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Settlement of Cross-Border Transactions through Central Bank Digital Currency

Analysis from a risk management perspective

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Casper van Ginneken
Amsterdam, June 2019

Executive Summary

Over the past decades, financial institutions have pursued cost efficiency in the payments industry. In its ongoing quest for speed to meet changing habits in society, the financial sector has sought venues for improvement to accelerate payments for both finance and commerce through the adoption of new technologies. One with high potential is Distributed Ledger Technology (DLT). This peer-to-peer network allows for decentralised authority based on consensus of replicated, shared, and synchronised digital data across all network members. Numerous financial institutions, academics and other stakeholders from around the globe are actively investigating the potential of DLT to improve payment systems. The focus is on cross-border (wholesale) payments, because banks still face several major issues in this area.

Due to a lack of standardisation across jurisdictions regarding operating hours, data standards and regulatory requirements, banks are forced to consult their network of intermediaries to facilitate a cross-border transaction. As a result, end-users experience significant delays in payments processing, potentially leading up to waiting times of multiple days or even a week. Upon initiation, a transaction's certainty of outcome and costs are unknown, whereas a payment's status during the process is not visible. In the meantime, exposure to financial risks increases, resulting in an inevitably larger cost burden, which is enhanced by each correspondent bank taking additional fees. These issues have progressed over decades due to the existence of technical barriers in legacy payments infrastructure, which restrict possibilities to innovate.

To overcome these issues, central banks are considering the concept of CBDC, essentially a digital currency issued and/or backed by the central bank. CBDC has the potential to improve cross-border interbank settlement by reducing the number of intermediaries required, taking away time zone impediments and speeding up transactions while reducing costs and scope for error. Most debate on CBDC is centered around qualitative reasoning and directed at society-wide implications of CBDC issuance. Quantitative analysis is however lacking at the moment. To fill this gap, this study is conducted from a risk management perspective.

Near real-time settlement of transactions on a peer-to-peer basis with round-the-clock availability would wipe out a substantial portion of financial risks. Our analysis of the relevant financial risks shows that liquidity risk decreases by 21%, as the release of 'trapped' liquidity at correspondent banking nostro accounts will centralise cash pools and thus stimulate liquidity management optimisation. This effect is magnified by an increased reach to potential counterparties. Removing intermediaries from the payment process causes interest rate risk to vanish completely, since accumulated interest can be used for other practices. Time becomes of marginal influence, so the possibility that the value of two currencies changes reduces to nil. Following the same reasoning, counterparty credit risk approaches zero as well. Exposure to settlement risk is solved due to atomic settlement in a PvP transaction.

Operational risk, however, will not face a reduction. The fact that DLT is a rather novel technology that has not yet seen mass adoption complicates the transition from legacy payments infrastructure to a new IT framework. Other interoperability issues arise regarding legal risks. Standardising legislative frameworks, harmonising regulatory differences between jurisdictions, and ensuring that CBDC is legal tender must be considered extensively. Thus, central banks should make cooperation on interoperability challenges between participating jurisdictions, both from a regulatory and technological perspective, central to their research activities. DLT's nature could mitigate the effects of interoperability issues. Its decentralised and immutable characteristics could help to underpin trust in the financial system, reduce systemic risk by removing single points of failure, and increase transparency and predictability.

We calculated that settling a cross-currency payment through CBDC instead of legacy payments infrastructure yields a reduction in transaction costs of 51%. Almost half of this reduction (46%) is due to cutting (typically fixed) operational expenses. These include payment operations, correspondent network management, and relieving manual back-office costs for error handling and reconciliation inquiries. Increased interest opportunities, liquidity management optimisation and covering for counterparty credit risk through CDS insurance account for the other half (54%) of total cost reduction. We calculated that total annual savings due to CBDC settlement are €37 million for a commercial bank. Although setup and transition costs will impose a substantial cost burden for participating financial institutions, we believe that a collaborative effort will result in a positive ROI.

Although CBDC will involve overcoming numerous legislative, technological and even political challenges, we believe that its introduction could dramatically innovate the cross-border interbank payments landscape. As speed, transparency and overall ease of payment processes increase significantly, we expect participating banks to achieve large competitive advantages. CBDC, with DLT as its underlying technology, offers the potential to catch up with domestic payment systems without having to overhaul legacy payment infrastructure entirely. All in all, we believe that the cross-border interbank transaction landscape is set for a prosperous future with CBDC.

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List of Acronyms

ABS Association of Banks in Singapore

AML Anti-Money Laundering

B2B business-to-business

BIS Bank for International Settlements

BNY Mellon Bank of New York Mellon

BOA Bank of America

BTC Bitcoin

CBDC Central Bank Digital Currency

CDS Credit Default Swap

CFT Countering Financing of Terrorism

CHAPS Clearing House Automated Payment System

CHF Swiss Franc

CPMI Committee on Payments and Market Infrastructures

DB Deutsche Bank

DLT Distributed Ledger Technology

DvP Delivery-versus-Payment

ECB European Central Bank

EFTA European Free Trade Association

EME Emerging Market Economy

EONIA Euro Overnight Index Average

EU European Union

EUR Euro

EURIBOR Euro Interbank Offered Rate

FED Federal Reserve System

FX Foreign Exchange

GBP Great Britain Pound Sterling

GDP Gross Domestic Product

ICO Initial Coin Offering

IPO Initial Public Offering

IT Information Technology

JPY Japanese Yen

KYC Know Your Customer

LIBOR London Interbank Offered Rate

LSM Liquidity-Saving Mechanism

MAS Monetary Authority of Singapore

OMFIF Official Monetary and Financial Institutions Forum

PD Probability of Default

PvP Payment-versus-Payment

RTGS Real-Time Gross Settlement

SARON Swiss Average Rate Overnight

SEPA Single Euro Payments Area

SOFR Secured Overnight Funding Rate

SONIA Sterling Overnight Index Average

STP Straight-Through Processing

SWIFT Society for Worldwide Interbank Financial Telecommunication

TARGET2 Trans-European Automated Real-Time Gross Settlement Express Transfer System

TONAR Tokyo Overnight Average Rate

USC Utility Settlement Coin

USD United States Dollar

WoW World of Warcraft

ZKP Zero-Knowledge Proof

Chapter 1

Project Description

1.1 Introduction

The international payments infrastructure that financial institutions use to transact with each other is an extremely complex network. Commercial banks utilise multiple payment systems alongside one another to settle financial transactions, each devised for a different purpose. Whereas some settlement systems process payments in batches (e.g. Single Euro Payments Area (SEPA) and EURO1 in Europe), so-called Real-Time Gross Settlement (RTGS) systems are used for high-value transactions for which immediate clearing is required and received. However, RTGS systems do not suffice for international transactions, since payment infrastructures of multiple jurisdictions need to be linked. The current solution to circumvent this issue is to consult correspondent banking services. As as result, global payments are fairly inefficient when compared to local payment mechanisms. In this research, we look at an improvement to the current cross-border interbank settlement process as there is substantial room for advancement on this topic. These advancements relate to five main issues that banks are subject to when conducting cross-border interbank payments. These issues are briefly discussed in the following paragraphs.

(1) **High transaction costs** — The costs of settling transactions is a substantial drawback of the current cross-border interbank payment system. The main cause of this disadvantage is the existence of correspondent banking channels. For a bank to arrange a cross-border payment, it must either have both parties currencies in its possession or else have a means of buying the foreign currency required to execute the transaction. Whereas some of the larger international banks might have the banking license and liquidity required in the respective currency, viability decreases rapidly as the number of transactions turns too low. As a result, most banks set up a strategically selected network of foreign banks to handle their international transactions. Multiple correspondent banks can be involved in a single transaction and every party is entitled to a fee of the transaction along the way. Operating costs, such as managing diverse messaging standards, dealing with complex infrastructures, manual intervention due to reconciliation errors, and adhering to regulatory obligations further increase the cost of a payment.

(2) **Limited availability** — Payment services of central and commercial banks are subject

to limited operating hours. This effect is intensified by the process often having to span multiple jurisdictions and time zones. This mismatch in the operating hours of payment systems across different jurisdictions and a reliance on multiple intermediaries hinder straight-through processing of payments.

(3) **Delays in payment processing** — Varying payment standards, guidelines and regulatory requirements further confine a smooth transaction process. Duplication of these processes across multiple entities and jurisdiction in a sequential manner can prevent straight-through processing of payments. This issue is especially important, since it involves several (financial) risks. As can be seen in Figure 1.1, the present system causes delays in the transaction process (ING, 2018b).

We will explain Figure 1.1 by means of an example. Suppose Dutch Shell (A.1) must make a payment to U.S. Steel in the United States (B.1). It cannot deposit the funds directly to its counterparty. In contrast, both Shell and its counterparty must use commercial banks (A.2 and B.2, respectively) to transact. Because it is expensive and resource-intensive to maintain accounts at every central bank, banks would use their corresponding network of banks (X.3) to transfer the payment along the chain, until the payment eventually reaches its destination. Consequently, a payment might take a week to arrive at its destination in a worst-case scenario. Basically, any commercial bank could take the role as correspondent bank to two other commercial banks that do not have direct connections or have restricted access to the currency in question. The different payment models considered will be elaborated more into detail in Section 2.1.

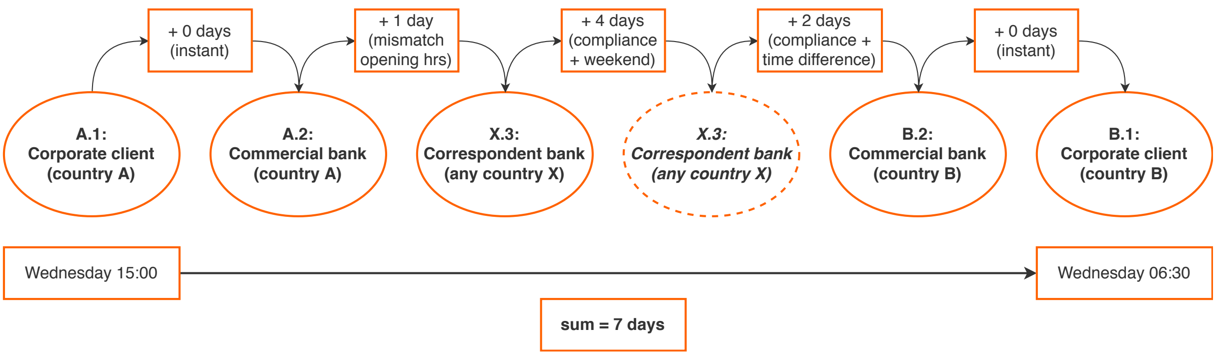


Figure 1.1: *Current situation with several intermediaries (based on ING, 2018b).*

(4) **Lack of transparency** — In the current system, the status of a transaction in the chain is unclear to end-users and banks. For example, a transaction currently being in the account of correspondent bank X.3 would mean that other parties in the network, such as A.2 and B.2, are not aware of this state. Also, the exact route of the payment, its fulfilment, and charges are unknown upfront. As a result, resilience against fraud and errors is reduced. This is a major drawback, since the payment could be cancelled and transferred back to the originating bank. Only after several days, this party will be notified about the cancellation of the transaction due to, for instance, legal issues.

Regulatory requirements in Japan, for example, might not always align with those in Europe. Hence the transaction might be blocked when certain regulations are violated.

(5) **Legacy payments infrastructure challenges** — There exist significant technical barriers to improve payment systems like RTGS. Incorporating new technology into existing Information Technology (IT) architecture adds significant costs and complexity. New types of risks (e.g. cyber-attacks) to payment systems impose further challenges on networks, mainly caused by an increase in the scale, nature, and sophistication of these risks.

The issues identified in settlement systems have given rise to extensive cross-border discussions about potential improvements. Concurrent with the rise of distributed ledger and blockchain technology use cases, numerous insiders, scientists and other stakeholders advocate for the adoption of such disruptive technologies in the financial industry. Since current settlement systems thwart an efficient payment process, hence indirectly hindering financial growth, the urgency of additional measures - or even a substitution - is higher than ever. One alternative might be the issuance of a Central Bank Digital Currency (CBDC), essentially a digital currency issued and backed by a central bank. Its concept has gained considerable interest over the last two years and numerous central banks are either conducting research into or experimenting with various applications to some extent. Among other things, it is for these reasons that we choose to focus our research on CBDCs and the potential implications to a commercial bank's cross-border transaction business.

On an overall level, CBDC can be split into two categories: wholesale and general public. Whereas the former would only be targeted at commercial bank transactions - and potentially include corporate clients in a later stadium - general public CBDCs could substitute for cash and increase financial inclusion in society. The latter involves greater (financial) risks, as it would rather drastically transform the monetary system, hence requiring regulatory changes in the central bank's monetary policy. We therefore focus on a wholesale variant.

The ultimate goal of CBDC is to provide customers the opportunity to transfer funds peer-to-peer to a counterparty (i.e. the person or institution receiving funds) via this network on an intraday basis, ideally without any intermediary and without the current delay of multiple days. We foresee significant potential in issuance of CBDCs due to the possibility of near real-time settlement of transactions worldwide. We therefore focus our research on this particular subset of digital currency. We are particularly interested in implications on the financial industry.

In the next section, we will elaborate on the current concerns of cross-border interbank settlement and propose our view on the core problem.

1.2 Core Problem

The issues identified in cross-border settlement systems have led to an industry-wide debate on their efficiency. New technologies are identified as potential solutions to current problems and the concept of CBDC has especially garnered much interest amongst central bankers and other stakeholders in cross-border transaction settlement. The effects of introducing CBDCs in interbank payment systems are however unclear. Several risks can be listed that might change due to reforming the cross-border interbank payment landscape. Examples of such risks are financial, reputational, IT infrastructural, cyber security, and legal risks. With regards to financial exposure, relevant uncertainties arise with regards to credit, liquidity, market, and operational risks.[1] To enhance clarity, a problem cluster is depicted in Figure 1.2.

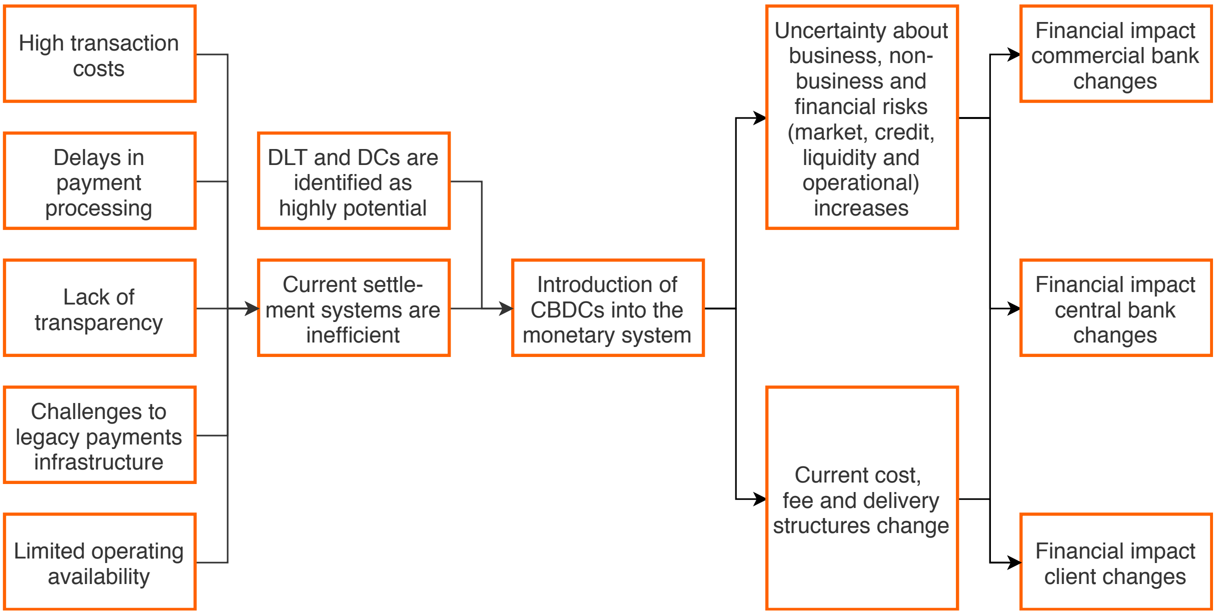


Figure 1.2: *Graphical display of the problem cluster.*

A different setup of cross-border interbank payment systems imposes changes to existing cost, fee and delivery structures of banks as well. Not only is current commercial bank business affected, the financial impact of clients and central banks would shift likewise. Our core problem can inherently be formulated as follows:

"The lack of insight in the effects of introducing wholesale Central Bank Digital Currencies into the monetary system on financial impacts and risks of cross-border interbank transactions."

Continuing on the core problem, we narrow our scope by delineating the actual research problem, i.e. the knowledge gap that is derived from the core problem. We

[1] The relevant market risk factors are interest rate and foreign exchange risk. These are diminished due to the increased speed of delivery, i.e. settlement is close to instant. There will be changes from a credit and liquidity point of view as well, which we will elaborate on later (cfr. Section 3.1).

define the respective research questions subsequently, in Section 1.3 and 1.5, respectively.

1.3 Research Problem

The research problem is derived from the core problem and addresses the actual research goal. In order to solve our core problem we need to research the various aspects of this statement. The core problem can be roughly classified into four categories, each of which has its own sub-classes. This rough distinction is displayed in Figure 1.3 below.

We distinguish between (the impact on) stakeholders. The effects of CBDC introduction will be totally different to everyone of interest. Second, we differentiate between wholesale and general public CBDC. A more extensive classification of the distinctive angles on digital currencies in general is explicated in Section 2.2. Our third distinction relates to financial topics. Not only is it unclear to commercial banks what a CBDC introduction will yield in terms of cost savings, and even additional expenses, detailed risk quantification is lacking at the moment. Lastly, we distinct between two transaction types. We define our research problem as follows:

"What is the financial impact of the introduction of Central Bank Digital Currencies on a commercial bank's cross-border interbank transactions?"

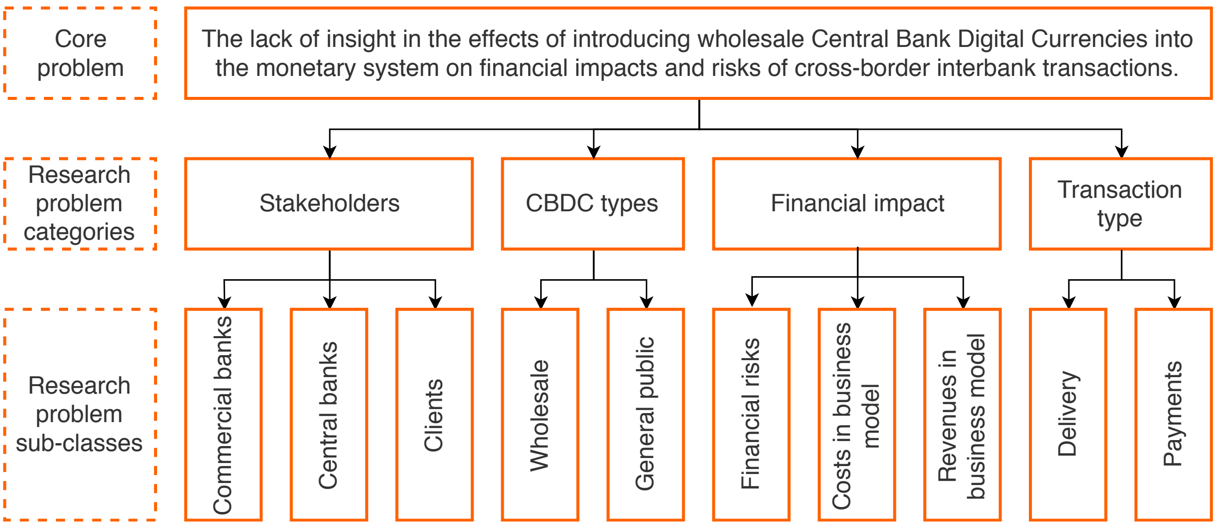


Figure 1.3: *Graphical display of the research problem classification.*

To understand what will happen in a future model with settlement through CBDC, we must first improve our understanding on the current situation, i.e. the current costs, revenues and risks that a commercial bank faces in the cross-border payment industry. We will further elaborate on the respective scope in Section 1.7.

Furthermore, there are plentiful other related matters and definitions that we must get a grasp on to define the setting in question. First, we must know what CBDCs are, which aspects are important to consider and advantageous to adopt, and how (central) banks are planning to implement them in the monetary system. The current cross-border interbank payment system must be mapped to provide context to our conclusions and implications. Determining which risk parameters are subject to change, thus prove relevant to research, is a vital part as well. In order to do so, we must know how a commercial bank calculates its financial risks, e.g. liquidity requirements and counterparty risk and what role central bank regulation obligations play. Once the overview on the current situation is clear, we are able to seek for indications of change required in terms of risk calculation and compute the effects consequently. Mapping the future model becomes more straightforward once we know how current risks are quantified and which ones are important.

1.4 Motivation

The reason for choosing the aforementioned research problem has multiple perspectives. A great opportunity for research on this particular topic relates to the soaring degree of future business potential. Currently, cross-border payments are a substantial cost item for organisations and the need for fast payments keeps increasing rapidly. Whereas domestic payment systems already are fast, there are still significant steps to be taken for the cross-border transaction landscape. On the other hand, research into this combination of topics has not yet been conducted to the best of our knowledge.

From a scientific point of view, we stress the need for fast, reliable, and most of all secure payments. It is vital that we keep our deposits safe due to rising threat levels for IT systems. One could also argue that there is a constant trade-off to be made between risk and performance. Due to the combination of the previous and the novelty of blockchain and distributed ledger technologies, we foresee significant potential in a relatively untapped research field with an auspicious road ahead. Combining the CBDC initiative with the extensive knowledge base on risk management could, according to our expectation, result in new findings. We hope to contribute to the debate on issues identified in cross-border transactions.

1.5 Research Questions

We now define our research questions. These questions are boxed below. For every research question, a number of sub-questions is defined that must be answered in order to solve the main research question.

(i) *What is CBDC and how is it perceived currently?*

- How are cross-border interbank transactions settled in the current correspondent banking model?
- What role do digital currencies play in the cross-border interbank payment system?
- How is the concept of CBDC perceived currently?
- How are cross-border interbank transactions settled in a future model with wholesale CBDC?

(ii) *How will CBDC introduction change the financial risks involved in cross-border interbank transactions?*

- Which financial risks are relevant to cross-border interbank transactions?
- How are the relevant financial risks in the current correspondent banking model quantified?
- How would the relevant financial risks in a future model with wholesale CBDC be quantified?
- How do the individual risk factors compare to each other?

(iii) *What are the effects of introducing CBDC into the settlement process of cross-border interbank transactions?*

- What are the potential savings in transaction costs in a system with wholesale CBDC?
- What do commercial banks need to consider regarding wholesale CBDC introduction?
- What do central banks need to consider regarding wholesale CBDC introduction?

1.6 Methodology

We now address the methodology of our research, which is twofold. We first set up the model for analysis in order to quantify the relevant financial risks that wholesale CBDCs are subject to. The financial risks will be quantified by means of data analysis. Most data used in our research is publicly available market data, such as interest and exchange rates. Historical rates are used to calculate our risk factors. For counterparty credit risk specifically we use market data as well, albeit retrieved from an internal database instead of online. Data was sorted and filtered in *Jupyter Notebook*, an open source web application based on programming-language *Python*. This serves as preparation for our analysis. The respective code is added to Appendix D. We will elaborate on data specifics in Chapter 3. Note that quantification of the relevant financial risks is subject to data availability and we might not be able to compute every risk factor exactly. Quantitative analysis will be supplemented by qualitative reasoning in case data availability is limited.

Second, a literature study will be conducted on CBDC in general. Here, one should think of subjects such as design choices, chances of implementation, advantages and drawbacks, and use cases. Furthermore, theories and models for financial risk quantification will be investigated. These are used for an assessment on the relevant financial risks and sound calculation of the potential impact induced by CBDC introduction. Not only will (academic) papers and specialist literature be used, internal documents can provide us with specific background information and insights from a commercial bank's perspectives. Moreover, using internal information directly affects the relevance of this research to commercial banks due to increased chances of applicability. We elaborate on the literature study in Section 2.3. The end goal of our research is to provide insights in the effects of introducing CBDC in cross-border transaction settlement by quantifying the financial risks for various scenarios and design choices. A more detailed plan of approach is added to this report as Appendix A.

1.7 Scope and Limitations

Besides stating the decisions that fall within our research, we must also determine what is omitted. The first restriction relates to the stakeholders. We focus on applications for commercial banks. Computing implications on society in general, which would especially be relevant for general public CBDC, is therefore out of scope. However, when we speak of the monetary system, we imply commercial and central banks due to their relevance. Although our main focus is on commercial banks, we do share some high-level insights on central bank considerations to provide an overall picture for our conclusions. Also, as the interest of a commercial bank should actually be the interest of its clients, we take their view into account as well.

We must state the scope of our research with respect to financial risks. This term encompasses an extensive range of risks, of which not all are relevant. Based on an extensive classification of financial risks (cfr. Figure B.1 in Appendix B) and consulting experts, we have decided to research interest rate, foreign exchange, counterparty credit, liquidity and operational risks. The latter will however not be quantified due to our focus on pure financial risks.

We need to define the term 'cross-border interbank payments' due to its comprehensiveness. International transactions encompass a great deal of products. Examples are regular cash payments, all kinds of derivatives, but also complex swaps. Quantifying swaps or derivatives, for instance, would increase the complexity tremendously due to having to take into account numerous pricing and valuation techniques. Consequently, the choice of which intermediaries and financial institutions to include may differ, as this is dependent on a financial transaction's nature and regulatory requirements. Therefore, we define three cross-border interbank cash transactions that are representative for a commercial bank. The types considered are listed as follows:

(1) Mono-currency payment (e.g. EUR to EUR).

(2) Cross-currency payment (e.g. EUR to USD).

(3) Cross-currency Payment-versus-Payment (PvP) (e.g. EUR to USD).

We will focus on a fixed set of currencies for which data is widely available, i.e. Euro (EUR), United States Dollar (USD), Great Britain Pound Sterling (GBP), Japanese Yen (JPY), and Swiss Franc (CHF). For all calculations, a notional of €1 million is used, which is converted to each currency to represent the same relative amount. This particular amount is chosen, because its size represents a wholesale transaction. Also, its round number enables the notional to be used as an index value for all subsequent calculations. As time plays a crucial role in our risk analysis, we assume three different lead times for the transactions considered, i.e. one, three and five business days. However, we use a settlement period of two days for cost calculations.

The limitation with respect to currency choice enables us to structurally compare scenarios. The same holds for CBDC types. Considering the novel phase and long-term horizon CBDC projects are bound to, we are hesitant to accentuate these opacities. Accordingly, we will focus on wholesale rather than general public CBDCs as these are more relevant at the moment.

Chapter 2

Settlement of Cross-Border Interbank Transactions

In this chapter, we address research question (i), which reads:

"What is CBDC and how is it perceived currently?"

First, we define the current situation and address its drawbacks. We propose an improvement and conduct a literature study to substantiate our proposal. Subsequently, we describe settlement of cross-border transactions in a future situation with CBDC.

2.1 Settlement in the Current Model

This section addresses the first sub-question of research question (i): *"How are cross-border interbank transactions settled in the current correspondent banking model?"*

Commercial banks use multiple payment systems alongside one another to settle financial transactions, each devised for a different purpose. For instance, SEPA was introduced to improve the efficiency of international euro payments conducted in the European Union (EU) and members states of European Free Trade Association (EFTA) (European Central Bank, 2019b). Banks utilise so-called RTGS systems for generally high-value transactions for which immediate clearing is required and received. Settlement is immediate, final and irrevocable, without bundling of or netting multiple transactions. RTGS systems are typically operated by central banks and incur excessive transaction fees due to payments' waiting periods being discarded (ING, 2018b). The RTGS system for large-value Euro interbank transfers, for instance, is Trans-European Automated Real-Time Gross Settlement Express Transfer System (TARGET2) (European Central Bank, 2007).

Similarly, international payment systems have been devised to provide for global settlements. Financial institutions worldwide use the widely-adopted Society for Worldwide Interbank Financial Telecommunication (SWIFT) network to send and receive information about financial transactions in a secure, standardised and reliable environment. The cross-border interbank settlement process is, however, not as efficient as local payment mechanisms.

Currently, banks are subject to five main issues when conducting cross-border interbank transactions: (1) high transaction costs, (2) limited availability, (3) delays in payment processing, (4) a lack of transparency and (5) legacy payment infrastructure challenges. The three most important issues are (1), (3) and (4), and relate to the existence of so-called correspondent banking channels that banks, and thus payments are subject to. These intermediaries are entitled to a cut of the transaction volume along the way. For a bank to arrange a cross-border transaction, it must either have both parties' currencies in its possession or else have a means of buying the foreign currency required to execute the transaction. Whereas some of the larger international banks might have the banking license and liquidity required in the respective currency, viability decreases rapidly as the number of currencies at hand increases at a given time. Furthermore, complexity and costs are added because of differing regulatory standards across jurisdictions combined with varying technical requirements.

Most banks set up correspondent banking channels to still be able to host any trade. These are relationships with strategically selected foreign banks that are capable of handling the desired payment. The reason why such networks exist is both the extensive process of acquiring a banking licence in another jurisdiction and the respective cost burden. Since maintaining and leveraging these connections is not feasible for everyone, smaller, local banks tend to rely completely on larger banks to host cross-currency transactions on their behalf. As a result, more financial institutions and other intermediaries are involved than expected at first sight, thus increasing transaction fees and clarity. Few banks actually have the scale required to maintain a global network of settlement accounts in multiple jurisdictions. As a result, the international financial system becomes more fragile due to the concentration of risks in a small number of firms[2] offering correspondent banking services and lengthening of payment chains (Financial Stability Board, 2017).

Besides the reliance on correspondent banking channels, dependence on the operating hours of RTGS systems obstructs the desired flexibility in transferring high-value funds across the globe on a daily basis. A consequence is that there are only very small windows of time when the systems across different countries are open simultaneously. This results in cross-border payments getting trapped in a country, waiting for the respective RTGS system to open, and thus drive the time lag in cross-border transactions reaching their final destination (KPMG, 2018). Legacy payment infrastructures like RTGS have seen an increase in new types of risks such as cyber-attacks and improving these systems entails large technical barriers.

[2]In the period 2011 to mid-2017, there was an 8% decline in active correspondent banks globally (Financial Stability Board, 2018).

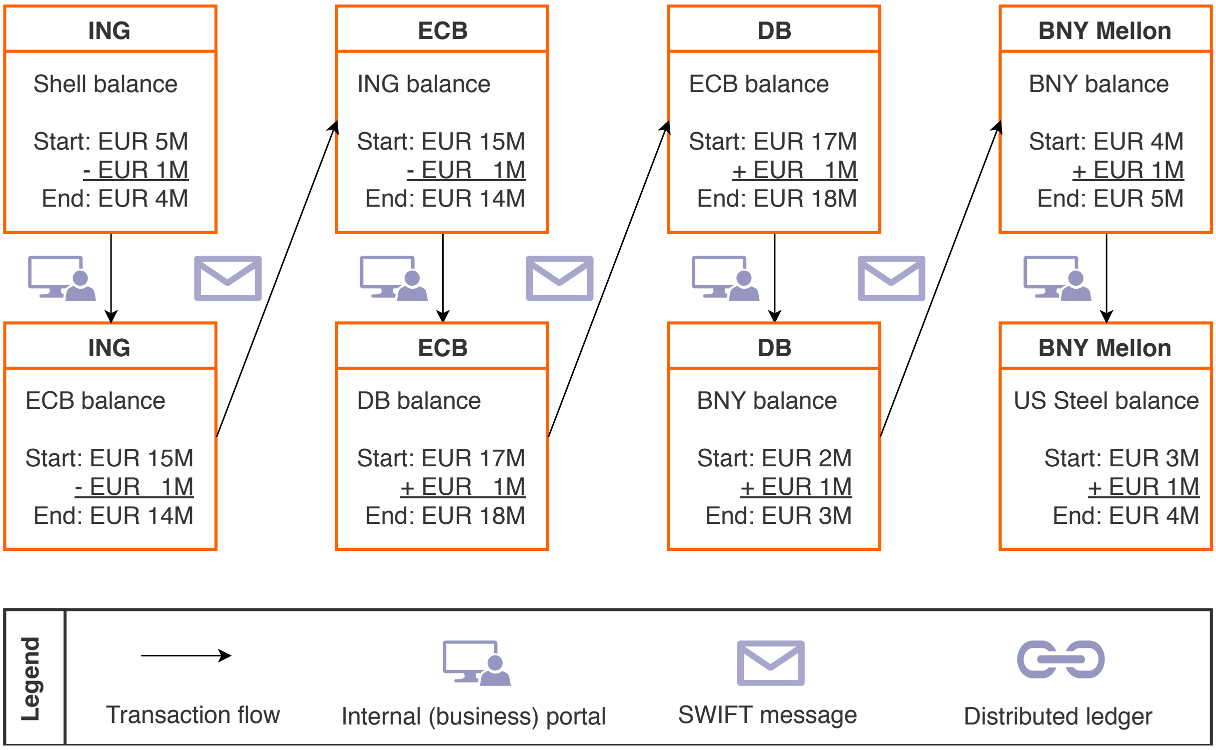


Figure 2.1: *Mono-currency payment in the current model.*

Figure 2.1 provides an example of a transaction in the current model. The transaction considered is a mono-currency single payment, which means that there is no exchange (of goods) involved. This example clearly shows the presence of intermediaries. It may take multiple days, and in some cases even over a week for a transaction to arrive at the Bank of New York Mellon (BNY Mellon) due to the existence of correspondent banking channels. Once Shell initiates a transaction, its balance at ING is adjusted through the an internal business portal. Then ING sends a SWIFT message to the European Central Bank (ECB) with the transaction details. The RTGS system of the ECB adjusts the balances of both ING and Deutsche Bank (DB) at the ECB. Consequently, DB receives a SWIFT message with the details of the transaction, and forwards it to BNY Mellon. Once BNY Mellon receives the payment, it adjusts US Steel's balance in the internal business portal.

For cross-currency payments, the model looks a bit different. Now ING must find a correspondent bank that is willing to exchange the EUR amount to a USD amount. An example of such a situation with Bank of America (BOA) as a correspondent bank is displayed in Figure 2.2. The third payment type we consider ia a payment-versus-payment transaction. In this situation, ING does not only pay a EUR amount (on behalf of a client), but receives a USD amount in return. In the current situation, a simple contract for an Foreign Exchange (FX) swap is signed to cover potential FX risk, obviously against a fee. Figure 2.3 displays an example of such a transaction.

What stands out from the correspondent banking analysis is that the cut taken in a given cross-border trade is determined by the number of financial institutions that engage in and the complexity of the network in the transaction process. This opposes the view that the nations or currencies involved are most decisive in the percentage forfeited. The lack of payment status and visibility, delays in payment processing, and lack of round-the-clock service availability result in significant issues for international corporate transactions. Consequently, settlement times for cross-border payments can take up to five days even for most common currency pairings, generally with limited clarity regarding the total amount of fees to be charged and the timing of settlement (Niederkorn, Bruno, Hou, Istace, & Bansal, 2015). Nevertheless, a mono-currency payment is close to instant, as local RTGS systems (e.g. TARGET2) are very efficient.

The previous reasoning results in the fifth issue of the current cross-border payment system, which relates to the fact that one can never guarantee that the recipient will actually receive the whole amount. A transaction might, for instance, be blocked due to legal distinctions between different jurisdictions, where other rules apply, for instance with respect to SWIFT messages. The same is true for other barriers, such as fraud and error detection, which are hard to detect beforehand. It might also be the case that there is insufficient liquidity to carry out the transaction. Hence, taking these obstacles into account, end-users are troubled with several inconveniences.

We conclude that cross-border interbank transactions in the current correspondent banking model are settled inefficiently. Whereas mono-currency payments are settled relatively fast, inefficiencies particularly arise when a transaction involves an exchange of currencies. This is mainly due to the existence of correspondent banking channels that raise costs of, slow down and blur the process. The five most considerable drawbacks with regards to current cross-border payments are summarised as follows:

(1) *High costs*: fees and FX margins as well as operating expenses are accumulated at every step in the correspondent banking process.

(2) *Limited availability*: reliance on multiple intermediaries and a mismatch in the operating hours of RTGS systems across different jurisdictions hinder straight-through processing of payments.

(3) *Delays in payment processing*: clearing and settlement procedures are sequential processes, and have to deal with varying payment standards, availability constraints, guidelines, and (regulatory) requirements.

(4) *Lack of transparency*: differing (regulatory) requirements and a lack of network interoperability increase uncertainty of a payment reaching its destination, while the status of the payment in the chain is unknown.

(5) *Legacy payments infrastructure challenges*: there are significant technical barriers to improve payment systems like RTGS.

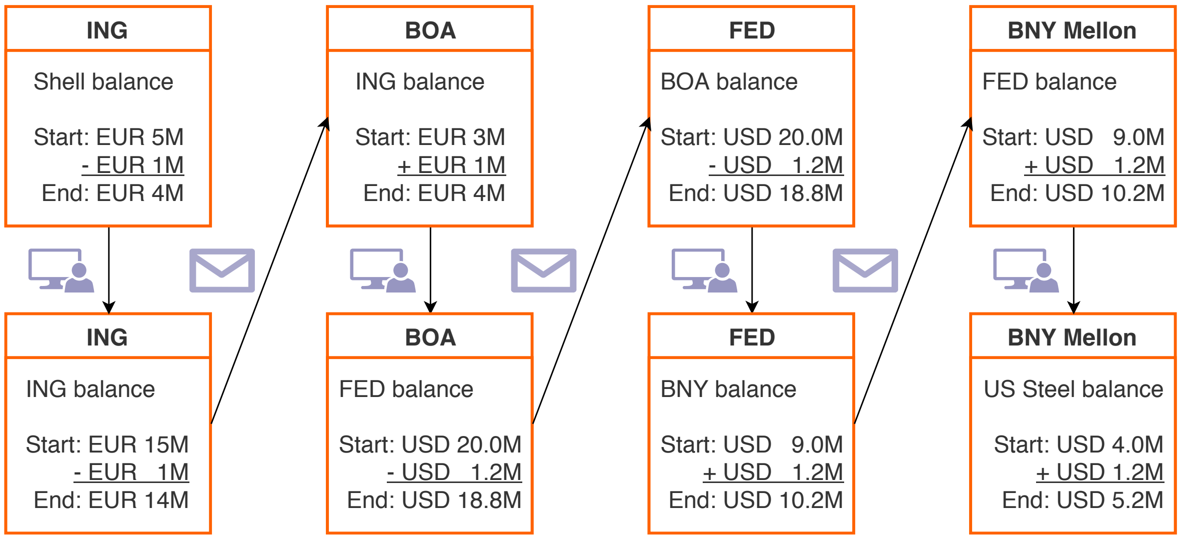


Figure 2.2: *Cross-currency payment in the current model.*

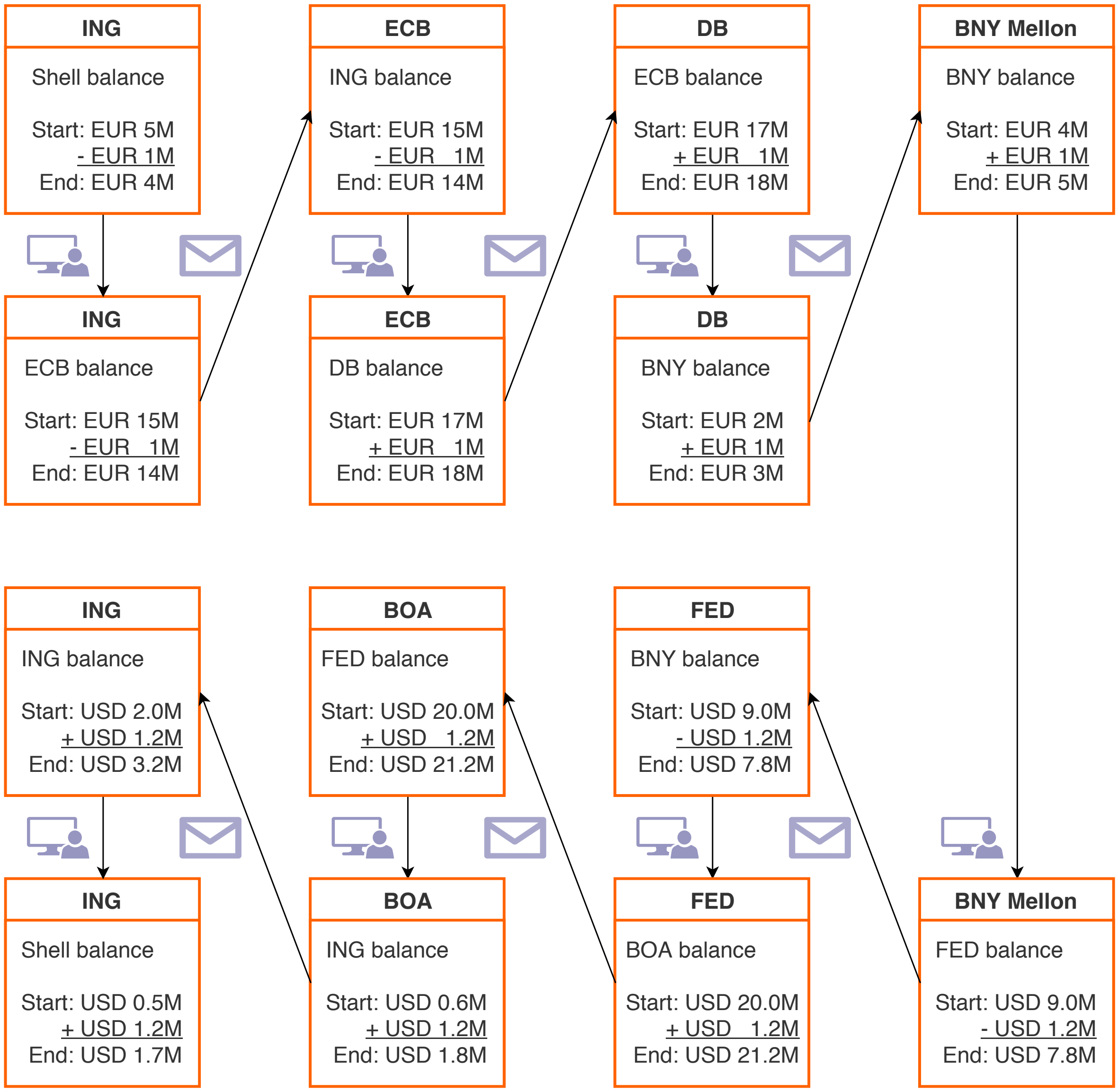


Figure 2.3: *Cross-currency payment-versus-payment in the current model.*

2.2 Emergence of Digital Currencies

This section addresses sub-question two of research question (i): *"What role do digital currencies play in the cross-border interbank payment system?"*

The issues identified in settlement systems have given rise to extensive cross-border discussions about potential improvements. Naturally, IT infrastructures have seen a tremendous advancement in terms of security, speed, interoperability, and resilience, but still experts warn for the vulnerability of our financial system's IT infrastructure, particularly in the face of the growing threat of cyber-attacks (KPMG, 2018). Concurrent with the rise of distributed ledger and blockchain technology use cases, numerous insiders, scientists, and other stakeholders advocate for the adoption of these disruptive technologies in the financial industry. Several consortia in the financial industry are currently working on initiatives that try to solve the major drawbacks of current settlement systems and thus improving, amongst others, transaction speed and costs of cross-border interbank payment procedures.

Since current settlement systems thwart an efficient payment process, hence indirectly hindering financial growth, the urgency of additional measures - or even a substitution - is higher than ever. One alternative might be the issuance of a CBDC, essentially a digital currency issued and backed by a central bank. Prior to discussing CBDC specifics, we first elaborate on the classification of (digital) money. The results of our line of thought are depicted in Table 2.2.

As most money already is digital, i.e. even in emerging market economies where on average only 8% of the Gross Domestic Product (GDP) is cash (this even approaches a mere 1% in Sweden) (e.g. Bech, Ougaard, Faruqui, & Picillo, 2018; Skingsley, 2016), we must clearly define what is meant by 'digital currencies'. A digital currency is a particular form of currency that is electronically transferred and stored, i.e. distinct from physical currencies, such as coins or banknotes. The digital money format encompasses both a regulated, e.g. e-money and commercial bank money (deposits), and an unregulated legal status, such as virtual currencies. We adopt the distinction made by the European Central Bank (2012). Table 2.1 represents this distinction in a matrix.

Virtual currency is a type of digital money that has been defined by the European Central Bank (2015) as "a digital representation of value, not issued by a central bank, credit institution or e-money institution, which, in some circumstances, can be used as an alternative to money". This means that all virtual currencies are digital, but the reverse is incorrect. Examples of virtual currencies are coins used in online games, for example to buy new players in FIFA or new weapons in World of Warcraft (WoW). Virtual currencies also include cryptocurrencies. A cryptocurrency is a digital currency using cryptography to secure transactions and to control the creation of new currency

Table 2.1: *ECB money matrix (European Central Bank, 2012).*

		Money format	
		Physical	*Digital*
Legal status	*Unregulated*	Coupons	Virtual currencies (e.g. game money, cryptocurrencies)
	Regulated	Banknotes, coins	E-money, commercial bank money (deposits)

units (Greenberg, 2011). It is important to note that not all virtual currencies use cryptography, hence not all virtual currencies are classified as cryptocurrencies. Virtual currencies are not legal tender (European Central Bank, 2015).

Cryptocurrencies are a relatively new phenomenon of which Bitcoin (BTC) is by far the best-known. The protocol was first proposed in the whitepaper of Nakamoto (2008) and launched in the beginning of 2009. BTC is developed under open-source license and its network runs on a type of DLT called blockchain. The underlying assumption of blockchain - and also DLT in general - is that multiple parties reach consensus on the distributed state of a ledger. After years of simmering in the shadows, only used by tech enthusiasts and by criminals to illegally transact on the dark web, the price of one BTC saw an incredible increase of more than 1,300% in 2017. As of today, over 2,000 cryptocurrencies have been developed and introduced in the market, most of which are issued by start-ups and FinTechs. These new companies are often funded through an Initial Coin Offering (ICO) (i.e. equivalent to an Initial Public Offering (IPO)) by issuing cryptocurrencies as shares. In this report, we exclude this ‘share-type’ when referring to cryptocurrency.

This speculative market will persist until the usage and trade of digital currencies is regulated by influential jurisdictions. Less speculative are stablecoins. This type of cryptocurrency is backed to the value of a fiat currency, i.e. the euro or dollar, or to financial assets, such as gold. Despite these developments, the paradigm of interest would need to move in the direction of the big players in the financial industry if the underlying technologies were to progress from the early-adopter to a more mature stage.

One of the key issues with most cryptocurrencies for widespread adoption is that anyone can use them to transact (public). Also, transaction information - despite being pseudo-anonymous - is widely available (permissionless) to any person with an internet connection. Whereas a permissionless network allows anyone to participate on the network, a permissioned network only permits a restricted set of users validation rights of block transactions. This does not necessarily imply, however, that all cryptocurrencies are permissionless, e.g. Ripple, or public. Contrasting to public and permissionless cryptocurrencies, such as Bitcoin and Ethereum, others operate on private permissioned networks. Examples of private, permissioned ledgers are Corda, Quorum and Hyperledger, developed by R3, JP Morgan and IBM, respectively. A distinction is set out in Figure 2.4. Since (commercial) banks are extremely cautious with providing privacy-sensitive information, they are also hesitant - and actually legally prohibited - to let anyone access their services without having fulfilled standard regulatory Know Your Customer (KYC) procedures.

Figure 2.4: *DLT types.*

Suitably, the financial industry's attitude on digital currencies is slowly shifting towards more positive attention rather than abandoning their concept entirely. Banks have monitored developments of cryptographic currencies closely and are starting to intensify resource allocation on research. Central banks do this mainly for monetary policy and regulatory purposes, whereas commercial banks tend to scan for business opportunities hoping to capitalise prosperous applications. Particularly the concept of CBDC has gained considerable interest over the last two years and numerous central banks are either conducting research into or experimenting with various applications to some extent. We provide more insight in the underlying motivation of these exploratory studies in Section 2.3.

An important consideration for central banks is the ability to collateralise a digital currency one-to-one to a fiat currency, because this would remove the drawbacks caused by introducing an entire new currency on the market. The risk embedded in the solution decreases with the extent to which the issuing party is involved in regulatory responsibilities (ING, 2018b). This is substantiated by Preiss (2018), who states that an important difference between cryptocurrencies and CBDCs is that the latter are the highly indebted central banks' liability, whereas cryptocurrencies are not the liability of anyone. Following the money matrix as outlined by the European Central Bank (2012), we elaborate on its digital elements in Table 2.2. This table sets out a distinction between different digital currencies, both regulated and unregulated (virtual currencies), and is derived from the widely-used 'money flower' of Bech and Garratt (2017). We have included their graphical representation of the taxonomy of money in Figure 2.5.

Table 2.2: *Distinction digital currencies.*

Legal status	Digital currency type	Examples	Issuance	Target group	Collateral
Unregulated	Game currencies	FIFA coins, money in WoW	Game developers	General public	None
	Cryptocurrencies	Bitcoin, Ethereum, Ripple	Start-ups, FinTechs	General public, SMEs, Investors	None, Shares (ICOs)
	Crypto stablecoins	Tether, Monerium	FinTechs, Corporates	General public, SMEs, Investors	Commercial Bank money, (Financial) Assets
	Commercial Bank DCs	Cash on Corda, JP Morgan Coin[3]	Commercial Banks	General public, Wholesale	1-1 Commercial Bank money
Regulated	Central Bank deposits	Settlement or reserve accounts	Central Banks	Wholesale, Financial Institutions	1-1 Central Bank money
	Commercial Bank deposits	Settlement or reserve accounts	Commercial Banks	General public, Wholesale, Financial Institutions	1-1 Commercial Bank money
	Wholesale CBDCs	Jasper, Ubin, USC[4]	Commercial Banks (supported by Central Banks)	Wholesale, Financial Institutions	1-1 Central Bank money
	General Public CBDCs	Senegal, Venezuela, Ecuador	(Commercial Banks supported by) Central Banks	General public, Wholesale, Financial Institutions	1-1 Central Bank money

As explained in Section 1.1, CBDCs can on an overall level be split into two main categories: wholesale and general public. Whereas the former would be targeted at wholesale clients, i.e. large companies and professional businesses, general public CBDCs would be available to the retail and consumer market as well. The latter involves more considerations to be made as it would rather drastically transform the monetary system. Hence, this requires regulatory changes in the central bank's monetary policy.

[3]JP Morgan recently became the first bank to create and successfully test a digital coin using blockchain technology. It will be available to a limited number of institutional clients (J.P. Morgan, 2019).

[4]USC is a special type of CBDC, as it is backed by central banks, but private sector-issued.

We elaborate on CBDC variants and their individual considerations throughout section 2.3.

To conclude, a digital currency with the advantageous properties of DLT might be of great value to financial institutions. The concept of CBDC omits the drawbacks of public, permissioned networks and the speculative aspects of the present cryptocurrency sphere. Multiple reasons exist for issuing CBDC. These include replacing cash as directly-accessible central bank money, strengthening central banks' monetary policy toolkit, and increasing clearing and settlement systems' efficiency (Lastra & Allen, 2018). We are particularly interested in the latter.

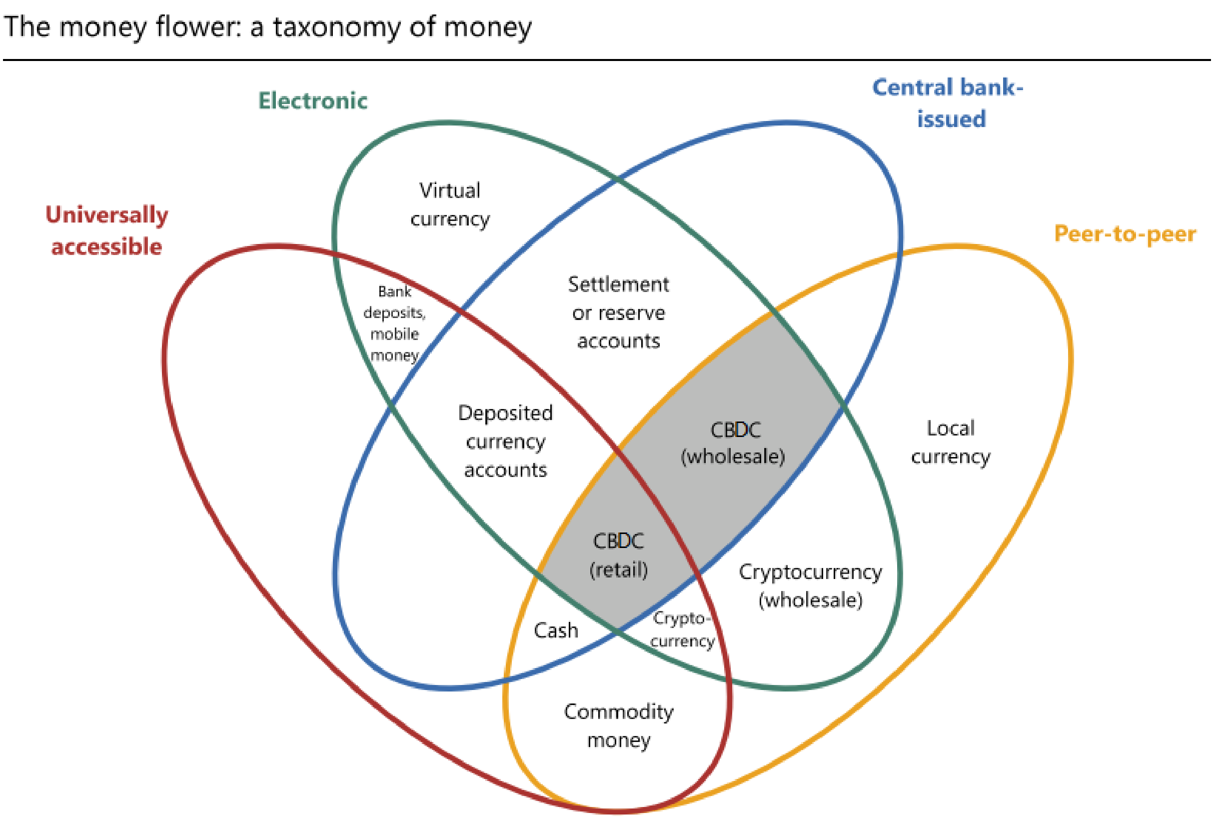


Figure 2.5: *The money flower: a taxonomy of money (Bech & Garratt, 2017).*

In the next section, we elaborate on our findings on CBDC through an extensive literature study.

2.3 Literature Study

In this section, we address CBDC in detail through a literature study, captured by the sub-question: *"How is the concept of CBDC perceived currently?"*

2.3.1 CBDC Experimentation

Similar to the emergence of RTGS systems to speed up wholesale payments in the 1980s, we have seen a recent acceleration in the adoption of fast retail payments. Users expect fast and convenient payments methods, available everywhere and anytime. Consumers in today's fast-paced society with, for instance, instant communication through social media, do no longer accept a payment delay of one business day (Bech, Shimizu, & Wong, 2017). Additional to changes in payment systems, the type of money itself could even be changing in the future. The concept of CBDC is gaining interest among central banks across the world as an addition or even replacement to traditional money formats. The Committee on Payments and Market Infrastructures (CPMI) of Bank for International Settlements (BIS) states that besides the declining rate of cash usage in advanced economies and the need for fast payments, digital advancements in the financial sector are major drivers for CBDC introduction (CPMI & Markets Committee, 2018). DLT and the emergence of new intermediaries are mentioned as examples of driving developments.

According to another study of the BIS, carried out by Barontini and Holden (2019), at least 40 central banks across the world[5] have researched and continue to monitor, or soon will be, experimenting with CBDC for potential implementation. This survey showed that out of all central banks, at least a dozen have progressed to running pilot projects or issuing an actual CBDC. Similarly, a report by the Official Monetary and Financial Institutions Forum (OMFIF) shows that 38% of central banks are researching and experimenting with various wholesale CBDC setups (OMFIF & IBM Blockchain, 2018). The most relevant case studies of current initiatives are alphabetically listed by issuing jurisdiction in Table 2.3 below.

Barontini and Holden (2019) show that the majority of central banks consider payments safety and domestic payments efficiency the most important factor for CBDC issuance. Examples of other factors are financial stability, monetary policy implementation, and financial inclusion. We note from the study by BIS that there exist substantial differences in motives between Emerging Market Economy (EME) and advanced economy central banks. According to the survey, EME central banks value financial inclusion

[5]63 central banks have responded to the survey, which has resulted in a comprehensive view on central bank motives for issuing CBDC. This number represents jurisdictions covering approximately 80% of total world population.

Table 2.3: *Most relevant CBDC experiments and pilots (based on ING, 2018a).*

Jurisdiction	**Currency/project**	**Degree of implementation**
Canada	Project Jasper	Experimentation started in 2016 in close collaboration with blockchain consortium R3.
Ecuador	Dinero Electronico	Launched in 2015 as a mobile general public CBDC, but terminated due to a lack of users.
Estonia	Estcoin	Development was terminated due to ECB criticism.
EU and Japan	Project Stella	Experimentation started in 2017 and test results proved positive.
EU, Japan, US, Great Britain and Canada	USC	Development of a wholesale CBDC was announced in 2019 and is expected to be fully operational within 12 months.
The Marshall Islands	SOV	Launched in 2018 as a general public CBDC and still operational.
Senegal	eCFA	Launched in 2016 as a general public CBDC and still operational.
Singapore	Project Ubin	Experimentation started in 2016 in close collaboration with blockchain consortium R3.
South Africa	Project Khokha	Experimentation started in 2018 in close collaboration with a consortium of national banks and partners.
Sweden	e-Krona	Experimentation started in 2017 and issuance is actively considered.
Thailand	Project Inthanon	Experimentation started in 2018 and test results proved positive.
Tunisia	eDinar	Launched in 2015 as a mobile general public CBDC and still operational.
Uruguay	e-Peso	A successful pilot was completed in 2018 and is currently up for review.
Venezuela	Petromoneda	Launched in 2018 as a general public CBDC and still operational.

and domestic payments efficiency most and cross-border payments efficiency least, whereas advanced economies consider financial inclusion by far to be the least important factor. This effect is magnified by general public CBDCs. However, when we only consider wholesale CBDCs in advanced economies, payments safety and cross-border payments efficiency are accentuated as the primary motives for potential issuance. This can be explained by the financial position of the economy and the purpose of the CBDC. Whereas motivations for issuing a general public CBDC focus on access to the wider public, a wholesale variant is intended purely for financial institutions. This inherently explains the differences in motives between EMEs and advanced economies. Increasing payment systems' resilience is also a major reason for central banks to investigate wholesale CBDC issuance (OMFIF & IBM Blockchain, 2018).

Based on the extensive studies by BIS and OMFIF on central bank perspectives on CBDC issuance, we conclude that our choice to focus on wholesale CBDCs aligns with the primary motives for potential CBDC issuance in advanced economies, i.e. increasing transparency in payments and cross-border payments efficiency. Although the majority of central banks deems short- and medium-term issuance unlikely, an increasing proportion considers issuance of any type to be possible (Barontini & Holden, 2019). Strikingly, the likelihood of issuing a wholesale and general public variant is approximately equal, in spite of the expected greater complexity of a general public variant in terms of operational risks and impact on the financial system's stability. This is because of greater uncertainty regarding design choices such as availability and anonymity. At the moment, most central banks seem to have researched the opportunities of CBDC, but are not yet convinced that they can overcome the challenges. The current strategy of central banks appears to be collaboration and sharing of knowledge. We will elaborate on some of the most considerable collaborations in the following paragraphs.

The declining rate of cash usage was one of the main reasons for the Sveriges Riksbank, the central bank of Sweden, to start researching the potential introduction of an e-Krona (Sveriges Riksbank, 2017). According to Skingsley (2016), the three most important areas to investigate are identification of potential technologies, potential effects on policy issues (e.g. the payments market, monetary policy and financial stability), and finally legal issues. Phase 1 and 2 of the e-Krona project have brought to light positive outlooks for the issuance of a digital Krona and stakeholders are currently contemplating starting a pilot programme aimed at developing the technical aspects of an e-Krona (Sveriges Riksbank, 2018). Therefore, Sveriges Riksbank remains one of the front-runners in CBDC research. Another extensive experiment programme has been carried out by the central bank of Uruguay (Licandro, 2018). This pilot on a general public CBDC involved the issuance, circulation and testing of an e-Peso, mainly to address current financial inclusion issues. Although the pilot did not use DLT, it was perceived a success and next steps are being considered.

In addition to experiments carried out in Sweden and Uruguay, other central banks show interest on CBDC as well. Project Ubin, for example, is a collaborative industry-wide project led by the Monetary Authority of Singapore (MAS) and the Association of Banks in Singapore (ABS). The goal was to "re-imagine interbank RTGS systems using DLT" (Accenture, 2017). The project was completed successfully and its members encourage greater experimentation among central banks and financial institutions. Similar projects on the potential role of DLT capabilities in financial markets infrastructures, wholesale payment systems for interbank settlement and liquidity saving mechanisms were evaluated positively.

These experiments include Project Jasper (Bank of Canada, TMX Group, & Payments Canada, 2018) in collaboration with delivery partners Accenture and R3, Project Stella of the European Central Bank and Bank of Japan (2017) and Project Khokha led by the South African Reserve Bank (2018). More specifically, Project Ubin proved that DLT is suitable to fulfil key functions of RTGS interbank systems in terms of volume, liquidity savings mechanisms, gridlock resolution, security, immutability, and resilience (Accenture, 2017). In coherence with the aforementioned key functions, Project Stella stressed the improved resilience and applicability of liquidity saving mechanisms for netting transactions as major potential benefits of using DLT-based systems (Bank of Canada et al., 2018). The largest project up to date is however Utility Settlement Coin (USC), a wholesale CBDC developed by Fnality that got a funding of $50 million (Noonan, 2019). This company was founded by a consortium of 14 banks, which includes banks from the EU, the U.S., Great Britain, Japan and Canada. Fnality's CEO argues that they expect the architecture to be fully operational within 12 months.

We note from the examples that projects tend to be labelled as successful when effects are calculated, pilots are devised or specific tests are run. Therefore, we conclude that an optimistic attitude with regards to CBDC is positively correlated with the degree to which CBDC research is carried out from a technical or quantitative perspective.

In the next section, we will elaborate on the different perspectives and reactions of both stakeholders from the financial industry and academia on the CBDC initiative.

2.3.2 Perspectives and Reactions on CBDC Initiative

In addition to the experiments carried out by (consortia of) financial institutions mentioned in Section 2.3.1, a considerable number of central banks (cfr. Section 2.3.1) has researched the impact of several characteristics and design choices, and financial stability and monetary policy issues of CBDCs as well. However, each central bank has developed its own perspective with regards to CBDC implementations and characteristics. Considerations vary due to, amongst others, differing economic conditions in the respective jurisdiction or urgency of issues to be tackled. The most important design features relate to interest-bearing characteristics (yes or no), availability (universal or limited), accessibility (ranging from current opening hours to 24/7) and anonymity (ranging from complete to none) (e.g. CPMI & Markets Committee, 2018; European Banking Federation, 2018; Koning, 2018). Other considerations include the transfer mechanism (peer-to-peer of through a bank) and limits or caps on transactions or accounts (e.g. Engert & Fung, 2017; Kumhof & Noone, 2018; Lastra & Allen, 2018).

Besides different perspectives amongst central banks, definitions of CBDC vary as well. After Broadbent (2016) made the idea of CBDC known to a wider public, multiple researchers have put forward new concepts. For instance, Yao (2018) states that a CBDC is (i) credit-based in terms of value, (ii) a cryptocurrency from a technical perspective, (iii) algorithm-based with regards to implementation and (iv) smart in application scenarios. Here, the author extends the view of Bordo and Levin (2017) that CBDC can be classified into account- and token-based.[6] Also, Koning (2018) distinguished CBDC from the concept of a central bank digital account and stresses anonymity to be the thorniest issue involved in a case study on a Brazilian general public CBDC. According to Yao (2018), the ideal digital currency "should have a set of brand new qualities that enable it to excel over existing private digital currencies and electronic currencies". Bank of Canada investigate the implications of a benchmark CBDC that does is non-interest-bearing, anonymous and token-based (Engert & Fung, 2017). Contrary, Bank of England concentrate on an interest-bearing, non-anonymous CBDC that is account-based (Meaning, Dyson, Barker, & Clayton, 2018). Clearly, there exist many views on potential CBDC designs.

In this research, we consider CBDC as an extension to current payment methods for wholesale clients. The money transferred between financial institutions already is digital; it is the addition of another underlying IT system that changes things. Furthermore, these funds are currently already issued by the central bank. This contrasts a situation in which the central bank introduces a completely new currency in the monetary system, similar to the cryptocurrency concept. The latter, however, is not within scope of our research and is disregarded.

Concluding, we should examine a more conceptual level than only looking at digital and issuance aspects when comparing 'regular' money with CBDC money. The essence lies in the fact that central banks take a greater role in the monetary system, because they would take over functions from commercial banks. As a result, we deem it irrelevant to look at specific design characteristics and instead focus on the implications of introducing a new payment option that leaves most current features of payment systems intact. The advantages of this new payment option, i.e. the CBDC regarded in this research, for cross-border interbank transactions relate to speed, reliability, transparency and availability.

Additional to the ongoing discussion on characteristics of CBDC, a lively debate about a much more fundamental question has emerged about whether or not a central bank should actually issue CBDC. This further complicates the matter. The concept of CBDC is being received with a positive attitude by several financial institutions and

[6] For a party to use an account-based CBDC, the account holder would need to be verified. Hence this feature relies fundamentally on identification. On the other hand, token-based systems would allow private individuals and firms to transact with each other while staying anonymous.

academics, including the following.

- De Nederlandsche Bank (2018) consider the application of DLT in effecting interbank payments or securities administration as a technology that "could potentially lead to more efficient payment markets, lower costs and enhanced resilience against cyber attacks and disruptions".
- Danezis and Meiklejohn (2016) demonstrate that the benefits of a decentralised blockchain-based transaction ledger should not necessarily be negatively affected by centralisation of control over monetary policy by central banks. Hence, a system could even be more scalable due to centralisation of some authority.
- Kiel Institute for the World Economy (2018) conclude that the CBDC initiative can be disruptive and at the same time bear a challenge to the fractional reserve system, i.e. commercial banks hold reserves of clients as deposits and central banks hold commercial banks' reserves on their balances. While this may look negative, it is actually presented as a beneficial development, since the current fractional reserve character of the banking system poses serious sources of financial instability.
- Gouveia, Dos Santos, Fernández de Lis, Neut, and Sebastián (2017) consider four types of CBDC of which they deem a wholesale variant most likely, as "the authorities would be reluctant to choose more disruptive schemes given their potential costs and the uncertainty about their impact". The authors expect CBDC adoption to be reasonable by at least some central banks over the next few years. Fernández de Lis and Gouveia (2019) add to this that adoption is most likely by central banks "that face a reduction in the use of cash and its potential elimination due to the use of alternative means of payment like credit cards".
- Although digital currency initiatives may impair enforcement of proper monetary policy, they do also present opportunities for enhancing macroeconomic stability. Risks relate to defunding of the banking sector and the potential of digital bank runs due to widespread availability and accessibility. However, if the right design choices are made, balanced decisions could promote policy effectiveness. Therefore, Stevens (2017) presses for further research on the effects of using DLT in settlement systems on monetary policy.
- Bank of England have carried out a study on the macroeconomic impact of CBDC introduction. Barrdear and Kumhof (2016) find that a regime with CBDC offers a number of clear macroeconomic advantages, with few obvious major costs. Calculations show that CBDC issuance of 30% of GDP could permanently raise GDP by approximately 3%. Central banks could use a counter-cyclical CBDC price or quantity rules, as a second monetary policy tool, to substantially improve a financial system's resilience in periods of stress.

Prior to concluding several positive perspectives on CBDC, we must take into account that some perspectives dispute the concept of CBDC as well. These attitudes are listed as follows. Here it is important to note that some views on CBDC are mainly focused on a general public variant.

- In a Bank of Canada staff discussion paper, Engert and Fung (2017) look at high-level CBDC characteristics and raise questions about central bank liability accessible to the general public. They, however, warn for a reduced appeal of CBDC from a benefit-cost perspective when taking into account technological means required and central bank reputation risk.
- KPMG (2018) have investigated five potential future-state models for cross-border payments and settlements. These are the (i) the collection of current and planned industry initiatives, (ii) an expansion of RTGS operators' role and (iii) three variations based on a wholesale CBDC. This study highlights the potential improvements to current RTGS systems, but wider issues underlying some of the pain points require an international collaborative effort.
- A study by Bruegel, the European think tank of the European Parliament that specialises in economics, concludes that cryptocurrency adoption would require overcoming a triple challenge. The authors stress that current technologies are far superior to cryptocurrencies, although the underlying technology presents an interesting research field (Claeys, Demertzis, & Efstathiou, 2018). A connotation to countries with "a history of negligent monetary policy" is made by stating that cryptocurrencies could have the positive effect of disciplining the central banks of such countries to "take their price stability mandates seriously". Surprisingly, they seem to miss the point of adapting the advantages of cryptocurrencies and altering these in such a way that central banks could profit from the technology. Two other studies on behalf of the European Parliament recognise the concept of CBDC only on a high level (Lastra & Allen, 2018) and go into detail (Kiel Institute for the World Economy, 2018). This suggests that the European Parliament leaves in-depth research up to central bankers.
- Mersch (2018) warns for being deceived by "the flashing lights of novelty", or, put in simpler terms, assuming that a new technology is inherently better than an older one. Speaking on behalf of the ECB, he claims that there is currently no convincing motivation to issue CBDC, at least not in the Eurosystem. However, it is possible that adoption of the technology may prevail in the future. On a side note, the reasoning of Mersch (2018) deals mainly with accessibility to the wider public.
- Danmarks Nationalbank (2017) focus on a general public variant and conclude that the potential benefits of a universal CBDC do not outweigh the considerable challenges that the introduction would yield. The central bank is afraid that its role in the Danish financial system will change substantially and considers the current payment system to be both secure and effective.

- Grym (2018) undertakes an attempt to tackle the concept of digital currencies entirely. The author argues that their features are unrelated to the fundamental characteristics of money. Furthermore, Grym (2018) states that digital currencies are actually account-based ledger systems that do not significantly differ from other financial record-keeping technologies. The cryptography and distributed computing features of digital currencies are dismissed as implementation details. Although we do not agree with Grym, the thoughts underlying the statements are intriguing, as they question the very basics of money. Not only do we find this view interesting, it is also a bold one, since it opposes the definitions of respectable authorities, including the ECB and BIS.

What stands out from the analysis above is that many academics, NGOs and financial institutions have researched the CBDC initiative and tried to relate its characteristics to the monetary policy toolkit of central banks. Studies differ, however, in definitions and design features used. Some consider CBDC a cryptocurrency that would be universally accessible and then conclude that adoption is highly unlikely (e.g. Danmarks Nationalbank, 2017; Grym, 2018; Lastra & Allen, 2018; Mersch, 2018). While others may share this particular conclusion, they focus on investigating wholesale variants of CBDC that have higher chances of actual adoption (e.g. Gouveia et al., 2017; Fernández de Lis & Gouveia, 2019; Kiel Institute for the World Economy, 2018).

We notice an interesting distinction between these opposite movements. Studies that have attempted a more detailed analysis by trying to quantify the costs and benefits have developed a more positive attitude towards the CBDC initiative, rather than abandoning the idea after a brief check. The main dilemma for central banks lies in anonymity. Issuing a token-based CBDC might attract crime-related activities. By contrast, the role of the central bank would be extended incredibly by issuing an account-based CBDC due to a transfer of end-client deposits from commercial banks to the central bank (Fernández de Lis & Gouveia, 2019). We outline our view on the different variants of CBDC in the next section.

Concluding, the quest for fast payments has been intensifying at an ever-accelerating pace throughout history. As of today, RTGS systems are the standard for wholesale payments around the world, but it took fifteen years until this innovation of the 1980s was fully adopted (Bech et al., 2017). Whereas regional retail payments are currently undergoing the same process, the wholesale market is still relatively slow. Nonetheless, we expect the same to happen to cross-border interbank settlement systems, as there is substantial room for improvement (cfr. Section 2.1). Additionally, we adopt the view of several authors that there is a need for additional research and debate with respect to quantification of CBDC risks in order to understand potential impacts (e.g. Barrdear & Kumhof, 2016; Engert & Fung, 2017; Gouveia et al., 2017; KPMG, 2018; Stevens, 2017).

2.3.3 Types of CBDC

Whereas most research is aimed at design choices of CBDC and its potential macroeconomic implications, we have developed our own model for comparing different CBDC types, in which we focus on issuance and ownership. This model is presented in Figure 2.6 below.

Issued (and operated) / Owned	Financial institutions	Corporates	General public
Central banks	**Wholesale CBDC** + Changes w.r.t. transaction settlement are minimal + Less transactional barriers (24/7 availability, no intermediaries) + Role of central bank does not change - High integration costs for commercial banks - High costs for central banks regarding governance and legislation	**Hybrid CBDC** + Direct access for clients + Less transactional barriers (24/7 availability, no intermediaries) - Role of central bank increases - Commercial banks loose payment-related revenues - High costs for central banks regarding governance and legislation	**General public CBDC** + Greater financial inclusion + Increased monetary policy toolkit - Adverse macroeconomic effects - Potential digital bank runs - Role of central bank increases tremendously - Commercial banks become largely redundant - High costs for central banks regarding governance and legislation
Commercial banks (backed by central banks)	**Wholesale CBDC** + Changes w.r.t. transaction settlement are minimal + Less transactional barriers (24/7 availability, no intermediaries) + Role of central bank does not change (only needs to give consent) - High costs for commercial banks regarding integration, governance and legislation	**Hybrid CBDC** + Direct access for clients + Less transactional barriers (24/7 availability, no intermediaries) - Commercial banks loose payment-related revenues - High costs for commercial banks regarding integration, governance and legislation	**General public CBDC** + Greater financial inclusion + Commercial banks focus on other financial activities - Adverse macroeconomic effects - Potential digital bank runs - Commercial banks become partly redundant - High costs for commercial banks regarding integration, governance and legislation

Evolution →

Figure 2.6: *CBDC considerations regarding issuance and ownership.*

First, we distinct between issuance by central banks and commercial bank partnerships, since consequences for both the distribution of responsibilities and costs are significant. A CBDC issued by central banks would involve high costs regarding harmonisation and standardisation of legislative frameworks, as well as governance challenges. As commercial banks would observe a significant cost reduction in the long term due to an expected decrease in financial risks and better service to clients, central banks will most likely want to transfer costs for platform development and integration to private parties. As a result, commercial banks will initially face high set-up costs. Central banks would still need to back the initiative by implementing a proposed common rulebook into current legislation and ensuring CBDC is legal tender, but they would not take the role of initiator.

The second dimension relates to ownership of CBDCs. Changes regarding transaction settlement will be minimal when access is limited to financial institutions, equivalent to the current situation. Expanding access to corporate clients as well is beneficial to companies, as they would no longer need to rely on commercial banks. However, commercial banks will loose payment-related income streams and might need to focus on other financial activities. We define this type as hybrid CBDC. In case the CBDC is not issued by a private partnership of commercial banks, KYC and screening of all participants would be the responsibility of central banks. The role of central banks in our monetary system could even change dramatically, if the retail market gained access to CBDC as well.

Making settlement through CBDC (and potentially holding savings accounts) available to the general public will induce great uncertainty for financial stability. Widening central bank balance sheets by replacing commercial bank deposits could have adverse macroeconomic effects, since systemic risk will be focused on one entity. The supply of bank credit would be seriously threatened if commercial banks cannot use deposits for their lending activities. Several authors have related general public CBDC issuance to a narrower banking system[7] (e.g. Engert & Fung, 2017; Meaning et al., 2018; Stevens, 2017), which has received increased attention since the global financial crisis. Yet, we expect adoption to be unlikely in the short to medium term due to uncertainties regarding macroeconomic effects.

As challenges regarding development and implementation, as well as potential repercussions for monetary policy increase with greater availability, we expect the evolution of the CBDC initiative to follow the same process. Therefore, we adopt a wholesale CBDC variant in our research that can only be owned by financial institutions. We expect this variant to have the greatest chance of success as only the underlying technology for settling transactions will change. We do not yet decide on who should be issuing and operating at this time.

In the next section, we explain how settlement is done in the future model with CBDC and compare this to our model presented in Section 2.1.

2.4 Settlement in the Future Model

This section addresses the first sub-question of research question (ii): *"How are cross-border interbank transactions settled in a future model with wholesale CBDC?"*

Current cross-border interbank settlement systems thwart an efficient transaction process, as we have seen in Section 2.1. We concluded from Section 2.3 that there is great interest from both the industry and regulators in the issuance of CBDCs, since experts

[7] In narrow banking, assets are as liquid as liabilities. This means that deposits would become more secure, as they would be backed by liquid assets rather than risky lending (Broadbent, 2016).

from various fields foresee huge potential in the adoption of such digital currencies by the financial industry. Before diving into the quantification of this new technology, we must first clearly discriminate between the differences with regards to actual settlement of transactions. We already know what CBDCs are (cfr. Section 2.2), but how do they affect the transaction landscape for cross-border interbank payments, which is currently subject to a great need for improvement. Therefore, we start by comparing settlement in the current model to the future model for three different scenarios.

Whereas in the current model it can take multiple days and in some cases even over a week for a transaction to settle, the future model offers a transaction to be settled in a matter of seconds. Figure 2.7 displays the future situation for a mono-currency payment, in this case a EUR transaction. Like in the current model, a bank would still send a SWIFT message to the settling party. However, instead of using an entire network of correspondent banks, only one operation is performed now. A distributed ledger is established for each currency at which each bank holds an account. The balances of ING in their own account and in the account at the central bank are adjusted based on the SWIFT message. Subsequently, the transaction value is converted to an equivalent amount of tokens and ownership transfers to the counterparty, via the distributed ledger. Within a matter of seconds, BNY Mellon sees the transaction value added to is own wallet at the ledger.

If BNY Mellon were to withdraw money from its account, again a SWIFT message is created and balances are adjusted accordingly. The value of these CBDC tokens is backed one-to-one to its respective fiat currency to prevent for introducing additional FX risk during conversion. A free-floating currency would have its own exchange rate to both EUR and USD, or any other currency pair, and hence increase issues regarding design choices and, it the end, implementation. The CBDC tokens are liquid to such an extent that they are pre-funded by fiat. They are merely used as tools for transacting fiat amounts, backed by the central bank.

Depending on legal restrictions and reciprocal agreements between jurisdictions, any bank can have an account at the central bank that manages the distributed ledger of the currency it issues. For instance, the ECB manages the EUR ledger, the Federal Reserve System (FED) manages the USD ledger, and so on. Another possibility is that some independent financial institution or governance authority is appointed to manage the new payment system. Legal risks arise when central banks in different jurisdictions are to gear to one another. Once the technology matures and sufficient experience with the new payment system has been gained, the SWIFT connection could be upgraded to a more direct message system.

Contrasting to the current model, the cross-currency payment does not exist in the future model. The main reason for this is the fact that banks can also have accounts

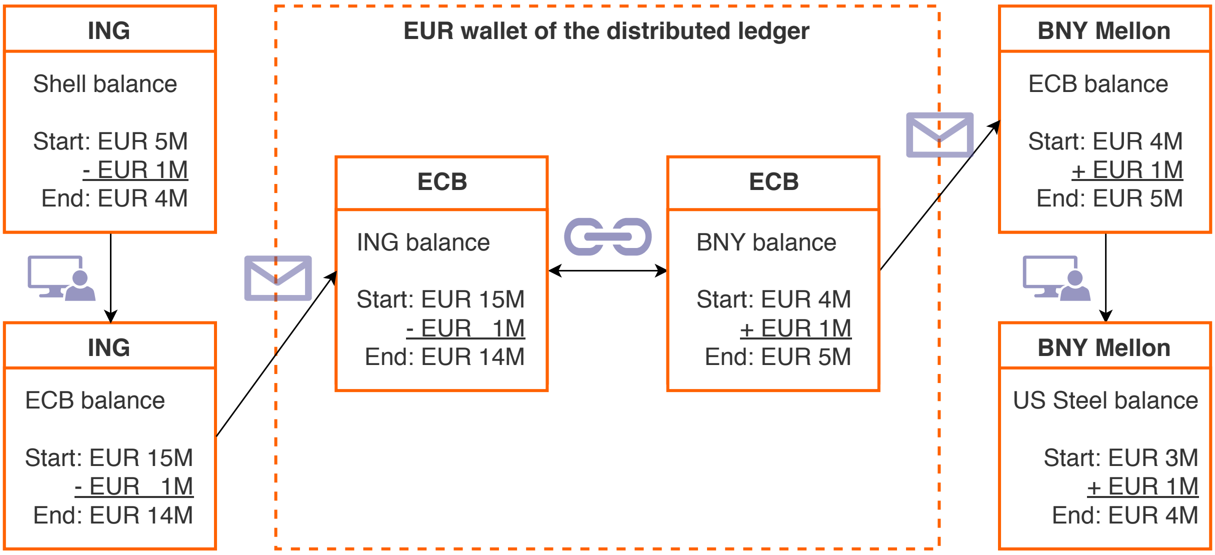


Figure 2.7: *Mono-currency payment in the future model.*

at central banks outside their own jurisdiction in a foreign currency. Imagine a bank - here ING - being required to pay BNY Mellon some amount in USD, then it may use its account in the dollar-denominated wallet to execute the payment. If this balance does not suffice, a bank could decide to perform a currency swap, which automatically is the third scenario, i.e. a cross-currency PvP. Thus, we conclude that the cross-currency payment scenario is a combination of the mono-currency payment and cross-currency PvP scenario.

In the cross-currency PvP scenario, a currency swap takes place. Figure 2.8 depicts this situation, using the EUR to USD transaction example. The commercial bank still needs to find a counterparty, here BNY Mellon, that is willing to swap a particular EUR amount to a USD amount. When both parties have agreed to the transaction (via SWIFT messaging), settlement occurs through an atomic swap, which means that the transfer of USD tokens from BNY Mellon's USD account to ING's USD account and EUR tokens from ING's EUR account to BNY Mellon's EUR account happens at exactly the same time. This prevents the possibility of double-spending.[8] Another possibility is that ING moves around its own liquidity at different wallets to quickly generate liquidity in another currency. The advantages of the latter are discussed in Section 3.2. ING would not need a counterparty such as BNY Mellon in this case. A major challenge for all affiliating parties, especially those who will have to design the technology, is interoperability.

There are three dimensions to interoperability: between two currencies on the same ledger, between different ledgers and between the ledger and legacy infrastructure. First, different currencies within a ledger must be connected to each other for a swap

[8]A potential flaw in digital cash schemes that relates to the risk that the holder counterfeits a digital token by sending a copy to the counterparty while retaining the original.

to succeed between two currencies. We assume that this is the case in our research. Second, interoperability between different ledgers could present an issue if each currency is on another ledger. Other financial products, such as securities and derivatives, would generally have to be settled on alternative ledgers or platforms as well. These must be linked, however, if Delivery-versus-Payment (DvP) transactions are to be included. The third dimension relates to the interoperability between the ledger(s) and legacy infrastructure, which will have to be accommodated for in any case. These are operational risks that must be considered elaborately prior to constructing the platforms.

The future model address all drawbacks of the current system (cfr. Section 2.1). First of all, transactions in the current system are expensive due to fees and FX margins being accumulated at every step in the process. With the elimination of correspondent

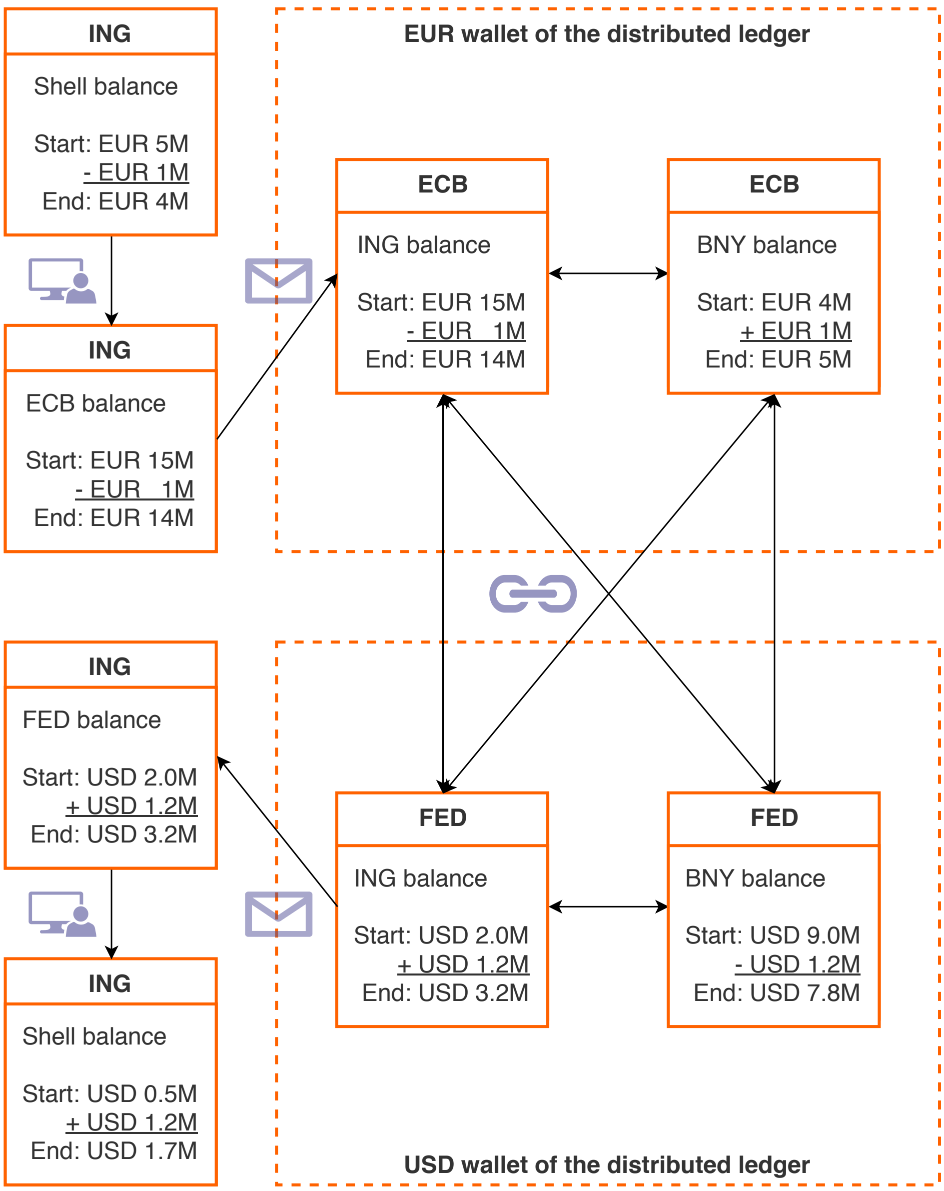


Figure 2.8: *Cross-currency payment-versus-payment in the future model.*

banks and only one settlement system in the future model, these costs should diminish. Obviously, the technology needs to be built, maintained, regulated and kept secure. We make an estimation on the potential cost savings in Section 4.1. Second, the speed of a transaction increases significantly. Whereas cross-border interbank transactions take several days to arrive at the counterparty, the future model offers settlement in the blink of an eye. On top of this, transparency and predictability increase due to the removal of intermediaries and rapid settlement. Lastly, the proposed system offers near real-time and round-the-clock availability of cross-border payment services.

All in all, we expect the future model to be far more efficient than the current model. The main difference lies in the way central banks provide access to their balance sheets, i.e. in the form of a digital version of ordinary fiat without participating banks having to obtain a banking license in the respective jurisdiction to access the actual currency. The financial risks in the future model are computed in the next section. Next to that, the overall impact of CBDC introduction will be discussed in Chapter 4.

2.5 Conclusion

The current correspondent banking network setup for cross-border interbank payments restrains transactions from being settled efficiently. Five issues were identified as main facilitators, which are high costs, limited availability, delays, a lack of transparency, and legacy payments infrastructure complexities. As a result, a cross-border interbank payment can take up to several days until it arrives at the counterparty, enhancing uncertainty and increasing financial exposure to risk.

Concurrent with the rise of private digital currency applications, central banks are investigating whether the concept of CBDC could be a potential solution to the aforementioned concerns. CBDC's underlying technology DLT supports near real-time settlement with round-the-clock availability on a peer-to-peer basis, which potentially solves the drawbacks of current systems. Numerous central banks have researched its potential and some have advanced towards experimenting with large-scale pilots for specific use cases. Opinions widely diverge, as there is no general consensus on variants, characteristics and design choices yet. Our use case aims at the issues identified in the wholesale payments market, for which we use a tokenised version of existing fiat currency that can be exchanged on a distributed ledger managed by the central bank or an appointed third-party authority. Access will be limited to commercial banks only and we exclusively consider cash payments.

Chapter 3

Risk Analysis

This chapter addresses research question (ii), which is formulated as follows:

"How will CBDC introduction change the financial risks involved in cross-border interbank transactions?"

We start by determining the relevant financial risks for cross-border interbank transactions. Subsequently, we quantify each risk factor and compare the current to the future situation.

3.1 Risk Classification

Prior to quantifying the financial risks of a cross-border interbank transaction, we must know which risks are relevant to our research. Hence, we provide an answer to the fourth sub-question of research question (i) in this section, which is formulated as follows: *"Which financial risks are relevant to cross-border interbank transactions?"*

Below, we provide the reasoning for either inclusion or exclusion of risks, according to a detailed classification of financial risks that is set out in Figure B.1 in Appendix B. As we have explained in Section 1.7, non-financial risks are out of scope. Within our scope, we expect market, in particular interest rate and FX risk, counterparty credit and liquidity risk to be most relevant.

(i) **Business risk** — When used by a bank, this refers to strategic risk and reputation risk. Business risks might be relevant to some extent, i.e. the public attitude towards digital currency involvement by banks might be negative, however, this type of risk is outside the scope of our research due to our choice to focus on financial risks.

  (a) *Reputation risk* — Refers to loss resulting from damages to a firm's reputation.

  (b) *Strategic risk* — Relates to a bank's decision to (not) enter new markets and develop new products, respectively (Hull, 2015).

  (c) *Moral hazard* — The lack of incentive to guard against risk where one is protected from its consequences, for instance by insurance.

(ii) **Non-business risk** — The second category refers to systemic risk and sovereign risk. The latter is relevant to CBDC, since a unilateral settlement system suddenly affects multiple jurisdictions. This has considerable political and legal consequences. Nevertheless, non-business risks are out of scope, due to our choice to focus on financial risks.

(a) *Systemic risk* — The possibility that one financial institution in default leads to other financial institutions defaulting as well. This creates risks for the whole financial system.

(b) *Sovereign risk* — This risk deals with political decisions, events, or conditions that might significantly influence the profitability of a business actor or the expected value of a given economic action (Hull, 2015).

(iii) **Financial risk** — The last and most important category includes market, credit, liquidity, and operational risks. The latter is not quantified as the scope of our research is composed to focus on pure financial risks.

(a) *Liquidity risk* — Liquidity risk is about the ability to make payments when they become due, thus relating to the movement speed of a given financial asset. In particular, liquidity funding risk is relevant. Settlement through CBDC would stimulate liquidity usage optimisation[9], since trapped liquidity in correspondent banking nostro accounts is unblocked, liquidity pools become centralised and payments can be offset against more (types of) transactions. Not managing liquidity risk in a healthy manner might result in a bankruptcy for the respective bank due to funding drying up.

(b) *(Counterparty) credit risk* — Hull (2015) defines counterparty credit risk as the possibility that a loss will be experienced because of a default by the counterparty in a derivatives transaction. Time being no longer a factor in transaction settlement, we expect counterparty credit risk to decrease. Settlement risk vanishes as well, since atomic swaps[10] should improve settlement reliability.

(c) *Market risk* — This risk encompasses movements in market variables, such as interest rates, FX rates and volatility, but also commodity and equity risk. We anticipate the first two to be of relevance to CBDC. FX and interest rate risks change when currencies are settled real-time. Time plays a vital role here, since processing times are decreased. As a result, there is less time for different currencies to fluctuate in value. Volatility risk would only be relevant

[9] For instance, the ECB offers reservations and priorities, limits, offsetting mechanisms and optimisation algorithms (European Central Bank, 2018). Liquidity-Saving Mechanism (LSM)s to offset transactions, such as netting and bundling, are performed prior to sending the net amount of the payment leg to the RTGS terminal.

[10] Simply, atomic swaps require both parties in a transaction to acknowledge receipt of funds using a smart contract with some cryptographic hash function. If one of the involved parties fails to confirm the transaction within a specified time frame, the entire transaction is cancelled and funds are not exchanged. The latter action helps removal of counterparty credit risk.

when the new system was developed for a new free-floating currency. Hence, this would induce amongst others volatility issues, although this is not the case. We confine ourselves to cash transactions, so equity and commodity risk are not relevant to our research.

(d) *Operational risk* — Operational risk is defined by Hull (2015) as losses resulting from inadequate or failed internal processes, people, and systems or from external events. Although these are important due to dependence on new technologies and potential legal issues in jurisdiction collaboration, we will refrain from quantification. This is because of our choice to focus on pure financial risks. However, they are too important to ignore as well.

We have stated which risks are both relevant to CBDCs and within the scope of our research in the classification risks above. However, we skip an important comparison by jumping to risks of CBDCs immediately, which is comparing the risks for digital currencies mutually. Following the various digital currency types laid out by Table 2.2, Table 3.1 compares the most important risks for the most relevant digital currency types. The risk profiles in the table are based on internal estimations of ING (2018b). Note that the risk qualification is an approximation and should not be considered as an objective measurement.

Table 3.1: *Digital currency risk comparison (ING, 2018b).*

Risk embedded in solution	**Digital currency type**	**Market risk**	**Counterparty credit risk**	**Liquidity risk**	**Operational risk**
High	Cryptocurrencies[11]	Very high	Medium	Medium	Very high
	Crypto stablecoins	Low[12]	Low	Medium	High
	Commercial bank digital currencies	Very low	Low	Low	Low
	General Public CBDCs	Very low	Very low	Very low[13]	High
Low	Wholesale CBDCs	Very low	Very low	Very low[13]	Medium

Note: The scale used in this comparison is as follows: very high - high - medium - low - very low. It is also important to note that the qualifications are relative to each other and approximated.

Table 3.1 lists the digital currencies from an overall high risk profile to a low one. It is

[11]We exclude the cryptocurrency type that consists of company shares achieved through an ICO. Greene and McDowall (2018) provide more insight into cryptocurrency financial risks.

[12]Low due to being backed to a currency or asset. For instance, fixing a stablecoin one-to-one to gold would involve the volatility of gold as market risk.

[13]Depends on funding and netting possibilities, but generally very low.

clear that a huge amount of risk is embedded in the concept of cryptocurrencies as they are subject to private issuers, hardly any regulations and prone to sudden value changes, i.e. volatility is high. Also, there are not backed by any tangible asset, which makes them purely speculative. Stablecoins are one-to-one backed to, for instance, fiat currencies or assets and have a stronger risk profile as a result. The risks embedded in commercial bank-issued and central bank-issued digital currencies are comparable, but generally lower due to the moderating effect of central bank issuance. Operational risks largely depend on the entity that issues the digital currency and operates the platform. Public, permissionless digital currencies involve higher operational risks than private, permissioned versions, mainly due to a significant difference in legal risks. Additionally, liquidity risks decrease as the issuing entity has regulatory obligations. Cryptocurrencies are not subject to any regulation, hence the risk that an asset cannot be sold because of a lack of willing investors is high. Since financial institutions are heavily regulated by central banks, liquidity risks tend to be managed adequately.

The main advantage of wholesale CBDC introduction would be a stimulus in the optimisation of liquidity usage due to the unlocking of trapped liquidity on the one hand and increased netting opportunities on the other hand. This is a result of increased availability (round-the-clock) to central bank settlement systems, the elimination of intermediary correspondent banks and CBDC potentially becoming the centralised and only liquidity pool to settle all financial transactions.

In addition to the above, it is important to note that risks of a general public CBDC to the monetary system are relatively high, as the impact on the financial stability might become substantial when everyone gets access to global highly liquid payment opportunities. A general public CBDC might become an attractive alternative to commercial bank deposits and in periods of financial stress, a digital bank run to the central bank might occur.

We can now express which financial risks are relevant to our research on CBDC after having classified the risk categories. The following risks are based on the reasoning above, as well as on findings and theories distilled from our literature study in Section 2.3. Note that not every risk category of Table 3.1 - and in a broader sense Figure B.1 - falls within our scope.

(1) Liquidity risk for a cross-border interbank transaction decreases in a future model with CBDC.

(2) Counterparty credit risk for a cross-border interbank transaction decreases in a future model with CBDC.

(3) Interest rate risk for a cross-border interbank transaction decreases in a future model with CBDC.

(4) Foreign exchange risk for a cross-border interbank transaction decreases in a future model with CBDC.

(5) Operational risk for a cross-border interbank transaction increases in a future model with CBDC.

These predictions will be considered individually to see which risk factors are most subject to change, but also collectively. For us to be able to address the overall impact of wholesale CBDC introduction, the collective comparison is especially important. We focus on quantifying financial risk, hence operational risk will be analysed in a qualitative manner. Nevertheless, we include this type of risk as it is relevant to the CBDC initiative in our opinion. The relevant financial risks vary for each transaction type. Thus, these risks do not all need to be considered every time. Table 3.2 lists the relevant financial risks per transaction type. Obviously, there exist considerably more types (e.g. DvP) but our research focuses on cash transactions only, as has been explained in Section 1.7.

Table 3.2: *Relevant risks per transaction type.*

Type	**Liquidity risk**	**Counterparty credit risk**[14]	**Interest rate risk**[14]	**Foreign exchange risk**[14]	**Operational risk**
Mono-currency payment	yes	no	yes	no	yes
Cross-currency payment	yes	no	yes	yes	yes
Cross-currency PvP	yes	yes	yes	yes	yes

When the relevant risks are quantified for each transaction type and the difference between the current and proposed situation is clear, we will change the input parameters to observe what happens in different scenarios. The objective is to find patterns and sensitivities that give more insight in future cross-border interbank transactions with regards to financial risk calculation. Ultimately, we will scale up the transactions that were identified as representative to a commercial bank's entire business to give balance sheet implications of the newly proposed payment system.

[14]Only in the current correspondent banking model. This risk vanishes in the future model due to near real-time and atomic settlement.

3.2 Liquidity Risk

Now we are able to quantify the relevant risks and provide answers to research question (ii). We consider two sub-questions in the following sections. These are defined as: *"How are the relevant financial risks in the current correspondent banking model quantified?"* and *"How would the relevant financial risks in a future model with wholesale CBDC be quantified?"*

3.2.1 Liquidity Management

The first risk we address is liquidity risk. The exact risk of a transaction is hard to calculate due to many influencing factors, so we must make estimations. We start by explaining the different sides to the role of liquidity in cross-border interbank transactions. In our case, liquidity risk consists of two elements. The first dimension to liquidity risk relates to the ordinary inability to pay. For a commercial bank to facilitate a transfer (from a client), it must have sufficient liquidity in the account that is used to fund the transaction. However, having sufficient funds available for settling payments results in fewer market opportunities to lend, trade, or invest.

By contrast, insufficient funds results in a transaction to fail, followed by a dissatisfied client and extra service costs. In an extreme case, this can even lead to the bankruptcy of a financial institution (cfr. the credit crisis in 2008). This issue mainly relates to a mismatch between incoming and outgoing payments and to unjustified asset and liquidity management. Extending the limited time windows in which RTGS systems are open will result in more opportunities to mitigate liquidity risk due to decreased pressure on time window constraints. The ECB, for instance, opens its RTGS system TARGET2 for processing cross-border interbank payments every working day from 07:00 to 18:00 CET (European Central Bank, 2019c). Transactions requested outside these hours are delayed until the moment the system opens again.

The proposed model is additional to the payment system. We assume here that the ECB issues the CBDCs and manages the euro-denominated ledger itself, equivalent to current Eurosystem's cross-border RTGS systems. A payment instruction (e.g. €1 million) through a SWIFT message is required for a commercial bank to execute a transfer. The amount is then transferred from ING's balance to BNY Mellon's balance. Settlement finality takes place on the ledger. Any commercial bank can fund and defund its balance by transferring funds back and forth from the RTGS terminal of the central bank to respond to continuously changing liquidity requirements. This is done from the TARGET2 account at the ECB in the case of ING. BNY Mellon must either manage its balance through using an intermediary or swap USD to EUR on the platform directly. Funding from the TARGET2 account is however only possible during the aforementioned opening hours of the central bank being considered. This problem presents a second dimension to liquidity risk as it concerns the ability to pay outside regular RTGS operating hours, which is now possible in the new situation. The process described above is depicted in Figure 3.1.

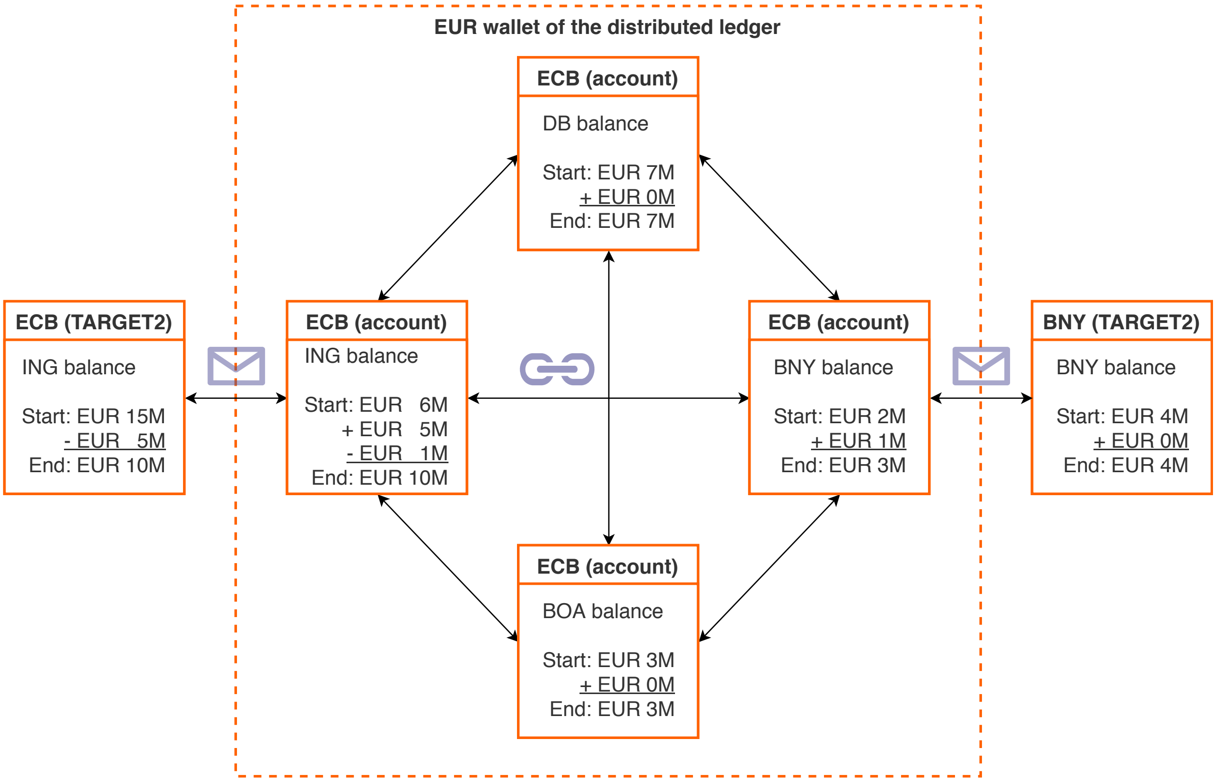


Figure 3.1: *Liquidity management during central bank opening hours.*

Paying outside RTGS system operating hours poses difficulties. Whereas in the current system the transaction would be delayed until the next morning (except for weekends and holidays), the future situation facilitates a 24/7 transfer opportunity. Figure 3.2 shows such a transfer outside central bank opening hours. It could be that a client requests a payment of €6.000.001. Then this transaction is cancelled, because the ING account at the EUR wallet only has a liquidity position of €6 million.

To overcome the problem of insufficient liquidity, ING could transfer all of its liquidity in the TARGET2 account to the ledger's EUR wallet at 17:59. This way, the bank can facilitate all transactions made overnight and restore the TARGET2 liquidity just before the system opens again. One could however question whether the ECB would approve this, which is up to consideration of central banks. Similar processes are currently being used in T2S and Euro1. T2S is the Eurosystem's pan-European platform for securities settlement in central bank money and Euro1 is a privately-owned settlement system focused on large-value transactions. At the end of each business day, at 17:45, all liquidity in T2S is automatically swept back to the RTGS accounts in TARGET2 (European Central Bank, 2018). Although the funding account of the EUR CBDC wallet would most probably also be a TARGET2 account, the ECB could decide to add restrictions to for instance the amount of liquidity allowed in this account. These specific design choices will however not be discussed in detail in this research.

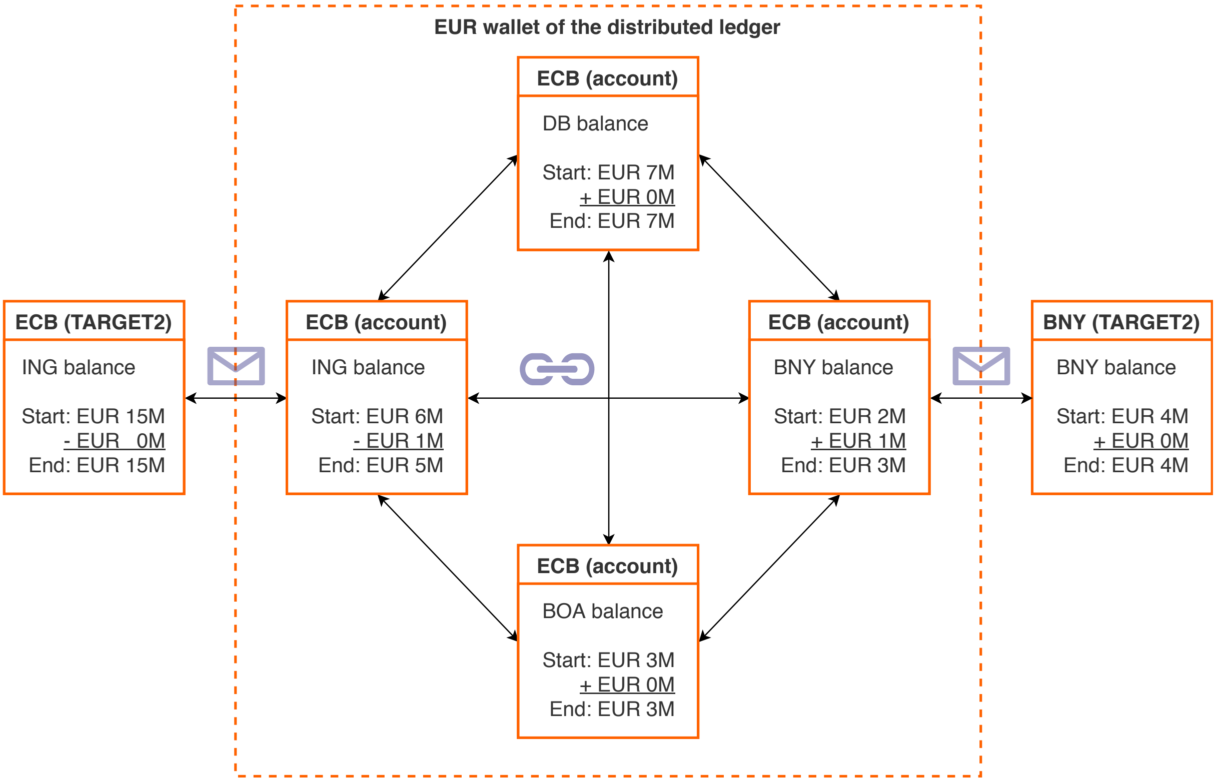


Figure 3.2: *Liquidity management outside central bank opening hours.*

To still be able to facilitate the payment, there might be ways to increase liquidity in the account even during times of central bank closure. First, we list the current options to manage liquidity positions below.

- The easiest way of managing an account's liquidity in the ledger is **direct funding from the TARGET2 account**. As has been explained before, this is only possible during an RTGS system's opening hours.
- Liquidity positions can be increased due to **incoming payments**, possibly through swaps coming from foreign currency ledgers as well. A major advantage of the new system could be increased optimisation of liquidity present on the platform due to 24/7 availability of these kinds of transfers.
- An option that is currently used frequently is the practice of **intraday credit line borrowing**. This facility in TARGET2 enables banks to overdraw their intraday account against eligible collateral posted. Collateral can for instance be government bonds. Intraday credit line borrowing is decreasing in usage due to the asset purchase programme of the ECB (European Central Bank, 2018). Currently, banks offer credit lines that greatly exceed their actual liquidity positions, as their models anticipate lower usage based on historic utilisation. Central banks might not allow an upheaval of the one-to-one backing of CBDC in circulation on the future platform.

A major advantage of CBDC with respect to liquidity management lies in the centralisation of cash pools due to the release of blocked liquidity. Instead of having to use correspondent banking relationships and manage liquidity positions in cash accounts at every correspondent bank to execute global trades, banks can reach any counterparty by transacting on the ledger. Providing instant delivery and the opportunity to spread liquidity needs over 24 hours will reduce peaks in payments processing.

As a result, liquidity positions of a commercial bank would be centralised in one account per currency with all kinds of transactions now being settled via this account. Increased access to other currencies even multiplies this benefit, because multiple currencies can be used to fund a transaction due to the possibility of a quick currency swap. Here, interoperability between the ledgers of different currencies is key. Optimally, banks could request a currency swap to quickly retrieve liquidity in the desired currency. Such a move might however incur high transaction costs. It is not hard for a counterparty to guess that the liquidity of the bank requesting the swap is insufficient to execute an important transaction, hence they might be more inclined to pay extra. In summary, introducing CBDC as an extra payment option increases access to central bank funds, since the need for using correspondent banks is erased. Subsequently, this results in the unblocking of trapped liquidity by providing instant delivery, which in turn reduces liquidity needs.

3.2.2 The Role of Liquidity-Saving Mechanisms

Another beneficial consequence of eliminating intermediaries is the opportunity for counterparties to join the network. As the number of connections to the ledger builds up, the potential of LSM usage increases as well. Queuing mechanisms are generally used for matching and offsetting transactions to scale down liquidity requirements before settlement. This is due to the fact that RTGS systems are demanding and expensive in terms of funding and liquidity needs. Such LSMs are intended to substantially reduce banks' intraday liquidity requirements by conditioning the release of queued payments on the receipt of offsetting or partially offsetting payments. As a result, gross payment orders are reconstructed to a netted amount before entering the RTGS system for settlement (Engert & Fung, 2017). We assume that similar LSM practices are added to the new platform as well.

An example of how payment orders are processed by queuing mechanisms in TARGET2 is depicted in Figure 3.3. Payments are either booked or queued based on their assigned priority after having been checked for offsetting possibilities and fulfilment of settlement criteria. Similar methods are applied by the central banks governing other RTGS systems. For instance, in a Bank of England working paper, Davey and Gray (2014) state that the LSM of the United Kingdom's RTGS system Clearing House Automated Payment System (CHAPS) has reduced banks' intraday liquidity requirements by around 20% (or £5 billion) since its introduction in 2013.

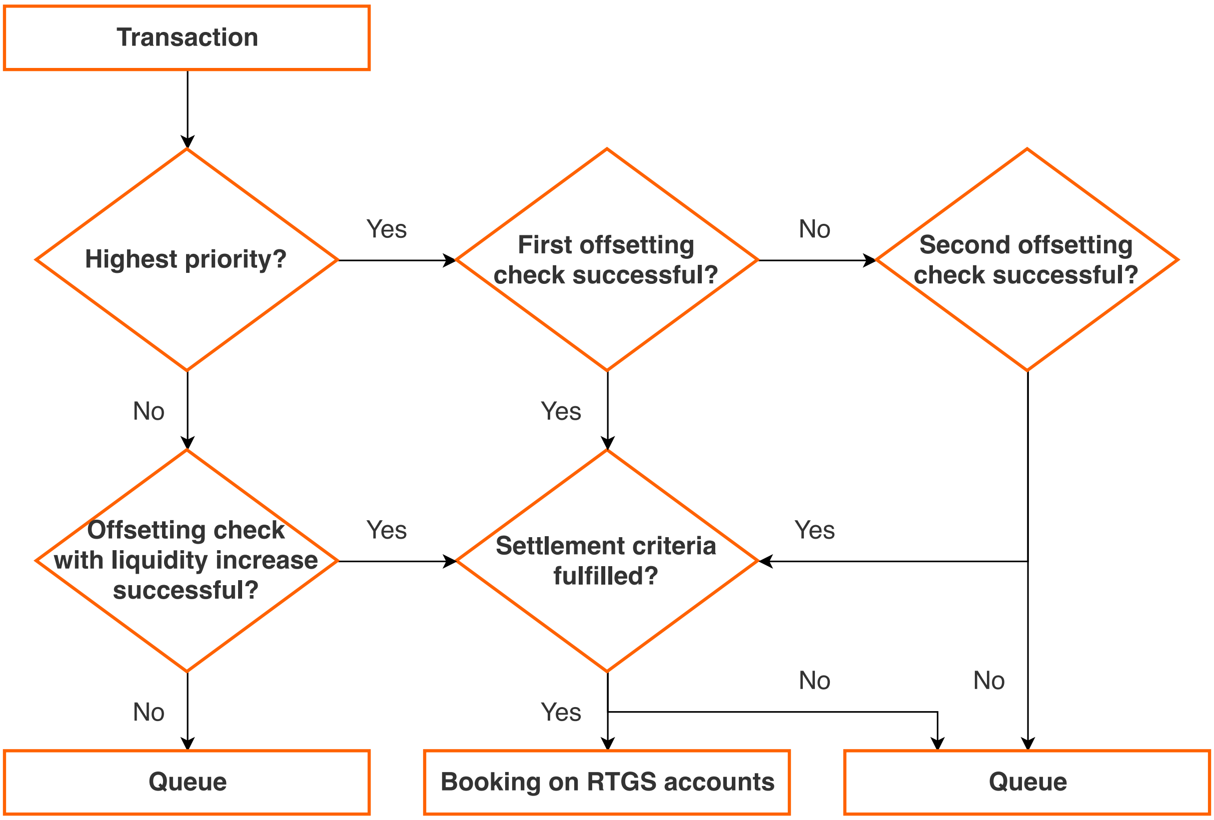
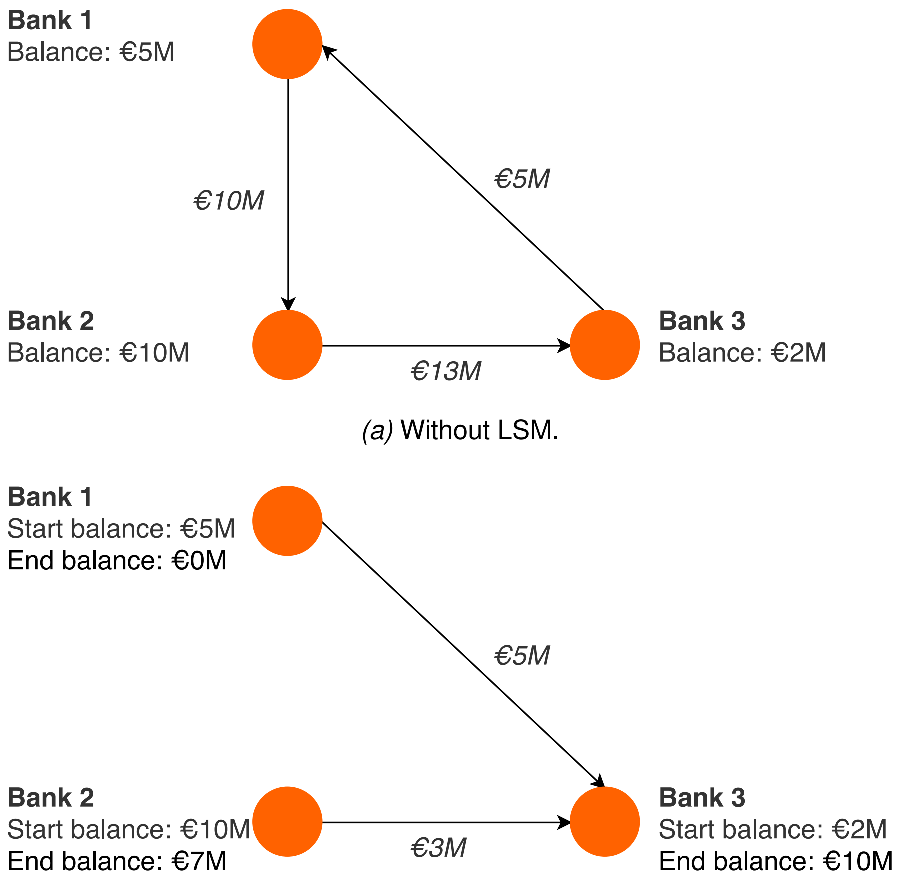


Figure 3.3: *Flowchart of the entry disposition algorithm in TARGET2 (European Central Bank & Bank of Japan, 2017).*

We expect the increased applicability of LSMs to be a major advantage of settlement through CBDC as now we will be able to net and offset all financial transactions that need to be settled between banks. Therefore, we estimate the impact of CBDC settlement on the new platform compared to current RTGS processes on liquidity usage. First, we give an example of a situation that is solved by applying an LSM, based on Accenture (2017). Figure 3.4a shows a scenario in which three banks are unable to settle (in a sequential matter) as each originating bank lacks sufficient liquidity. By applying a netting mechanism, such a gridlock scenario (see Figure 3.4b) can be resolved as LSM algorithms offset the transactions. Total liquidity required in the example drops from €28 million to €8 million, thus saving 71%. As more parties join the network, offsetting opportunities increase. It can therefore be expected that the new settlement system allows for greater efficiency regarding LSM algorithms. Besides, adding standard denominations to transactions (e.g. cutting them into portions of €0.1 or €1 million) could further enhance netting possibilities and as such the liquidity optimisation process.



(a) Without LSM.

(b) With LSM.

Figure 3.4: *Example of a simple gridlock scenario.*

3.2.3 Liquidity Benefits

A study on the total liquidity needs in a system using CBDC compared to current RTGS processes using equal LSM methods shows that a reduction of 21.1% in liquidity requirements could be realised (ING, 2019). Here, a model is built upon real RTGS data that cover 50 representative days of CHAPS operations. It therefore provides a valid approximation of actual RTGS systems and can be generalised accordingly, for instance to TARGET2. TARGET2 turnover in 2017 amounted to a total value of € 432.8 trillion, corresponding to a daily average of € 1.7 trillion transacted. Following the same logic that is used for CHAPS calculations, the total reduction in daily liquidity needs for TARGET2 could be as high as € 66 billion.

In an Oliver Wyman report, Sawjiany, Sooklal, and Min Lee (2018) discuss cost savings that banks could achieve by cutting intraday liquidity requirements. The report argues that every $1 billion saved in the liquidity buffer can save $10 million in annual costs. Potential savings depend on the interest rate on these lines. We assume this is 1%.[15] This would mean that total savings with respect to the liquidity buffer in TARGET2 could be as high as € 660 million on an annual basis. If we assume that a large commercial bank in the Eurosystem accounts for 1% of the total liquidity buffer, its annual savings could be €6.6 million.

Besides the major intraday advantages of cash pool centralisation described above, CBDC issuance would be beneficial to interday payment operations as well. The possibility to transact on a continuous basis alleviates pressure on participants to place payment orders prior to closure time of the respective RTGS system. Whereas the average value of a TARGET2 payment fluctuates around €3 million during the day, a dramatic increase is seen between 17:00 and 18:00. In the last hour, the average size of payments rises to €110 million, owing to banks squaring their balances and refinancing themselves on the money market (European Central Bank, 2018). We expect this congestion to loosen up as 24/7 transaction availability reduces the need to meet the deadline. As a result, there would be less pressure on liquidity positions and managing them.

A potential disadvantage relates to losing revenues from correspondent banking activities. Currently, financial markets make money from handling each other's payments. Commercial banks could loose business in this case. Potential loss of access to intraday credit line borrowing is a second drawback. In the current model, banks can apply to credit lines from correspondent banks when they are short on cash, which are often offered for free to maintain good relationships. However, total intraday credit line availability exceeds total liquidity in the current system. In the future model, these credit lines could no longer be free as the correspondent banking model is drastically overhauled. Also, they would be reduced if central banks chose to not extend the one-to-one intraday credit line availability by swapping collateral for credit on an intraday basis. Regulators would have to allow for such measures to be added to the revised monetary policy for this to happen.

What the total yield of CBDC introduction would be remains unclear. We expect LSMs to perform more efficiently. More transactions can be settled by one pool due to the release of trapped liquidity and an increase in the number of counterparties to transact with. We have estimated that annual savings could lead up to €6.6 million for a large commercial bank. However, this number is subject to many assumptions. CBDC can reduce liquidity risk due to extended availability of payment systems operating hours and near real-time settlement of transactions. Instant and round-the-clock availability induces a new dimension of liquidity risk, since banks must now also ensure sufficient liquidity outside ordinary RTGS operating hours. The exact gain per transaction is difficult to calculate due to the complexity and number of factors concerned, but we are

[15] The average interbank interest rate on EUR is 1.0038% for the period 2005 - 2018 (cfr. Section 3.4). However, the interest rate on EUR is currently negative and intraday credit lines are often offered for free as part of correspondent banking services. These relationships will disappear, or at least become under pressure in the new system.

fairly certain that CBDC introduction will significantly decrease liquidity risks. Following the reasoning outlined in previous paragraphs, we use a reduction in liquidity risk of 21.1% in our analysis.

3.3 Counterparty Credit Risk

3.3.1 Risk Definition and Methodology

The second risk factor concerned is counterparty credit risk. We define this type of risk as the probability that one of those involved in a transaction might default on its obligation to pay. A consequence of the restricted opening hours of RTGS systems is that there are only very small windows of time when the systems across different countries are open simultaneously. This results in cross-border payments getting trapped in a country, waiting for the respective RTGS system to open, and thus drive the time lag in cross-border transactions reaching their final destination (KPMG, 2018). In the current correspondent banking model, there is a likelihood that a party participating in a transaction defaults during the execution of that particular transaction. This concerns both intermediaries and counterparties. As a result, an originating bank must bear the risk of a counterparty default probability during the settlement of a transaction and might lose the payment amount. We want to quantify the risk of that probability in this section.

In our case, counterparty credit risk relates to the exposure during settlement. The probability that the correspondent bank(s) consulted in a particular transaction default(s) during the actual settlement of the transaction, i.e. between the moment of instruction and reception of the transaction is also referred to as settlement risk. Counterparty credit risk vanishes due to the atomic settlement of transactions in the future situation. There is no longer a risk that a party participating in the transaction defaults during execution, since settlement is near real-time and will not happen when one party does not meet the (liquidity) requirements for execution. The risk that the counterparty in a cross-currency PvP fails to deliver its side of the agreement while the originating party has already delivered security or cash value is also referred to as 'Herstatt' risk.[16]

In order to estimate the ability of the counterparty to pay back the debt within a given time horizon, one would use the credit rating of the prospective debtor. This credit rating represents an evaluation of a credit rating agency, the largest of which are Moody's,

[16] Named after a small German bank (Bankhaus Herstatt) that made a famous example of this risk. In June 1974, it failed to deliver a contract after having already received the payment from the counterparty. That failure caused a string of cascading defaults in a rapid sequence, totalling a loss of hundreds of millions to the international banking sector (KPMG, 2018).

Fitch Ratings and Standard & Poor's. We adopt the latter in our research. Credit ratings include quantitative as well as qualitative information of the prospective debtor, both publicly and non-publicly available material. The credit rating definitions and scale used by Standard & Poor's are listed in Table B.2 in Appendix B.x

We use the Credit Default Swap (CDS) database from IHS Markit (2019) to calculate the counterparty credit risk in a transaction. CDS contracts are generally used to insure long-term positions against default risk, but we use them as an indication for counterparty and settlement risk in short-term transactions. The CDS spread is the amount paid per year for protection as a percentage of the notional principal. Equivalent to the method applied to interest rate and FX risk computation, we base the counterparty of a transaction on day i on the same randomly selected transaction characteristics. This means for example that if a transaction on some day i involved a payment from EUR to USD, the CDS spread of either one of two US-based counterparty banks was chosen. Two of the largest banks per currency were picked as counterparties, which resulted in a total of eight banks. These banks are listed in Table 3.3.

Table 3.3: *Counterparty banks per currency.*

Currency	**Counterparty bank 1**	**Counterparty bank 2**
USD	Citi Bank	Bank of America
GBP	Barclays	HSBC
JPY	MUFG	SMBC
CHF	Credit Suisse	UBS

We have calculated the historical 1-year CDS spreads for every counterparty bank. The CDS database was formatted using the *Python*-based tool *Jupyter Notebook* to retrieve the appropriate historical credit ratings for our analysis. The corresponding code is added to this report as Appendix D for reference purposes. Data was available from March 17, 2008 onwards, except for Credit Suisse (from 2015), MUFG (from 2018) and SMBC (from 2012). We have taken the senior unsecured debt seniority level for data consistency purposes. Furthermore, a fixed restructuring clause was chosen for each bank to remove the spread between different restructuring clauses, thus ensuring CDS spreads to be independently consistent per bank.

3.3.2 Expression of Risk

Historical 1-year CDS spreads for each counterparty bank are depicted in Figure 3.5. The figure shows that 1-year credit spreads were especially high during the great financial crisis. The probability that a counterparty would default on, for instance, a financial loan was substantial. Hence, originating parties had to pay a great deal to insure against counterparty credit risk. It can be observed that in particular American banks were in financial distress, whereas British banks maintained relatively positive credit ratings. As of 2019, credit spreads for investment-grade financial institutions are typically in the range 0.1% to 0.5%, with an average spread of 23 basis points. This means that there is about 0.23% probability that the average bank in our data set will default on their financial obligations in the next year. For some AA- and AAA-rated banks (e.g. HSBC), 1-year credit spreads have even dropped below 10 basis points.

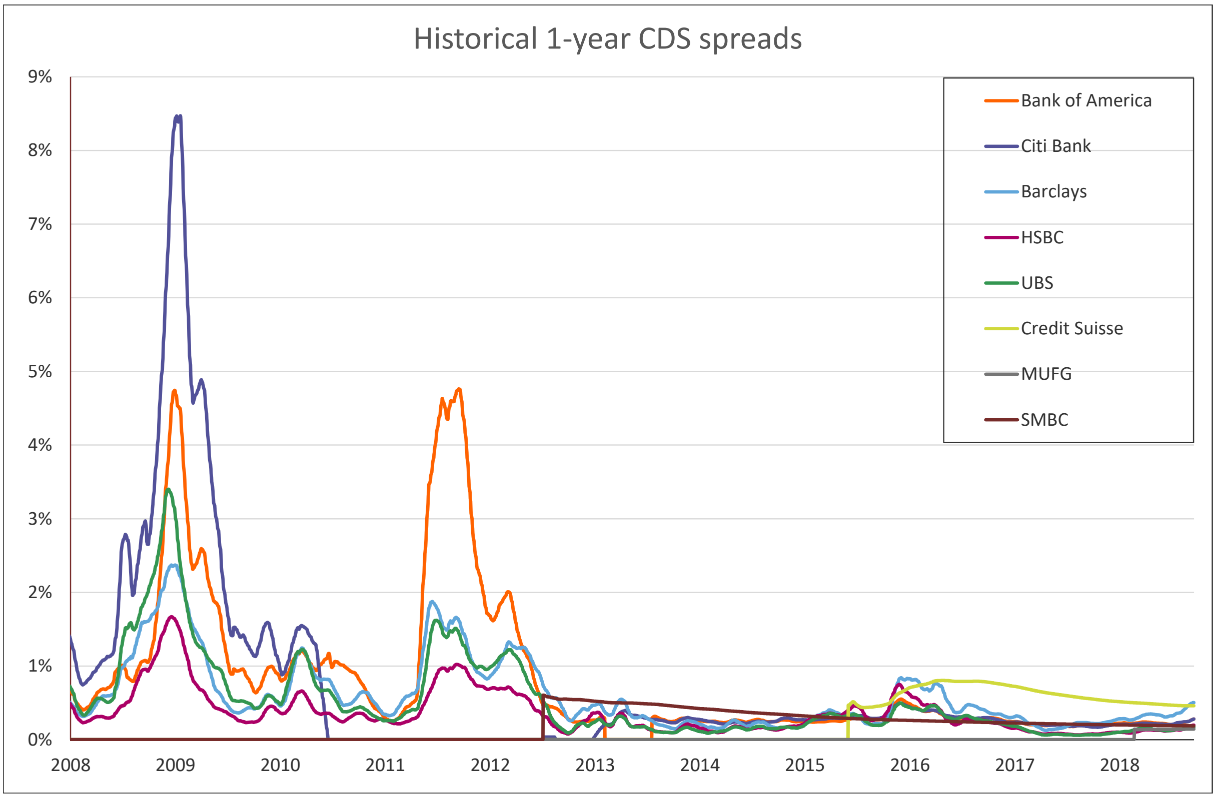


Figure 3.5: *Historical 1-year CDS spread per counterparty bank.*

We are able to estimate an implied Probability of Default (PD) and calculate the counterparty credit risk for a transaction by using CDS spreads. We are not interested in an exact PD in, for example, five years from now. However, the general probability of a default during a transaction period of only a few days is what concerns us. A default does not necessarily mean that the entire transaction amount is lost, but that the company has failed to meet its interest or principal obligations by the due date. Usually, the amount can be (partially) recovered at a later stage. Hence, we include a recovery rate in our analysis to come up with a sound estimation of expected loss. Hull (2015) uses cumulative default rates to calculate the PD in a certain period. This unconditional default probability is referred to as the hazard rate or default intensity. Applying the hazard rate to approximate the PD of a bond, company, or country is common practice in both the financial and academic world, so we must first obtain those rates. Equation 3.1 provides the solution to determining hazard rates.

$$\overline{\lambda} = \frac{s(T)}{1-R} \tag{3.1}$$

Where

- $\overline{\lambda}$ = the average hazard rate between time zero and time T;
- $s(T)$ = the credit spread for a maturity T; and
- R = the recovery rate.

Now we are able to compute the counterparty credit risk costs of a transaction by multiplying the notional principal with the hazard rate during the settlement period.

$$CP_{C,D,i} = N_C * (1 - e^{-\overline{\lambda}*t}) \tag{3.2}$$

Where

- $CP_{C,D,i}$ = the counterparty credit risk costs for a cross-currency PvP transaction on day i;
- N_C = the notional amount of currency C;
- C = the currency sent C, C = EUR;
- D = the currency received D, D = USD, GPB, JPY or CHF;
- i = business day i, i = 1, 2, ...; and
- t = the settlement time for a cross-currency PvP transaction, t = 4.2 days.

The default tier used for the recovery rate is senior unsecured debt, which typically indicates a recovery rate of 40% (IHS Markit, 2010). The 1-year tenor is used regarding maturity. We assume a constant unconditional probability of default to approximate daily costs to compensate for counterparty credit risk. In our opinion, this method suffices due to the fact that we are interested in single transactions instead of long-term investments. We can also approximate the risk-neutral default probability implied from the hazard rate directly, according to Equation 3.3 (Hull, 2015). Both methods show consistent results.

$$P = 1 - e^{\frac{-S*t}{1-R}} \tag{3.3}$$

The costs of compensating for counterparty credit risk are summed for each year in Table 3.4, following equation 3.2. We observe that trust in the industry was rather low in post-crisis years. The worst historical days were all observed in 2009. Credit spreads were high, because quite a few companies had defaulted on their obligations.

Recently, these costs have dropped due to banks having continuously strengthened their balance sheets. Contrary, the best historical results stem from recent years with credit spreads continuously reaching new lows.

Table 3.4: *Potential historical cost savings related to counterparty credit risk.*

Year	**EUR/USD**	**EUR/GBP**	**EUR/JPY**	**EUR/CHF**
2008	€ 5.161,71	€ 3.701,97	€ 3.426,26	€ 4.403,37
2009	€ 20.287,07	€ 6.203,07	€ 9.652,96	€ 9.648,76
2010	€ 7.306,02	€ 3.101,76	€ 3.934,30	€ 4.486,98
2011	€ 8.772,40	€ 4.961,86	€ 4.881,95	€ 6.111,17
2012	€ 7.602,92	€ 4.377,24	€ 5.794,81	€ 3.961,38
2013	€ 1.723,98	€ 1.689,24	€ 1.823,59	€ 1.149,97
2014	€ 1.397,38	€ 992,17	€ 1.088,65	€ 1.025,90
2015	€ 1.561,82	€ 1.514,66	€ 923,03	€ 1.653,25
2016	€ 2.357,19	€ 2.331,12	€ 1.244,35	€ 3.521,14
2017	€ 1.164,25	€ 634,05	€ 702,41	€ 893,34
2018	€ 1.114,76	€ 1.081,49	€ 627,27	€ 954,37
Total	€ 58.449,50	€ 30.588,63	€ 34.099,58	€ 37.809,62
Average day	€ 83,62	€ 44,75	€ 53,70	€ 54,17
Worst day	€ 842,49	€ 223,94	€ 578,68	€ 743,15
Best day	€ 14,49	€ 3,56	€ 3,53	€ 3,03

Note: For each business day i, the costs of compensating for counterparty credit costs of one transaction of €1 million were computed. For each historical day, it was randomly selected which currency pair the transaction included, consistent with the analyses on interest rate and FX risk. Data was available from March 17, 2008 onwards. The settlement period used is *T+2*.

A major advantage of CBDC is avoidance of counterparty credit risk altogether. Due to atomic settlement across the central bank's balance sheet, there is no longer a need for posting collateral to guard against the possibility that a counterparty becomes insolvent with outstanding liabilities to the originating party in a transaction. Typically, tiered systems require assets with high liquidity and low credit risk (such as government bonds or cash) to be posted as collateral. Thus, the new system would free up significant amounts of collateral for non-settlement transactions. This could have important macroeconomic and financial stability benefits to the extent that there is a shortage of good collateral in financial markets today (Barrdear & Kumhof, 2016). The exact effects of an alleviated collateral burden are not quantified in this report, but it is important to keep its benefits in mind.

We conclude that counterparty credit risk has historically been a significant cost burden for cross-border transactions. Recent rates have however dropped to 23 basis points on average for the banks included in our data set, whereas some of the highest-rated banks even demonstrate rates of only 7 basis points. Counterparty credit risk vanishes due to atomic settlement in the future model. Because of low credit spreads in recent years, cost savings of counterparty credit risk for current transactions are marginal. However, we have seen in Figure 3.5 that CDS spreads can rise to hundreds of basis points in times of financial distress. What remains is nominal credit risk on the central bank, which is nil due to central banks generally being unable (although the central bank of Argentina went bankrupt at the turn of the millennium) to go bankrupt (Skingsley, 2016). The current status of the world economy and particularly the financial sector do not guarantee everlasting stable conditions. Gains might be marginal at the moment, but everything could be different in a couple of years from now. For now, removing correspondent banks from the payment process especially improves transparency and predictability. We elaborate on these advantages in Section 3.6.

3.4 Interest Rate Risk

3.4.1 Risk Definition and Methodology

We continue our risk analysis with a comparison of the interest rate risk for the current correspondent banking model and the future situation. We have seen in Section 3.2 that there are costs related to 'trapped liquidity' in correspondent banking nostro[17] accounts. Interest that originating banks currently miss out on is what we refer to as interest rate risk. This type of risk could be described as the risk that the value of money will change due to a change in the absolute level of interest rates. Banks miss out on interest during payments settlement as well. Since the new situation would involve instant transactions, a bank could use the money reserved for the transaction until the actual moment of transacting, for instance to fund other business. Thus, interest rate risk in our situation refers to the opportunity cost of blocked liquidity during settlement.

The most common interest rate to compute the value of money with is the London Interbank Offered Rate (LIBOR). This is widely accepted as the risk-free rate that banks offer each other for large short-term loans. This market enhances the possibility to maintain liquidity requirements, since they are able to quickly take out a loan from other banks that have surpluses. The Euro Interbank Offered Rate (EURIBOR) is the

[17] The terms nostro and vostro are used when one bank keeps funds at another bank. Both parties must keep records of how much capital is being kept on behalf of the other. In order to distinguish between the two sets of records of the same balances and set of transactions, banks refer to the accounts as nostro (our money, held by other banks) and vostro (other banks money, held by us) (Niederkorn et al., 2016).

Euro variant of LIBOR. A downside to using LIBOR is the enormous credibility loss as a result of the LIBOR fixing scandal in 2012 (Arnold & Dunkley, 2017). The demand for a reliable alternative rate is still high, because rates are often estimated and not transaction-based (Brettell, 2017).

The Bank of England (2019b) has announced the Sterling Overnight Index Average (SONIA) as the new benchmark interest rate for financial transactions, not only to minimise opportunities for misconduct, but to increase the representativeness of the calculated rate more with respect to the underlying market as well (Ross, 2018). We use the overnight SONIA rates to compute the interest rate risk for the 1-day and 3-day transaction lead time (Bank of England, 2019a), and 1-week LIBOR for the 5-day transaction lead time. For the 3-day transaction lead time, the overnight rate is compounded. Similarly to SONIA, we use the 1-week EURIBOR rates for the 5-day payments (European Money Markets Institute, 2019b) and the overnight EURIBOR, which is actually the Euro Overnight Index Average (EONIA) rate, for both the 1- and 3-day payments (European Money Markets Institute, 2019a). For USD, JPY and CHF, the respective alternatives to LIBOR are Secured Overnight Funding Rate (SOFR), Tokyo Overnight Average Rate (TONAR) and Swiss Average Rate Overnight (SARON), respectively. As historical rates for the latter three currencies could not be retrieved, LIBOR rates will be used. We have listed the interest rates used for the calculations in Table 3.5.

Table 3.5: *Interest rate benchmarks used for calculations.*

Currency	1-day transaction	3-day transaction	5-day transaction
EUR	overnight EONIA	overnight EONIA (compounded)	1-week EURIBOR
USD	overnight LIBOR	overnight LIBOR (compounded)	1-week LIBOR
GBP	overnight SONIA	overnight SONIA (compounded)	1-week LIBOR
JPY	overnight LIBOR	overnight LIBOR (compounded)	1-week LIBOR
CHF	overnight LIBOR	overnight LIBOR (compounded)	1-week LIBOR

3.4.2 Expression of Risk

Taking the above into account, we compute the interest rate risk for a single transaction according to Equation 3.4.

$$
\begin{aligned}
IR_{C,i} &= r_{C,i}^{\frac{(i+1)-i}{365}} \\
&= r_{C,i}^{\frac{(i+1)}{365}-\frac{(i)}{365}} \\
&= r_{C,i}^{\frac{\Delta i}{365}}
\end{aligned}
\tag{3.4}
$$

Where

- $IR_{C,i}$ = the 1-day net interest rate risk for a transaction in currency C on day i;
- $r_{C,i}$ = the risk-free interest rate of currency C on day i. For the 3- and 5-day transaction, $r_{C,i}$ is compounded to $\frac{(i+3)-i}{365}$ and $\frac{(i+5)-i}{365}$, respectively;
- C = the currency sent C, C = EUR, USD, GPB, JPY or CHF; and
- i = business day i, i = 1, 2, ...

The overnight interest rate is compounded for three business days for 3-day payments. Similarly, the interest rate for 5-day transactions is compounded for five business days, although the 1-week rate is taken instead of the overnight rate. This operation is repeated for historical dates, spanning January 1st, 2005 until December 31st, 2018. Figure 3.6 displays a histogram of the historical returns of interest rates in basis points for EUR transactions. For comparison reasons, the respective distributions of the 3- and 5-day transactions are added to Appendix C as Figure C.1a and C.1b, respectively. Looking at Figure 3.6, it becomes clear that the distribution of historical interest returns is severely skewed to the left. The skewness can be explained by the fact that observed historical interbank rates have most of the time been close to zero, hence its distribution is concentrated around nil as well. Thus, taking only the average might not be the most appropriate value for conducting a solid interest rate risk valuation. We must therefore find rates that better suit our situation.

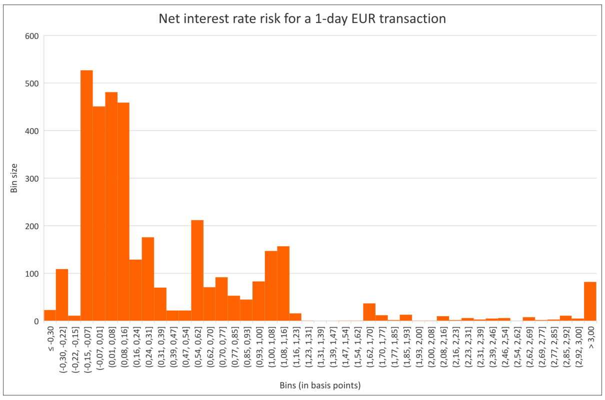


Figure 3.6: *Net interest rate risk distribution for 1-day EUR transactions.*

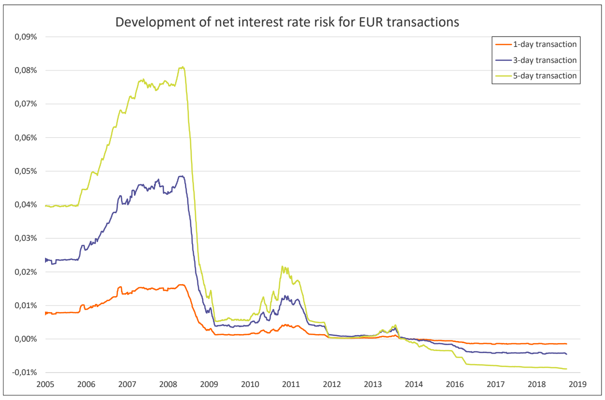


Figure 3.7: *Historical development of average net interest rate risk.*

In order to determine suited rates, we have depicted the historical returns of the net interest rate risk for EUR transactions with a notional of €1 million in Figure 3.7, using a moving average of thirty days. It becomes immediately clear that the financial crisis of 2008 has left its scars on interbank lending rates. The ECB bond-buying programme has even caused interest rates to drop below zero. We choose three different rates that cover all interesting situations based on the interest rate development. These are a steady-state rate, which was observed the years prior to the financial crisis, a representative (negative) rate of the last five years, and the long-term projected rate by the ECB[18]. For the other four currencies, the historical returns with respect to interest rate risk are displayed in Figure C.3 in Appendix C and rates are determined similarly. The rates are listed in Table 3.6.

Based on the rates in Table 3.6, interest rate risk for a €1 million payment can be expressed as a percentage of the transaction value lost due to trapped liquidity. Figure 3.8 displays the risk for mono-currency payments, cross-currency payments and cross-currency PvPs. The individual payment type figures are included as well in Figure C.4. Although mono-currency payments are already close to instant, we include them to show the effect of time on risk.

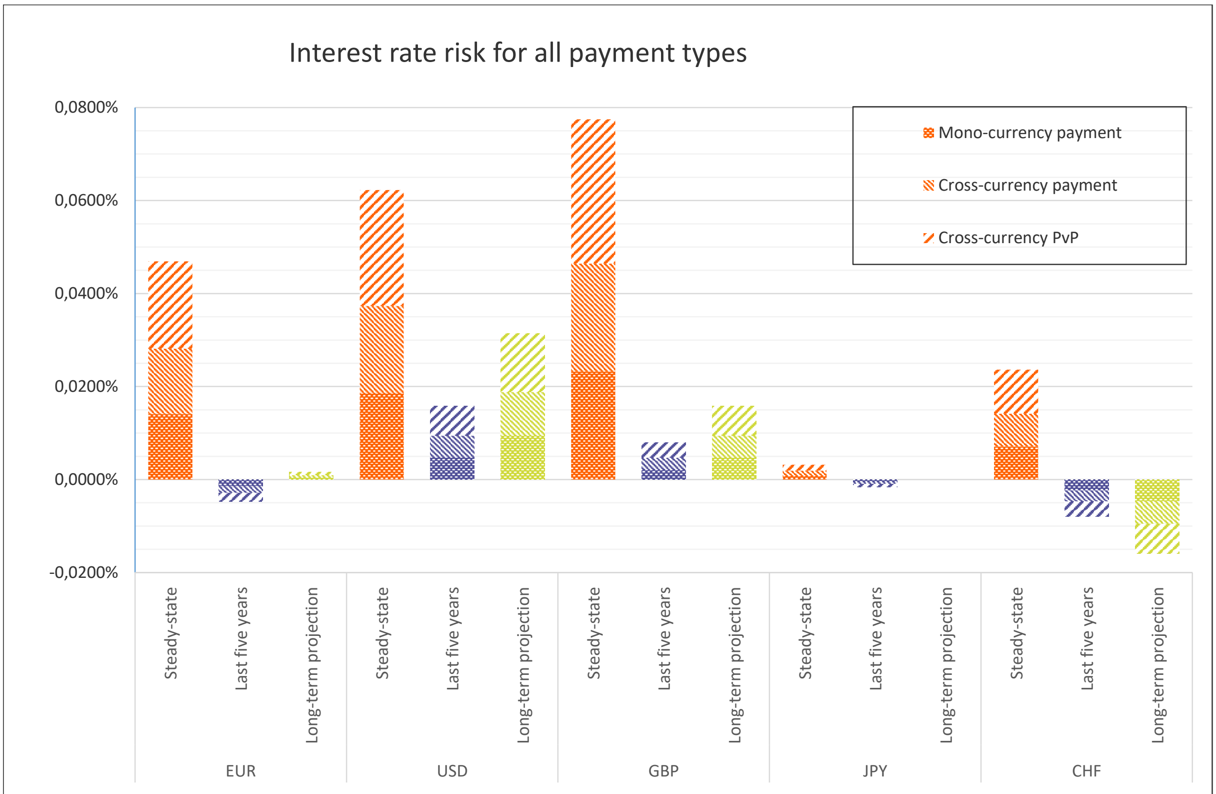


Figure 3.8: *Interest rate risk of trapped liquidity for €1 million transactions.*

It is clear that uncertainty in the financial sector prior to the global financial crisis caused LIBOR rates to grow even higher as banks in stress did no longer want to lend money.

[18]The ECB predicts a moderate recovery of the current negative rate and at least three more years until positive values are restored (European Central Bank, 2019a). Hence, we assume a conservative long-term prediction of +0.1%.

They feared they would inherit each other banks' subprime mortgages as collateral. LIBOR rose steadily to all-time highs, reflecting the increased cost of borrowing. Post-crisis rates dropped close to zero and central bank asset purchase programmes of the last years have even resulted in negative rates in some jurisdictions. This means that banks actually have to pay interest on funds that they lend due to the abundance of cash made available by central banks. Although LIBOR rates have steadily but slowly been rising the last five years, long-term projections show that they remain modest.

Table 3.6: *Interest rates used for calculations.*

Currency	Steady-state	Last five years	Long-term projection
EUR	+3.0%	- 0.3%	+0.1%
USD	+4.0%	+1.0%	+2.0%
GBP	+5.0%	+0.5%	+1.0%
JPY	+0.2%	+0.0%	- 0.1%
CHF	+1.5%	- 0.5%	- 1.0%

Note: The steady-state rate refers to the period before interest rates spiked, assume 2006. The long-term projection rate applies approximately to 2019 - 2024.

Whereas interest rate risk has historically presented significant costs to banks, it will pose less of an issue in future transactions. If we look at EUR payments, interest rate risk for a €1 million cross-currency PvP would have been 2.4 basis points on average in the pre-crisis period, which is equivalent to €235. In the current market, the same transaction would actually save the originating bank €24. The average historical cost savings related to interest rate risk are €81 based on our data set of historical interbank lending rates. These numbers are based on a settlement period of two days (cfr. Section 1.6).

Table 3.7 should give an indication of the potential cost savings in a future model with near real-time settlement through CBDC. It lists the annual cost savings that could have been realised in the future situation compared to the current model with an assumed settlement period of two days. The results are analogous to Figure 3.8. For instance, interest rate costs in the years prior to the financial crisis (i.e. 2007 and 2008) were of significant proportions. Moreover, it can be observed that EUR, JPY and CHF have experienced negative interest rates since 2015. Note that we have assumed one transaction per business day i with a notional of €1 million. Obviously, this is significantly out of proportion to the total amount a commercial bank transacts on a daily basis. The effects would therefore need to be multiplied by a large factor to realistically replicate the actual situation.

We conclude that interest rate risk has particularly been an issue during periods of financial distress or high economic growth due to fear and high inflation, respectively.

Table 3.7: *Potential historical cost savings related to interest rate risk.*

Year	EUR	USD	GBP	JPY	CHF
2005	€ 8.349,10	€ 12.672,69	€ 16.170,97	€ 148,43	€ 2.674,43
2006	€ 12.410,38	€ 15.442,94	€ 16.399,91	€ 736,82	€ 5.433,78
2007	€ 15.353,44	€ 21.441,29	€ 16.687,21	€ 2.507,76	€ 8.137,03
2008	€ 19.075,50	€ 6.937,31	€ 14.374,54	€ 2.057,70	€ 8.085,72
2009	€ 2.291,00	€ 691,94	€ 1.930,97	€ 736,80	€ 356,63
2010	€ 1.989,41	€ 753,54	€ 1.891,22	€ 378,35	€ 313,54
2011	€ 3.279,55	€ 679,24	€ 1.579,41	€ 384,55	€ 192,44
2012	€ 805,85	€ 507,47	€ 2.063,69	€ 412,49	€ 68,25
2013	€ 404,18	€ 523,62	€ 1.529,22	€ 358,58	€ -14,58
2014	€ 419,42	€ 314,64	€ 1.904,59	€ 200,77	€ -27,45
2015	€ -421,67	€ 503,15	€ 1.699,46	€ 100,61	€ -3.602,98
2016	€ -1.245,98	€ 1.383,87	€ 1.409,91	€ -135,07	€ -2.882,39
2017	€ -1.264,80	€ 3.895,06	€ 1.124,74	€ -76,48	€ -2.502,61
2018	€ -1.375,19	€ 7.694,59	€ 2.225,20	€ -200,42	€ -2.975,65
Total	€ 60.070,19	€ 73.441,35	€ 80.991,04	€ 7.610,89	€ 13.256,17
Average day	€ 80,74	€ 110,77	€ 116,87	€ 10,78	€ 19,05
Worst day	€ 469,69	€ 634,24	€ 685,92	€ 100,23	€ 294,14
Best day	€ -40,51	€ 4,79	€ 11,05	€ -16,70	€ -127,86

Note: For each business day *i*, the interest costs of one transaction equivalent to €1 million were computed. It was randomly selected whether the transaction of that day originated either from EUR, USD, GBP, JPY or CHF. Every transaction on business day *i* was converted to EUR according to the FX rate on that specific date. The settlement period used is *T+2*.

With current interbank lending rates being relatively low - and in some jurisdictions even negative - instant and round-the-clock settlement of payments would be a drawback rather than an advantage over longer settlement times. However, as interest rates slowly recover due central banks phasing out their asset purchase programmes, we should consider interest rate risk in our risk analysis on CBDC.

3.5 Foreign Exchange Risk

We continue with specifying the FX risk for cross-border interbank payments. This type of risk can best be explained by the change in an investment's value due to changes in the underlying value of two different currencies. FX risk vanishes for the new model, because transactions are processed instantly instead of taking several days or even a week to settle. Note that FX risk is about the change in the exchange rate between two currencies as time passes and not about the difference in the exchange rate itself.

Four combinations of currency pairs were taken for this analysis, i.e. transactions from EUR to either one of the remaining four. Data was retrieved from Investing.com (2019). Subsequently, FX risk is determined according to Equation 3.5.

$$FX_{D,i} = \frac{P_{D,i+1} - P_{D,i}}{P_{D,i}} \quad (3.5)$$

Where

- $FX_{D,i}$ = the net FX risk for a EUR transaction to currency D on day i;
- $P_{D,i}$ = the price of currency D expressed in EUR on day i;
- D = the currency received D, D = USD, GPB, JPY or CHF; and
- i = business day i, i = 1, 2, ...

Figure 3.9 displays a histogram of the historical returns of FX rates for EUR to USD transactions. For comparative reasons, the respective distributions of the 3- and 5-day transactions are added to Appendix C as Figure C.2a and C.2b, respectively. It can be concluded from Figure 3.9 that the distribution of historical FX returns is close to a perfect normal distribution. Not only is this true for all $FX_{EUR,USD}$ transactions, other currency pairs display approximately the same distribution. We take the 95th percentile to give give an indication of FX risk. FX risk at the 95th percentile for the different payment types is displayed in Table 3.8.

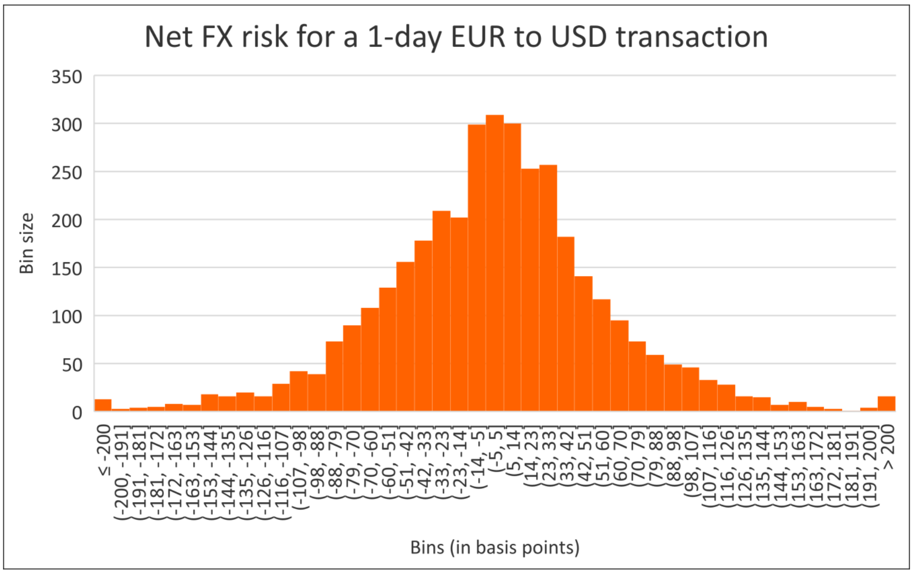


Figure 3.9: *Net FX risk distribution for 1-day EUR to USD transactions.*

Another way to express FX risk is by computing daily volatility. This is the standard

Table 3.8: *FX risk of historical FX transactions at the 95th percentile.*

Duration	EUR/USD	EUR/GBP	EUR/JPY	EUR/CHF
1-day transaction	0.98%	0.83%	1.11%	0.56%
3-day transaction	1.63%	1.48%	1.88%	0.94%
5-day transaction	2.04%	1.86%	2.46%	1.22%

deviation of historical daily price changes between two currencies. The daily volatility of all our currency pairs are provided in Table 3.9. Our results show consistency in both directions. Unfortunately, the volatility between JPY and the other currencies is inaccurate, because our data is limited to four decimals. This is insufficiently accurate for JPY as the exchange rate for JPY to commonly-used currencies is approximately 1:100. We have annualised our volatility measures as well, which can be observed in Table 3.10.

Table 3.9: *Daily volatility of FX transactions.*

to from	EUR	USD	GBP	JPY	CHF
EUR	-	0,60%	0,52%	1,10%	0,55%
USD	0,61%	-	0,60%	0,91%	0,71%
GBP	0,52%	0,60%	-	0,87%	0,72%
JPY	0,77%	0,65%	0,84%	-	0,75%
CHF	0,52%	0,70%	0,70%	0,74%	-

Table 3.10: *Annualised volatility of FX transactions.*

to from	EUR	USD	GBP	JPY	CHF
EUR	-	9,56%	8,28%	17,53%	8,77%
USD	9,62%	-	9,45%	14,41%	11,30%
GBP	8,32%	9,56%	-	13,81%	11,38%
JPY	12,16%	10,33%	13,27%	-	11,97%
CHF	8,25%	11,16%	11,08%	11,80%	-

It is common practice for a client to accept the bank's offered spot price. Whereas financial market departments continuously update all global ratings, prices and other valuations, a bank's treasury department sets a bid and an offer price every few hours as an indication of the fixed price. These prices are fixed end-of-day and nonnegotiable. Actual settlement occurs at *T+2*, since the entire cross-border payments market functions on the basis of fixed *T+2* spot prices. Some payments, however, are specified as urgent by customers. In this case, the commercial bank debits its nostro account in, for instance, USD and credits the customer's account in EUR at *T=0*. Subsequently, the commercial bank receives its USD purchased from financial markets at *T+2*. Banks are exposed to the difference in institutional interest rate between USD and EUR during the settlement period. Obviously, this additional risk is incorporated in pricing.

Transactions generally take longer to settle in the correspondent banking model. Particularly payments in exotic corridors add time to settlement periods. Hence, the *T+2* reasoning only applies to most liquid currency pairs for which banks have sufficient liquidity available at any given time. Payments to other corridors usually involve a settlement period of *T+(2+1)* to *T+(2+3)*.

A fee is charged as service costs for handling the transaction on top of the spread (both on the bid and offer side) that a bank accepts for taking on exchange rate risk. Since the bank takes on exchange rate risk, the client is left without any. The interbank FX spread varies per currency pair, day, time, size, counterparty and market events. Despite the multitude of factors they are subject to, both bid and offer spreads on common currency pairs (e.g. EUR to USD) are generally only several basis points in competitive markets. Other costs, as well as a commercial margin are added to arrive at a total revenue margin. We will quantify these factors in Section 4.1.

Due to the high volatility cross-currency transactions are subject to, the effect of FX on a payment's total risk seems significant. We conclude that FX risk is actually surprisingly low in practice for a single transaction. A bank's payments policy would typically hedge large FX risks with forward options and hedge remaining balances for payments with spot contracts as the latter market is most liquid, transparent as well as the largest.

3.6 Operational Risk

Operational risk is defined as "losses resulting from inadequate or failed internal processes, people, and systems or from external events" (Hull, 2015). Although this type of risk is outside our area of expertise, it is vital for the overview of total risk that we consider operational risk at least on a high level. In this section, we touch upon the most relevant issues.

To start with, operational risks relate to a broad range of factors. Costs arising from standard operations contribute to a large extent to a bank's expenses. This includes keeping all processes running, such as treasury operations, compliance, and payment operations, but ensuring the safety of infrastructures as well. A substantial portion of the operational costs originates from legacy infrastructure in commercial banks, partly inherited from RTGS infrastructure they interface with. As explained in Section 2.4, interoperability requirements present significant challenges. Especially interoperability between the DLT platform and legacy infrastructure may induce vulnerabilities that require careful management. Potential transition risks of introducing a new technology include careful design and market-testing of the new settlement system, the need for a meticulously-tested and reliable digital infrastructure, suitable training of the human operators of such a system upfront, thorough analysis of the legal implications (potentially including additional legislation), appropriate changes to financial sector regulation, full coordination with foreign central banks and financial institutions, and many others (Barrdear & Kumhof, 2016).

Compliance challenges relate to the mandatory application of both international and domestic regulatory frameworks. Financial institutions are obliged to perform KYC checks and adhere to Anti-Money Laundering (AML) and Countering Financing of Terrorism (CFT) regulation. This entails large costs for banks. On top of this, fulfilment of public policy requirements of other supervisory and tax regimes must be ensured by central banks, which can induce additional costs as policies would most likely need to be adjusted. Potential substantial fines due to lacking execution of policy requirements can also be regarded as an operational risk. The difficulties related to correspondent banking network management further increase costs (Niederkorn et al., 2016). Payments being blocked due to the reasons outlined above result in reconciliation errors, which incurs additional costs. If two parties each have another version of the truth, manual intervention by back-offices is required to solve the problem.

Complex interbank pricing rules also create the need for manual invoicing and handling of claims and disputes (Niederkorn et al., 2016). Such claims and treasury operations cause significant delays and corresponding costs. Other legal considerations relate to the central bank's authority to introduce new types of payment and expand access to its balance sheet. Nabilou (2019) argues that CBDC would not merely be a technological upgrade to the current technology of issuing money, but its programmable properties could accommodate features that can potentially grant additional powers to central banks, e.g. having higher surveillance power over transactions.

Access to the new settlement system would initially only be available to financial institutions as providing large corporates access as well would require central banks to perform KYC and screening on them. Central banks are hesitant to accept these obligations and would therefore prefer a private institution to run the platform. Other legal risks arise when CBDC settlement is introduced as an extra payment facility. Because ledgers of different currencies need to interoperate to effectively exchange funds and assets on an instant basis, the underlying legal framework must be equal for every participant as well. This is a reason for collaboration with the private sector as well, which could try to harmonise legal differences. In practice this means that banks operating in different jurisdictions gain direct access to each other instead of having to use correspondent banking channels. For example, for BNY Mellon to have an account in the euro-denominated wallet, it must to some extent comply to European financial law. The same goes for any European bank that wishes to obtain an account in the dollar-denominated wallet. Establishing mutual compatibility could pose serious challenges to the implementation. Moreover, keeping two separate platforms operational during the transition period incurs additional expenses.

For the interoperability of the various ledgers to function smoothly, not only technical issues should be considered, but regulatory differences between for instance the ECB and FED as well. Although benefits build up as more jurisdictions participate in the new model, complexity and challenges increase as well. The founding jurisdictions must therefore establish structured legislative frameworks and operational requirements for joining the model. A joint overarching rulebook with separate local rulebooks might do the trick. How consensus around governance, common standards, cyber security requirements, etc. is reached should be examined by the parties setting up the platform.

Stakeholders should carefully consider public policy design choices to guarantee the appropriate degree of privacy in the digital environment. One of the key characteristics of DLT is that transaction details are transparent and traceable, but banks would not want to share this information with competitors. Potential cryptographic solutions could be the use of dynamic stealth addresses or obfuscation techniques (e.g. bundling and denomination techniques or Zero-Knowledge Proof (ZKP)) to hide exact amounts as well as the identity of the originating and beneficiary bank. Data integrity and traceability could be vital requirements for compliance with KYC, AML and CFT regulations (CPMI, 2017). Yet, the central bank or independent governance authority must be able to inspect the relevant history of the record to verify the legality of each transaction. Thus, privacy must be conscientiously weighted against traceability.

Another factor is the possibility of external events to compromise a system's security. Cyber-threats (e.g. malware and fraud) currently pose substantial operational challenges to every payment, clearing and settlement system. The underlying technology must be resilient to such security hazards, which have increased dramatically in recent years. The reason for this increase is primarily due to attacks being more sophisticated, attackers being better educated and the technology used becoming more powerful (European Central Bank, 2018). At the same time, costs for launching an attack are dropping. The ease with which large amounts could be transferred electronically might increase the potential effects of fraud. As in any IT network, system resiliency and security are critical components. Besides cyber-threats, failures could occur regarding system outages, insufficient capacity, data loss and leakage (Mills et al., 2016).

One could argue that DLT is not yet mature, as there are hardly any real implementations of the technology out on the market. Contrary, DLT could also be considered as an incremental update over current IT arrangements. More specifically, infrastructures and frameworks enabling high levels of resilience do not change to that respect, but the underlying concepts of trust and reaching consensus do. Several industry experts state that a major benefit of DLT is the sharing of data across key entities, which results in greater market transparency and more effective risk management across systems (CPMI, 2017). Nonetheless, development of the proposed platform concentrates operational risk in a new infrastructure, hence bearing greater risk. One could however argue that current RTGS systems are more vulnerable to single points of failure due to their centralised nature. If a single node in a multiple-node consensus mechanism is brought offline, the system continues to function (OMFIF & IBM Blockchain, 2018). Additional research should point out whether DLT is sufficiently robust to guarantee reliability, scalability, throughput, confidentiality and resilience of payment systems.

All in all, we expect the benefits and drawbacks of the new system to balance out, hence keeping operational risk at the same level. An increase is mainly caused by interoperability issues regarding the implementation of a new technology and its corresponding changes to legal frameworks. On the other hand, systemic risk could be reduced by mitigating the effects of a single point of failure. The number of reconciliation errors should also decline significantly due to increased transparency, predictability and by sharing the same version of the truth. We refrain from making estimations on the specifics, because of our choice of scope for this research.

3.7 Comparison of Risk Factors

Following the analysis of risk factors in throughout this chapter, we continue by evaluating them comparatively in this section. This assessment is captured by the sub-research question *"How do the individual risk factors compare to each other?"*

Ultimately, risk can be defined as the exposure of an asset to loss, generally due to a change in its value as time progresses. With time no longer being a factor in cross-border interbank payments, most risk vanishes as well. The analysis on financial risks of cross-border interbank transactions in a system with CBDC has marked five risk factors as relevant. First, liquidity risk is expected to decrease, as both cash pools at correspondent banking nostro accounts and separate central bank accounts (e.g. TARGET2, T2S and EBA) can be centralised in one account on the ledger in a new system, which leads to optimisation of LSM. We have quantified liquidity management advantages at a reduction in liquidity requirements of 21%.

Replacing correspondent banking structures by a peer-to-peer network with 24/7 access and instant settlement of payments reduces the time factor in cross-border interbank transactions to near zero. This significantly affects interest rate risk, since banks do no longer miss out on interest garnered by correspondent banks during a transaction's processing period. Foreign exchange rate risk vanishes as well due to a replacement in price volatility between two currencies by an instant current-market rate. As banks will no longer be exposed to the possibility that both intermediaries and counterparties might default on their payment obligations, counterparty credit risk can be disregarded entirely. Additionally, atomic swaps (i.e. cryptographic hash functions stipulated in smart contracts) reduce settlement risk in PvP transactions.

We expect improvements and costs of operational risks to balance out. The expected reduction in error and claims handling should mitigate the effects of increased interoperability issues. Both the new DLT platform and legacy payments infrastructure must interoperate correctly for cross-border interbank funds to be successfully interchanged. Moreover, central banks must harmonise and standardise legislative frameworks to facilitate the legal basis for cross-jurisdictional transactions. Most jurisdictions however have regulatory differences that might need to be resolved at a political level, for instance about whether the proposed CBDC design is legal tender.

However, CBDC reduces a number of operational costs that mitigate this effect. The possibility to monitor transactions results in a reduction of reconciliation errors as well as lower compliance risk and potential fines. Back-office error and claims handling should further mitigate the effects of increased interoperability issues. Additionally, DLT's decentralised and immutable characteristics could help to underpin trust in the financial system and reduce systemic risk by removing single points of failure.

Standardisation and harmonisation of both regulatory and technological differences between jurisdictions is vital for successful CBDC adoption. All stakeholders must proceed cooperatively in experimenting with DLT and piloting potential applications as interoperability remains a major challenge. Moreover, central bankers will need to work on cross-jurisdictional legislative frameworks to iron out regulatory differences and ensure CBDC is legal tender. Nonetheless, commercial banks could significantly diminish their exposure to financial risks in the cross-border interbank payment and settlement landscape. It is crucial for the technology's adoption that stakeholders translate their qualitative research efforts into actual experimentation phases, thus increasing experience on this novel subject.

3.8 Conclusion

Based on our comparison, we conclude that the greatest relative reduction in exposure to risk is owed to FX risk. As we have seen in Section 3.5, daily volatility is 0.6% for a common EUR to USD payment. Yet, we will see in the next chapter that a 100% reduction in FX risk does not generate most cost savings as all risk is hedged through spot contracts. Liquidity risk decreases, but we are not able to quantify the exact reduction due to a lack of transparency embedded in banks' liquidity management. We expect operational risk to be the only increasing factor in terms of exposure to risk, but it is unclear by how much this would be. Overall, we see a major reduction in total exposure of a cross-border interbank payment to financial risk. Our prediction is that operational risk will account for the majority of residual risk in the new situation, whereas liquidity risk justifies only a fraction of total risk. Interest rate, FX and counterparty credit risk will vanish almost completely.

Chapter 4

Implications

In this chapter we address Research Question (iii), which reads:

"What are the effects of introducing CBDC into the settlement process of cross-border interbank transactions?"

Subsequently discussed are potential cost savings for a cross-border interbank transaction and considerations for commercial and central banks.

4.1 Potential Cost Savings

In this section, we discuss the potential cost savings related to the introduction of CBDC into the interbank payment system. The corresponding sub-research question reads as follows: *"What are the potential savings in transaction costs in a system with wholesale CBDC?"*

4.1.1 Transaction Cost Model

In consultancy firm McKinsey's latest report on global payments, Bansal, Bruno, Denecker, Goparaju, and Niederkorn (2018) analyse the cost breakdown of an international payments transaction (cfr. Figure 4.1). We can compare McKinsey's cost breakdown with our cost estimation for individual risk factors (cfr. Chapter 3). Following Section 3.6, the cost factors payment operations, claims and treasury operations, compliance, and network management belong to operational expenses in our opinion. Nostro-vostro liquidity relates to liquidity management and the issue of liquidity trapped in correspondent banking accounts. We have classified the latter as interest rate risk in Section 3.4. FX expenses are the cost of spread for the purchase and sale of a currency pair in the wholesale market at institutional rates. Cost savings related to covering for counterparty credit risk in the current model are not explicitly taken into consideration by McKinsey, because banks usually agree on large long-term contracts with specific counterparties. We add counterparty credit risk costs to the analysis to present our own view on transaction costs.

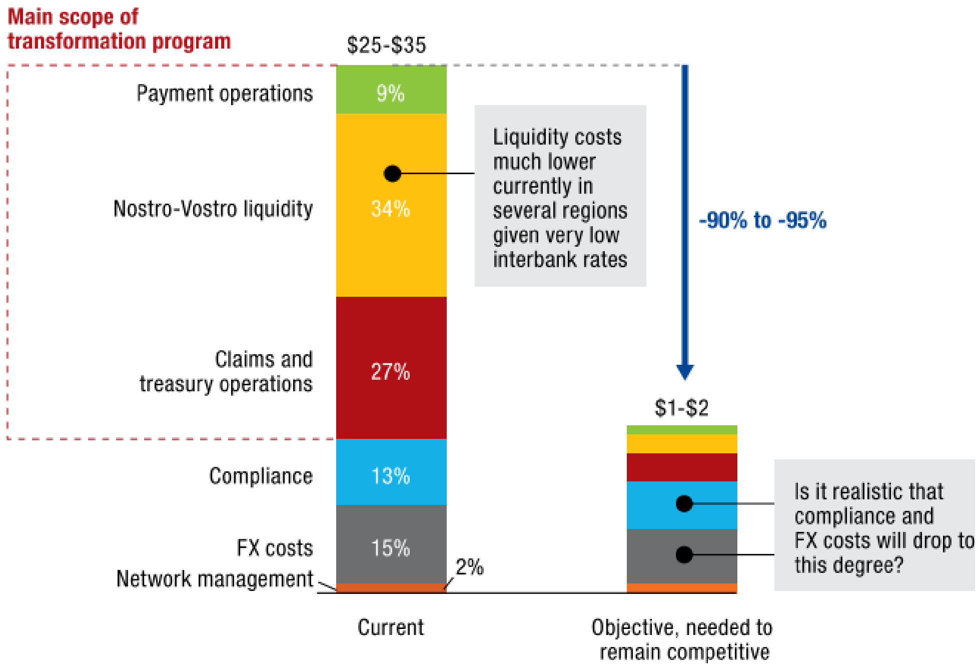


Figure 4.1: *Estimated cost per international payments transaction (Niederkorn et al., 2016).*

We compare the model of Niederkorn et al. (2016) with a cost breakdown on international payments developed by Ripple (2016). Although the cost factors used by Ripple are slightly different, we spot significant similarities between both models. Payment operations in Ripple's model include both payment operations and compliance costs of the McKinsey model. Foreign exchange costs are slightly different but of the same order, i.e. 10% in Ripple's model and 15% in McKinsey's model. Ripple includes costs for currency hedging, which are included in total liquidity costs by McKinsey. Ripple estimates the cost per international payments transaction at 20.9 basis points and McKinsey adopts a cost of 20 basis points in their analysis. Definitions of the relevant cost categories are provided in Table B.3 in Appendix B.

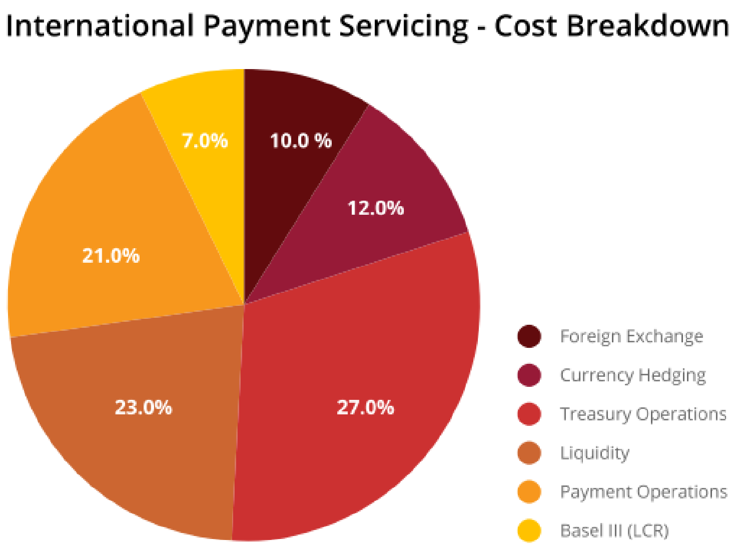


Figure 4.2: *Estimated cost per international payments transaction (Ripple, 2016).*

Whereas McKinsey is a global consultancy firm with a proven track record in payments analyses, Ripple is a private company that has built its own use case. Hence, we adopt the cost category distribution from Niederkorn et al. (2016) due to its reliability. We must however make several assumptions regarding cost factors in order to estimate the potential cost savings for cross-border interbank transactions due to a lack of data.

Bansal et al. (2018) estimate the cost per international payments transactions at $45. Yet, a revenue margin of 0.2% for cross-border business-to-business (B2B) transactions (Bansal et al., 2018) implies a transaction value of only $22.500. We scale transaction costs to €1 million, since we have consistently applied a typical large-value notional. We assume an average settlement period of *T+2*, which follows from prior analysis in Section 3.5. OMFIF and IBM Blockchain (2018) underpin our assumption by stating that a foreign exchange transaction typically takes two days to settle. The results of our view on the cost per cross-border payments transaction can be examined in Table 4.1.

Manual handling will no longer be required to cover up reconciliation errors due to increased transparency both in advance of and during transaction settlement. Establishing a common rulebook, which would be the distributed ledger in the new system, will lead to automated data validation. This should in turn solve the lack of standardisation across banks. Therefore, we expect payment operations costs to fall to zero. Settlement through CBDC will reduce complexity of interbank pricing mechanisms due to a vast reduction in the number of parties involved and increased availability to liquidity. Based on this, we assume costs for claims and treasury operations to drop by approximately 50%. Network management costs disappear due to the almost entire disappearance of correspondent banking relationships. What remains of operational costs besides claims and treasury operations are compliance expenditures. We assume these expenses to remain equal, because banks must still adhere to sound and consistent application of regulatory frameworks. This might seem a significant cost factor, but in particular KYC policies generate tremendous expenditures, for large banks even up to $500 million per year (Callahan, 2018).

Near real-time settlement means less need for hedging FX risk. Although we expect banks to retain FX margins on cross-currency transactions, actual hedging costs for a bank drop to near zero. We split up nostro-vostro liquidity into (i) opportunity costs of trapped liquidity in correspondent banking nostro accounts, (ii) optimisation of netting opportunities in LSMs and (iii) removal of managing correspondent banking accounts. Whereas interest rate risk reduces by a 100%, we have seen in Section 3.2.3 that centralisation of cash pools yields a reduction in liquidity requirements of 21.1%. Although costs related to managing liquidity in correspondent banking nostro accounts will drop close to zero, we were not able to distinct between (ii) and (iii). Hence, the actual cost reduction related to liquidity management is most likely significantly higher than 21.1%.

Table 4.1: *Estimated cost per international payments transaction.*

Cost item	**Risk category**	**Current situation**		**Future situation**		**Difference**	
		Average cost	*Share*	*Average cost*	*Share*	Savings	*Change*
Payment operations	Operational risk	180,00	9%	-	0%	180,00	-100%
Claims and treasury operations	Operational risk	540,00	26%	270,00	27%	270,00	-50%
Compliance	Operational risk	260,00	13%	260,00	26%	-	0%
Network management	Operational risk	40,00	2%	-	0%	40,00	-100%
FX spread	FX risk	300,00	15%	-	0%	300,00	100%
Nostro-Vostro liquidity	Interest rate risk	80,74	4%	-	0%	80,74	-100%
Liquidity management	Liquidity risk	599,26	29%	472,82	47%	126,44	-21%
CDS insurance	Counterparty risk	60,90	3%	-	0%	60,90	-100%
Total costs		***€ 2.060,90***	***100%***	***€ 1.002,82***	***100%***	***€ 1.058,08***	***-51%***
Revenue margin		**0.21%**		**0.10%**			

4.1.2 Estimated Transaction Costs

Table 4.1 displays the estimated cost per international payments transaction. These results are depicted in Figure 4.3 and show the potential savings for a cross-border transaction when settled via CBDC.

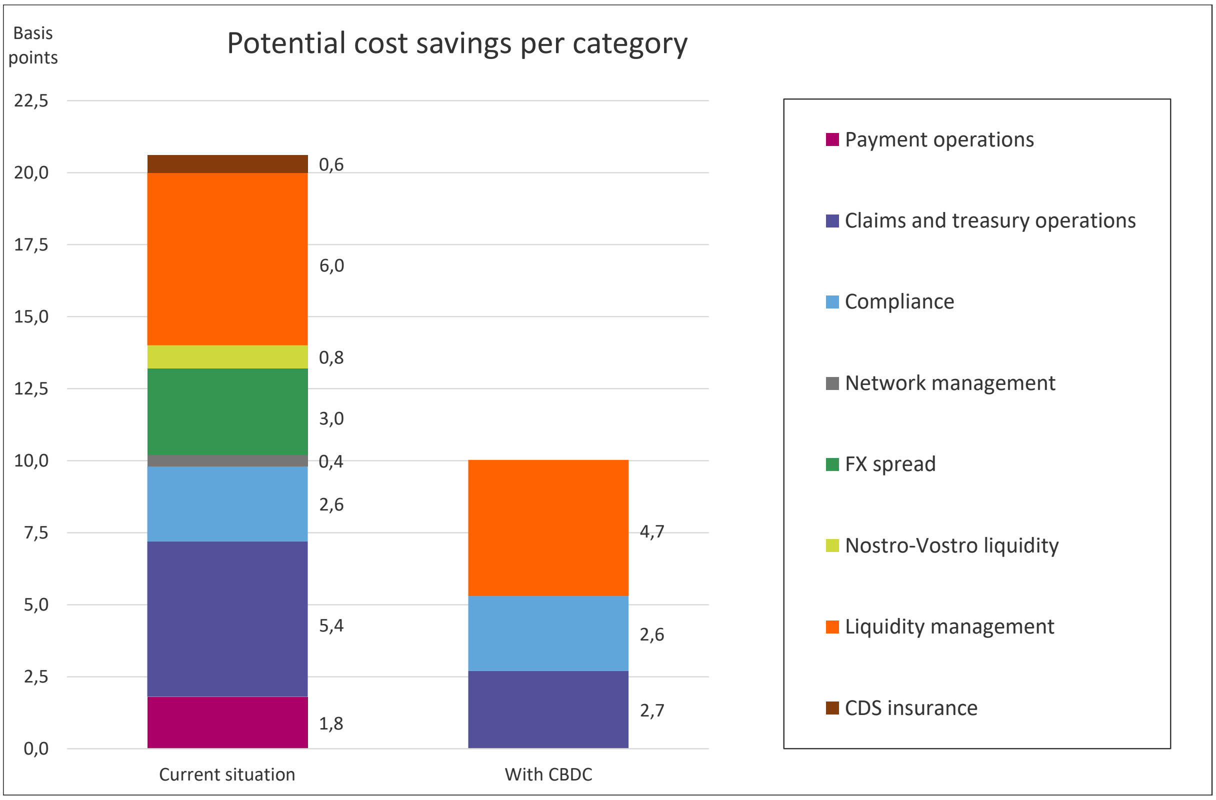


Figure 4.3: *Cost comparison for a cross-border transaction when settled via CBDC.*

Whereas the average €1 million cross-border payment in the current situation incurs a transaction cost of €2,061, we find that a decrease of 51% can be realised with settlement through CBDC, resulting in remaining costs of €1,003 and a corresponding revenue margin of 0.10%. This leaves a potential additional profit margin of 11 basis points per transaction. We take daily TARGET2 volume as a proxy for total potential cost savings. The average daily value transacted in TARGET2 equals €977 million per participant.[19] Large commercial banks easily outsize the average RTGS system participant, but we stick to the average volume in this analysis.

We assume that all transactions in TARGET2 carry the same characteristics as the historical transactions we have looked at in our analysis. Mono-currency payments can already be settled instantly in RTGS systems and do currently not present much of an issue. The proposed platform might not include each currency at first hand as

[19] According to the 2017 annual report of TARGET2 (European Central Bank, 2018), the average daily volume equals 354,274 transactions, shared across a total of 1,757 direct and indirect participants. The average transaction value in 2017 was approximately €4.8 million.

well, although it might be expected that most common currencies will be included in an initial project. We therefore take a reserved fraction of 14% to account for cross-currency payments (European Central Bank, 2018). Hence, we find that a commercial bank could save €0.14 million on a *daily* basis. This is equivalent to annual savings of approximately €37 million.

It is clear the the proposed platform offers substantial benefits money-wise. Cost savings could either be used to offer customers a discount on their transaction fee or increase the profit margin of the bank. Since overall service levels increase due to greater transparency and predictability in both the process and pricing, the latter is more likely. The processing speed of payments receives an incredible boost too, leading to more satisfaction across the entire value chain. One should not forget that the platform needs to be built and maintained by some technology partner or consortium, which would require multi-million funding. Other operational risks, such as cyber security and transition issues must be taken into careful consideration as well. Unfortunately, we are not able to quantify setup costs and estimate an ROI. Nonetheless, we remain confident that the benefits outweigh the drawbacks as all of the current correspondent banking model's disadvantages are solved by our proposed CBDC variant.

4.2 Considerations for Commercial Banks

Throughout this research, we have seen that CBDC introduction gives rise to plentiful benefits to commercial banks. On the other hand, CBDC introduction poses threats to a commercial bank's business as well. This section therefore deals with the following sub-research question: *"What do commercial banks need to consider regarding wholesale CBDC introduction?"*

We have seen that the potential benefit of using CBDC to settle cross-border interbank transactions is significant. However, CBDC issuance is not all sunshine and roses. Its potential opportunities and threats are elaborated on below. Our variant of wholesale CBDC is only available to commercial banks, which can initiate transactions on a customer's behalf. Note that considerations for the customer are taken into account as well, since a decision of a commercial bank theoretically always aligns with the interests of the end-user.

The opportunities of introducing a CBDC into the cross-border payment system to commercial banks are outlined as follows.

- Raising the speed of cross-border interbank transaction settlement should lead to more satisfied clients. Moreover, opportunity costs arise from eliminating the time taken for a transaction. Instead of waiting on funds that are somewhere in the chain at some intermediary, the end-user, i.e. the originating or beneficiary party, could use those funds to gain interest or undertake other profitable activities.

- With a lower entry hurdle to becoming a payments provider due to the shift from a tiered banking system towards a distributed system, competition in the provision of payment services should increase. This should ensure a more accurate reflection of the marginal cost of verification, and hence a decrease in transaction fees (Barrdear & Kumhof, 2016).
- Removal of correspondent banks from the payment process and replacing them by one transparent platform should enhance end-to-end visibility. In turn, this should lead to better service to clients.
- A peer-to-peer direct payment mechanism reduces counterparty credit risk between the originating and beneficiary bank. This is due to atomic settlement of transactions on the platform. As a result, exposure of participants to settlement risk from their counterparty disappears, resulting in freeing up significant amounts of collateral to guard against it. Given the fact that there is a shortage of good collateral in financial markets today, this could have important macroeconomic and financial stability benefits (Barrdear & Kumhof, 2016).
- The release of trapped liquidity from nostro accounts at correspondent banks enables more efficient liquidity management, hence reducing liquidity risk.
- Providing instant and round-the-clock availability to the wholesale cross-border payment system should attract corporate clients. This should strengthen overall service levels, while profit margins increase at the same time.
- Introduction of CBDC could come with first-mover advantages and economies of scale that might lure away clients from competitors. Due to instant and round-the-clock availability to settle cross-border transactions, conducting business with providers of this competitive advantage suddenly becomes particularly attractive. This aspect is an opportunity and a threat at the same time to commercial banks in general. Issuance by central banks, however, would create an even playing field for all participants.

The previous analysis provides a clear overview of the opportunities of CBDC introduction to a commercial bank and its customers. There might, however, also be certain drawbacks of changing the nature of international transaction settlement. These potential threats are listed as follows.

- Cost of ownership and implementation of the platform are most likely higher in comparison to using RTGS systems. The new platform induces substantial integration costs as well as two infrastructures must be kept running side by side during the transition period. Hence, initial expenses will be high and might only be feasible for the largest banks. It is unclear how much the cost of ownership and implementation, as well as the ROI will be.

- Commercial banks currently realise economical benefits from correspondent banking activities. Also, with a payment system that is far more efficient than the current solution it can be expected that transaction costs decrease. Whereas this is beneficial to end-users, commercial banks would witness lower income from correspondent banking services. Moreover, poorer relationships between banks might result in an increase in mutual costs. Increased competition and a reduction of costs is anyway an ongoing trend in existing payment systems, driven by technological and regulatory innovations. In Europe for instance, new directives like PDS2 open up the payments market to new entrants (Fernández de Lis & Gouveia, 2019).

Most considerations apply with added force to a general public CBDC, e.g. larger central bank balance sheets or the possibility of a digital bank run.[20] However, we believe that introducing a wholesale CBDC will yield a positive outcome for commercial banks, as the benefits for clients are significant. Among these benefits are lower transaction costs and improved service. Although increased competition and more transparent settlement will deteriorate payment-related income margins, we expect benefits to outweigh drawbacks.

4.3 Considerations for Central Banks

Similar to the potential benefits and threats to commercial banks, we discuss the impact of CBDC introduction on the role of central banks. This is captured by the sub-research question: *"What do central banks need to consider regarding wholesale CBDC introduction?"*

Opportunities for central banks regarding CBDC introduction are outlined as follows.

- DLT could help to further underpin trust in the monetary system (Stevens, 2017). Compliance with KYC, AML and CFT concerns and requirements should be enhanced by increased transparency and traceability. Moreover, Mills et al. (2016) conclude that "DLT has the potential to provide new ways to transfer and record the ownership of digital assets, immutably and securely store information, provide for identity management, and other evolving operations through peer-to-peer networking, access to a distributed but common ledger among participants, and cryptography".

[20] In times of economic stress, a general public CBDC could function as a safe alternative to bank deposits as funds are backed by the central bank (e.g. CPMI & Markets Committee, 2018; Mersch, 2018). This effect is accentuated in an international environment. Combining this with the real-time and continuous availability characteristics of CBDC could prove to be particularly challenging.

- According to CPMI (2017), introducing a wholesale CBDC with comparable characteristics of traditional central bank reserves into interbank payment systems could potentially improve risk management in transaction settlement. We have shown that our wholesale CBDC variant would improve liquidity, counterparty credit, interest rate, FX and a number of specific operational risks.
- Other forms of CBDC could offer central banks an expansion to their role by widening electronic access to their balance sheets, i.e. beyond commercial banks (Stevens, 2017; Broadbent, 2016). This can also be regarded as negative.
- CBDC could substitute liquidity-absorbing instruments (e.g. reverse repo facilities, time deposits and central bank bills) to provide intraday liquidity to non-bank money market participants. CBDC has an advantage over these short-term money market instruments with regards to liquidity and creditworthiness (CPMI & Markets Committee, 2018).
- Implementing significant changes to current legacy infrastructure could lead to improved payment systems in terms of flexibility, scalability and resilience. Due to the centralisation in tiered payment systems, distributed payment systems are more robust to operational risk by design, as any one transaction verifier may confirm the validity of any transaction (Barrdear & Kumhof, 2016). This would be an advantage over current settlement systems that are prone to a single point of failure due to their centralised nature. Moreover, CBDC could function as an alternative to current payment systems, hence facilitating greater diversification in international payment processes and monetary systems (World Economic Forum, 2019).
- CBDC could enrich the central bank's monetary policy toolkit by tweaking interest rates. According to CPMI and Markets Committee (2018), the zero lower bound[21] on interest rates could be alleviated by CBDC issuance. Negative rates on central bank liabilities could provide the monetary stimulus required in times of financial distress. Another option for central banks could be allowing for dynamic policy rates to steer overnight CBDC demand.
- One of the key features of DLT is that the entire history of a transaction can be made transparent and traceable for regulators. This characteristic would present policymakers with vastly more data to observe the effects of policy changes or economic shocks to macroeconomics stability (Barrdear & Kumhof, 2016).

We note that the opportunities for central banks relate to different topics. The same is true for the potential drawbacks. We describe these threats in a similar manner below.

- Implementation of DLT key features must be weighted against potential disad-

[21] The zero lower bound is a macroeconomic problem that occurs when the short-term nominal interest rate approaches zero. This results in a liquidity trap and limits the central bank's capacity to stimulate economic growth. The zero nominal interest rate acts as an interest rate floor.

vantages, since participating financial institutions do not want their confidential payment data compromised. On the other hand, central banks should be able to examine each payment. Hence, design implementations regarding transparency and traceability must be considered very carefully.
- Word of a central bank issuing a digital currency might give rise to public discussions about financial institutions' operations. To mitigate the potential reputational risk, participants should clearly communicate the advantages of the new technology and similarities to current payment systems, hence refraining from participating in the cryptocurrency sphere.
- Commercial banks could store all their liquidity in the ledger's wallet overnight to facilitate payments outside regular RTGS operating hours. Careful design choices (e.g. enforcing per-user quantity limits or caps) should prevent such balance sheet distortions (Barrdear & Kumhof, 2016).
- Legal risks are expected to increase due to the added complexity related to agreeing on a cross-jurisdictional governance framework - and perhaps even an independent governance authority - between participating central banks.
- Broadening access to commercial banks originally operating in other jurisdictions could lead to an increase in responsibilities of central banks. Complexities might arise with regards to compliance and regulatory risks, since they would have to conduct KYC on new participants. This effect would be magnified when access is expanded to corporate customers.
- A consequence of lower margins from correspondent banking services-related income streams could result in commercial banks trying to offset lost revenues by engaging in riskier forms of lending to restore profitability. This could create financial stability risks (CPMI & Markets Committee, 2018).
- Introduction in a sudden and unexpected manner could lead to large capital movements from countries not participating to jurisdictions that do. Disturbances on the global liquidity market could easily occur.

In comparison to the considerations for commercial banks, central banks face more challenges. They would have to deal with the increased operational risks and ensure the smooth functioning of a cross-jurisdictional governance framework. Careful design choices must be made to rule out or at least mitigate potential adverse effects. Besides, participating entities must agree on the role and legal liability of each stakeholder. For instance, central banks could assign a third party to develop, integrate and operate the new platform, and install an independent governance authority to lay off parts of the workload and corresponding responsibilities.

4.4 Conclusion

A commercial bank could save €37 million annually on transaction costs for cross-border interbank payments. The potential cost savings are based on two models and include our calculations and assumptions made in Chapter 3. We conclude that the potential benefits are significant and provide a solid business case for setting up a new platform to settle cross-border transaction with CBDC.

Cost of ownership and implementation of the proposed platform will however pose a significant cost burden. Hence, stakeholders should very carefully consider who will be granted access, and who issues the CBDC and operates the platform. First, we recommend restricting access to financial institutions that currently already have access to the central bank balance sheet via RTGS systems in order to limit expansion of the role of central banks. These drawbacks are intensified in a hybrid or general public variant, since these models require central banks to screen a multitude of customers and drain commercial banking business.

Our second recommendation relates to issuance of CBDC and operation of the new platform. We consider implementation more feasible if a partnership of commercial banks takes up the challenges and costs relating to integration, governance and legislation instead of central banks having to fund a multi-million project. Most challenges affect central banks so relieving them of costs and uncertainties will increase their willingness to cooperate.

Chapter 5

Conclusions

In this chapter, we conclude our findings, discuss potential limitations of our work, state our recommendations with regards to CBDC implementation in the cross-border interbank payment system and lastly, suggest venues for future research.

5.1 Conclusions

The concept of CBDC is on the rise within the financial industry and has especially gained interest among central bankers over the last few years. Whereas most research is directed at a general public variant that would be available to the entire economy, we focus on a specific use case on the wholesale domain. This combined with a lack of insight into financial risks led to the following research question:

"What is the financial impact of the introduction of Central Bank Digital Currencies on a commercial bank's cross-border interbank transactions?"

Issues identified in the current cross-border payment and settlement space have become a major burden for commercial banks with respect to granting high customer satisfaction levels in this fast-paced society. Cross-border transactions are lacking behind their domestic equivalents and continue to be dependent on the correspondent banking model. Banks are forced to consult their network of intermediaries to facilitate a cross-border transaction due to a lack of standardisation across jurisdictions regarding operating hours, data standards and regulatory requirements. As a result, end-users experience significant delays in payments processing, potentially leading up to waiting times of multiple days or even a week. Upon initiation, the certainty of outcome and transaction costs are unknown, whereas a payment's status during the process is not visible. In the meantime, exposure to financial risks increases, resulting in greater uncertainty and an inevitably larger cost burden. Each correspondent bank is entitled to additional fees, which further increases transaction costs. These issues have progressed over decades due to the existence of technical barriers in legacy payments infrastructure, which restrict possibilities to innovate.

Settlement via CBDC could potentially solve these issues by providing near real-time settlement of transactions on a peer-to-peer basis with round-the-clock availability. This would significantly reduce a substantial portion of financial risks. Our variant of CBDC does not introduce new risks to the financial system's stability or impose additional issues for monetary policy. Whereas access to central bank balance sheets is currently limited to RTGS systems' operating hours, CBDC would extend availability to 24/7 access, but remains restricted to commercial banks only. Our analysis of the relevant financial risks shows that interest rate, foreign exchange rate and counterparty credit risk approximate zero due to near real-time settlement. The exchange rate between two currencies is far more likely to fluctuate within a time window of three days than in a matter of seconds. Accumulated interest can be used for other practices. Exposure to settlement risk is solved due to atomic settlement in a PvP transaction.

Based on our calculations, a smaller but substantial reduction is achieved for liquidity risk. The release of so-called 'trapped' liquidity at correspondent banking nostro accounts will centralise cash pools and thus stimulate liquidity management optimisation. This effect is magnified by an increased reach to potential counterparties. Funding a CBDC account on the ledger will either be possible from existing central bank RTGS accounts, incoming transfers or collateral agreements. We have quantified a liquidity risk reduction of 21% due to optimisation of liquidity management through cash pool centralisation.

Contrary to a reduction in financial risks, operational risk does not. The transition from legacy payments infrastructure to a new IT framework will pose a challenge to all stakeholders. The fact that DLT is a rather novel technology that has not yet seen mass adoption further complicates platform interoperability issues. We expect a significant rise in legal risks due to regulatory differences between jurisdictions. Harmonising legislative frameworks, determining liabilities and ensuring that CBDC is legal tender must be considered extensively. Therefore, central banks should cooperate on interoperability challenges between participating jurisdictions, both from a regulatory and technological perspective, and make this central to their research activities. The effects of increased interoperability issues could, however, be mitigated by the nature of distributed ledger technology. Its decentralised and immutable characteristics could help to underpin trust in the financial system, reduce systemic risk by removing single points of failure and increase transparency and predictability.

In terms of transaction costs, settling a cross-currency payment through CBDC instead of legacy payments infrastructure yields a reduction of 51%. Lost interest due to trapped liquidity in correspondent banking nostro accounts will no longer induce costs, thus lowering the opportunity cost of lost interest. Liquidity costs reduce due to centralising nostro balances into one cash pool, which stimulates liquidity optimisation. Insuring transactions against counterparty credit risk through purchasing CDS contracts will conserve expenses as well. Almost half (46%) of the total cost reduction is related to cutting operational costs. These are typically fixed and additional expenses can easily be passed on to clients on account of contractually determined insurances. Increasing Straight-Through Processing (STP) rates will relieve manual back-office handling costs to resolve errors in the payment process. Additionally, removing intermediaries from the payment chain should eliminate expenses for managing these networks as well as the need for reconciliation and investigation inquiries.

Settlement of cross-border payments via CBDC could save a commercial bank €37 million on an annual basis. Potential benefits to the financial industry are therefore far up in the billions. We expect setup and transition costs to be significant, so it is vital that a multitude of banks join the CBDC initiative in order to mitigate operational risks. We believe that a CBDC designed exclusively for financial institutions by a partnership of commercial banks has the highest chance of success. The role of central banks in our monetary system would not change in this setup and operational risks are passed onto the commercial sector. Potential advantages increase significantly when more types of transactions (e.g. DvP) can be settled on a distributed ledger platform.

Although CBDC will involve overcoming numerous legislative, technological and even political challenges, we believe that its introduction could dramatically innovate the cross-border interbank payments landscape. As speed, transparency and overall ease of payment processes increase significantly, we expect participating banks to achieve large competitive advantages. CBDC, with DLT as its underlying technology, offers the potential to catch up to domestic payment systems without having to overhaul legacy payment infrastructure completely. All in all, we believe that the cross-border interbank transaction landscape is set for a prosperous future with CBDC.

5.2 Discussion

The sum of annual cost savings owed to each risk factor is based on pseudo-data, i.e. generated data based on both quantified and assumed risk factor effects. We generated one payment of €1 million for each historical business day to find potential historical savings and related that to the potential cost reduction in a new situation with CBDC. We have applied a random generator to determine a transaction's characteristics for each business day. Nevertheless, we believe our conclusions are representative as we have used actual historical data.

Data used for the quantification of relevant financial risks was validated by experts to underpin our findings. Data for liquidity risk was lacking however, so the conclusions on this particular risk factor are less accurate. Subsequently, each risk factor's respective costs were computed. We have calculated that operational expenses will have the greatest impact on total transaction costs. However, compared to the other risk factors, fewest data was available to underpin these findings. An additional assumption was made regarding average processing times of transaction variants. In particular mono-currency payments are already close to instant, depending on the settlement system used. Thus, the effects of introducing CBDC for mono-currency payments are limited, especially in well-developed and regulated infrastructures such as the Eurosystem.

We have applied a fixed notional for all transactions. Although this would realistically not be the case, our goal was to give an indication of the effects of CBDC introduction into the cross-border interbank settlement system. According to the European Central Bank (2018), the average TARGET2 payment value in 2017 was €4.8 million. Moreover, the share of traffic related to cross-border interbank payments was 28%, whereas volume only accounted for 14%. Hence, the actual value of an average cross-border interbank payment might be a factor 9.6 higher. Additionally, a payment's size might have consequences for the transaction fee applied. For instance, discounts might be applied to larger transactions due to economies of scale, while simultaneously their burden on liquidity reserves weighs more heavily.

Another point of discussion is whether DLT is the appropriate technological framework to underpin CBDC. We have assumed it is in our study due to its potential to solve the issues of current cross-border interbank payments. However, Danezis and Meiklejohn (2016) discuss that other technologies might serve the same purpose comparably. Mersch (2018) argues that genuine progress is made with conventional technology, e.g. by TIPS in Europe. A recent transformation to SWIFT gpi should already improve speed, transparency and ease in cross-border payments significantly (SWIFT, 2019).

The main problem, however, lies in the fact that these payment mechanisms are designated for local markets. Contrary, cross-border interbank transaction systems experience serious delays, so advantages of CBDC settlement can primarily be achieved in the international landscape. Moreover, Niederkorn et al. (2015) note that not adapting to novel technologies might turn out to be even costlier due to increased competition by new players, e.g. non-banks.

We show that settlement in the new situation incurs significantly lower transaction fees. In comparison to the current situation, commercial banks could offer their clients comparable prices, while concurrently delivering better service levels. Another option would be to lower transaction costs and maintaining current profit margins. We leave the decision on this trade-off up to the considerations of commercial banks affected. However, our variant of wholesale CBDC would simply be designed as a digital reserve. As a result, out model would have limited repercussions on policy-making by regulators. As most debate in research papers on CBDC is focused on macroeconomic effects on financial markets, we find that most considerations of central bankers have become obsolete in our situation.

5.3 Future Work

Future work is split into two types of recommendations. First, we provide recommendations for the financial industry with respect to CBDC implementation. Second, we suggest venues for further research.

5.3.1 Recommendations

The approach used in this research was to compute the effects of relevant risk factors for a generalised historical transaction of €1 million per day. We strongly recommend commercial banks to apply our methods to their extensive historical databases to link the actual transaction history for different payment types or asset classes to potential risk reduction and in the end cost savings. Cost savings are significant and could lead to substantial competitive advantages based on our calculations. Although banks might choose to leverage these opportunities by lowering transaction fees, we recommend vigilance in the pricing process, since a new platform might incur high costs in case setbacks are encountered.

Although disagreement on the preferred design of a wholesale variant still presents a challenge, most debate is centered around general public CBDCs. Introducing a digital currency that is widely available to retailers and households would induce far more significant implications to financial systems than one that would only affect banks (and corporates in a hybrid variant). While the majority of research papers and public discussions is focused on the general public debate, we strongly recommend gaining experience with a wholesale model first before looking into society-wide applications. In order to facilitate the first step to cross-border interbank settlement on a DLT platform, we stress our recommendation that central banks must agree on cross-jurisdictional governance frameworks to harmonise reciprocal standards. Authorities should also lay the groundwork for legislative changes to recognise CBDC as legal tender for interbank payments and settlements.

The setup and integration of a new technology incurs substantial expenses. We recommend financial institutions to make collaborative efforts into realising the potential of CBDC settlement, since central banks have generally been renowned as conservative institutions. Moreover, we believe that financial institutions should collectively bare initial costs and persuade central bankers to provide the underlying cross-jurisdictional frameworks that pave the road for innovation in the cross-border transaction landscape.

Much is yet unclear about the right fit of technology to each use case. It will take time to answer these questions. In the shorter term, industry and policy-makers should collaborate on private sector innovation to address the main challenges of cross-border interbank payments identified in this report, because revolutionising their corresponding settlement systems will most likely require patience.

5.3.2 Further Research

We have focused on one specific variant of wholesale CBDC. However, if we were to extend our research, one could test additional scenarios. These include for example the effects of increased availability of liquidity and efficiency of LSMs. With data on liquidity management in both RTGS systems and correspondent banking nostro accounts one should be able to determine the benefits of cash pool centralisation. One could include more currency (pairs), variation in processing times and correspondent and counterparty banks as well. Calculating STP rates could give an indication of operational costs related to claims and error handling, since these back-office costs are currently substantial.

Research could also be extended by quantifying the effects of scenarios in which various interest-bearing, availability, accessibility and anonymity characteristics are tested. Technological challenges, such as interoperability, scalability, security and the trade-off between privacy and legislation deserve further exploration, but most attention should be devoted towards experimentation and piloting. More specifically, additional attention should be dedicated at suggesting a target operation model and developing a corresponding large-scale pilot.

Since stakeholders have not even agreed yet on which use case should be explored first, an important area for further research is understanding the potential range of DLT adoption and evaluating its value proposition for ecosystem participants. Much is unclear about the link of DLT to changing the financial market structure as well. Every application requires a specific technology fit which must be investigated thoroughly. Examples of research areas include DvP solutions, feasibility of decentralising LSMs and broader financial market considerations. Other future work contains fine-tuning regulatory diversity between participating jurisdictions, more specifically by central banks and regulators. Eligibility criteria must be devised to ensure adequate coordination of participation requirements.

We adopt the predominant view amongst both central bankers and academics that conducting further research is a necessary precondition for successful adoption. In our opinion, quantitative analysis of financial risks is lacking in particular, which provides an excellent opportunity to investigate this interesting combination.

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Appendix A

Plan of Approach

A.1 Research Strategy

In order to solve our core problem, we must define a clear research strategy. This includes for instance applying adequate project management, acquiring missing knowledge and making balanced choices.

As explained in Section 1.2, our core problem is defined as *"the lack of insight in the effects of introducing wholesale Central Bank Digital Currencies into the monetary system on financial impacts and risks of cross-border interbank transactions."* For us to be able to address this problem, we must obtain knowledge on various aspects. Since CBDC and DLT as its underlying technology are novel concepts, we must first acquire a general understanding. Subsequently, we can extend our knowledge base by conducting a literature study on CBDC and learn about the different variants and industry perspectives.

The concept of CBDC has not yet been implemented in the financial system, which means that we can only speculate about the effects of its introduction. Because quantification on the financial risks of CBDC introduction is lacking at the moment, we must find a way to relate existing risk management frameworks to this topic. It is vital that we consult with the risk management department to ensure we apply the relevant methods correctly to our specific use case.

The success of our research depends partly on knowledge and data obtained from important stakeholders, but also on support from the supervisors that mentor our research. Firstly, we must agree on the direction and scope of, but also limitations to our research with both the relevant project manager and our main research mentor. Potential obstacles regarding data availability are addressed in Section A.2. Secondly, close connections with the risk modelling department are required to tackle the data dependency issue. Lastly, we must keep in mind that the university would like to see a contribution to research, existing literature, and, in the end, society.

A.2 Potential Obstacles

Conducting sound research involves identification of potential obstacles along the road beforehand. A possible threshold that might object the success of completing our research is the lack of available data. Hence, we must maintain close relations to the people that have access to the right data. Due its infancy, there is no operational data of transactions via CBDC settlement available. At the same time, a bank's databases are highly confidential, which further complicates our challenge to obtain interbank transaction data. A potential solution would be to use widely-available market data and/or generate data based on assumptions that are backed by literature and risk management experts.

In order to provide implications of CBDC introduction, we will quantify the financial risks of payments settlement through CBDC for generalised transactions. Although our conclusions will be based on generalised transactions, there still remains a great opportunity for research on this particular topic, as we have explained in Section 1.4. To overcome such obstacles, it is vital to specify the exact purpose and associate with the right people. Commercial banks could use our model with real data input to find the effects of CBDC introduction to their specific business case.

Problems may be encountered regarding confidentiality. On the one hand, we must satisfy the university that emphasises methodology objectivity, a sound contribution to research, and openness from a society point of view. Our employer, on the other hand, values the business side, practical implications, and most of all exclusiveness. It is crucial to be aware of both interests and align these. The final obstacle relates to time. As the research is to be conducted within six months, it is vital to be aware of the planning constantly. Therefore, a detailed planning is included in Section A.4.

A.3 Ethical Code of Conduct

As of October 1st, 2016, the University of Twente requires a mandatory ethical assessment of research with human subjects. This includes not only standard interviews and surveys, but also observations and experiments, e.g. living labs, social media, and laboratory experiments. Interventions in human behaviour and/or physiological functioning are subject to an ethical assessment as well.

Since our research is based on data and literature and excludes research with human beings, an assessment procedure is superfluous. We will not include any personal opinions in our thesis, nor will we conduct interviews. Any conclusion made in this study merely reflects the assessment of the author on either literature or data analysis.

A.4 Project Schedule

Developing a sound planning in advance will enhance the research structure and prevent for loosing track of time. The planning is depicted in Table A.1 and serves as a reminder on how much time to devote on each subject. It should not be regarded as decisive rules that might restrict potentially important topics.

A.5 Personal Learning Objectives

Personal learning objectives on which I want to improve during the duration of the thesis are listed below, including a short motivation for each objective.

- *Aligning interests*: Since I will be dealing with different stakeholders that might have opposing interests, or at least contrasting perspectives, I need to make sure I have everyone aligned on my goals. Hence I must keep my stakeholders motivated to contribute to my research.
- *Affiliation*: Courses taught in class may not always reflect their real-life application and might thus result in wrong expectations. Therefore, I would like to use this opportunity to compare the theory and knowledge I have gained at university with the practical implications to discover to what extent my study interests match my real-life interest.
- *Career perspective*: Writing a thesis full time for half a year at a company provides an excellent opportunity to get a grasp on what 'working life' is like. Hence I would like to get a clear view on my preferences with regards to the type of company, department, activities, and responsibilities.

The personal leaning objectives above will be evaluated at the end to increase my personal awareness and hopefully steepen my learning curve.

A.6 Reflection

Looking back at my graduation period, I can say that I did not encounter major issues. Guidance was excellent, both from a methodological and content-wise perspective. I managed to stick to my planning and enjoyed freedom in directing my own course. Although retrieving data was a challenge, I managed to find workarounds. Finding the right people for specific questions was hard as well. People tend to direct me to colleagues whom they taught could answer my questions, which was often not the case. Regarding personal learning objectives, I think I have improved on all goals and will continue to address them in the future.

Table A.1: Project schedule proposal.

Month	December				January					February				March				April				May				
Week number	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Meeting int. supervisor			x			x			x				x				x					x				
Meeting ext. supervisor	x	x	x		x	x		x		x		x		x				x		x		x		x		x
Gathering information	x	x	x		x	x	x	x	x	x																
Literature study								x	x	x																
Gathering data								x	x	x		x	x													
Building model												x	x	x	x		x	x	x	x	x					
Processing results																				x	x	x	x	x		
Write project proposal	x	x	x		x	x	x																			
Writing report								x	x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x
Holidays				x							x					x										

Appendix B

Definitions

Table B.1: *Definitions of different bank types.*

Type of bank	Definition
Commercial bank	An institution that provides services such as accepting deposits, providing business loans and offering basic investment products. The main function of a commercial bank is to accept deposit from the public for the purpose of lending money to the borrowers.
Central bank	A monopolised and often nationalised institution given privileged control over the production and distribution of money and credit. In modern economies, the central bank is usually responsible for the formulation of monetary policy and the regulation of member banks. It is also referred to as the bankers bank and governments bank.
Beneficiary bank	The bank identified in a payment order in which an account for the beneficiary, i.e. the receiving end, is to be credited pursuant to the order or which otherwise is to make payment to the beneficiary if the order does not provide for payment to an account.
Intermediary / Correspondent bank	A third-party bank used by the beneficiary bank to facilitate international transfer and settlement of funds. Since banks do not necessarily have direct relationships with one another, they use intermediary banks as a means to find relationships, acting as brokers for transactions.

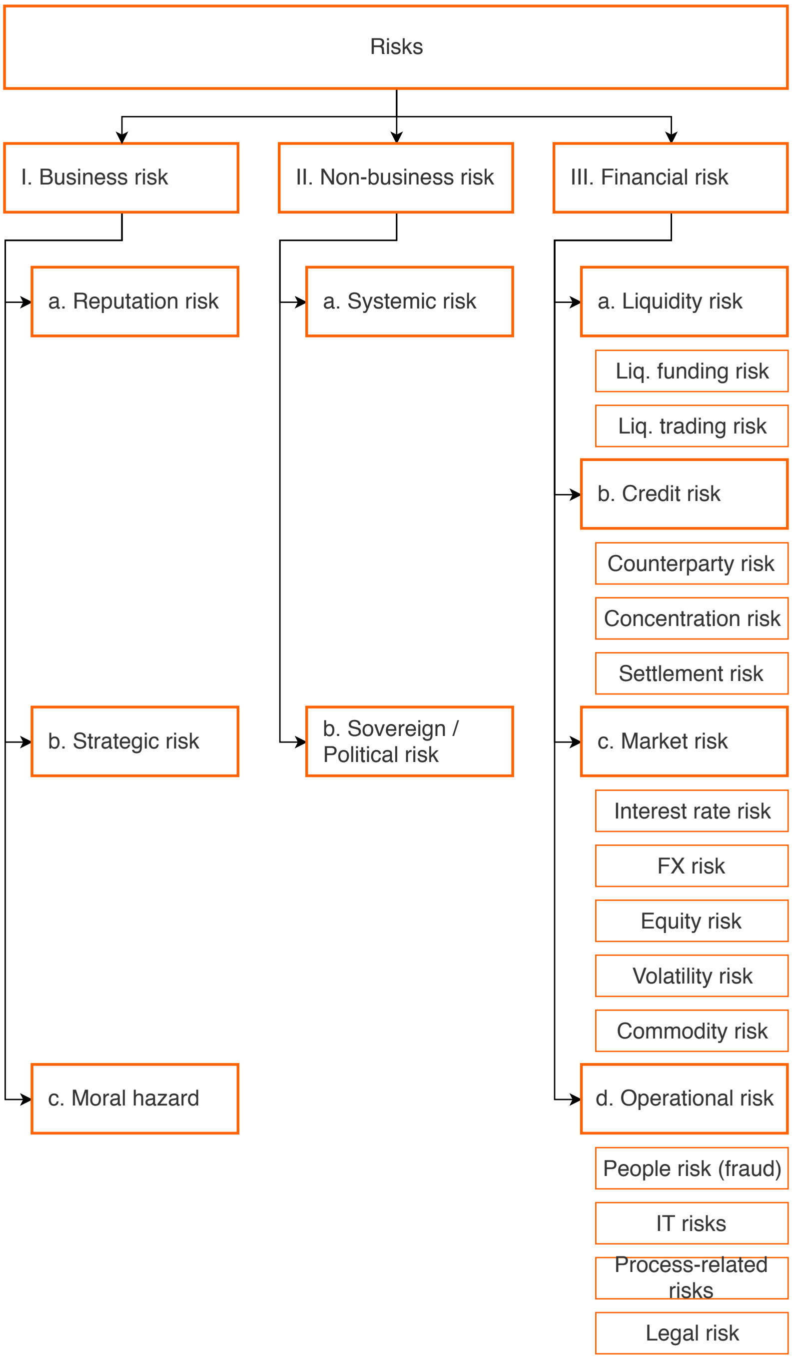


Figure B.1: *Graphical display of the (financial) risks classification.*

Table B.2: *Standard & Poor's credit rating definition scale (Standard & Poor's Global Ratings, 2018).*

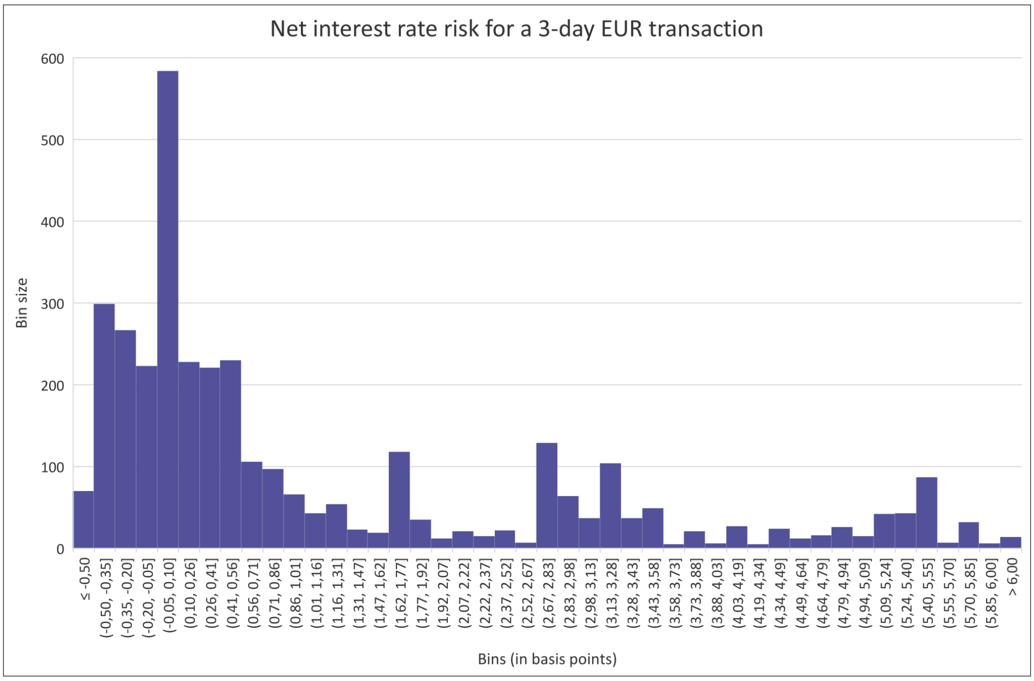
Credit rating	Grade	Definition
AAA	Investment	An obligation rated 'AAA' has the highest rating assigned by S&P. The obligor's capacity to meet its financial commitments on the obligation is extremely strong.
AA	Investment	An obligation rated 'AA' differs from the highest-rated obligations only to a small degree. The obligor's capacity to meet its financial commitments on the obligation is very strong.
A	Investment	An obligation rated 'A' is somewhat more susceptible to the adverse effects of changes in circumstances and economic conditions than obligations in higher-rated categories. However, the obligor's capacity to meet its financial commitments on the obligation is still strong.
BBB	Investment	An obligation rated 'BBB' exhibits adequate protection parameters. However, adverse economic conditions or changing circumstances are more likely to weaken the obligor's capacity to meet its financial commitments on the obligation.
BB	Speculative	An obligation rated 'BB' is less vulnerable to nonpayment than other speculative issues. However, it faces major ongoing uncertainties or exposure to adverse business, financial, or economic conditions that could lead to the obligor's inadequate capacity to meet its financial commitments on the obligation.
B	Speculative	An obligation rated 'B' is more vulnerable to nonpayment than obligations rated 'BB', but the obligor currently has the capacity to meet its financial commitments on the obligation. Adverse business, financial, or economic conditions will likely impair the obligor's capacity or willingness to meet its financial commitments on the obligation.
CCC	Speculative	An obligation rated 'CCC' is currently vulnerable to nonpayment and is dependent upon favorable business, financial, and economic conditions for the obligor to meet its financial commitments on the obligation. In the event of adverse business, financial, or economic conditions, the obligor is not likely to have the capacity to meet its financial commitments on the obligation.
CC	Speculative	An obligation rated 'CC' is currently highly vulnerable to nonpayment. The 'CC' rating is used when a default has not yet occurred but S&P expects default to be a virtual certainty, regardless of the anticipated time to default.
C	Speculative	An obligation rated 'C' is currently highly vulnerable to nonpayment, and the obligation is expected to have lower relative seniority or lower ultimate recovery compared with obligations that are rated higher.
D	Speculative	An obligation rated 'D' is in default or in breach of an imputed promise. For non-hybrid capital instruments, the 'D' rating category is used when payments on an obligation are not made on the date due. The 'D' rating also will be used upon the filing of a bankruptcy petition or the taking of similar action and where default on an obligation is a virtual certainty, for example due to automatic stay provisions. A rating on an obligation is lowered to 'D' if it is subject to a distressed exchange offer.

Table B.3: *Cost category definitions.*

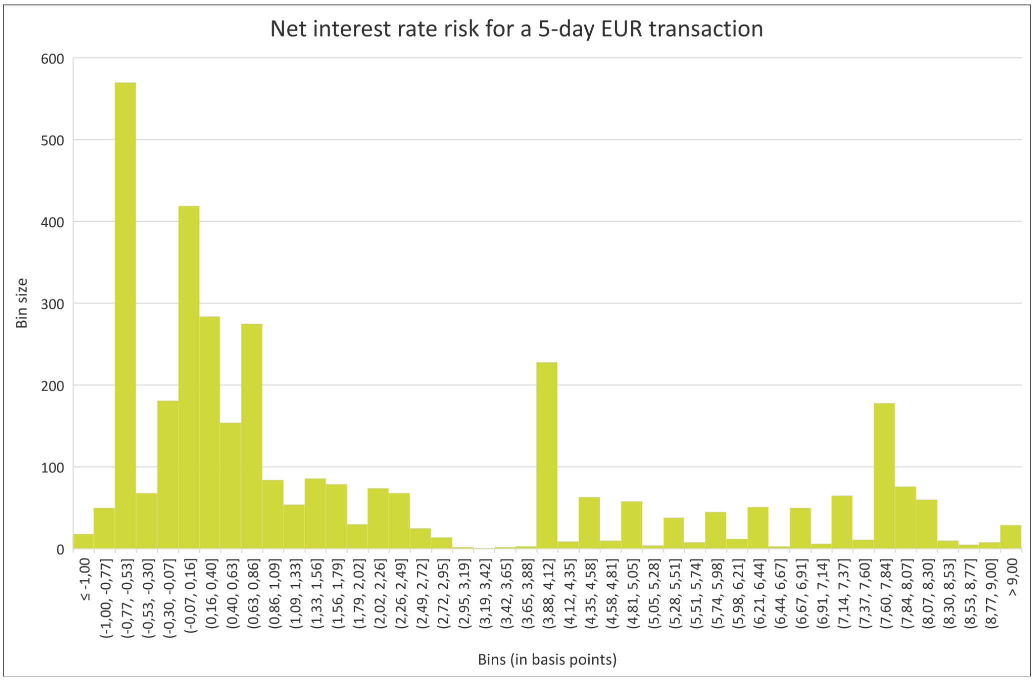
Category	Ripple		McKinsey		Definition
Payment operations	21%	4.4 bp	9%	1.8 bp	The manual intervention cost of exceptions and error handling requiring headcount and the cost of using local rails.
Claims and treasury operations	27%	5.6 bp	27%	5.4 bp	The cost of manual invoicing, claims-handling and dispute management due to complex interbank pricing rules.
Compliance	nA	nA	13%	2.6 bp	The cost of ensuring sound application of laws, regulations and rules.
Network management	nA	nA	2%	0.4 bp	The cost of negotiating and maintaining the multitudes of bilateral agreements and large numbers of correspondent banking relationships.
Nostro-Vostro liquidity	23%	4.8 bp	34%	6.8 bp	The opportunity cost of trapped liquidity in correspondent banking nostro accounts.
FX costs	10%	2.1 bp	15%	3.0 bp	The cost of spread for the purchase and sale of a currency pair in the wholesale market at institutional rates.
Basel III (LCR)	7%	1.5 bp	nA	nA	The opportunity cost to the sending institution of holding lower-yielding, high-quality liquid assets (as designated by pending Basel III regulations) against credit exposure during the in-flight period.
Currency hedging	12%	2.5 bp	nA	nA	The cost of hedging a basket of currencies held in nostro accounts globally.

Appendix C

Figures

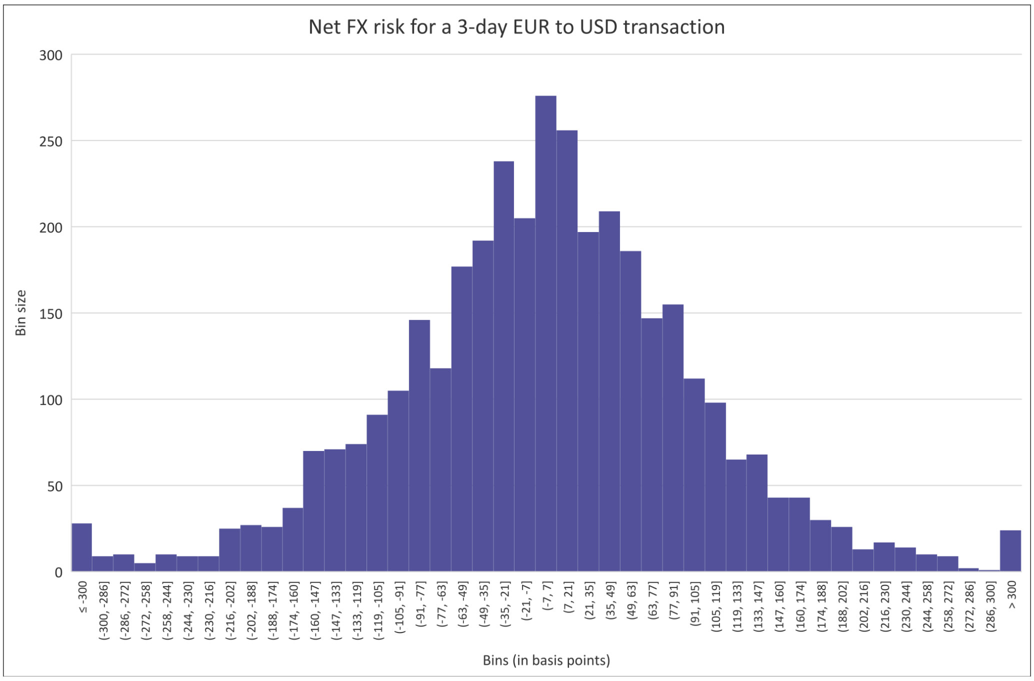


(a) 3-day EUR transaction.

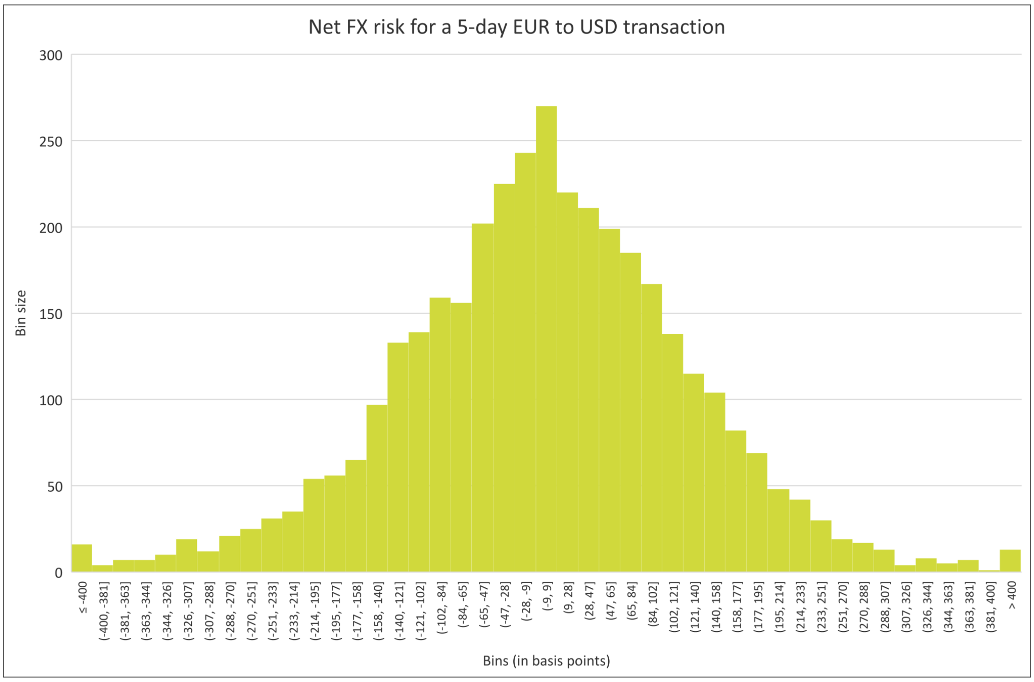


(b) 5-day EUR transaction.

Figure C.1: *Net interest rate risk distribution.*

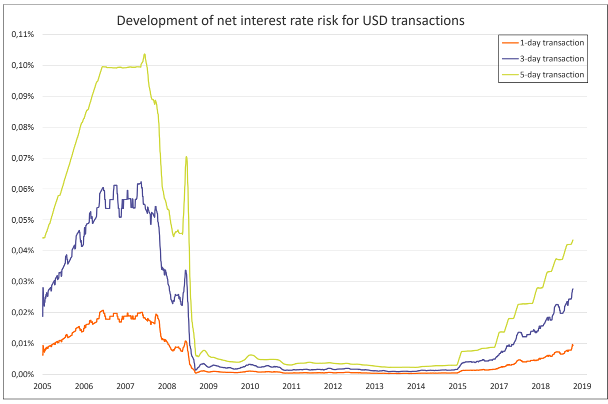


(a) 3-day EUR to USD transaction.

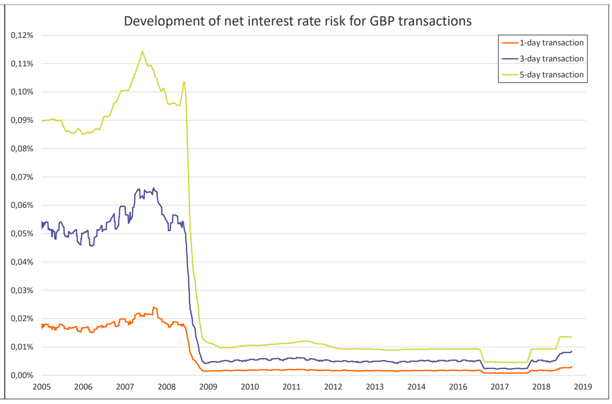


(b) 5-day EUR to USD transaction.

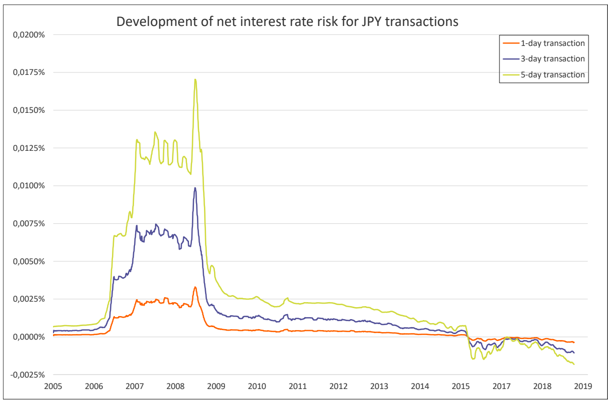
Figure C.2: *Net FX risk distribution.*



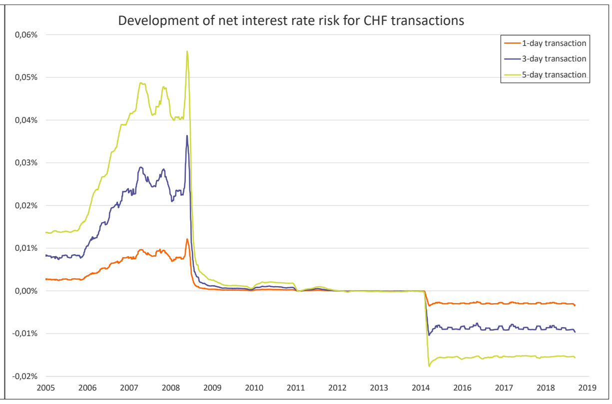
(a) USD transactions.



(b) GBP transactions.

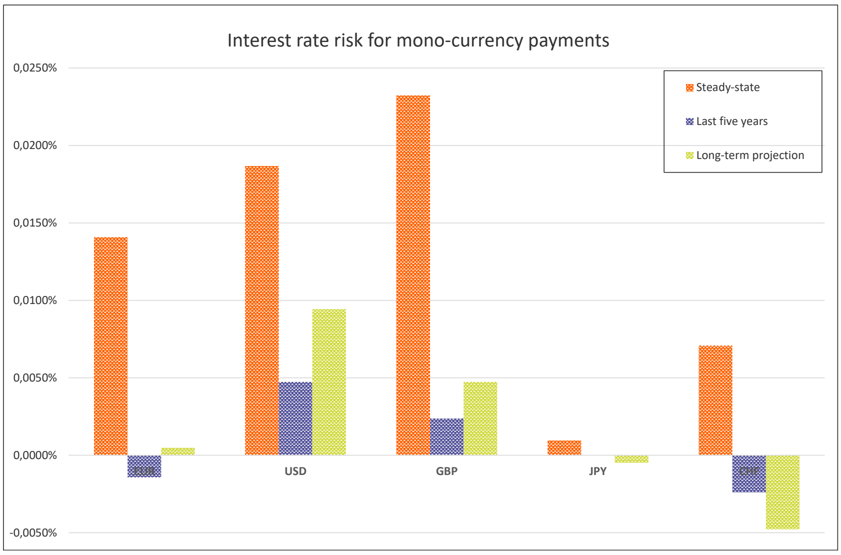


(c) JPY transactions.

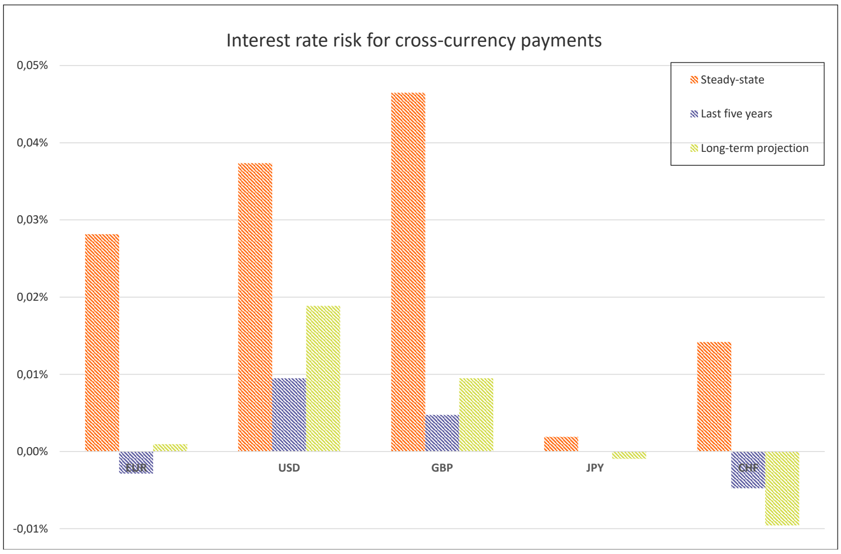


(d) CHF transactions.

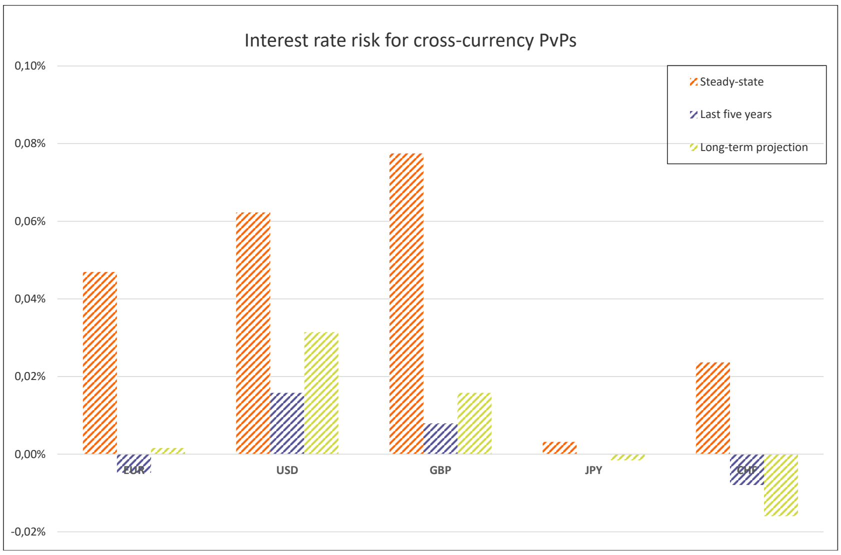
Figure C.3: *Historical development of average net interest rate risk.*



(a) Mono-currency payments.



(b) Cross-currency payments.



(c) Cross-currency PvPs.

Figure C.4: *Interest rate risk of trapped liquidity for € 1 million transactions for individual payment types.*

Appendix D

Data Preparation

Import data

```
In [1]: import pandas as pd
        import glob
        print("modules are loaded")
```

```
modules are loaded
```

Read filenames

```
In [2]: csv_path =
        "C:\Data\CDS\www.gmdb.intranet\data\markit\composites\cds\generic\*.csv"
        gz_path =
        "C:\Data\CDS\www.gmdb.intranet\data\markit\composites\cds\generic\*.gz"

        csv_files = glob.glob(csv_path)
        gz_files = glob.glob(gz_path)

        files = csv_files + gz_files

        print('csv_files found: ' + str(len(csv_files)))
        print('gz_files found: ' + str(len(gz_files)))

        print("files found: " + str(len(files)))
```

```
csv_files found: 878
gz_files found: 2338
files found: 3216
```

Iterate over all files to read into one dataframe

```
In [3]: df = None
        relevant_companies = ["Citigroup Inc", "Bk of America Corp",
        "SMBC Consumer Fin CoLtd", "MUFG Bk Ltd", "Credit Suisse Gp AG", "UBS AG",
        "Barclays Bk plc", "HSBC Bk plc"]
```

```
relevant_tiers = ["SNRFOR"]
relevant_currencies = ["EUR"]
relevant_docclause = ["MM", "MM14", "CR", "CR14", "MR", "MR14", "XR", "XR14"]
relevant_cols = ["Date", "ShortName", "Tier", "Ccy", "DocClause", "Spread1y",
'Recovery', 'Rating1y']
i = 0
check_len = 0
print("Started reading")
for file in files:

    temp_df = pd.read_csv(file, sep = ',', skiprows = 2)
    temp_df = temp_df[temp_df['ShortName'].isin(relevant_companies)]
    temp_df = temp_df[temp_df['Tier'].isin(relevant_tiers)]
    temp_df = temp_df[temp_df['Ccy'].isin(relevant_currencies)]
    temp_df = temp_df[temp_df['DocClause'].isin(relevant_docclause)]
    temp_df = temp_df[relevant_cols]

    if df is None:
        df = temp_df
    else:
        df = pd.concat([df, temp_df], axis = 0)

    check_len = check_len + len(temp_df)
    i += 1

    if i % 200 == 0:
        print("\t Added " + str(i) + "nr of files")
        print("\t Current len df = " + str(len(df)))
        print("-------------------------------------")

df.to_csv("all_files_raw.csv", index = False, sep = ";")
```

```
Started reading
         Added 200nr of files
         Current len df = 3600
-------------------------------------
         Added 400nr of files
         Current len df = 7712
-------------------------------------
         Added 600nr of files
         Current len df = 12112
-------------------------------------
         Added 800nr of files
         Current len df = 16961
-------------------------------------
         Added 1000nr of files
         Current len df = 21215
-------------------------------------
```

```
         Added 1200nr of files
         Current len df = 24963
-------------------------------------
         Added 1400nr of files
         Current len df = 28551
-------------------------------------
         Added 1600nr of files
         Current len df = 32042
-------------------------------------
         Added 1800nr of files
         Current len df = 35227
-------------------------------------
         Added 2000nr of files
         Current len df = 38309
-------------------------------------
         Added 2200nr of files
         Current len df = 41575
-------------------------------------
         Added 2400nr of files
         Current len df = 44633
-------------------------------------
         Added 2600nr of files
         Current len df = 47833
-------------------------------------
         Added 2800nr of files
         Current len df = 51738
-------------------------------------
         Added 3000nr of files
         Current len df = 56083
-------------------------------------
         Added 3200nr of files
         Current len df = 60456
-------------------------------------
```

Clean data

```
In [6]: # Import datetime

        raw_df = pd.read_csv("all_files_raw.csv", sep = ";")
        print(raw_df.columns.values)
        df = raw_df

        # Filter data
        docclauses_dict = {"Citigroup Inc": {"docclauses": ["MR", "MR14"]},
                    "Bk of America Corp": {"docclauses": ["MR", "MR14"]},
                    "SMBC Consumer Fin CoLtd": {"docclauses": ["CR", "CR14"]},
                    "MUFG Bk Ltd": {"docclauses": ["CR", "CR14"]},
```

```
                    "Credit Suisse Gp AG": {"docclauses": ["CR"]},
                    "UBS AG": {"docclauses": ["CR"]},
                    "Barclays Bk plc": {"docclauses": ["CR"]},
                    "HSBC Bk plc": {"docclauses": ["CR"]},
                   }

        new_df = None
        for company, value_dict in docclauses_dict.items():
            print("Company: ", company)
            temp_df = df[df["ShortName"] == company]
            relevant_docclause = value_dict["docclauses"]
            print("Relevant docclause = ", relevant_docclause)
            temp_df = temp_df[temp_df["DocClause"].isin(relevant_docclause)]
            if new_df is None:
                new_df = temp_df
            else:
                new_df = pd.concat([new_df, temp_df], axis = 0)

        df = new_df

        # Clean data
        df['Date'] =  pd.to_datetime(df['Date'], format= '%d-%b-%y')
        df['Date'] = df['Date'].dt.strftime('%d-%m-%Y')
        df["Spread1y"] =  df["Spread1y"].str.replace('.', ',')
        df["Recovery"] =  df["Recovery"].str.replace('.', ',')

        print(df.head(5))

        df.to_csv("all_files_clean.csv", index = False, na_rep ='', sep = ";")
        df.to_excel("all_files_clean.xlsx", index = False)
```

```
['Date' 'ShortName' 'Tier' 'Ccy' 'DocClause' 'Spread1y' 'Recovery'
 'Rating1y']
Company:  Citigroup Inc
Relevant docclause =  ['MR', 'MR14']
Company:  Bk of America Corp
Relevant docclause =  ['MR', 'MR14']
Company:  SMBC Consumer Fin CoLtd
Relevant docclause =  ['CR', 'CR14']
Company:  MUFG Bk Ltd
Relevant docclause =  ['CR', 'CR14']
Company:  Credit Suisse Gp AG
Relevant docclause =  ['CR']
Company:  UBS AG
Relevant docclause =  ['CR']
Company:  Barclays Bk plc
Relevant docclause =  ['CR']
Company:  HSBC Bk plc
```

```
Relevant docclause =  ['CR']
          Date      ShortName   Tier  Ccy DocClause             Spread1y  \
10  17-03-2008  Citigroup Inc  SNRFOR  EUR        MR  2,0120252336377003%
28  18-03-2008  Citigroup Inc  SNRFOR  EUR        MR    1,54464669156041%
46  19-03-2008  Citigroup Inc  SNRFOR  EUR        MR    1,48996106046298%
64  20-03-2008  Citigroup Inc  SNRFOR  EUR        MR  1,5725614094127298%
82  21-03-2008  Citigroup Inc  SNRFOR  EUR        MR    1,54431114642616%

   Recovery Rating1y
10      40%       AA
28      40%      BBB
46      40%      AAA
64      40%       AA
82      40%      AAA
```

```
In [7]: df.to_excel("all_files_clean.xlsx", index = False)
```