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Tom Bernhardsen and
Arne Kloster

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Tokenised bank deposits, wholesale CBDC and the central bank's liquidity management

Tom Bernhardsen and Arne Kloster[1]

Executive summary

CBDC is digital money issued by a central bank. It can be designed as a retail CBDC (rCBDC) or as a wholesale CBDC (wCBDC). wCBDC is envisaged as a means of settlement in new financial infrastructures, where key elements are tokenisation of assets, smart contracts and atomic settlement, all brought together in a "unified ledger". In this memo we discuss the consequences of wCBDC for the central bank's and banks' liquidity management. We take a theoretical view, focusing on overall balance sheet issues resulting from the central bank's need to steer reserves in the banking system and the banks' need to redistribute reserves overnight. With wCBDC, two types of central bank money for settlement purposes will exist, wCBDC and traditional central bank reserves, both digital but with different technical properties.

Regarding consequences for the central bank's and the banks' liquidity management we distinguish between (i) whether tokenised deposits are settled in traditional reserves in the central bank's RTGS system or in wCBDC on a ledger, and (ii) whether reserves in the banking system are scarce or ample. This gives us four different model specifications (in a 2x2 space). Of the four models, the two with scarce reserves in the banking system may pose challenges for the banks' and the central bank's liquidity management (at least from a theoretical point of view). The two other models, with ample reserves in the banking system, are more manageable from the point of view of the central bank's and banks' liquidity management (again, at least theoretically).

The challenge to liquidity management in the two models with scarce reserves in the banking system is that tokenised payments shortly before closing time of the central bank's RTGS system may change banks' reserves and wCBDC balances. Then, with scarce reserves, banks may on short notice be forced to redistribute reserves/wCBDC overnight or to take recourse to the central bank's overnight standing facilities at unfavorable interest rates. This could disturb both the central bank's and banks' liquidity management, affect short-term interest rates and therefore, also disturb the central bank's monetary policy implementation.

For the model with ***scarce reserves and settlement of tokenised deposits in reserves*** we show the advantage of deferred settlement of tokenised deposits. Deferred settlement means that the bank of the payee credits the funds to the payee's account before the settlement between the banks has taken place in the central bank, i.e. the payment is finalised before the settlement in the central bank has been completed. This is as opposed to real-time settlement where the payment from the payer to the payee is finalised after the settlement in the central bank has been completed. With deferred settlement, tokenised payments on the ledger shortly before closing time of the RTGS system do not simultaneously change banks' reserve balances in the central bank, they only change banks' net position in the banks'

[1] Tom Bernhardsen (Tom.Bernhardsen@Norges-Bank.no) and Arne Kloster (Arne.Kloster@Norges-Bank.no) are Special Advisors in Norges Bank/Markets. The memo was written as part of Norges Bank's CBDC research project (see Central bank digital currency). Note that the discussion in this memo cannot be taken as a guideline to how a wCBDC should be designed in Norway. This remains to be decided and will be a topic for further analysis and research. Thanks to Thorbjørn Hægeland, Gaute Langeland, Ketil Rakkestad, Knut Sandal, Ylva Søvik, Line Vogt, Kjetil Watne and Peder Østby for comments. Any errors or omissions are the responsibility of the authors.

accounting system on the ledger (to be explained in detail below). These net positions are to be settled in reserves during the opening hours of the RTGS the next business day. With deferred settlement, transfers of tokenised deposits can take place 24/7 without extending the opening hours of the central bank's RTGS-system. Deferred settlement of tokenised deposits on ledgers follow the same logic as deferred settlement of *instant payments* in some countries, including Norway. With deferred settlement of instant payments, a payer's deposit is transferred to the payee immediately (within seconds), while the settlement in reserves between the participating banks takes place at specific times during the opening hours of the central bank's RTGS system.

For the model with ***scarce reserves and settlement of tokenised deposits in wCBDC,*** the central bank's and the banks' liquidity management is trickier. The reason is that tokenised payments 24/7 may change banks' wCBDC balances shortly before closing time of the central bank's RTGS system. Hence, banks may on short notice be forced to redistribute reserves/wCBDC overnight to avoid recourse to the central bank's overnight standing facilities at unfavorable interest rates. This may disturb both the central bank's and the banks' liquidity management, and therefore also disturb the central bank's process of monetary policy implementation. Moreover, as opposed to the models where tokenised deposits are settled in reserves, deferred settlement in wCBDC is not an option: *In a tokenised financial infrastructure, atomic settlement is required, meaning that payment and settlement take place simultaneously.* We argue that the problem can be solved by imposing limits on tokenised payments on the ledger in a say ¾ hours' time window prior to the closing time of the RTGS system. This would solve the problems related to the central bank's and the banks' liquidity management but the payment system would be somewhat less efficient compared to a complete 24/7 set-up. However, compared to today's payment system, this would still be a significant step forward in terms of efficiency. We also point out the possibility of letting reserves and wCBDC operate with different business-day cut-off times This could (perhaps) solve the problem resulting from wCBDC inflows and outflows shortly before closing time of the central bank's RTGS system, but new challenges for liquidity management could arise.

With **ample *reserves*** in the banking system, the central bank's and the banks' liquidity management is more straight-forward, regardless of whether tokenised deposits are settled in reserves or in wCBDC. The reason is that with ample reserves, all banks' overnight balances (reserves and wCBDC) are remunerated at the policy rate. Hence banks do not need to redistribute reserves/wCBDC overnight to avoid the central bank's overnight facilities at unfavorable interest rates.

Issues related to the central bank's liquidity management have not gained much attention in the wCBDC literature. Some studies touch upon monetary policy implementation and emphasize that wCBDC and reserves should be remunerated at the same rate of interest and traded at par without any restrictions, as this will prevent segmentation of money markets and ensure singleness of money. However, some also discuss the possibility and consequences of remunerating wCBDC and reserves at different rates of interest. Others study monetary policy implementation from a more technical point of view in that they conduct experiments on ledgers where the central bank uses market operations to steer the volume of wCBDC on the ledger.

However, less focus has been on consequences of wCBDC for the central bank's and the banks' liquidity management depending on whether reserves in the banking system are scarce or ample. One reason may be that, with ample reserves, liquidity management in general (with or without wCBDC) will be less of a challenge than with scarce reserves (to be discussed further

below). During the last 15 years, many central banks have adopted floor systems with ample reserves. Hence in the wCBDC literature it seems to be an implicit assumption that wCBDC will coexist with ample reserves in the banking system. For countries with scarce reserves, however, the introduction of wCBDC may pose challenges to liquidity management.

In the next section, we discuss the concepts of tokenised deposits and wCBDC, and we provide an overview of the different models where tokenised deposits are settled in central bank money (i.e., reserves or wCBDC). In section 2 we outline a benchmark model, a starting point, which captures the basic idea of most central banks' settlement systems. In the benchmark model, neither tokenised deposits nor wCBDC exist, and traditional bank deposits are settled in reserves during the opening hours of the central bank's RTGS system only. We then extend the benchmark model and show how tokenised deposits on ledgers can be settled in reserves in the central bank's RTGS system (section 3) and in wCBDC on a ledger (section 4). In all cases we discuss the consequences for the central bank's and the banks' liquidity management. Section 5 summaries.

1. Settlement of tokenised deposits in central bank money (reserves or wCBDC)

For at least a decade, central bank digital currency (CBDC) has been a topic of interest and research. A CBDC is digital money issued by a central bank. It can be designed for settlement purposes among financial intermediaries or as a means of payment for the broader public. The former is referred to as wholesale CBDC (wCBDC), the latter as retail CBDC (rCBDC). Both give rise to several issues related to efficiency and safety in the payment system, financial stability, the central bank's liquidity management and monetary policy implementation in addition to technical and legal matters. The purpose of this memo is to discuss the consequences of wCBDC for central banks' and banks' liquidity management.

For many central banks, the first step in monetary policy implementation is to ensure that short-term money market rates are close to the key policy rate. The central bank achieves this by setting the terms for banks' loans and deposits in the central bank and by controlling the quantity of central bank reserves in the banking system. How the central bank maintains control of central bank reserves and sets the terms and conditions for banks' loans and deposits is referred to as the *liquidity management system*.[2]

Wholesale CBDC is envisaged as a means of settlement in new financial infrastructures with programmable properties. We will not discuss these new technologies in detail here. For surveys, we refer to a series of papers published by the Bank for International Settlements, BIS.[3] In short, BIS refers to "a blueprint for a future monetary system", where key elements are tokenisation (the process of representing claims digitally on a programmable platform), smart contracts (self-executing programmable contracts between two or more parties), composability (several actions are bundled into one executable package) and atomic settlement (a settlement that ensures that either all or none of the legs of the transaction are executed simultaneously). The system envisages tokenised central bank money (i.e. wCBDC), tokenised bank deposits/payments[4] and other tokenised assets being brought together in a new type of financial

[2] Central bank reserves, or simply reserves, are banks' overnight sight deposits held with the central bank (also referred to as banking system liquidity). Reserves are today the only generally accepted ultimate means of interbank settlement. A bank is willing to accept customer deposits from other banks (a liability) because a corresponding amount of central bank reserves (a claim on the central bank) is transferred at the same time to its account.
[3] See BIS (2021a, 2022, 2023, 2024, 2025).
[4] Note that "tokenised deposits" and "tokenised payments" are used interchangeably, depending on the context.

market infrastructure, a "unified ledger".[5] As noted by Shin (2023) at the BIS, this would be a … *game changer in how we think about money and how transactions take place …* Moreover, BIS strongly advises that tokenised deposits on ledgers should be settled in central bank money (and not, for example, in stablecoins or other crypto currencies), as this will ensure confidence in the ledger payment system, payment finality and the singleness of money (the concept of singleness of money will be discussed further below).[6,7]

Retail and wholesale CBDCs have different consequences for the central bank's and banks' liquidity management. Regarding rCBDC, a major issue relates to banks' loss of deposit funding and, with scarce reserves in the banking system, that banks' deposit funding must be replaced by central bank funding. This may have consequences for the balance sheets of banks and the central bank, banks' funding costs, the central bank's liquidity management and financial stability. These issues, with the potential negative financial/macroeconomic consequences, are discussed extensively in the literature. Much of the discussion focuses on how a rCBDC can be designed to contribute to a more efficient and secure payment system, while avoiding or at least reducing the macroeconomic/financial drawbacks. Proposed solutions include limits on rCBDC holdings and a multi-interest rate system for rCBDC. Retail CBDC will not be further discussed here, for a detailed discussion, see Bindseil (2020), Bindseil and Senner (2024), BIS (2021a), Ahnert et. al. (2022), Ahnert et. al. (2023) and Bernhardsen and Kloster (2023).

A wCBDC may have consequences for the central bank's liquidity management, since two types of central bank money for settlement purposes will coexist, wCBDC and reserves. Both are digital central bank money, albeit with different functionalities. While reserves are designed to settle conventional bank deposits in the central bank's RTGS system[8], a wCBDC is designed to settle tokenised deposits on ledgers. A wCBDC must therefore have the same functionality as other tokenised assets, so that it can be executed on ledgers with smart contracts etc.[9] Introducing a wCBDC as a second form of digital central bank money raises several questions regarding how a wCBDC should be designed. Issues relate, for example, to how a wCBDC should be remunerated and the degree of interoperability with ordinary reserves.

Note that introducing a wCBDC as a means of settlement for tokenised deposits on ledgers maintains key features of conventional payment and settlement systems. First, tokenised deposits on ledgers will be settled in central bank money, the most secure and liquid means of payment that exists. This is analogous to traditional systems, where ordinary bank deposits are settled in reserves in the central bank's RTGS system. Second, using wCBDC as a means of

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[5] Note, however, as discussed by BIS and others in the literature, that wCBDC may not necessarily be on a unified ledger shared with other tokenised assets, but, alternatively, on a separate ledger with wCBDC only. In the latter case, a technical interface between the wCBDC ledger and the other ledgers must exist. In fact, following BIS (2025, box C, page 96), the technological architecture for a unified ledger can be represented on a "continuum of unification", ranging from a single distributed ledger architecture to a coupled set of disparate ledgers.

[6] This also follows from Principles for Financial Market Infrastructure (PFMI), according to which (Principle 9), … *An FMI should conduct its money settlements in central bank money where practical and available …*
Principles for Financial Market Infrastructures (PFMI)

[7] Note that the new financial infrastructure based on tokenisation, smart contracts, composability and atomic settlement may – or may not – be based on distributed ledger technology (DLT). In fact, our discussion below is based on a centralised system where ownership of tokenised deposits and wCBDC is transferred on the balance sheets of banks and the central bank, respectively.

[8] Real-Time-Gross-Settlement (RTGS) is the name for central banks' traditional settlement systems, where transfers of deposits between banks are settled in reserves.

[9] Some even prefer not to use the term "wholesale CBDC", as this could indicate a more substantial difference between wCBDC and reserves. One could argue that the difference is a technical one as wCBDC is engineered to act as a means of settlement on ledgers. Panetta (2022) and ECB (2023), for example, emphasize that central bank money has long been available in digital form for wholesale transactions (in the form of reserves). For this reason, the Eurosystem has announced that it is exploring new technologies for wholesale central bank money settlement, rather than wCBDC. However, we adhere to the broadly accepted definition and distinguish reserves from wCBDC, the former acting as a means of settlement in central banks' RTGS systems, the latter engineered to act as a means of settlement on ledgers. We find it practical to have two different linguistic terms for these two technically different forms of central bank money used for settlement purposes.

settlement for tokenised deposits on ledgers maintains the two-tier division of labor between private banks and the central bank in the payment and settlement system and contributes to safeguard the singleness of money (*see Box A:* The t*wo-tier monetary system and the singleness of money with wCBDC).*

Regarding how tokenised payments on ledgers can be settled in central bank money, Chart 1 illustrates four models (in a 2x2 space). We distinguish between (i) whether tokenised deposits are settled in traditional reserves in the central bank's RTGS system or in wCBDC on a ledger and (ii) whether reserves in the banking system are scarce or ample. In all four models we show that tokenised payments on the ledger can be carried out 24/7, which may or may not, depending on the set up of the system, have consequences for the opening hours of the central bank's RTGS system. Of the four models, the two with scarce reserves in the banking system may pose challenges for the banks' and the central bank's liquidity management. These two models, referred to as model 1 and 4 in Chart 1, are labelled possible/difficult. The two other models, both with ample reserves in the banking system, are less challenging for liquidity management and are labelled easy.[10] In the sections below, these four models, in particular the two models designated as challenging for liquidity management, will be discussed in detail.

Chart 1. How tokenised deposits can be settled in central bank money: Reserves or wCBDC, with scarce or ample reserves in the banking system

	With reserves in the RTGS-system	**With wCBDC on a ledger**
With scarce reserves "corridor/ quota"	**Model 1** Possible (with deferred settlement)	**Model 4** Difficult (but possible with limits on tokenised payments)
With ample reserves "floor"	**Model 2** Easy	**Model 3** Easy

In the literature and the central banking community, one model dimension has gained particular interest: whether tokenised deposits on ledgers should be settled in reserves in the central bank's RTGS system or in wCBDC on a ledger. One should note the following:

- If tokenised deposits on the ledger are to be settled in traditional reserves, an interface between the ledger for tokenised assets and the central bank's RTGS system must exist. This is illustrated by the upper line in Chart 2, in which case wCBDC does not exist.
- If tokenised payments are to be settled in wCBDC on a ledger, the wCBDC may be hosted either on a unified ledger shared with other tokenised assets (as primarily envisaged by BIS), or on a separate ledger. In either case, reserves and wCBDC must be fully and frictionlessly convertible at par in both directions (through an interface between the wCBDC ledger and the central bank's RTGS system). This is illustrated in

[10] Note that "easy" refers solely to the theoretical balance sheet and liquidity management issues, depending on whether reserves are scarce or ample. Even if liquidity management is easy in that sense, other issues, like technical and legal ones, may not be.

Chart 2, where wCBDC is on a unified ledger shared with other tokenised assets (the middle arrow in the chart) or on a separate ledger (the lower arrow in the chart). From a liquidity management perspective, the distinction between a separate and a shared ledger for wCBDC is largely inconsequential (at least theoretically). By contrast, whether tokenised deposits are settled in wCBDC or in reserves may have a substantial impact on the central bank's and the banks' liquidity management.

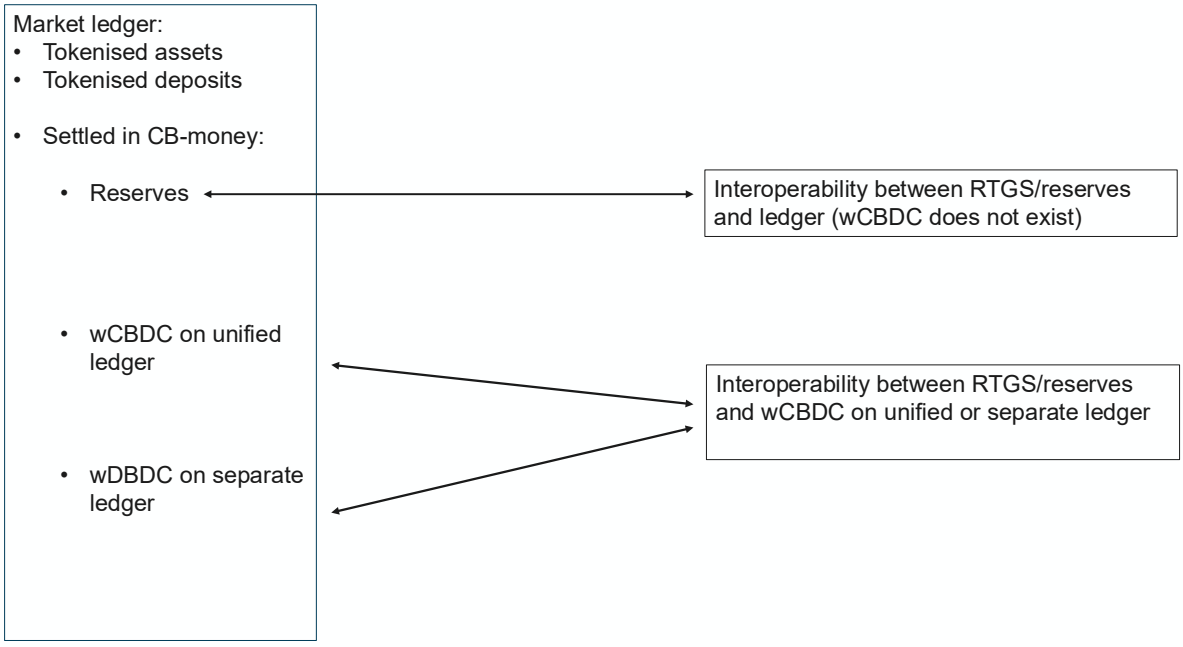
It is generally acknowledged that the RTGS link is operationally simpler and as a starting point "safer", although it provides less scope for future innovation and efficiency gains in payment and settlement processes. This is succinctly summarised by Danmarks Nationalbank (2025):

… The first approach [the RTGS link] is considered more straightforward and quicker to establish, as it does not require central banks to develop or participate in a new type of platform; instead, it involves integrating existing systems with new platforms. A potential drawback of this approach is that not all the benefits of having assets and central bank money on the same platform are realized … … The second approach [wCBDC on a ledger] seems to represent a more long-term and technologically ambitious solution as it can better realise the potential benefits of DLT. Bringing central bank money and assets together on the same platform reduces the friction caused by different technological systems having to communicate with each other. However, the implementation of such solutions requires significant technical, legal and operational considerations, as it involves making central bank money available alongside financial assets on new infrastructure based on DLT …

The European Central Bank (ECB) has announced a two-track approach: first, to develop a solution that is interoperable with existing infrastructure (the central bank's RTGS system, T2/TARGET), and in the longer term, look into integrated solutions with wCBDC (ECB, 2025a,b,c).[11] The Bank of England has announced a link with the central bank's RTGS system through so-called omnibus-accounts (Bank of England, 2025). The Swiss National Bank focuses on integrated solutions in its Helvetia-project ((BIS, SIX and Swiss National Bank (2020, 2022), Jordan (2024), Maechler and Moser (2023)). Whether tokenised deposits should be settled in reserves in central banks' RTGS systems or in wCBDC on a ledger (separate or shared) is discussed extensively in the literature (with pros and cons), see for example ECB (2025a) and Banque de France (2021, 2023). Danmarks Nationalbank (2025) provides an overview. Moreover, either tokenised deposits are settled in reserves in the central bank's RTGS system or in wCBDC on a ledger, transfers of tokenised deposits will affect the balance sheets of both banks and the central bank (*see Box B: The balance sheets of banks and the central bank when settling tokenised deposits in reserves or wCBDC)*.

[11] ECB (2025c) refers to the short-term track "Pontes" to link the distributed ledger technology platforms to TARGET, and the long-term track "Appia" to shape future-ready, innovative, integrated financial ecosystems.

Chart 2. Tokenised deposits settled in reserves or wCBDC



Box A: The two-tier monetary system and the singleness of money with wCBDC

A fundamental property of today's monetary framework is the two-tier system and the singleness of money. The two-tier system implies that commercial banks create money (M1), and that transfers of bank deposits between banks' customers are settled in central bank reserves (M0) with finality on the central bank's balance sheet. It is a division of labor between commercial banks and the central bank.

Since bank deposits are settled in central bank reserves, the central bank also ensures the singleness of money. Singleness of money means that all payment assets in the country's unit of account are exchanged at par value. Cash and bank deposits are exchangeable at par, and because banks hold central bank reserves and have access to the central bank's balance sheet, deposits from all banks can be transferred between banks' customers at par.

Singleness of money is perhaps the most fundamental aspect of a modern monetary economy as:
… The linchpin of modern monetary arrangements is ultimate settlement at par, meaning that the price of money relative to the unit of account is fixed at one. Sometimes referred to as the singleness of money, this is the key coordination mechanism of the economy that sustains the social convention of money. When singleness is maintained, money is information-insensitive in that agents in the economy accept it at par without due diligence, ie with no questions asked … (BIS, 2025, p. 80).

Moreover, one should note that, … *The singleness of money is not a statement about the credit risk embedded in bank deposits but a statement about the payment. Any payment goes through at par because it can be settled with central bank reserves. In other words, singleness of money does not imply that all commercial bank liabilities are or should be equal in value. For example, negotiable certificates of deposits or bank bonds can and often do trade at varying spreads to government bonds. But payments always go through at par, because the central bank*

homogenises the credit risk of deposits from different banks, making them into a uniform payment instrument … (BIS, 2025, p. 81).

It is of utmost importance to preserve the singleness of money also in future monetary systems based on tokenised bank deposits and other assets. Singleness of money must be the backbone of any monetary system. BIS (2023, 2025) therefore strongly advises to settle tokenised payments in central bank money (and not, for example, in stablecoins or other crypto currencies), as this will ensure confidence in the ledger payment system, payment finality and the singleness of money. Note that BIS refers to *central bank money*, meaning that tokenised deposits could be settled in reserves in the central bank's RTGS system, or in wCBDC on separate or common ledgers (c.f. Chart 2 and the discussion above).

Finally, it is worth noting that an increasing number of commentators and analysts, when underlining the importance of wCBDC to ensure singleness of money in a tokenised world, refer to the key role that traditional reserves play in ensuring singleness in today's monetary system. Analogously, in a tokenised world, the singleness of money will be maintained as tokenised deposits will be settled in wCBDC (or in reserves in the RTGS system). In much of the *retail CBDC* literature, however, it is commonly argued that rCBDC is necessary to ensure the singleness of money if cash disappears. The argument seems to rest on the assumption that singleness is ensured by cash rather than reserves. We have always been skeptical to this claim, and as we discuss in an earlier note, we believe that it is reserves and not cash that safeguards singleness of money in today's monetary system (Bernhardsen and Kloster (2023, ch. 5). This view was also put forward by Governor Wolden Bache in a BIS symposium in 2023 (Wolden Bache, 2023). Put differently, were cash to disappear and not to be replaced by rCBDC, we would not be concerned about the singleness of money.

Box B. The balance sheets of banks and the central bank when settling tokenised deposits in reserves or wCBDC

Transfers of tokenised deposits on ledgers affect the balance sheets of banks' and the central bank, both when the tokenised deposits are settled in reserves in the central bank's RTGS system and in wCBDC on a ledger. The chart below shows simplified balance sheets for two banks (A and B) and the central bank. On the banks' balance sheet, both conventional bank deposits (D) and tokenised deposits (TD) are liabilities, while reserves (R) and wCBDC are assets. For the central bank, both reserves (R) and wCBDC are liabilities. The following example illustrates the balance sheets' transactions:

- Our starting point is a bank customer converting a conventional bank deposit into a tokenised deposit on a ledger. On the liability side of the bank's balance sheet, conventional deposits fall, while tokenised deposits rise.
- The customer buys a tokenised asset on the ledger and pays with the tokenised deposit. The tokenised deposit is transferred from the buyer of the asset (the payer) to the seller of the asset (the payee). This means, in fact, that the payer's tokenised deposit is destroyed on the balance sheet of the payer's bank, while an equivalent tokenised deposit will be created in the name of the payee on the balance sheet of the payee's bank.[12]
- The payments on the ledger, i.e. the transfer of the tokenised deposit from the payer to the payee, must be settled in central bank money. Two options exist, settlement in

[12] The process is analogous to the conventional payment system: If a bank deposit is transferred between two customers with different banks, the payer's deposit on the balance sheet of the payer's bank is destroyed, while a new deposit is created in the name of the payee on the balance sheet of the payee's bank.

(conventional) reserves in the RTGS system, or settlement in wCBDC on a ledger (c.f. the discussion in section 2):

- If settled in reserves in the RTGS system, there will be an interface between the ledger for tokenised assets and the RTGS system. Transfers of tokenised deposits on the ledger will trigger a transfer of reserves between banks in the central bank. Reserves will decline for the payer's bank and rise for the payee's bank.
- If settled in wCBDC on a ledger, the banks need to create wCBDC by converting reserves to wCBDC on the ledger. On the banks' asset side and on the central bank's liability side, reserves decline, while wCBDC increases. To settle tokenised deposits on the ledger, wCBDC is transferred from the payer's bank to the payees' bank. On the asset side of the payer's bank, wCBDC declines, while wCBDC increases on the asset side of the payee's bank. The wCBDC remains on the ledger (as a liability of the central bank), but the ownership changes. Note that we here make no distinction between wCBDC on a separate ledger and wCBDC on a ledger shared with other tokenised assets (a unified ledger). This difference may certainly be of technical importance, but less so for the balance sheets of banks and the central bank and for liquidity management.

Simplified balance sheets for the banks and the central bank

Bank A		**Bank B**		**The Central Bank**	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
R_A	Deposits (D_A)	R_B	Deposits (D_B)		R_A
$wCBDC_A$	T-Deposits (TD_A)	$wCBDC_B$	T-Deposits (TD_B)		R_B
					$wCBDC_A$
					$wCBDC_B$

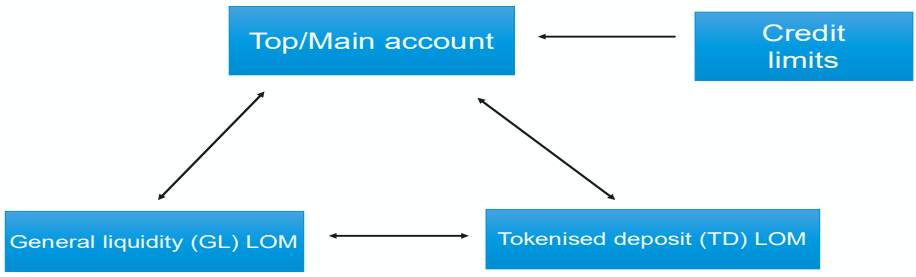
2. A benchmark model for settling bank deposits in reserves in the central bank's RTGS system

In this section we outline a benchmark model, a starting point, which captures the basic idea of most central banks' settlement systems. In the benchmark model neither tokenised deposits nor wCBDC exist, and traditional bank deposits are settled in reserves during the opening hours of the central bank's RTGS system only. In the sections below we extend the benchmark model and show how tokenised deposits on ledgers can be settled in central bank money, i.e. reserves or wCBDC.

Chart 3 shows a typical structure of banks' accounts at the central bank. Within credit limits, determined by the amount of pledged collateral, banks borrow liquidity intraday, which in the morning (start of day) is transferred to a main top account.[13] The liquidity is further transferred from the top account to liquidity sub-accounts, here referred to as LOM accounts (Liquidity Operational Management accounts). In our benchmark model, only a general liquidity LOM account exists (GL LOM). GL LOM serves the purpose of settling traditional bank deposits in the central bank's RTGS system. In the extended models also a tokenised deposit LOM account exists (TD LOM), to be explained below.[14]

[13] Note that we use the terms "central bank reserves", "reserves" and "banks' liquidity" interchangeably, c.f. footnote 2.
[14] Note that how banks' accounts in the central bank are structured, and how banks take up intraday loans and transfer liquidity to different sub accounts, can be organized in many (but similar) ways. Our benchmark model captures the basic idea of how most central banks organize the settlement system. Moreover, the operational schedule outlined for the benchmark model below is just an example, but we will stick to this schedule also in the extended models in the next sections. The term "LOM Account" is taken from how these accounts are named in the central banks of Norway, Sweden and Denmark.

Chart 3. Banks' accounting structure at the central bank



We assume that banks operate a payment clearing system outside the central bank. Payments from the banks' clearing system are forwarded to the central bank either individually and consecutively (gross settlement) or via net clearings. While net clearings are settled at specific times in the opening hours of the RTGS system, say five times a day, gross payments are settled continuously (but also only in the opening hours of the RTGS system). Both gross payments and net clearings are settled in reserves on the banks' general liquidity accounts, GL LOM.[15]

More precisely, the operating schedule is assumed to be as follows in the benchmark model (very simplified to illustrate the basic idea):

- **07.00:** The central bank's RTGS system opens. Banks take up intraday loans and repay overnight interbank loans from the day before.
- **From 07.00 until 15.45:** Bank deposits are settled in reserves on the banks' GL LOM accounts, either on a gross or a net basis (via the banks' clearing system outside the central bank). For banks with net deposit inflow the GL LOM account will increase (credited), while for banks with net deposit outflow GL LOM will decrease (debited). The settlement in reserves in the RTGS system is finalised before the bank of the payee credits the customer's account, referred to as *real-time settlement*. The concept of real-time settlement will be discussed in detail in the next section.
- **Between 15.45 and 16.30** there is a "quiet time window" prior to the closing of the RTGS system at **16.30**. In this ¾ hours' time window no payments between banks' customers take place. Hence banks' reserve balances will not change due to customers' payments, only due to interbank loans and market operations carried out by the central bank.[16]
- The closing time for the RTGS system is **16.30** with change of business day taking place between **16.30-16.45.** In this ¼ hours' time window banks' reserve balances are the basis for overnight interest rate calculations (after repayment of intraday

[15] We do not describe banks' clearing systems outside the central bank in detail here, as this is common for payments/clearings/settlement systems in many countries. Readers interested in more details on how such clearing systems work may benefit from studying banks' clearing system in Norway (Norwegian Interbank Clearing System, NICS), see NICS - Bits AS

[16] This means that banks have imposed payment rules on their customers or that the central bank has declared rules for the operation of the RTGS system (or both), so that neither gross payments nor net clearings will/can be forwarded from the banks' clearing system to the central bank in the last time window prior to closing time of the RTGS system.

loans). How overnight balances are remunerated depends on the liquidity management system of the central bank.
- **Between 16.45 and 07.00** the next morning the RTGS system is closed.

Regarding the central bank's liquidity management, it is of crucial importance whether reserves in the banking system are ample (as in floor systems) or scarce (as in corridor and quota systems). This applies for both our benchmark model and the extended models to be discussed in the next sections. (For more details on floor and corridor systems, see *Box C: Corridor and floor systems in liquidity management.)*

2.1 Liquidity management with scarce reserves in the banking system (corridor/quota)
Assume that reserves in the banking system are scarce, as in corridor and quota systems. In systems with scarce reserves, surplus banks typically need to lend reserves to other banks overnight, while deficit banks need to borrow reserves. Otherwise, banks with surpluses and deficits are forced to take recourse to the central bank's overnight standing facilities at unfavorable interest rates.[17]

As a consequence, in systems with scarce reserves both the central bank and the banks need a "quiet time window" before closing time of the central bank's RTGS system. This is because the central bank needs time to carry out market operations and the banks need time to redistribute reserves overnight to avoid the central bank's overnight standing facilities at unfavorably interest rates. In our benchmark model, this quiet time window is envisaged to be between 15.45 and 16.30, i.e. ¾ hour before the RTGS system closes at 16.30. In this last time window, no payments between banks' customers occur, hence there is no need to settle customer payments in reserves in the last ¾ hour before closing time of the RTGS system. Then both the central bank and banks have a "time-out", a sort of "rest", without being disturbed in their liquidity management.

Assume, in contrast, that gross payments from the banks' clearing system could be settled in reserves up until closing time of the RTGS system at 16.30.[18] Late gross payments would change the distribution of reserves between banks shortly before closing time. Then, if banks on short notice do not manage to successfully redistribute reserves, they could be forced to use the central bank's overnight facilities. Banks facing inflow of reserves could be forced to use the overnight deposit facility. Banks facing outflow of reserves could be forced to use the overnight lending facility. Moreover, the need to settle late payments in reserves could happen at the same time as the central bank may need to carry out market operations. Hence settlement of bank deposits shortly before closing time of the RTGS system could disturb both the central bank's and the banks' liquidity management, it could affect short-term interest rates and therefore also disturb the central bank's monetary policy implementation.

2.2 Liquidity management with ample reserves in the banking system (floor)
Assume that reserves in the banking system are ample (as in floor systems). With ample reserves all of banks' overnight deposits are typically remunerated at the key policy rate.[19] Then, changes in the distribution of reserves between banks shortly before closing time of the RTGS

[17] Surplus of reserves are balances above the quota in a quota system and balances larger than zero in a corridor system (without reserve requirements). For both systems a deficit means negative balances in the central bank.
[18] Note that the problem of late settlements shortly before closing time of the RTGS system would mainly be related to gross payments from the banks' clearing system. In contrast, net clearings are assumed to be settled at specific times during the opening hours of the RTGS system and, obviously, the last net settlement would then be set in due time before closing time.
[19] Throughout the rest of the memo, we make this an explicit assumption: With ample reserves, banks' overnight balances are all remunerated at the key policy rate, while with scarce reserves, banks must lend/borrow reserves to avoid the central bank's overnight standing facilities at unfavorable interest rates.

system will not force banks with large reserves balances into unfavorably overnight interest rates, as all reserves are remunerated at the key policy rate. With ample reserves, gross payments from the banks' clearing system can easily be settled up until closing time of the RTGS system at 16.30. Hence there is no need for the "quiet time window" prior to closing time. This in line with the general perception that systems with ample reserves (floor systems) have the advantage over systems with scarce reserve when it comes to operational "simplicity".[20] However, this "simplicity advantage" does not mean that floor systems are superior to corridor/quota systems in all respects. All liquidity management systems have their pros and cons (*See box D: Norges Bank's principles for liquidity management*).

Box C. Corridor and floor systems in liquidity management

Corridor system
In a corridor system, the policy rate is (normally) midway between the central bank's overnight lending rate (upper limit in the corridor) and the central bank's overnight deposit rate (lower limit in the corridor). The central bank aims to maintain reserves at zero. [21] Towards the end of the day, some banks show a positive balance in their central bank account (surplus of reserves), while others show a negative balance (reserve deficit).[22] Banks with a surplus have incentives to lend reserves to banks with a deficit (and vice versa), otherwise surplus banks must deposit reserves overnight at the central bank's deposit rate, and deficit banks must borrow reserves overnight at the central bank's lending rate. If banks do not borrow reserves from each other overnight, banks are forced to use the central bank's standing facilities overnight, which proves expensive for banks. Under a corridor system, banks have incentives to use central bank reserves *solely as a means of payment and not as a store of value*.

Floor system
Under a floor system, the policy rate is equal to banks' deposit rate in the central bank. In order to keep the market rate close to the policy rate, the central bank must supply the banking system with sufficient reserves to push the market rate down towards the central bank's overnight deposit rate. The required amount of reserves in such a system is considerably greater than zero. A floor system provides the central bank with two independent instruments, the policy rate and the amount of reserves. The central bank can supply reserves to the banking system without the overnight rate falling below the policy rate.[23]

The essence of a floor system – unlike a corridor system – is that the alternative cost for banks of holding surplus reserves at the central bank is low. While banks in a corridor system must deposit surplus reserves at a low interest rate in the central bank, all reserves are remunerated at the policy rate in a floor system. Through the central bank's market operations, banks can borrow reserves from the central bank at an interest rate only marginally higher than the policy rate and may at the same time deposit them in the central bank at the policy rate. Apart from the cost of providing collateral for the loans, banks pay a small amount to acquire reserves. In other words, central bank reserves are more affordable in a floor system. Hence, a floor system

[20] Note, however, that also in floor systems with ample reserves banks with overnight deficits must to use the central bank's lending facility at unfavourable terms. Hence banks must manage their reserve balances to ensure that they do not run out of liquidity overnight.
[21] In practice, the central bank tends to steer reserves towards a level marginally greater than zero. In a corridor system with reserve requirements, the central bank aims to keep reserves at the level determined by the reserve requirement.
[22] Banks may show a negative balance towards the end of the day because they borrow reserves from the central bank throughout the day (intraday loans), which are transferred to other banks' accounts at the central bank.
[23] If some market participants are active in the money market and do not possess an account with the central bank, the overnight rate may fall below the interest rate on the standing deposit facility. These types of market participants must hold overnight deposits in banks, which have accounts with the central bank.

incentivises banks to use central bank reserves *both as a means of payment and as a store of value*. A vast amount of literature discussing floor and corridor systems exist, see for example, Keister, Martin and McAndrews (2008), Borio (2023, 2024), Bernhardsen and Kloster (2012) and Norges Bank (2021).

Box D: Norges Bank's principles for liquidity management

Although systems with ample reserves (floor systems) may have an advantage over systems with scarce reserve when it comes to operational simplicity, all liquidity management systems have pros and cons. As an example, Norges Bank has decided to operate liquidity management within a quota system, with scarce reserves in normal times. This follows from the principles for liquidity management laid down by Norges Bank, where one primary objective is to *… provide a framework for liquidity and credit risk to be borne as far as possible by private agents in the financial system …* Norges Bank (2021). According to the arguments put forward by Norges Bank, this objective suggests a liquidity management system with scarce reserves, where central bank reserves serve as a means of settlement and not as a store of value. Hence using reserves as a store of value should be costly, which is the case in quota and corridor systems, but not in floor systems with ample reserves. The arguments are related to how a large supply of central bank reserves can weaken banks' incentives to manage liquidity risk and have implications for the central bank's footprint in financial markets. Norges Bank's point of view is further discussed in Norges Bank (2021) and in a speech by Governor Wolden Bache in 2024[24]. Other proponents of scarce reserve systems are Borio (2023, 2024) and Selgin (2018), the latter with the title *Floored! How a misguided Fed experiment deepened and prolonged the Great Recession and why the Fed – or Congress – ought to end it*. Moreover, see ECB Occasional Paper (2021) for a discussion of whether a floor system creates endogenous demand for reserves.

3. Tokenised deposits settled in reserves in the central bank's RTGS system (models 1-2)

In this section we will discuss how tokenised deposits on ledgers can be settled in reserves in the central bank's RTGS system and consequences thereof for the central bank's and the banks' liquidity management. We will distinguish whether reserves are scarce (model 1) or ample (model 2). Settlement in wCBDC will be discussed in section 4.

The settlement of tokenised deposits on ledgers will take place on the banks' TD Lom accounts at the central bank (c.f. Chart 3). Compared with the benchmark model, banks will transfer liquidity in the morning (at 07.00) not only to the general liquidity account (GL LOM) but also to the tokenised deposit account, TD LOM.

Two settlement models exist, real-time settlement and deferred settlement. The difference between real-time and deferred settlement lies in the timeline between "payment" and "settlement". While payment is the transfer of deposit from the payer to the payee, settlement is the transfer of central bank money (reserves) from the payer's bank to the payees' bank on the balance sheet of the central bank. Both real-time and deferred settlement are designed to eliminate credit risk between banks in the settlement process, but how credit risk is eliminated differs.

With **real-time** settlement the bank of the payee credits the funds to the payee's account after the settlement between the banks has taken place in the central bank, i.e. the payment is

[24] See Wolden Bache (2024).

finalised **after** settlement in the central bank has been completed. This is how bank deposits are normally settled in central banks' RTGS systems (c.f. the benchmark model above). Credit risk between the banks is thus eliminated at the outset, as the payee's bank has the central bank money (reserves) at its disposal before the payee's account is credited.

If settlement is **deferred**, the payee's bank credits the funds to the payee's account before settlement between the banks has taken place in the central bank, i.e. the payment is finalised **before** settlement in the central bank has been completed. With deferred settlement there will be an accounting system on the ledger, calculating each bank's net position. Inflow of tokenised deposits increases banks' net positions, while outflow of tokenised deposits decreases banks' net positions. Then a bank's net position in the accounting system on the ledger will always be summarised in a single number. This number will be forwarded to the central bank at specific times during the opening hours of the RTGS system and settled on banks' TD LOM accounts. Banks with a positive position will have their TD LOM accounts credited, while banks with a negative position will have their TD LOM accounts debited. As settlement between banks takes place after payments between the banks' customers have been finalised, banks' TD LOM accounts in the central bank will serve as collateral. One very important requirement for deferred settlement is that reserve balances in the banks' TD LOM accounts (the collateral) must be large enough to cover the payment obligations of the payer's bank, not only during the opening hours of the RTGS system but also when the system is closed. Tokenised payments that do not pass the collateral check will not go through. For more details on real-time and deferred settlement, *see Box E: Real-time settlement and deferred settlement of tokenised deposits*.

3.1 Tokenised deposits settled in reserves. Scarce reserves in the banking system. The advantages of deferred settlement (model 1)

In this section we will show the advantages of deferred settlement when reserves are scarce, with tokenised payments on the ledger 24/7. This is model 1 in Chart 1.

The model is an extension of the benchmark model. The operating schedule will be as follows:

07.00-15.45:

- The central bank's RTGS system is open for real-time settlement of bank deposits on banks' GL LOM accounts, as in the benchmark model, and deferred settlement of tokenised deposits on banks' TD LOM accounts.
- We assume that both real-time settlements and deferred settlements take place say five times during the operational schedule, and that both the last real-time settlement and the last deferred settlement take place at 15.45.[25]
- Tokenised payments on the ledger are registered in banks' accounting system on the ledger and checked for collateral against banks' TD LOM accounts. Banks' net positions are forwarded to the central bank and settled on the banks' TD LOM accounts at the next deferred settlement in the operating schedule.[26]

[25] As in the benchmark model, gross payments from the banks' clearing system will be settled individually and consecutively, in our model up until 15.45.

[26] As an example, assume that both (net) real-time settlement of bank deposits and deferred settlement of tokenised deposits take place at 07.00, 11.00, 12.00, 14.00 and 15.45 in the central bank's RTGS system. Tokenised payments on the ledger between say 12.00 and 14.00 are registered in banks' accounting system on the ledger, and the net positions are forwarded to the central bank and settled at 14.00 on banks' TD LOM accounts. The new balances on bank's TD LOM accounts (plus/minus banks' own liquidity transfers to/from the TD LOM accounts) serve as new collateral until the next deferred settlement 15.45.

15.45-16.30:

- This is the “quiet time window” prior to closing time of the RTGS system. As in the benchmark model, banks redistribute reserves to avoid being forced to use the central bank’s overnight standing facilities. Banks’ total liquidity is the sum of GL LOM and TD LOM.
- Tokenised payments on the ledger are registered in banks’ accounting system on the ledger and checked for collateral. Bank’s net positions are forwarded to the central bank and settled on the banks’ TD LOM accounts in the morning of the next business day.

16.30-16.45: Change of business day:

- During the ¼ hours’ change of business day, the RTGS system is closed. Deposits on both GL LOM and TD LOM are transferred to the main top account, intraday loans are repaid and net deposits in the main top account are the basis for interest rate calculations.
- Tokenised payments on the ledger are registered in banks’ accounting system on the ledger and settled on the banks’ TD LOM accounts in the morning of the next business day.
- A technical setup ensures that reserve balances on TD LOM at 16.30 will be tied up and serve as collateral during the ¼ hours’ change of business day.

16.45-07.00:

- Banks can take up new intra-day loans and transfer liquidity to the TD LOM account. Except for funding TD LOM with new intraday loans, the central bank’s RTGS system is closed until it opens on the next business day at 07.00.
- Tokenised payments on the ledger are registered in banks’ accounting system on the ledger and settled on the banks’ TD LOM accounts in the morning of the next business day.

The crucial issue with deferred settlement is that the “quiet time window” prior to closing time of the central bank’s RTGS system can be maintained, as in the benchmark model. To recall, in the benchmark model we showed that with scarce reserves in the banking system real-time settlement of gross payments shortly before closing time could disturb both the central bank’s and the banks’ liquidity management. Late gross payments could change the distribution of reserves between banks, and if banks on short notice would not manage to successfully redistribute reserves overnight, they could be forced to use the central bank’s overnight facilities. Hence, a “quiet time window” prior to closing time was required, where the central bank could carry out market operations and banks could redistribute reserves overnight.

The same logic holds for tokenised payments. If settled in real time, tokenised payments would change banks’ reserve balances immediately, also in the time window prior to closing time of the RTGS system. Then, with scarce reserves in the banking system, banks could be forced to redistribute reserves overnight on short notice or to take recourse to the central bank’s overnight standing facilities.

With deferred settlement, however, tokenised payments on the ledger shortly before closing time of the RTGS system do not change banks’ reserve balances in the central bank, they only change banks’ net position in the banks’ accounting system on the ledger. And these net positions are to be settled in reserves during the opening hours of the RTGS system the next business day. Hence, with deferred settlement tokenised

payments on the ledger in the last ¾ hours' time window will not disturb neither the central bank's nor banks' liquidity management, and therefore, not interrupt the central bank's process of monetary policy implementation.

Furthermore, we note that with deferred settlement of tokenised payments the central bank does not need to extend the opening hours of the RTGS system. This may be different if tokenised payments are settled in reserves in real time. If settled in real time, each tokenised payment on the ledger triggers an immediate settlement on the banks' TD LOM accounts in the RTGS system and the bank of the payee credits the customer's account only after settlement between the banks has taken place. Real-time settlement of tokenised deposits 24/7 may require some changes in the RTGS system, at least for parts of the RTGS system the opening hours must be extended. This may or may not imply large administrative and technical changes for the central bank, depending on how the system is set up in the first place. Hence one advantage of deferred settlement over real-time settlement may be that tokenised payments can be carried out on the ledger 24/7 without extending the opening hours of the RTGS system and without exposing the participating banks to credit risk.

4.2 Tokenised deposits settled in reserves. Ample reserves in the banking system (model 2)

Model 1 above with deferred settlement and scarce reserves can easily be adapted to a situation with ample reserves in the banking system (model 2 in Chart 1). Since tokenised payments occur 24/7, outside the central bank's RTGS system's opening hours, settlement in the central bank still needs to be deferred. However, from the point of view of banks' and the central bank's liquidity management, deferred settlement is simpler with ample reserves than with scarce reserves, as all overnight balances are remunerated at the key policy rate when reserves are ample. As in the benchmark model, ample reserves mean that banks do not need to fine-tune liquidity management and redistribute reserves overnight to avoid the central bank's standing facilities. The basis for banks' interest rate calculation will be total net reserves, the sum of GL LOM and TD LOM minus intraday loans, at 16.30.[27]

Moreover, note that with deferred settlement of tokenised payments there is no reason to restrict tokenised payments to the opening hours of the central bank's RTGS system. Deferred settlement can handle settlement of tokenised payments 24/7 regardless of whether reserves are scarce or ample (though as explained above, it is easier with ample reserves). However, if (for some reason) deferred settlement is not an option, tokenised payments on the ledger can occur in the opening hours of the RTGS system only. Put differently, deferred settlement means that the central bank's RTGS system does not need to be in continuous operation to settle tokenised payments continuously.

Box E: Real-time settlement and deferred settlement of tokenised deposits

When settling tokenised deposits in reserves in the central bank's RTGS system, two settlement models exist: real-time settlement and deferred settlement. Both models are designed to eliminate credit risk between the banks in the settlement process, but how credit risk is eliminated differs. In either case a technical interface between the RTGS-system and the ledger

[27] In fact, tokenised payments in the opening hours of the RTGS system could be settled in real time up until the system's closing time at 16.30, as late inflows and outflows of tokenised payments would not require banks to redistribute reserves overnight on short notice (but note the remark in footnote 20). Tokenised deposits during the change of business day (16.30-16.45) and outside opening hours (16.45-07.00) would, however, have to be settled with deferred settlement, as in model 1.

must exist, so that the transactions outlined below can take place in an efficient manner. The difference between real-time settlement and deferred settlement lies in the timeline between payment and settlement. While "payment" is the transfer of deposit from the payer to the payee, "settlement" is the transfer of central bank money (reserves) from the payer's bank to the payees' bank, on the balance sheet of the central bank.

If settled in real time, each tokenised payment on the ledger will trigger an immediate settlement in reserves on the banks' TD LOM accounts in the RTGS system. The sequence of transactions, intended to be carried out within seconds, will be (roughly):

- A payer sends a message to his bank to transfer a tokenised deposit to a payee (the payer and the payee are assumed to be customers in different banks).
- The payment is settled in reserves in the RTGS system, i.e. the payer's bank reserve balances on the TD LOM account decrease (debited), while the payee's bank reserve balances on the TD LOM account increase (credited).
- The tokenised deposit is transferred from the payer to the payee (or more precisely, the tokenised deposit of the payer will be destroyed on the balance sheet of the payer's bank, while a new tokenised deposit will be created in the name of the payee on the balance sheet of the payee's bank).

With real-time settlement the bank of the payee credits the funds to the payee's account after settlement between the banks has taken place in the central bank, i.e. the payment is finalised after the settlement in the central bank has been completed. This is how bank deposits are normally settled in central banks' RTGS systems (c.f. the benchmark model above).

If settlement is deferred, the bank of the payee credits the funds to the payee's account before the settlement between the banks has taken place in the central bank, i.e. the payment is finalised before the settlement in the central bank has been completed. In this case banks' TD LOM accounts in the RTGS system serve as collateral for the deferred settlement. If not collateralized, deferred settlement would create a credit risk between the participating banks.[28] The system functions (roughly) as follows:

- A payer sends a message to his bank to transfer a tokenised deposit to a payee (the payer and the payee are assumed to be customers in different banks).
- A technical interface between the ledger and the central bank's RTGS system automatically checks the payment for collateral. Reserve balances on the TD LOM account of the payer's bank must fully cover the payment obligation. If the payment passes the collateral test, the tokenised deposit is destroyed on the balance sheet of the payer's bank and a new tokenised deposit is created in the name of the payee on the balance sheet of the payee's bank.
- On the ledger there will be an accounting system, calculating each bank's net position. Inflow of tokenised deposits increases banks' net positions. Outflow of tokenised deposits decreases banks' net positions. Then a bank's net position will always be summarised in a single number.
- Banks' net positions on the ledger are forwarded to the central bank's RTGS system for settlement in reserves on banks' TD LOM accounts at specific times during the opening hours of the RTGS system. For banks with a net positive position the balance of the TD

[28] The credit risk arises if the payer's bank goes bankrupt and runs out of reserves before reserves are transferred to the payee's bank. Then the payee's bank will have more debt on the liability side (the customer's new tokenised deposit) but no reserves on the asset side.

LOM account increases (credited). For banks with a net negative position the balance of the TD LOM account decreases (debited).
- The new balances on banks' TD LOM accounts are messaged to the ledger system and serve as collateral until the next deferred settlement in the RTGS system takes place.

One important deferred settlement requirement is that reserve balances on banks' TD LOM accounts (the collateral) must be large enough to cover the payment obligations of the payer's bank, not only during the opening hours of the RTGS system, but also when the RTGS system is closed (as during the night/weekend/easter etc.). Deferred settlement outside of opening hours will then work as during opening hours: Payments passing the collateral test will change banks' net positions in the accounting system on the ledger and will be settled in reserves on the banks' TD LOM accounts in the central bank's morning settlement on the next business day. Moreover, to provide sufficient collateral, liquidity may be transferred to the TD LOM accounts during the RTGS system's opening hours, but, depending on the design of the system, also outside of opening hours. Outside of opening hours, banks take up new intraday loans which must be repaid the next day.

Deferred settlement of tokenised deposits on ledgers follows the same logic as how settlement of instant payments is deferred in some countries, including Norway.[29] With instant payments a payer's deposit is transferred to the payee immediately (within seconds), while the settlement in reserves between the participating banks takes place at specific times during the central bank's RTGS system's opening hours. With deferred settlement, both instant payments and tokenised payments on ledgers can occur 24/7 and be settled in reserves during the central bank's RTGS system's opening hours without participating banks being exposed to credit risk.[30] Hence instant payments refers to the speed of the payments between banks' customers, while real-time settlement and deferred settlement refer to whether payments are settled in reserves between banks before or after the payee's bank has credited its customers' account. For a detailed discussion of deferred settlement of instant payments, see BIS (2016, 2021).

5. Tokenised deposits settled in wCBDC on a ledger (models 3-4)

In this section we consider models where tokenised deposits are settled in wCBDC (models 3 and 4 in Chart 1). As noted in section 2, wCBDC may be on a separate ledger or on a ledger shared with other tokenised assets. This difference is of less importance for the central bank's and banks' liquidity management (at least from a theoretical point of view). Below we will refer to the "wCBDC ledger", without specifying whether the ledger is separate or shared.

Issues related to the central bank's liquidity management have not been given much attention in the wCBDC literature. Some studies touch upon monetary policy implementation and emphasize that wCBDC and reserves should be remunerated at the same rate of interest and traded at par without any restrictions, as this will avoid segmentation of money markets and ensure the singleness of money. However, some also discuss the possibility and consequences of remunerating wCBDC and reserves at different rates of interest. Some study monetary policy implementation from a more technical point of view in that they conduct experiments on ledgers where the central bank uses market operations to steer the volume of wCBDC.[31]

[29] Norway has decided to connect to ECB's instant payment system TIPS as from late 2028.
[30] Note that the reference to the instant payment system in Norway is only to illustrate the general idea of deferred settlement, not to suggest a future design for settlement of tokenised deposits in Norway. This remains to be decided and will be a topic for further analysis and research.
[31] For examples, see BIS, SIX and Swiss National Bank (2020, 2022) and Phister (2024).

However, there has been less focus on the consequences of wCBDC for the banks' and the central bank's liquidity management depending on whether reserves in the banking system are scarce or ample. One reason may be that with ample reserves, liquidity management in general (with or without wCBDC) will be less of a challenge than with scarce reserves. During the last 15 years, many central banks have adopted floor systems with ample reserves. Hence, there seems to be an implicit assumption in the wCBDC literature that wCBDC will be living side by side with ample reserves in the banking system. For countries with scarce reserves, however, the introduction of wCBDC may pose challenges to liquidity management.

In the discussion below, we make the following assumptions for all models where tokenised payments are settled in wCBDC:

- Central bank reserves and wCBDC are convertible at par, in both directions, on banks' demand without limits and frictions. This assumption is common in the wCBDC literature.
- To the extent that wCBDC can be held overnight, wCBDC and reserves will bear the same rate of interest and have the same change of business day. Hence remuneration of wCBDC is "neutral", in as much as financial institutions' choice between holding wCBDC and reserves will not be influenced by interest rate considerations and arbitrage opportunities. This assumption is in line with a broad recommendation in the literature: Both rCBCD and wCBCD are parts of the monetary base issued by the central bank and should be remunerated like their "conventional peers", rCBDC like cash (no remuneration) and wCBDC like reserves. The literature emphasizes that this avoids fragmentation of money markets and contributes to ensuring the singleness of money (c.f. box A above).
- Also in line with the literature, a wCBDC is not considered to be an independent monetary policy tool. To some extent this follows from the assumption of wCBDC and reserves being remunerated at the same rate of interest.[32]

Compared to the benchmark model, in the morning (at 07.00) banks will transfer liquidity not only to the general liquidity account (GL LOM) but also to the tokenised deposit account, TD LOM. The TD LOM account will serve as a bridge between the RTGS system and the wCBDC ledger. When banks transfer reserves from the RTGS system to the wCBDC ledger, reserves are destroyed and wCBDC is created (hence TD LOM balances decline and wCBDC balances increase). When banks transfer wCBDC from the ledger to the RTGS system, wCBDC is destroyed and reserves are created.[33]

In the discussion below, it is convenient to start with the model with ample reserves in the banking system, in which case the central bank's and banks liquidity management is straightforward (at least from a theoretical point of view). This is model 3 in Chart 1.

With ample reserves, the operating schedule will be as follows:

07.00:

- The central bank's RTGS system opens

[32] Note that in the practically oriented central bank literature, there is fairly strong agreement that neither rCBDC nor wCBDC should be considered independent monetary tools (although assigning such a role to CBDC in the future it is not necessarily ruled out). It should be noted, however, that many academic studies claim that a rCBDC can fulfil the role of an independent monetary policy instrument.

[33] Exactly how reserves and wCBDC are destroyed and created may depend on det design of the system. Here we envisage that banks initiate the process of creating and destroying wCBDC and that the central bank transfers reserves/wCBDC between the RTGS system and the wCBDC ledger on banks' demand. This seems to be a common assumption in the literature.

- Banks take up intraday loans and transfer reserves from the top account to the general liquidity account (GL LOM) and the tokenised deposit account (TD LOM).

07.00-16.30:

- Banks can take up intraday loans during the day and transfer reserves between the top account, GL LOM and TD LOM without restrictions, until closing time of the RTGS system at 16.30.
- Ordinary bank deposits are settled on the banks' GL LOM accounts, as in the benchmark model.
- Liquidity is transferred between the RTGS system and the wCBDC ledger on banks' demand (via the TD LOM accounts), i.e. wCBDC and reserves are created and destroyed.
- Tokenised deposits are transferred between banks' customers on the ledger. The tokenised deposits are settled in wCBDC, meaning that wCBDC changes owner on the balance sheet of the central bank. For banks with tokenised deposit inflow wCBDC balances increase. For banks with tokenised deposit outflow wCBDC balances decrease.
- A technical interface between the ledger and the central bank must exist, so that wCBDC can be transferred between banks – i.e. change owners - on the balance sheet of the central bank. This technical interface must be in operation 24/7 and not only during the opening hours of the RTGS system. This is necessary to allow tokenised deposits to occur 24/7 with atomic settlement in wCBDC.

16.30-16.45:

- Balances on the GL LOM account are transferred to the top account.
- A "snapshot" of wCBDC balances is taken at 16.30 ("end of day wCBDC balances").
- Banks repay intraday loans.
- Net overnight balances after repayment of intraday loans, the basis for the interest rate calculations, are the sum of the wCBDC snapshot at 16.30 and reserves on the top account.
- The banks may take up new intraday loans (to be repaid before closing time the next day) to fund wCBDC balances (via the TD LOM account). This ensures that a sufficiently large amount of wCBDC will be available on the ledger 24/7.

16.45-07.00

- The ledger will be open for tokenised transactions.
- Tokenised deposits will be settled in wCBDC continuously, in the same way as during the opening hours of the RTGS system. The abovementioned technical interface between the ledger and the central bank ensures that wCBDC can change owner on the balance sheet of the central bank 24/7.
- The system could be set up to allow banks to take up new intraday loans also between 16.45-07.00. This would be a technical solution to simplify banks' liquidity management without implications for the central bank's liquidity management.

With ample reserves, all reserves and wCBDC overnight balances are remunerated at the key policy rate, hence banks do not need to fine-tune liquidity and redistribute reserves overnight, provided that no bank gets a negative account balance, cf. the remarks in footnote 20.

With *scarce reserves*, however, settling tokenised deposits in wCBDC 24/7 is more challenging (model 4). In fact, out of the four models illustrated in Chart 1, this is the trickiest one. The reason is that tokenised payments 24/7 will also change banks' wCBDC balances 24/7, also in the time window prior to closing time of the central bank's RTGS system (atomic settlement). To recall, in the benchmark model we explained how gross real-time settlement of ordinary deposits could disturb both the banks' and the central bank's liquidity management. The reason was that late payments would change the distribution of reserves between banks shortly before closing time. Then, if banks on short notice were unable to successfully redistribute reserves overnight, they could be forced to use the central bank's overnight facilities. Hence both the banks and the central bank needed a quiet time window prior to the RTGS system's closing time to handle liquidity management.

The same logic holds true when tokenised payments are settled in wCBDC 24/7. Tokenised payments in the last time window prior to closing time of the central bank's RTGS system change banks wCBDC balances; hence banks may need to redistribute reserves/wCBDC overnight or take recourse to the central bank's overnight standing facilities. This may disturb both the central bank's and banks' liquidity management, and therefore also the central bank's monetary policy implementation. Furthermore, unlike models where tokenised deposits are settled in reserves, deferred settlement is not an option. The basic idea of the new financial infrastructure with tokenised assets and wCBDC on ledgers is atomic settlement with smart contracts. To recall the timeline discussion in section 3 (and box D), deferred settlement means that payments from the payer to the payee are finalised **before** the settlement in the central bank has been completed, while real-time settlement means that payments are finalised **after** the settlement in the central bank has been completed. Atomic settlement of tokenised deposits, however, requires simultaneous payment and settlement, i.e. the timeline collapses to zero: No timeline, atomic settlement. Moreover, most market participants envisage tokenised payments with atomic wCBDC settlement 24/7, also in the time window prior to the RTGS system' closing time. If tokenised payments are to occur 24/7 with scarce reserves in the banking system and if the volume of tokenised payments becomes large, there is no easy way out of this dilemma.

One way to solve the problem would be to limit tokenised payments on the ledger in the time window prior to closing time of the RTGS system. Assume, for example, that no tokenised payments occur in the last time window between 15.45-16.30. In this time window all wCBDC on the ledger would be converted to conventional reserves and transferred to the RTGS system, and banks would redistribute reserves to avoid the central bank's overnight facilities. Banks' net position during the change of business day at 16.30-16.45 would be the basis for interest rate calculations. Thereafter, banks would take up new intraday loans with interest rate effect the next business day, and transfer liquidity to the wCBDC ledger (via the TD LOM accounts). After 16.45 wCBDC would be available on the ledger and tokenised payments could be carried out until the start of the quiet time window the next business day.[34]

This would, at least from a theoretical point of view, solve the problems related to the banks' and the central bank's liquidity management. The suggestion, however, has an obvious drawback. In a specific time window prior to the RTGS system's closing time, in our model envisaged between 15.45 and 16.30, tokenised payments cannot be carried out. The ledgers are closed (or at least there will be some restrictions regarding tokenised trading). From the point of view of market participants, and also from the point of view of banks and the central bank, this could be considered as an inefficiency in the payment and settlement system. The basic idea of the new

[34] In fact, one could also imagine a technical setup where the wCBDC stays on the ledger and is not transferred to the RTGS system prior to the RTGS system's closing time. This is first and foremost a technical matter without consequences for the central bank's liquidity management.

financial infrastructure, with smart contracts and atomic settlement, is 24/7. The quiet time window could perhaps be shortened. Perhaps a window of 15-20 minutes would be sufficient for banks and the central bank to carry out their liquidity operations. This would reduce the inefficiency problem but not remove it. On the other hand, one could argue that compared to today's conventional payment system, near-24/7 settlement of tokenised payments in wCBDC would still be a significant step forward in terms of efficiency of the payment system.

Another solution could (perhaps) be to let reserves and wCBDC have different times for change of business day for interest rate calculation. Assume that for wCBDC, change of business day (the snapshot) is at 15.30, while it is at 16.30 for reserves. wCBDC balances at 15.30 plus reserves balances at 16.30 (minus intraday loans at 16.30) would then be the basis for the overnight interest rate calculation. Then, inflow of wCBDC due to tokenised deposits inflow after 15.30 would be part of next day's wCBDC balance and not force banks to redistribute reserves/wCBDC or to take recourse to the central bank's overnight standing facilities today. This would, however, require some restrictions on transfers between reserves and wCBDC in the same time window, to prevent banks from circumventing the interest rate conditions inherent in the liquidity management system. Assume, for example, that banks, after the wCBDC snapshot has been taken at 15.30, have surplus (conventional) reserves at the central bank, implying that they either have to lend reserves overnight to other banks or to take recourse to the central bank's overnight deposit facility. Without restrictions on transfers between reserves and wCBDC in the said time window, banks could transfer liquidity from the RTGS system to wCBDC balances, and thereby not be forced to lend reserves to other banks or to use the overnight standing deposit facility.[35] This could interrupt the central bank's liquidity management. Moreover, imposing such restrictions would (at the very least) complicate liquidity management for both the central bank and banks. However, this is a potential topic for further research.

5. Concluding remarks

Tokenised payments on ledgers should, according to international recommendations, be settled in central bank money. This may have consequences for the central bank's and banks' liquidity management. Several models with different implications for liquidity management exist. We have distinguished between (i) whether tokenised deposits are settled in traditional reserves in the central bank's RTGS system or in wCBDC on a ledger, and (ii) whether reserves in the banking system are scarce or ample. Only the two models with scarce reserves required a detailed discussion.

It was straightforward to show that with ample reserves in the banking system the central bank's and the banks' liquidity management is manageable. With ample reserves all banks' overnight deposits at the central bank are remunerated at the key policy rate (be it reserves or wCBDC). Changes in banks' reserve and wCBDC balances shortly before closing time of the central bank's RTGS system do not force banks to redistribute reserves overnight or to take recourse to the central bank's overnight facilities at unfavorable interest rates.

This left us with two models more challenging for the central bank's and the banks' liquidity management, depending on whether tokenised deposits are settled in reserves or wCBDC, both models with scarce reserves in the banking system:

- In the model where tokenised deposits are settled in reserves (with scarce reserves), we showed the advantage of deferred settlement over real-time settlement. Real-time settlement of tokenised deposits changes banks' reserve balances immediately,

[35] Alternatively, they could in some situation receive interest payments from the central bank twice.

and with reserve inflow or outflow shortly before closing time of the central bank's RTGS system, banks may on short notice need to redistribute reserves overnight or take recourse to the central bank's overnight standing facilities at unfavorable interest rates. With deferred settlement, however, tokenised payments on the ledger shortly before closing time do not change banks' reserve balances in the central bank, they only change banks' net position in their accounting system on the ledger. And these net positions are settled in reserves during the opening hours of the RTGS system on the next business day. We showed that with deferred settlement, as opposed to real time settlement, the central bank does not need to extend the opening hours of the RTGS system.

- We showed that with scarce reserves, however, settling tokenised payments in wCBDC 24/7 is more challenging. The reason is that tokenised payments 24/7 will also change banks' wCBDC balances 24/7 (atomic settlement), also in the time window prior to the central bank's RTGS system's closing time. Hence banks may need to redistribute reserves/wCBDC overnight or take recourse to the central bank's overnight standing facilities. This may disturb both the central bank's and banks' liquidity management, and therefore also disturb the central bank's process of monetary policy implementation. Furthermore, as opposed to the models where tokenised payments are settled in reserves, deferred settlement is not an option. We argued that the problem could be solved by imposing limits on tokenised payments on the ledger in the time window prior to closing time of the RTGS system. This would solve the problems related to the central bank's and the banks' liquidity management but the payments would be somewhat less efficient compared to a fully-fledged 24/7 set up. We also pointed out the possibility of letting reserves and wCBDC have different times for change of business day, although this would introduce new challenges for the central bank and the banks in their liquidity management that needs to be investigated further.

All in all, liquidity management systems based on scarce reserves complicate the settlement of tokenised deposits. At present, many central banks around the world operate floor systems with ample reserves and are not really faced with these challenges. Norges Bank's liquidity management system is based on the premise that liquidity and credit risk should be borne as far as possible by private agents in the financial system. This implies a system with scarce reserves. Our analysis in this note suggests that a potential future need to settle tokenised deposits in central bank money is indeed possible within a system with scarce reserves. However, some additional amendments are likely to be necessary compared to the case with a floor system with ample reserves.

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