\,\mathrm{d}\varepsilon^A \\ &- \int_{-(1/T)D_{i,1}-\Delta}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,h})\,\mathrm{d}\varepsilon^A. \end{aligned}$$

Expected total borrowing costs associated with the slightly altered reserve demand pattern are thus

$$\begin{aligned} E_1\left[\widetilde{TBC}_{i,1}\right] &= E_1\left[TBC_{i,1}\right] \\ &+ \int_{-(1/T)D_{i,1}}^{-(1/T)D_{i,1}+\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,l})\,\mathrm{d}\varepsilon^A - \int_{-(1/T)D_{i,1}-\Delta}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,h})\,\mathrm{d}\varepsilon^A. \end{aligned} \tag{A.15}$$

Now note that the cumulative distribution function $\Gamma_{\varepsilon^A}(\cdot)$ is strictly increasing, i.e. $\Gamma'_{\varepsilon^A}(\cdot) > 0$, so that

$$\int_{-(1/T)D_{i,1}}^{-(1/T)D_{i,1}+\Delta} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,l})\,\mathrm{d}\varepsilon^A > \int_{-(1/T)D_{i,1}-\Delta}^{-(1/T)D_{i,1}} \Gamma_{\varepsilon^A}(\varepsilon^A_{i,h})\,\mathrm{d}\varepsilon^A.$$

It then follows that $E_1\left[TBC_{i,1}\right] < E_1\left[\widetilde{TBC}_{i,1}\right]$.

A.2.5 Equation (3.18)

Reformulating Equation (3.4), the market clearing overnight rate can be written as

$$i_t = i^d + (i^b - i^d)\,\Phi\left(\frac{D_t - R^{mc}_t}{\sigma_{\varepsilon^A}}\right). \tag{A.16}$$

As of t_o, the time when the open market operation is conducted, D_t is known but $R^{mc}_t = R^{bod}_t + L_{t,t+1} - \bar{L}_t + \eta^M_t$ is a random variable. Choosing the neutral allotment $L^n_{t,t+1}$ such that $E_{t_o}(i_t) = i^*_t$ then implies that

$$\begin{aligned} \tfrac{i^*_t - i^d}{i^b - i^d} &= E_{t_o}\left[\Phi\left(\tfrac{D_t - R^{bod}_t - L^n_{t,t+1} + \bar{L}_t - \eta^M_t}{\sigma_{\varepsilon^A}}\right)\right] \\ &= \Phi\left(\tfrac{\mu}{\sqrt{1+\sigma^2}}\right) \end{aligned} \tag{A.17}$$

where

$$\mu = \frac{D_t - R^{bod}_t - L^n_{t,t+1} + \bar{L}_t}{\sigma_{\varepsilon^A}}$$

and

$$\sigma^2 = \frac{\sigma^2_{\eta^A}}{\sigma^2_{\varepsilon^A}}.$$

Solving Equation (A.17) for $L^n_{t,t+1}$ then yields

$$L^n_{t,t+1} = D_t - R^{bod}_t + \bar{L}_t - \Phi^{-1}\left(\frac{i^*_t - i^d}{i^b - i^d}\right)\sigma_{\varepsilon^A}\sqrt{1 + \frac{\sigma^2_{\eta^A}}{\sigma^2_{\varepsilon^A}}}. \tag{A.18}$$

A.2.6 Equation (3.19)

Implementing the neutral allotment requires to chose $L_{t,t+m}$ such that $E_{t_o}(i_T) = i^*$, where the market clearing overnight rate on T is known to be

$$i_T = i^d + (i^b - i^d)\,\Phi\left(\frac{D_T - R^{mc}_T}{\sigma_{\varepsilon^A}}\right). \tag{A.19}$$

Now, note that at the time when the last operation within the reserve maintenance period is conducted, there is only one allotment for which $E_{(T+1-m)_o}(i_T) = i^*$. In contrast, at the time of earlier operations, there is an infinite number of reserve supply paths that allow to achieve the interest rate target. In order to have a unique solution, it is thus assumed that the implementation desk has a preference for a smooth reserve supply path and that it will therefore chose $L_{t,t+m}$ such that the anticipated size of future open market operations is equal to the size of the current operation, e.g. $E_{t_o}(L_{t+m,t+2m}) = L_{t,t+m}$.

Then, note that as of t_o, the time when the open market operation is conducted on day t, D_T and R^{mc}_T are random variables that can be written as follows:

$$R^{mc}_T = R^{bod}_t + L_{t,t+m} - \bar{L}_t + \sum_{j=0}^{T-t-1}\left(\eta^M_{t+j} + \eta^A_{t+j}\right) + \eta^M_T$$

and

$$\begin{aligned} D_T &= D_t - (T-t)(R^{bod}_t + L_{t,t+m} - \bar{L}_t) \\ &\quad - \textstyle\sum_{j=0}^{T-t-1}(T-t-j)\left(\eta^M_{t+j} + \eta^A_{t+j}\right). \end{aligned}$$

Accordingly, as of t_o, $X_t = \frac{D_T - R^{mc}_T}{\sigma_{\varepsilon^A}}$ can be interpreted as a normally distributed random variable with mean

$$\mu_t = \frac{D_t - (T-t+1)\left(R^{bod}_t + L_{t,t+m} - \bar{L}_t\right)}{\sigma_{\varepsilon^A}} \tag{A.20}$$

and variance

$$\sigma_t^2 = \sum_{j=1}^{T-t-1} j^2 \sigma_{\eta^M}^2 + \sum_{j=2}^{T-t-1} j^2 \sigma_{\eta^A}^2. \tag{A.21}$$

Applying the relationship in Equation (A.13), Equation (3.19) follows immediately.

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