Consumer Preferences and Design Choices for the Digital Euro

Exploring Trade-Offs in CBDC Design

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Consumer Preferences and Design Choices for the Digital Euro

Exploring Trade-Offs in CBDC Design

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Foreword

This thesis explores the design and adoption of the digital euro, a topic where technology and policy intersect. As central banks worldwide consider the potential of digital currencies, the digital euro represents a significant step forward in digitising public money. This research aims to contribute to the understanding of how design attributes influence consumer preferences and adoption, providing insights into the broader implications of central bank digital currencies.

This thesis also marks the completion of my time at TU Delft and the Complex Systems Engineering and Management (CoSEM) program. Over the past five years, I have had the privilege to study at TU Delft, gaining valuable knowledge and experience that have shaped both this work and my academic journey.

I would like to express my sincere gratitude to my supervisors for their guidance throughout this process. Their support helped me stay on track and their feedback was always thoughtful and constructive. Special thanks to my first supervisor, Sander, who was always patient with me and willing to answer my questions.

I would also like to thank all the respondents who took the time to fill in the survey. Their input formed the foundation of this research.

Finally I would like to thank my family, friends and partner for always supporting me. They have all had their contributions, not only for this thesis, but throughout my entire study path. Their encouragement has been a constant source of motivation.

That's it, enjoy reading!

Levi van Kersen
January, 2025

Executive Summary

The digital euro is a retail central bank digital currency (CBDC) issued by the European Central Bank (ECB) to provide a secure, efficient and inclusive digital payment option that complements physical cash. Developed in collaboration with the European Commission, the digital euro aims to address challenges such as declining cash usage, reliance on non-European payment providers and the rise of private digital currencies. To mitigate potential risks on financial stability, the ECB has proposed design features such as holding limits and the absence of remuneration. However, the success of the digital euro depends heavily on its ability to align with consumer preferences and achieve adoption, as the failure of previous CBDC projects have proven.

This thesis addresses a knowledge gap by investigating how specific design features, such as holding limits, remuneration and privacy, impact consumer adoption of the digital euro. The findings offer insights into how the ECB can design a digital euro that balances consumer appeal with their broader policy objectives. The central research question guiding this thesis is:

What design choices can the ECB make to enhance consumer adoption of the digital euro?

The research question was addressed in two phases: design science research and discrete choice modelling. The first phase mapped the digital euro's design space, using an institutional morphological chart to structure design features and evaluate trade-offs. The second phase involved a discrete choice experiment, where Dutch consumers compared digital euro accounts with their current bank accounts. Respondents were presented with various digital euro accounts and their current bank account, allowing for the analysis of how specific design features influence adoption.

The stakeholder analysis highlighted the trade-off between preserving financial stability and encouraging adoption as a key challenge in designing the digital euro.

A comparison with other payment solutions found that some goals of the digital euro overlap with private initiatives, such as the European Payments Initiative, although these solutions lack some unique features of a CBDC. However, this overlap still raises questions about whether the digital euro can differentiate itself enough to justify its introduction.

The discrete choice experiment provided empirical insights into how specific attributes influence adoption. Out of the attributes and levels varied in the experiment, holding limits emerged as the most significant driver of preferences. Removing limits entirely provided the largest impact on adoption, while increasing the limit from €3000 to €6,000 or €9,000 improved market share. Interest rates were found to play an important role in influencing consumer adoption, with remuneration options increasing the appeal of the digital euro compared to a non-remunerated design. An improvement in privacy protection had a smaller but still notable impact on preferences. The suitability for offline payments also contributed significantly to the utility of the digital euro accounts. The results show that whether the digital euro is issued by the ECB or a commercial bank is less relevant to consumers when choosing between the current bank account and a digital euro account. The results also show a significant baseline preference for respondents' current bank accounts over a digital euro account. The derived market share for the ECB's current digital euro proposal, based on the model, was estimated at 15.3%. While the figure offers insight into the design's appeal, it should be interpreted cautiously, as the predominantly young, male and highly educated sample that was present in this survey may not be representative of the broader Dutch population.

To enhance the digital euro's appeal and adoption potential, the thesis provides several recommendations to the ECB. The first one is to increase the flexibility in holding limits and to incorporate consumer preferences more prominently in the design process. For example, the current holding limit of €3,000 may deter users by limiting the digital euro's utility, whereas increasing it could significantly improve adoption rates.

Second, the ECB should explore financial incentives. Consumers value financial incentives like remuneration on holdings. While paying interest on digital euro holdings could have broader monetary implications, alternative mechanisms such as sign-on bonuses or rewards programs could potentially achieve similar effects.

Third, transparent messaging about important design features, such as privacy levels, offline functionality and waterfall mechanisms for holding limits, could build trust and positively influence consumer perceptions. The ECB should therefore try to keep improving their communication. Additionally, the ECB should emphasise the unique benefits and use cases of the digital euro to encourage adoption. Highlighting abstract goals, such as enhancing Europe's strategic autonomy, is unlikely to persuade individuals to use it. Instead, the ECB must clearly provide the practical advantages of the digital euro over existing payment methods.

The study also raises the question of whether the goals of the digital euro, such as financial inclusion and payment resilience, could be better addressed through targeted solutions rather than a single solution in the form of a CBDC. Policymakers must carefully evaluate whether the digital euro offers unique and essential benefits, or if refining current systems could achieve similar outcomes with fewer complexities and risks.

Additionally, the involvement of commercial banks in the design process likely influenced restrictive features like holding limits and the absence of remuneration. While their expertise is valuable, their role as competitors to a retail CBDC may have contributed to decisions that prioritise the stability of banks over consumer appeal. This shows the importance of balancing stakeholder involvement to make sure that competing interests do not negatively impact the overall objectives of a project.

The thesis contributes to societal and scientific discussions on CBDCs. It provides recommendations for enhancing the digital euro's design and adoption potential while highlighting broader implications for designing consumer-facing financial innovations. Future research should explore preferences in diverse contexts, assess the feasibility of alternative designs and examine targeted solutions that could complement or substitute the digital euro. These efforts will inform not only the ECB's digital euro project but also the design and governance of other policy initiatives where consumers play an important role.

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1. Introduction

The ECB is working together with national central banks of the euro area to develop and introduce a new digital euro, a so-called central bank digital currency (CBDC). Its functions will be equivalent to cash but CBDC will not be a replacement for cash. According to the ECB, introducing digital currency issued by the central bank would serve as a foundational pillar of stability for both payment and monetary systems (ECB, 2022a). Unlike cryptocurrencies, the digital euro will be issued and regulated by a central authority (ECB), which would ensure the value of one digital euro to be the same as a €1 coin. Currently, the ECB is examining the potential design and distribution strategies for a digital euro, along with the market implications it might entail.

This thesis investigates the design configurations of the digital euro, focusing on identifying key design attributes and understanding consumer preferences for some of these attributes. The research adopts a two-part approach: first, by conducting a design study to map potential design choices and their implications, and second, by using a discrete choice experiment (DCE) to analyse how these choices influence consumer adoption. According to the ECB, a successfully designed digital euro can bring benefits to society, including, but not limited to an increase in the efficiency of payments, a way to promote digital financial inclusion and a reinforcement of Europe's autonomy and monetary sovereignty (ECB, 2022a). However, the success of the digital euro will also depend on public acceptance and the ability to come up with a design that aligns with consumer preferences and concerns. Despite its potential benefits, certain design features can negatively impact adoption rates.

This thesis investigates how the design of the digital euro can balance consumer preferences with the ECB's policy goals, addressing challenges to its adoption and societal relevance. By empirically quantifying the effects of features such as holding limits, remuneration and privacy protections on consumer preferences, it highlights how design choices impact adoption rates. The study reveals that a proposed €3,000 holding limit, while mitigating financial stability risks, may negatively impact adoption and increasing it could significantly improve the digital euro's attractiveness.

The methodological approach combines design science research with discrete choice modelling, offering a structured framework to explore trade-offs and quantify adoption potential. These findings are not only relevant for the digital euro but also provide broader insights into the governance of design processes in complex systems. Specifically, the role of commercial banks in co-designing the digital euro raises questions about whether stakeholder involvement has been properly balanced to avoid potential conflicts of interest.

By addressing these gaps, this thesis contributes to the growing body of CBDC research and provides actionable insights for policymakers, emphasising that consumer adoption should play a central role in the development of innovative systems like the digital euro.

1.1 Context

This section will provide context to central bank digital currencies and the digital euro specifically, giving an overview of different CBDCs as well as the development and timeline of the digital euro.

1.1.1 Central Bank digital currencies

Traditionally, central banks are known for issuing two types of money, namely cash and reserve deposits which financial institutions hold with the central bank (Grym et al., 2017). Recently, central banks have been looking to a third type: central bank digital currencies, which can be

defined as a form of digital money, denominated in the unit of account of the central bank, which forms a direct liability of that central bank (Group of Central Banks, 2020).

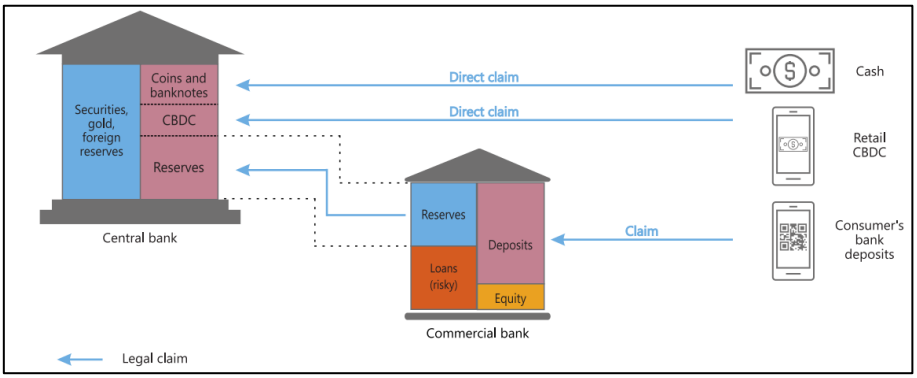

Figure 1: Cash, electronic payment instruments, and retail CBDC (Auer & Böhme, 2021)

Figure 1 shows the conceptual differences between cash, commercial bank money and retail CBDC. Distinction is usually made between wholesale and retail CBDCs. Wholesale CBDCs are primarily aimed at financial institutions that hold reserve deposits with the central bank, which makes it an alternative for the reserve deposits system which is currently in place in the Eurozone. A wholesale CBDC system could provide a fast and secure infrastructure for transaction settlement between (major) financial institutions (Auer et al., 2022). Retail CBDC on the other hand is focused on the general use of the public. For this audience, CBDC could serve as a means of payment, store of value and a unit of account, which are the three functions of money.

Auer & Böhme (2021) distinct three different types of retail CBDC architectures with different roles for the private sector: direct, hybrid and intermediated CBDC. The difference between these types of architectures is situated in the role of the private sector. For a single-tier retail CBDC, the private sector does not play any role in settling or distributing the CBDC. For two-tier retail CBDCs, private sector banks and non-bank payment service providers are responsible for the onboarding of customers and payments. Whether the central bank executes and settles payments determines whether it is a hybrid or intermediated CBDC architecture. Figure 2 gives a conceptual overview of these different architectures.

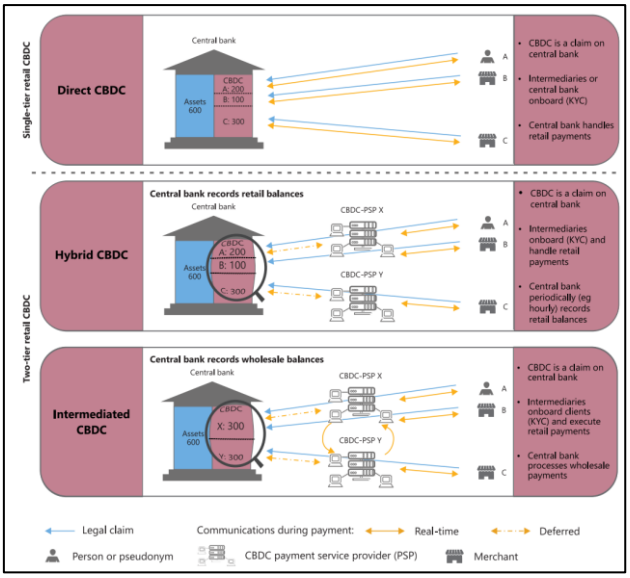

Figure 2: Retail CBDC architectures: direct, hybrid and intermediated (Auer & Böhme, 2021)

As of 2024, 3 central banks have launched a CBDC, while over 60 central banks are running pilots or developing CBDCs (Atlantic Council, 2024). The digital currencies implemented so far are the e-Naira (Nigeria), Sand Dollar (the Bahamas) and JAM-DEX (Jamaica), all retail CBDCs. All three have seen low adoption rates (Dowd, 2024). In Nigeria, the e-Naira struggles with issues of trust in government and privacy concerns, despite the availability of instant payment systems (Dowd, 2024). These cases illustrate that the success of CBDCs depends not just on technology but also on public trust, existing financial systems and specific socio-economic contexts. So far, live CBDC projects have reached limited success (Dowd, 2024).

1.1.2 Current status of the digital euro

Although the digital euro has not yet been launched, the development of both the technical design as well as the legislative proposal are currently taking place. So far the ECB has come with a preliminary design, highlighting the major motives and design choices. According to the Stocktake report (ECB, 2023a), the digital euro is being designed with a primary focus on payment functionality, facilitating physical, online and (offline) peer-to-peer payments. The store of value and saving possibilities of the digital euro are limited in the current design by not renumerating the currency and applying holding limits. The digital euro is proposed to be recognized as legal tender, which would legally arrange its acceptance, so that it can be use across our economy. In the current design, it will be distributed through payment service providers (PSPs), who will handle end-user onboarding, servicing, payment initiation, validation, post-settlement and offboarding, following a hybrid CBDC approach (see figure 2).

In 2024, the ECB has advanced the development of the digital euro through a series of tenders aimed at securing European providers for essential components, enhancing the infrastructure needed for its deployment (ECB, 2024a):

- *Alias Lookup:* This component facilitates Payment Service Providers (PSPs) in identifying necessary details for routing payment requests by employing a lookup function. This would allow end-users to use aliases when initiating a payment, instead of account numbers.
- *Offline Solution:* An offline, hardware-based payment instrument is being developed to allow transactions without third-party involvement, aimed at enhancing both resilience and privacy.
- *App and Software Development Kit (SDK):* The digital euro app and SDK are designed to enable PSPs to integrate digital euro services into their mobile apps and online interfaces, focusing on user experiences across dedicated and existing platforms.
- *Risk and Fraud Management:* A central fraud detection and prevention mechanism will be established to support PSPs in managing and mitigating fraud risks in digital euro transactions.
- *Secure Exchange of Payment Information:* This component supports the tokenization and detokenization of transactional information, ensuring the secure exchange of payment data within the digital euro's payment workflow.

In addition to the development of prior named components, the ECB, sometimes in collaboration with other organizations, has already done some prototyping and proof of concept developing. Examples are the design of a mobile application prototype for the digital euro, developed by Caixa Bank (CaixaBank, 2023) and a prototype to test how design choices could be technically implemented into the existing European payments landscape (ECB, 2023c).

1.1.3 Digital euro timeline

In October 2021, the ECB launched the digital euro project, starting with an investigation phase of 2 years. During this phase of 2 years, the European Commission came up with a legislative proposal for the digital euro (Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Establishment of the Digital Euro, 2023), and the ECB concluded this phase with a high level product design and design requirements (ECB, 2023a). After the investigation phase, the preparation phase started in November 2023, in which the ECB will further focus on testing, experimenting and consulting with all stakeholders, including the public, for a period of 2 years (ECB, 2023a). The development of the digital euro consists of 2 main components which are being designed in parallel: a legal path led by the European Commission and a technical design led by the Eurosystem (the combination of national central banks in Europe and the ECB). Issuance of the digital euro can only happen once both are finished and the legislative proposal is adopted in the EU. The current expectations are that, if the legislative proposal gets adopted, the digital euro could not be issued before 2028 (Deutsche Bank, 2023; Deutsche Bundesbank, 2024).

1.2 Problems

In this section, we categorize two distinct types of problems. The first encompasses the problems that prompted the ECB to initiate the digital euro project. The second category addresses potential problems concerning the consequences and effectiveness of a digital euro and its implementation.

1.2.1 Problems prompting the digital euro initiative

The rise of private currencies is seen as a threat to financial and monetary stability, prompting the ECB (and other central banks) to consider a CBDC as a countermeasure (Auer et al., 2020). The initiative for a CBDC gained momentum following the announcement of Libra, a stablecoin initiative by Facebook, which although never launched, underscored the urgent need for regulatory and central banking responses to such private sector initiatives (Duncan, 2022). This aligns with another critical issue: the necessity of an official digital currency like the digital euro to maintain sovereignty against the influence of large, overseas tech companies (Panetta, 2022). This goes further than just private currencies because great parts of our payment infrastructure in Europe are dominated by players like Visa and Mastercard, which are both companies from the US.

Furthermore, despite high levels of bank account ownership within the EU (98%), approximately 60% of the European population still lacks access to essential digital banking services, highlighting a significant gap in digital financial inclusion (Digital euro project team, 2023; Martyn, 2023). Alongside this, the declining use of cash—despite its critical role in maintaining direct links between the ECB and the public and ensuring the stability of the payment systems—illustrates a shift that the digital euro could potentially address. By emulating some of cash's critical functions, such as safeguarding privacy and promoting financial inclusion, the digital euro could potentially serve as an anchor of stability for the payments system as a whole (Zamora-Pérez, 2022).

1.2.2 Problems related to the consequences and effectiveness of a digital euro

The transition towards a digital euro, characterized as a Central Bank Digital Currency (CBDC), has captured significant attention and debate within the European Central Bank (ECB) and national central banks of the euro area. While the primary objective of the digital euro is to enhance payment and monetary system stability, there are critical issues concerning its design, implications for the intermediary role of banks and societal relevance.

1.2.2.1 Do we need a digital euro?

The initiative to create a digital euro is sometimes described as an objective-centred solution, indicating that it seeks to fulfil specific institutional goals rather than addressing pre-existing problems, thereby questioning the utility a digital euro could bring (Angeloni, 2023; Faunce et al., 2023). The ECB has stated goals such as enhancing transaction efficiency, fostering financial inclusion and strengthening monetary sovereignty. However, the necessity of a digital euro as a solution may not be evident, as the underlying problems it intends to solve are not universally recognized or felt. This approach raises questions about the justification for the digital euro, particularly when the existing monetary system appears to be stable and functional without it.

Additionally, the Eurozone already possesses robust payment infrastructures, such as the TARGET Instant Payment Settlement (De Nederlandsche Bank, 2024a) system and the ongoing European Payments Initiative, which aims to enhance digital payments with solutions like digital wallets. These developments demonstrate the capabilities of existing payment systems to address the needs that a digital euro aims to fulfil. Consequently, for the digital euro to be deemed necessary, it must offer distinct advantages or innovative functionalities that differentiates it from these established systems

1.2.2.2 Possible implications of CBDC from the literature

The introduction of a CBDC, such as the digital euro, could have significant implications and introduce risks to the financial and payment landscape. Existing literature highlight several potential concerns associated with CBDCs:

- **Destabilization of Banking System:** Direct access to central bank balance-sheets by individuals and non-bank institutions could destabilize the two-tier banking system (Fegatelli, 2022). This could be the case when consumers are capable of transferring great amounts of their commercial bank deposits to digital euros, potentially causing bank runs. The same idea is argued by Laguna de Paz (2023), who states that having unlimited access to a risk-free asset (which the digital euro would be) could lead to de-funding of commercial banks and therefore argues that a holding limit of digital euros would be necessary. Azzone & Barucci (2023) found that large adoption rates may have significant consequences for the market value of deposits at commercial banks, which would also impact the banking system.

- **Changes in the ECB's Institutional Role:** Another issue could be that central banks may evolve into a systematic auxiliary funding provider for commercial banks, which would require them to have a more active role in the economy and makes them thereby more liable to political interference, which could affect central banks' independent status (Fegatelli, 2022). Similar issues are raised by Rehman et al. (2023), who conducted research on the macro-financial implications of CBDCs and found that CBDCs could increase the link between both central banks and the government as well as the link between central banks and the financial industry.

- **Privacy Concerns vs. Regulatory Objectives**: Tronnier et al. (2023) underline the importance of privacy and its concerns for future CBDC users. At the same time, the objectives of anti-money laundering, combating the financing of terrorism and combating tax evasion are also considered important by the ECB (ECB, 2023a). Therefore, a challenge would be to find a solution that guarantees the protection of personal data but also allows for the identification of illegal payments (Terták & Kovács, 2022).

1.2.2.3 Importance of consumer adoption

In light of the systemic risks posed by CBDCs to the banking sector, the ECB has taken a cautious approach to design the digital euro, aimed at preserving financial stability. Measures such as

holding limits and the absence of interest on digital euro balances are intended to mitigate the potential for large-scale deposit migration from commercial banks. These design features aim to minimise disruption to the traditional banking system.

However, the success of the digital euro depends significantly on consumer adoption. Previous CBDC implementations have shown that even well-intentioned projects may fail without broad public engagement. Dowd (2024) highlights that countries such as Finland and Ecuador already terminated their CBDC initiatives due to poor uptake, while ongoing projects in Nigeria, the Bahamas and China report limited usage despite considerable government efforts to promote them. In each case, low adoption was driven by a lack of clear benefits for consumers, raising questions about whether CBDCs can truly transform payment systems.

For the ECB, finding the right balance between protecting financial stability and driving consumer adoption is crucial. Design restrictions risk making the digital euro less appealing to consumers, which could result in the same difficulties as seen in other CBDC projects. At the same time, without enough consumer adoption, the digital euro project may fail to achieve goals like improving payment efficiency, boosting financial inclusion and strengthening Europe's monetary sovereignty, which are the main drivers of this project for the ECB.

1.3 Knowledge gap

While central banks globally are actively exploring the introduction of CBDCs, much of the existing literature predominantly focuses on technical design, regulatory frameworks and macroeconomic implications. However, there remains a significant gap in empirical research examining the factors that drive consumer adoption of CBDCs, particularly in the context of the digital euro.

Research conducted by De Nederlandsche Bank (Bijlsma et al., 2021) explored the potential for CBDC adoption in the Netherlands, finding that approximately half of the surveyed population expressed interest in opening CBDC accounts. The study highlighted that factors such as trust in central banks, privacy concerns and the perception of CBDC as a safer alternative to commercial bank accounts play a role in determining consumer attitudes. Additionally, financial incentives—such as higher interest rates—were shown to influence the willingness to adopt CBDC savings accounts. Despite these insights, the DNB study was conducted at the very beginning of the digital euro project, prior to the ECB's more detailed design proposals. As the digital euro has since evolved to address systemic risks (e.g., through holding limits and non-remunerated accounts), the trade-offs between ensuring financial stability and fostering widespread consumer adoption have become more pronounced.

Past CBDC projects have shown that low adoption rates can significantly limit their success, preventing them from meeting their intended objectives. These examples highlight the need to better understand which design features drive user adoption and build trust. Without enough public uptake, the digital euro risks falling short of goals like improving payment efficiency, increasing financial inclusion and strengthening Europe's monetary sovereignty. Existing research does not fully address how design choices of CBDC design impact consumer adoption or whether the ECB's current digital euro design sufficiently aligns with consumer expectations.

1.4 Research objective

The objective of this thesis is to investigate how specific design features and choices can drive consumer adoption of the digital euro. While the ECB sees the digital euro as a tool to enhance payment efficiency, financial inclusion and monetary sovereignty, its success depends largely on whether consumers are willing to adopt and integrate it into their daily payment activities. Past CBDC projects have demonstrated that technical feasibility alone is not sufficient. Consumer preferences, trust and perceived benefits play an important role in determining adoption rates.

This research focuses on identifying the design attributes of a digital euro and exploring how consumers evaluate trade-offs between design features. By understanding these dynamics, the thesis aims to provide insights into how the ECB can design a digital euro that appeals to consumers. The central research question guiding this work is:

What design choices can the ECB make to enhance consumer adoption of the digital euro?

To address this question, the thesis first maps the objectives and design space of the digital euro, analysing the ECB's current proposal and potential design alternatives. The second part of the research involves conducting a discrete choice experiment (DCE) to empirically assess how different design features influence preferences of Dutch consumers.

1.4.1 Societal and Scientific relevance

A successful digital euro could improve accessibility to digital payments and increase competition in the payments market. However, challenges such as consumer adoption and potential impacts on financial stability remain critical. If perceived as unattractive or redundant, adoption may fall short, raising questions about the project's value. This thesis addresses these challenges by identifying design configurations that promote consumer adoption and support effective policy decisions for the digital euro. Furthermore, this thesis addresses a gap in CBDC research by quantifying the effects of design features, like holding limits, on consumer preferences using discrete choice experiments in the Dutch context, contributing to the growing literature on CBDCs and consumer adoption.

A more detailed discussion of the societal and scientific relevance is provided in Chapter 8.2 and 8.3

1.4.2 Fit to CoSEM program

This master thesis fits well within the CoSEM program because the topic concerns a design issue within a complex system where a multidisciplinary design challenges play a role. A more detailed discussion can be found in Chapter 8.4

1.5 Structure

After introducing the background, problem statement and research objectives of this thesis, the report continues with Chapter 2 which outlines the research methodology. Chapter 3 identifies the key stakeholders, their interest and the potential trade-offs that shape the design space of the digital euro. Building on this, Chapter 4 maps the design features of the digital euro. Here, the current design proposal will be analysed, as well as alternative configurations. Then, in the second phase of the thesis, Chapter 5 describes the development and implementation of the discrete choice experiment on the consumer preferences of digital euro designs. Chapter 6 presents the results of this experiment, highlighting the most important design features that drive consumer adoption. Chapter 7 synthesizes these findings into recommendations on the digital euro design and consumer preferences for the ECB. Finally, Chapter 8 concludes the thesis and offers a discussion of the thesis, where it reflects on limitations.

2. Research Approach

Chapter 2 outlines the research approach used in this thesis. First, it generally describes Design Science Research and gives an overview of the stages of design science used for this research. Then, the consumer preference analysis and the use of discrete choice modelling will be explained. The chapter finishes with a Research Flow Diagram and a statement on the gathering and processing of data.

2.1 Design Science Research

Design science research provides a framework for developing and refining technology solutions through a series of iterative processes. Design Science Research is chosen because it allows for the iterative exploration of complex socio-technical systems, such as the digital euro, by integrating stakeholder objectives and refining artefacts through continuous evaluation. This iterative approach aligns with the evolving nature of the ECB's digital euro project. Following the design science research method framework by Johannesson & Perjons (2014), it separates five main activities and corresponding results. These activities, as shown in figure 3, include problem identification, define requirements, design and develop artefact, demonstrate artefact and evaluate artefact.

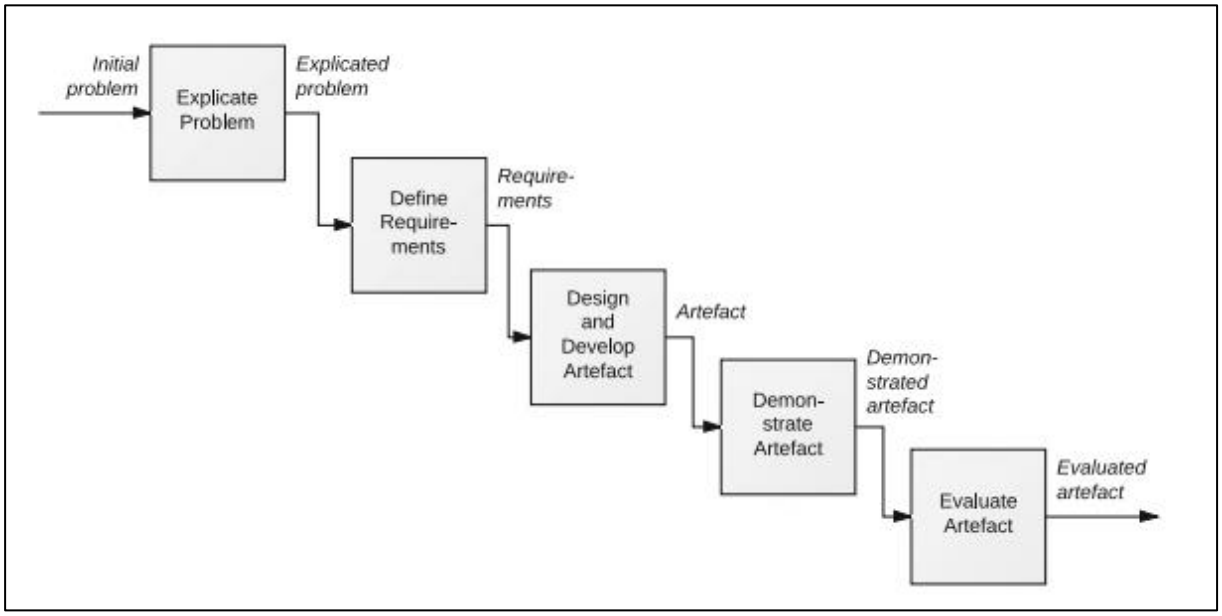

Figure 3: Overview of the method framework for design science research (Johannesson & Perjons, 2014) p.77

It is important to note, as Johannesson & Perjons (2014) point out, that not all design science projects engage deeply with each of the five activities. Many projects, depending on their scope and objectives, may concentrate on one or two activities, treating the others more lightly. In this thesis, the digital euro's design process is approached as an iterative process aligned with an objective-centred solution framework (rather than a problem-driven project) as previously mentioned in chapter 1.2.2.1. This approach is adopted due to the ECB's explicitly stated objectives and the relatively vague nature of the problems it aims to address. Given that these objectives support the requirements for the digital euro's design, this research will be scoped as a blend of 'Requirements- and Development-Focused Design Science Research', as identified by Johannesson & Perjons (2014, p. 79 & 80).

While the ECB is actively designing the digital euro, this thesis complements and expands upon their work by exploring the broader design space. It integrates insights from ECB publications and public consultations but goes beyond by examining alternative configurations and design choices that may not be part of the ECB's current proposal. This thesis investigates how a retail CBDC, such as the digital euro, *could* have been designed. Here the focus lies in analysing design features that influence consumer adoption and trust. Therefore, the goal of this part of the thesis will be to determine the design space and designing the artefact of a digital euro. In the second part of the thesis, where consumer preferences will be analysed, the artefact will be demonstrated (in a simple and limited way) and evaluated on key design attributes for consumers, using discrete choice experiments.

2.2 Discrete Choice Modelling

Discrete Choice Modelling (DCM) is a quantitative method used to analyse decisions made by individuals when faced with multiple alternatives. It predicts consumer behaviour by examining how different attributes of a product or service influence their choices. This method has been widely adopted in various fields, for example in transportation (for example Ortúzar et al. (2021)) and health (for example Hansen et al. (2019) and Ostermann et al. (2020)). DCM is a stated-preference (opposed to revealed preference where actual choices are made by individuals) technique that relies on the principles of random utility theory, pioneered by Daniel McFadden (Manski, 2001). This theory assumes that the utility derived from each alternative includes a deterministic component, based on measurable attributes and a random component that reflects unknown influences or individual-specific preferences. The model estimates the probability of choosing one option over others by quantifying the impact of these attributes on the decision-making process. In practice, DCM is implemented through Discrete Choice Experiments (DCE), where different combinations of attributes are varied to capture how consumers makes choices based on the features. This method provides insights into the relative importance of design features and predicts the likelihood of adoption under different configurations.

As explained in Chapter 1, the success of the digital euro will depend on the level of consumer adoption. DCM is an effective tool for exploring consumer preferences by letting the respondents make decisions so that the trade-offs individuals make between various design attributes can be identified. Since market data is currently not availably (there is no digital euro yet), DCM provides a solid alternative to infer choice preferences and evaluate the importance of different design features and choices. Discrete choice modelling allows for the analysis of how different configurations of the digital euro, such as the level of privacy, affect consumer choices. As demonstrated by Fairweather et al. (2024), who applied a discrete choice experiment to assess consumer preferences of CBDC in Australia, the method provides empirical insights that are useful for guiding design decisions. In addition to identifying the most important design attributes, this method is used to give some insights into the potential market share of a digital euro.

The goal of using discrete choice modelling in this thesis is to understand which design features of the digital euro are most important to consumers and how these features influence their likelihood to adopt it. The outputs include insights into consumer preferences, the relative importance of design attributes (such as privacy, offline functionality and holding limits) and forecasts of adoption rates under different design configurations. These results can help policymakers refine the digital euro's design to make sure certain levels of adoption are in reach.

2.2.1 Discrete choice experiment

The development of a discrete choice experiment consists of several stages, which are shown in Figure 4. In this section, each stage will be explained in detail.

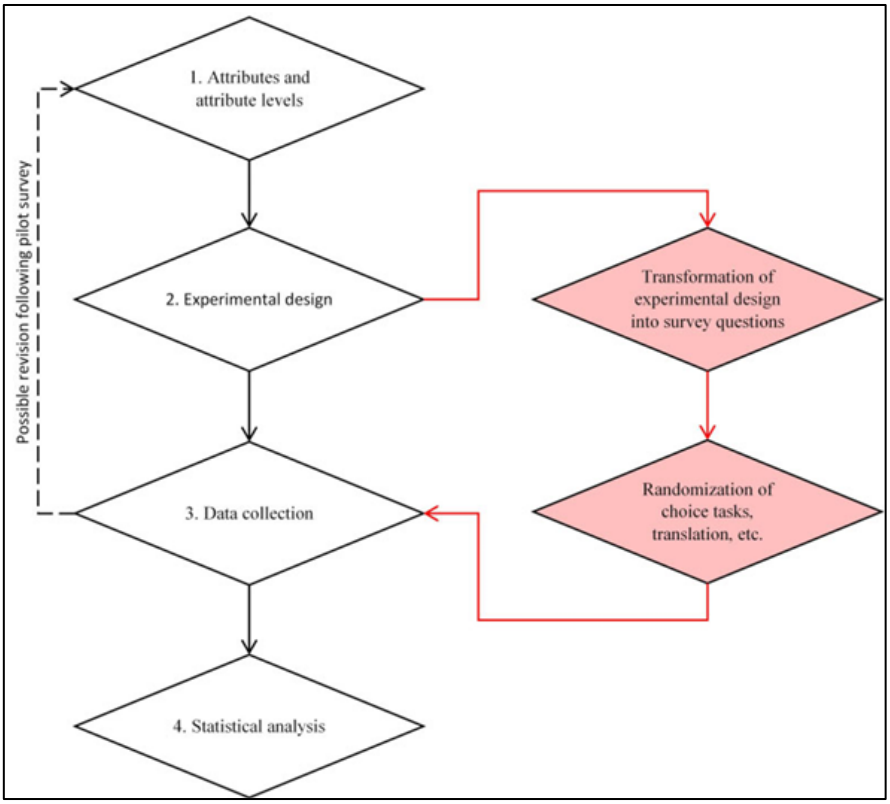

Figure 4: Key stages in the development of a discrete choice experiment (Weber, 2021)

2.2.1.1 Establishing attributes

Establishing the right attributes is an important step in developing a DCE, as the validity of the results depends on accurately identifying the factors that influence consumer choices. Attributes should reflect the most important features for respondents while remaining adjustable by and relevant to policymakers or designers (Molin, 2023). Literature reviews, including both published and grey sources like policy documents and government reports, provide a solid foundation for selecting attributes (Mangham et al., 2009). In this thesis, the attributes are drawn from the design features identified during the initial phase of research, focusing on features that differentiate the digital euro from traditional payment methods, are significant for Dutch consumers and that are still adjustable for the design of the digital euro. During this phase, policy documents and government reports were consulted. However, also secondary sources often need to be supplemented with primary data to ensure the attributes align with the specific context of the study (Mangham et al., 2009). In the case of the digital euro, supplementary data is for example the study on digital wallet features (Kantar Public, 2023), where the authors conducted a focus group with participants from different countries in the context of the digital euro. Finally, it's important to balance the number of attributes, as increasing the complexity can raise the cognitive burden on respondents (Mangham et al., 2009). Therefore, the number of attributes included in the choice experiment has been kept to the minimum necessary.

2.2.1.2 Assigning attribute levels

Once the attributes are determined, the next step is to assign different levels to the attributes. Assigning appropriate levels to each attribute is important for making the experiment valid and

reliable. The levels should represent the range of conditions that respondents might expect to experience (Mangham et al., 2009). This also means that combinations of different attributes with certain levels should at least be graspable and not completely impossible. Making sure that the attribute levels are meaningful and realistic also helps increasing the precision of the model's parameter estimates, which would then lead to more reliable insights into consumer preferences (Hall et al., 2004). Molin (2023) suggest that equidistance between attribute levels should be preserved in order to assure orthogonality between attributes. The attribute levels for this study are covering the design features explicitly or implicitly proposed by the ECB. To explore a broader design space, additional levels beyond the ECB's current proposals are included. This allows the experiment to assess how alternative configurations might influence consumer adoption and preferences.

2.2.1.3 Experimental design

The next stage of a DCE is to generate the choice sets by combining different choice alternatives. Presenting every possible combination of attributes isn't feasible, as the number of alternatives can grow rapidly. For instance, four attributes with four levels each would generate 256 combinations, making full factorial designs often too time-consuming to implement (Kuhfeld, 2010). To manage this, a fractional factorial design is used to select a subset of combinations that still provides reliable estimates of the key effects (Mangham et al., 2009). If the final design results in a large number of choice tasks, blocking will be used to partition the tasks into smaller, more manageable sets (Weber, 2021). Using this technique, each respondent completes only a subset of the total choice tasks, while still ensuring that the full range of attribute and level combinations is covered across the sample.

The design tries to achieve orthogonality and attribute level balance. Orthogonality means that the attributes in the experiment vary independently of each other, in other words, that there exists no correlations between attributes, which results in low standard errors (thus reliable parameters) (Molin, 2023). Attribute level balance makes sures that each attribute level appears an equal number of times across the choice sets. This prevents certain levels from being overrepresented, which could skew the results or make it harder to identify the importance of less frequently shown levels.

The constructed choice sets are checked for dominant alternatives, which occurs when one alternative is clearly better across all attributes than the other option(s). Although it could be useful to include dominant alternatives to see whether respondents answer rationally (Mangham et al., 2009), these choices do not reveal information about trade-offs. Therefore, dominant choice sets are removed from the experimental design (Molin, 2023). To avoid any order effects that could influence responses, the survey is created in such a way that the order of the choice sets is randomized for each respondent, as suggested by Kjaer et al. (2006). This makes sure that respondents' choices are driven by the attributes themselves, rather than the structure of the questionnaire. To make sure that the experiment reveals information about the demand for the digital euro as well, a base alternative, consisting of the respondent's current bank account, is added to the choice sets (Molin, 2023).

2.2.1.4 Pre-testing the questionnaire

Before distributing the full survey, a pilot study has been conducted to refine the design, assess the clarity of the choice tasks and ensure the questionnaire performs as intended. Pre-testing the experiment is important to identify potential issues, such as overly complex tasks and difficult wording. It also gives a first indication for the results and helps to validate the time respondents need to fill in the survey.

2.2.1.5 Data collection

The data collection phase involves distributing a survey that presents respondents with a series of discrete choice tasks. The survey is designed and administered through Qualtrics, which is a web based application to create surveys. Next to filling in the choice tasks, respondents are asked to provide some basic demographic information, specifically age, gender, education level and income. This information is used to evaluate the representativeness of the sample and identify potential biases. Due to limited resources, convenience sampling was employed to gather responses. The survey was primarily be distributed through the researcher's personal network, including platforms such as LinkedIn and WhatsApp groups. While this method is cost-effective and time-efficient, it inherently introduces some sampling bias, as the respondents may potentially not reflect the broader population of the Netherlands.

2.2.1.6 Statistical Analysis

The analysis of DCE data follows Random Utility Theory, which assumes that respondents choose the option that gives them the highest utility. This utility consists of a part that can be explained by observable attributes and a random part that reflects unobserved factors. For individual *n*, the utility $U_{n,j}$ of alternative *j* is given by:

$$U_{n,j} = V_{n,j} + \varepsilon_{n,j}$$

Where $V_{n,j}$ is the deterministic utility component and $\varepsilon_{n,j}$ is the random unobserved component of utility, which is assumed to follow an IID extreme value distribution (Beggs et al., 1981). In this study, each choice set includes a baseline alternative (the current bank account) and two digital euro account options. Respondents select their first and second preference, creating a ranking of three alternatives. Because of this structure, the analysis can apply an Exploded Logit Model. The probability of the observed ranking is given by the following formula (Hess & Palma, 2023):

$$P_{n,t} = \prod_{i=i}^{J-1} \frac{e^{V_{R_{nt,i}}}}{\sum_{j=1}^{J} e^{V_{R_{nt,j}}}}$$

Where $P_{n,t}$ is the probability of observing ranking $R_{n,t} = [R_{n,t,i}, \dots, R_{n,t,J}]$, where $R_{n,t,1}$ is the index for the highest ranked alternative for individual *n* in choice task *t*. J is the total number of alternatives available, which for this analysis will be equal to 3. The summation in the denominator presents the sum of exponentials of the utilities for all alternatives still available at step *i.* This model extends the standard Multinomial Logit (MNL) by incorporating the second choice, allowing for a more detailed analysis of trade-offs between options. The Exploded Logit Model makes use of the full ranking data, providing richer insights into consumer preferences.

2.3 Sub-questions

Section 2.3 outlines the sub-questions that guide the research process and help address the central research question regarding the design of the digital euro to enhance consumer adoption. The sub-questions are divided into two phases, reflecting the dual approach of this thesis. The first phase focuses on understanding objectives and mapping design attributes, while the second phase evaluates how these attributes influence consumer preferences through empirical analysis. Each sub-question is accompanied by an explanation and a description of the methodology used. Together, these sub-question should answer the main research question:

What design choices can the ECB make to enhance consumer adoption of the digital euro?

2.3.1 First phase: Design Science Research

Sub-question 1: *What are objectives of the digital euro as outlined by the ECB and relevant stakeholders?*

This sub-question seeks to identify and analyse the objectives driving the development of the digital euro, as articulated by the European Central Bank (ECB), as well as the vision of other key stakeholders. Understanding these objectives is an important step before framing the design process and evaluating the trade-offs that influence consumer adoption. To address this sub-question, a comprehensive document analysis is conducted, focusing on official publications from the ECB, such as consultation papers, reports and legislative proposals. Stakeholders positions' have been mapped. Additionally, relevant materials from national central banks, the European Commission and industry groups are reviewed to capture a broader perspective on the motivations and goals underlying the project. Where possible, insights from interviews or statements made by policymakers and central bank representatives will supplement this analysis to provide more context on the evolving objectives. It is essential to note that the accuracy of the results will depend on the transparency of information available.

Sub-question 2: *What are the key design attributes of the digital euro as per the current proposal?*

This sub-question focuses on identifying the key design attributes of a digital euro, drawing from the ECB's current proposals as well as relevant stakeholder publications and other literature on CBDCs. By mapping these possible attributes, this sub-question provides a structured overview of the design space of a digital euro. Johannesson & Perjons (2014) provide guidelines for the design and development of an artefact. Each component should be clearly described and justified, specifying the sources that contributed to the designed components. To approach the design process systematically, each design feature has been mapped to specific functions it aims to fulfil. These features and functions are compiled into an institutional morphological chart, which outlines various options by which each function can be achieved, adapting the traditional approach described by Dym et al. (2014). The chart serves as a tool to visualise and organise the design space, presenting a range of configurations for each attribute. This approach helps to structure the ECB's current proposal but could also be used to draft alternative design paths.

Sub-question 3: *What are alternative designs of the digital euro?*

This sub-question aims to explore and conceptualise alternative designs for the digital euro by leveraging the institutional morphological chart developed in response to the previous sub-question. While the ECB has outlined a preliminary design for the digital euro, the inherent flexibility in several design attributes allows for the examination of alternative configurations that may better align with consumer preferences, policy goals and stakeholder requirements. The institutional morphological chart serves as the foundation for this exploration. Each design feature identified in the chart is linked to multiple potential options of implementation, representing a wide array of configurations. By selecting different combinations of these options, multiple design alternatives can be generated. Since this sub-question explores alternative designs, it directly contributes to the main research question.

Sub-question 4: *Are there existing digital payment solutions that can achieve similar goals to those of the digital euro?*

This sub-question investigates whether existing digital payment solutions can achieve the same objectives as the digital euro, such as enhancing payment efficiency, promoting financial inclusion and reinforcing monetary sovereignty. To address this, a comparative analysis has been made to evaluate the capabilities of existing digital payment methods against the core goals of the digital euro. The outcome of this analysis helps clarifying whether the digital euro represents a necessary

innovation or if expanding and refining current payment infrastructures could achieve similar benefits. Besides, it also gives insight into how a digital euro might differ from existing payment solutions. Clarifying the originality of the design is one of the guidelines by Johanneson & Perjons (2014) for designing and developing an artefact. By mapping the strengths and limitations of existing solutions, this sub-question provides a clearer perspective on the unique value proposition of the digital euro and its potential role within the European financial ecosystem.

2.3.2 Second phase: Discrete Choice Modelling

Sub-question 5: *How do different design attributes influence consumer preferences and adoption of the digital euro?*

This sub-question explores how specific design attributes of the digital euro influence consumer preferences and adoption decisions. Since consumer adoption is critical for the digital euro's success, understanding which design features drive user interest and trust is essential. To answer this, a discrete choice experiment has been conducted, as outlined in Section 2.2. This method presents different digital euro configurations to respondents, allowing them to choose between alternatives based on varying attribute levels. The designs used in the DCE has been derived from the institutional morphological chart created during the design phase. The selected attributes should be both policy-relevant and critical to consumers' decisions regarding adoption. To determine which features are most important to potential users, a literature review has been conducted to examine existing studies on consumer preferences. This includes for example the focus group on digital euro wallet features by Kantar Public (2023). The results revealed the trade-offs consumers are willing to make, highlighting which design attributes are most influential in driving adoption.

Sub-question 6: *Which design attributes are most important for consumer adoption of the digital euro?*

This sub-question aims to identify which design attributes play the most significant role in driving consumer adoption of the digital euro. It involves an ex-ante evaluation, assessing the digital euro's potential effectiveness without the artefact being fully developed or implemented. As Johannesson & Perjons (2014) highlight, the core objective of evaluation in design science is to measure how well an artefact addresses the problem or goals it was created for. In the case of the digital euro, achieving a certain level of adoption is important to fulfilling the project's objectives.

To conduct this evaluation, data from the discrete choice experiment has been statistically analysed using R, applying the methodologies outlined in Section 2.2. This analysis quantifies the utility consumers derive from various design attributes, highlighting which features are most influential in their decision to adopt the digital euro. By identifying the attributes that generate the highest levels of utility, this evaluation aims to provide practical insights for policymakers and the ECB, guiding refinements to the digital euro's design to better align with consumer preferences.

Sub-question 7: *Based on consumer preferences, how should the ECB incorporate these insights into the further design and finalization of the digital euro?*

This sub-question aims to assist the ECB in evaluating whether the digital euro project, in its current format, holds the potential to become a success. By identifying the design attributes that are most significant to consumers and analysing their impact on adoption, the research sheds light on potential strengths and weaknesses in the existing proposals. If the findings suggest that the current design may not fully resonate with user preferences, the thesis will provide insights into alternative directions that could enhance adoption and engagement. To address this sub-question, the findings from the DCE are synthesised into clear recommendations for the ECB. This step

connects with the concept of communicating artefact knowledge, as outlined in Chapter 10 of Johannesson & Perjons (2014), which emphasises the importance of tailoring communication to different audiences. For this research, policymakers require practical insights on how design choices impact user adoption.

2.4 Research Flow Diagram

This section outlines the research flow of the thesis, presented in the form of a research flow diagram. The diagram is shown in Figure 5.

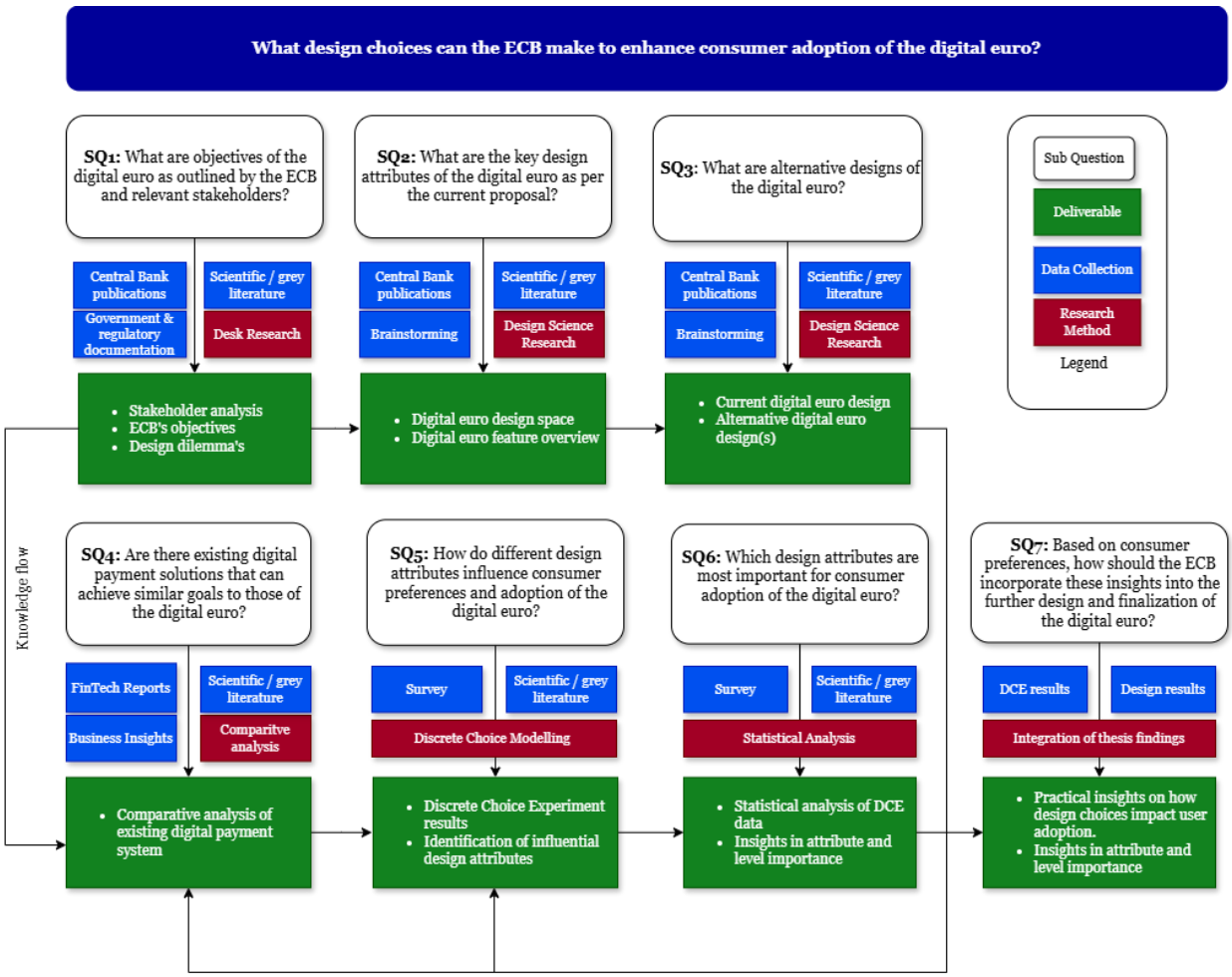

Figure 5: Research Flow Diagram

2.5 Data management

This research involves two primary methods of data collection: literature and document analysis,and a discrete choice experiment. For the literature and document analysis, data is gathered from academic databases such as Google Scholar, Scopus and ScienceDirect, alongside publications from governments, institutions and businesses. References and citations are managed using Zotero to maintain accuracy and consistency throughout the research process.

This second part of the research involves human participation through the discrete choice experiment. To mitigate risks associated with data collection, a risk assessment and mitigation plan has been developed, accompanied by a detailed data management plan. Participants are

informed about the purpose of the study and asked to provide consent before participating. Only general demographic information, such as age group and gender, is collected to minimize the risk of reidentification. All personal data collected during the experiment has been securely managed and only aggregated results are presented in the thesis. The final MSc thesis, including findings and conclusions, will be published in the TU Delft Research Repository. Personal data will be permanently deleted upon the successful completion of the project.

3. Actors and Interests

This chapter explores the motivations, stakeholders and conflicting interests surrounding the development of the digital euro. Section 3.1 outlines the challenges prompting the digital euro, including the rise of private currencies, strategic autonomy, financial inclusion and the decline of cash. Section 3.2 explores the ECB's motivations, focusing on modernizing payments, enhancing resilience and trust and promoting inclusion and privacy. Section 3.3 analyses the roles and interests of key stakeholders, including EU institutions, market participants and consumer groups. Finally, Section 3.4 identifies dilemmas, such as balancing privacy with traceability and financial stability with adoption. The chapter concludes with Section 3.5. This chapter provides a foundation for understanding the goals and complexities that influence the design and implementation of the digital euro.

3.1 Digital euro problem identification

Starting with what is usually described as the first step in design science research (Johannesson & Perjons, 2014; Peffers et al., 2006), the problem identification serves as a foundation for developing solutions. Although the ECB did not specify concrete problems initially and later provided more objective-centred reasons for issuing a digital euro, certain challenges can be inferred from these objectives and have been identified by other research. This section gives the problem identification from the ECB's perspective that underlines the digital euro project.

3.1.1 Rise of private currencies

The rise of private currencies, especially stablecoins, has been a driver for the ECB to start investigating a CBDC. Stablecoins, unlike highly volatile cryptocurrencies like Bitcoin, aim to maintain a stable value by linking to assets such as national currencies. However, their stability depends heavily on the governance and reserves backing them (Auer et al., 2022). The ECB has warned that private issuers of digital payment instruments, like stablecoins, could collect large amounts of sensitive user data, creating more risks than if a central bank issues digital money (ECB, 2020). This risk is increased by the influence of big tech companies that are entering the digital payments market. As these companies expand their role in the financial system, the concentration of power, due to the network effects these companies can have, raises challenges for central banks (Auer et al., 2022). Especially Facebook's plan to launch a stablecoin called Libra (later called Diem) is seen as one of the main drivers that triggered central banks to start actively considering and developing CBDCs (Ahnert et al., 2023; Auer et al., 2022).

3.1.2 Lack of strategic autonomy

The push for a digital euro is increasingly tied to the concept of strategic autonomy. It is the idea that Europe must safeguard its financial sovereignty as digital payments grow and reliance on non-European service providers becomes more important. The ECB recognizes that Europe's dependency on foreign payment providers, particularly U.S.-based companies like Visa, Mastercard and big tech firms, poses long-term risks. This dependency became even more pronounced during global crises such as the COVID-19 pandemic and the war in Ukraine, which highlighted the vulnerabilities of relying on external suppliers for essential services, which Europe's payment infrastructure is considered to be (ECB, 2023a).

While the initial momentum for CBDCs stemmed from the rise of private currencies like stablecoins, strategic autonomy has emerged as a central theme only in later stages of the digital euro's development. In fact, before 2018, not a single central bank speech cited strategic autonomy as a motivation for the digital euro. By 2022, nearly half of all ECB speeches referenced this concern (Berg et al., 2024)

3.1.3 Financial exclusion

In the EU, more than 13 million adult citizens still do not have a bank account (WSBI, 2022), although this number has decreased over the years. Despite this progress, a portion of the population still faces challenges in accessing essential financial services, especially in countries like Romania, Bulgaria and Hungary. In the Netherlands, only 0.3% of adults do not have a bank account, however it could be that these people are 'unbanked' by choice. Many central banks see the possibility for CBDCs to increase financial inclusion (Auer et al., 2022; Esposito, 2022), although this will be mainly among underserved populations and not necessarily for people who are 'unbanked' by choice (Galotto & Vangelisti, 2022).

3.1.4 Decline in cash usage

The use of cash for payments across Europe has been steadily declining in recent years. In the Netherlands, for example, only one in five transactions is now made with cash, reflecting a broader trend seen across the Euro area (De Nederlandsche Bank, 2024b). This shift towards digital payments highlights the growing preference for electronic and contactless methods. However, despite this decline, the availability of public money remains important for the ECB's. Beyond its practical function as a means of payment, cash plays a role in preserving the direct link between citizens and the central bank, serving multiple important goals such as trust in the euro currency, accessibility and inclusivity (De Nederlandsche Bank, 2024b). In line with these trends, the ECB therefore has said: "in response to a decline in the use of cash, the Eurosystem could introduce a digital euro as an additional form of public money and means of payment" (ECB, 2020).

The privacy aspect is another reason why cash is still so relevant. Cash transactions provide a level of anonymity that digital payment methods (usually) lack, making them valuable for individuals who prioritize privacy. As cash usage declines, the ECB views the development of a digital euro as a way to retain the benefits of cash while adapting to the increasing digitization of payments (ECB, 2023a).

3.2 ECB's motivation

Building on the problems identified in Section 3.1, the ECB's motivations for a digital euro represent a blend of reactive measures to address risks and proactive efforts to achieve strategic objectives. Rather than solely responding to well-defined problems, the digital euro is framed as a forward-looking initiative and tries to achieve long-term societal, economic and strategic goals. The following objectives are presented by the ECB as the reason for why a digital euro is being developed:

3.2.1 Modernizing payments

As discussed in 3.1.4, the decline in cash usage across the Eurozone reflects a broader societal shift toward digital payment solutions. While this trend offers many conveniences, it also highlights the need to preserve the unique benefits of cash, such as its accessibility, universality and role as a public good. The ECB's vision for a digital euro aims to digitise cash by creating a payment solution that fits into a modern economy while maintaining the core attributes of physical currency. To achieve this vision, the ECB has outlined several objectives related to modernizing payments through the digital euro:

- **To Complement Cash in the Digital Age:** A digital euro would offer a digital payment option that maintains the benefits of cash as a public good, such as wide acceptance and ease of use, even in an increasingly digital society (ECB, 2021b)
- **Instant Settlement:** The digital euro would settle payments instantly (ECB, 2023a).
- **Multiple Use Cases:** The digital euro would be designed in a way that physical, online and person-to-person transactions are possible (ECB, 2023a).

- **Coexistence with Other Payment Forms:** The digital euro is intended to exist alongside euro cash and other electronic means of payment, offering additional freedom of choice to end users (ECB, 2023a).

3.2.2 Increasing payment resilience, trust and autonomy

Linked to 3.1.1 Rise of Private Currencies and 3.1.2 Lack of Strategic Autonomy, the digital euro is positioned by the ECB as a tool to enhance the resilience and sovereignty of the European payment system. Private currencies, such as stablecoins and the dominance of non-European payment providers have exposed vulnerabilities in Europe's financial ecosystem, raising concerns about dependency and trust. By offering a central bank-issued digital currency, the ECB aims to address these challenges, reinforcing the stability of the payment infrastructure while reducing reliance on non-European firms. The following objectives underline how the digital euro seeks to increase payment resilience, trust and autonomy:

- **Risk-Free Currency:** As money issued by the central bank, the digital euro would be risk-free, enhancing trust and stability in the payment system (ECB, 2023a).
- **Backup Payment System**: The digital euro could serve as a backup payment system, ensuring that everyone can continue to make payments if other systems are temporarily unavailable (ECB, 2023a). Whether caused by technical disruptions or geopolitical tensions, the digital euro would provide all users with access to a dependable payment method.
- **Reducing Dependency on Non-European Providers:** A digital euro would help reduce European reliance on foreign service providers, supporting strategic autonomy and resilience against geopolitical tensions and supply chain vulnerabilities (ECB, 2023a).
- **Enabling European Private Payment Solutions:** By providing a pan-European payment solution under European governance, a digital euro would encourage competition and innovation, driving down costs and fostering the development of new services with pan-European reach (ECB, 2023a).

3.2.3 Promoting inclusion and privacy

Linked to 3.1.3 Financial Exclusion and 3.1.4 Decline in Cash Usage, the digital euro aims to address two societal needs: ensuring financial inclusion and preserving the privacy benefits traditionally associated with cash. As cash usage declines, segments of the population without access to banking or digital payment systems risk being excluded from the economy. At the same time, the shift to digital payments has raised concerns about the loss of transactional privacy. The ECB positions the digital euro as a solution that promotes inclusivity and offers a payment method that respects user privacy and avoids the commercial exploitation of personal data. The following objectives underline how the digital euro seeks to promote inclusion and privacy:

- **Privacy and Security:** Emphasising privacy, a digital euro aims to offer a secure solution that fully respects users' privacy, with no commercial interests in monitoring payment patterns (ECB, 2023a). Unlike private payment solutions, the ECB has no commercial interest in monitoring payment patterns or storing identifiable user data. In line with the cash-like features it aims to replicate, the digital euro would achieve a high level of privacy, particularly for offline transactions.
- **Financial Inclusion:** Ensuring inclusivity by providing a basic service that is accessible to all, enabling individuals who may not have a bank account or payment card to participate in the digital economy (ECB, 2023a).

3.3 Stakeholders

This section examines the range of stakeholders involved in the development of the digital euro, highlighting their roles, interests and potential challenges. It categorizes stakeholders into three groups: EU institutions and policymakers, market stakeholders and the general public. To complement this analysis, a power-interest matrix mapping the influence and priorities of key stakeholders is provided in Appendix A.

3.3.1 EU institutions and policymakers

In this section, the roles and interests of key EU institutions involved in the development of the digital euro are described. The focus is on the ECB, national central banks within the Eurozone and EU policymakers and legislators.

3.3.1.1 European Central Bank

The ECB is the problem owner of the digital euro project and the central actor driving its development. As discussed in 3.1 and 3.2, the ECB's motivation for the digital euro stems from its mandate to preserve monetary sovereignty, address the decline in cash usage and promote financial inclusion. While the European Commission is leading the development of the regulatory framework for the digital euro, the ECB is responsible for its technical design and overall feasibility.

As the initiator of the digital euro, the ECB leads the research and design phases, working closely with national central banks and other stakeholders. The ECB also focuses on the technical aspects, such as offline capabilities, privacy safeguards and distribution model. They try to ensure that the digital euro is designed to meet the practical needs of users, while addressing systemic goals like financial stability and accessibility. As the problem owner, the ECB's leadership and technical expertise are central to translating policy objectives into a functional, user-friendly digital currency that complements existing monetary systems.

3.3.1.2 National Central Banks within the Eurozone

The National Central Banks within the Eurozone play a critical supporting role in the development of the digital euro. As part of the Eurosystem, these central banks collaborate closely with the ECB in co-designing and assessing the technical and policy aspects of the digital euro. Their involvement ensures that the digital euro aligns with the specific economic and financial conditions of each member state, safeguarding regional financial stability while advancing the overarching goals of the Eurosystem. This collaboration is formalised through governance structures such as the High-Level Task Force on Digital Euro, which includes representatives from central banks who contribute expertise and regional perspectives to guide decision-making (Eurosystem, 2024). Additionally, national central banks act as intermediaries between the ECB and national stakeholders, including commercial banks, payment service providers and policymakers. This dual role ensures that local perspectives are integrated into the design process while fostering acceptance and collaboration among key actors. If and when the digital euro would be implemented, national central banks would probably play a role in enforcing compliance with the regulations in place.

The central banks' primary interest lies in ensuring that the digital euro complements existing monetary policies and does not disrupt national financial ecosystems, as for example argued in a speech by the Governor of the Banque de France (Villeroy de Galhau, 2023), or on the website of Banca D'Italia (Banca d'Italia, n.d.). They aim to maintain stability in their respective regions by addressing potential risks, such as disintermediation of commercial banks or adverse effects on credit provision. By contributing their expertise on regional payment habits, regulatory

environments and stakeholder needs, national central banks try to play a role in tailoring the digital euro to meet diverse local requirements.

3.3.1.3 European Union Policymakers and Legislators

European policymakers and legislators are responsible for establishing the regulatory framework and strategic direction for the digital euro. Among the key EU institutions involved, the European Commission (EC) and the European Parliament have distinct roles that contribute to the project's development. The European Commission leads the regulatory process, working closely with the ECB and member states to define the legal and operational framework of the digital euro. This includes drafting legislative proposals concerning the digital euro (Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Establishment of the Digital Euro, 2023), as well as engaging with stakeholders, such as national governments and financial institutions. The European Parliament debates and potentially approves the legislative proposals developed by the European Commission. As the EU's directly elected body, the Parliament represents the interests of European citizens. The Council of the European Union, representing member state governments, also provides input and must approve the final legislative package before the digital euro could be implemented. Therefore, reaching an agreement among these three European institutions is necessary for the digital euro to progress and gain formal acceptance.

Policymakers and legislators have varying priorities, reflecting the economic and political contexts of different member states. Some may emphasise financial inclusion, while others focus on financial stability or competition in the payments market. Based on the explanatory memorandum from the legislative proposal for the digital euro (Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Establishment of the Digital Euro, 2023), the European Commission's objectives and reasoning align significantly with the ECB's goals. Both institutions emphasise maintaining monetary sovereignty, adapting to digitalisation, ensuring trust in the euro and promoting accessibility and financial inclusion

3.3.2 Market stakeholders

Market stakeholders are actively involved in the digital euro project through various working groups, such as the Digital Euro Market Advisory Group and the Euro Retail Payments Board. These forums provide opportunities for collaboration between the ECB and market participants, including commercial banks, payment service providers, fintech companies, businesses and retailers. Each stakeholder group contributes its perspectives and expertise to the development of the digital euro, reflecting its position and priorities within the payment ecosystem. This section explores the roles, interests and potential challenges faced by these market stakeholders in the light of the digital euro.

3.3.2.1 Commercial Banks and Financial Institutions

Commercial banks and financial institutions play a significant role in the development and potential implementation of the digital euro. Through various working groups, including the Digital Euro Market Advisory Group and the Euro Retail Payments Board (ERPB), banks have been involved in discussions and consultations on the design and distribution of the digital euro since the investigation phase (ECB, 2021a, 2024g). These institutions are expected to act as distributors of the digital euro once it is implemented. Banks are also involved in the Rulebook Development Group through the European Banking Federation. This Rulebook Development Group is creating a standardised set of rules, standards and procedures that supervised intermediaries must follow when distributing the digital euro (ECB, 2024d).

One of the primary concerns for commercial banks is the potential impact of the digital euro on their traditional business models. The introduction of a central bank digital currency raises the

possibility of disintermediation, where consumers may transfer deposits from commercial banks to digital euros. A study commissioned by the European Banking Federation and conducted by Copenhagen Economics estimated that a digital euro with a €3,000 holding limit could lead to an outflow of up to €739 billion from commercial banks (Copenhagen Economics, 2023). The report also highlighted that the current proposals for the digital euro might not fully achieve their intended objectives and could increase costs for the financial system, potentially affecting financial stability and consumer welfare during periods of market uncertainty. These findings underline the expressed concerns of commercial banks, which generally prefer a digital euro design that mitigates these risks through measures such as holding limits and restrictions on central bank-to-consumer relationships. For these banks, it is important that their current business model is safeguarded.

Throughout the development process, commercial banks have expressed reservations about the digital euro. In earlier stages, banks such as ING, Rabobank and Commerzbank highlighted risks related to financial stability and the potential erosion of their role in the financial system on their websites (Boonstra, 2019, 2022; ING, 2020; Ledger Insights, 2021). ING emphasised the importance of a cautious approach to central bank digital currencies, while Rabobank called for thorough evaluation before implementation. Commerzbank described the digital euro as a potential shift in power toward the ECB, emphasising the need for balanced design choices. These concerns have continued in later stages, with banks actively working to protect their business models. For instance, Crédit Agricole's response to the EC's legislative framework stressed the importance of designing the digital euro in a way that does not undermine the banking sector's capacity to provide loans and financial services (Crédit Agricole, 2023).

Based on the analysis, commercial banks appear open to the concept of a digital euro and are actively involved in its development. However, their support largely depends on a design that, in their view, minimises risks to their current business models and safeguards financial stability.

3.3.2.2 Payment Service Providers & Fintech companies

Payment Service Providers (PSPs) also have an important role in the digital euro project. They will be responsible for the end-user relationships and the retail payment services of the digital euro. This covers tasks such as onboarding users, facilitating transactions and providing services that enable payments between digital euro users, as defined in the Digital euro glossary (ECB-PUBLIC, 2023). PSPs also contribute to the development of the digital euro by participating in a number of working groups related to the project. It is worth noting that some commercial banks also function as PSPs, depending on whether they offer payment services in addition to their 'traditional' banking activities.

For PSPs, the digital euro presents both opportunities and challenges. Basic digital euro services must be provided to end users free of charge, but PSPs will receive transaction fees from businesses and other parties, similar to current payment models. These fees, which must be conform to market standards, represent the primary revenue stream for PSPs in the digital euro ecosystem. However, PSPs will need to transition from their current payment business to digital euro transactions to fully capitalise on this revenue, which will depend on the level of demand and user adoption. Market responses to the digital euro reflect optimism. Berg et al. (2024) found that stock prices of European payment firms increased following positive announcements on the digital euro, signalling market confidence in its potential benefits.

Fintech companies could see the digital euro as a platform for creating value-added services. These could include digital wallets, payment analytics and other innovations that complement the core payment functionalities of the digital euro. They could leverage the digital euro to disrupt traditional banking models and capture EU-wide market share through innovative products. It is

in their interest to drive adoption of new technologies since this usually fits their digital nature. The primary interest of fintech companies in the digital euro lies in its potential to create additional opportunities for innovation and market expansion. While they are already well-positioned to innovate and disrupt traditional financial services without relying on the digital euro, the project could represent a new platform on which they can build. For instance, Nexi, a European pay-tech company, has been involved in prototyping front-end solutions for the digital euro (Nexi, 2022). This demonstrates how fintech companies can benefit from the digital euro by creating additional business opportunities.

3.3.2.3 Businesses and Retailers

An efficient and convenient payment system is important for businesses and retailers. In their role of accepting and processing transactions, they engage with financial institutions such as PSPs to streamline these operations. It is in their interest to have low transaction costs, secure and convenient processing of payments and to keep up with their customers' demand. A well-designed digital euro could possibly foresee in this.

Businesses and retailers are the end-point facilitators of transaction and are therefore an important player in the payment ecosystem. Although current payment methods already function efficiently in countries like the Netherlands, the digital euro might have the potential to form a competitive payment method by offering a secure, low-cost and convenient system. However, if the digital euro is granted legal tender status, businesses may be required to accept it for payments. While this could benefit consumers, it may necessitate investments in new payment terminals or software upgrades, which could be costly for businesses. Some big retailers have been involved in discussions on the digital euro through the Digital Euro Market Advisory Group, such as representatives from IKEA (ECB, 2021a), so they could contribute insights during the investigation phase.

The Study on Digital Wallet Features provides insights into merchants' perspectives on electronic payments. Merchants generally view digital payment methods positively, citing benefits such as faster transaction processing, reduced reliance on cash and improved security. Their willingness to adopt new payment methods, including the digital euro, is influenced by several factors, such as customer demand, transaction fees, ease of use and the financial and technological investment required (Kantar Public, 2023). Regional differences exist in merchants' readiness to adopt digital payment systems. For example, merchants in Nordic countries are accustomed to advanced digital payment solutions, while those in parts of Germany raised concerns about infrastructure challenges, such as unreliable internet connections (Kantar Public, 2023). Additionally, merchants frequently highlight concerns about the high fees associated with existing payment solutions, which they hope a digital euro might mitigate (Merchant Payments Coalition Europe, 2024). In the same document, they emphasise the importance of low transaction fees and proper integration into the existing payment systems to ensure that the digital euro meets merchants' needs.

In summary, businesses and retailers are open to adopting the digital euro if it provides tangible benefits, such as reduced costs and improved transaction efficiency, without imposing significant burdens on their operations.

3.3.2.4 Financial Institutions and Central Banks outside the Eurozone

Financial institutions and central banks outside the Eurozone are unlikely to play a direct role in the development or implementation of the digital euro. However, the project holds significant relevance for these actors as a potential case study for their own financial systems. Central banks globally are closely monitoring the progress of the digital euro as part of the broader exploration of CBDCs. In the case of CBDC, there is the potential for a last-mover advantage for central banks

that adopt a more cautious approach, allowing them to learn from the experiences of early adopters (Koning, 2021).

The extent of the digital euro's impact on international actors will depend largely on consumer uptake and the regulatory frameworks governing its use outside the Eurozone. If legal frameworks permit widespread usage of the digital euro beyond Eurozone borders, foreign central banks and financial institutions may need to play a more active role in understanding and responding to these dynamics. For instance, the availability of digital euros for international payments could increase foreign interest in collaborating or adapting to the new payment ecosystem. Conversely, restrictive regulations on cross-border use might limit its influence on non-Eurozone economies, reducing the need for active involvement from these actors.

3.3.3 General public

This section examines the role of the general public in the development and adoption of the digital euro. It discusses how consumer interest groups represent public concerns and advocate for features such as privacy, accessibility and fairness.

3.3.3.1 Consumer Interest Groups

Consumer interest groups act as advocates and representatives for the general public. These groups actively engage in discussions with policymakers and regulators, in this case to ensure the digital euro addresses consumer interests and rights. They strive to ensure that a digital euro would be safe, private, accessible, transparent and fair for its users. The European Consumer Organisation (BEUC) advocates for a digital euro that ensures privacy in both offline and online transactions, providing consumers with a public alternative to private digital payment methods (BEUC, 2023). BEUC also underscores the importance of free access to an inclusive digital payment method for all individuals, while maintaining the availability and accessibility of cash for those who prefer it. Different consumer groups may prioritise varying aspects of the digital euro. For example, privacy organizations advocate for cash-like anonymity in transactions, while consumer advocacy groups focus on inclusivity and low-cost usage to ensure the digital euro benefits all societal segments. Insights from the Study on Digital Wallet Features (Kantar Public, 2023) indicate that consumers value simplicity, reliability and integration with existing payment systems. A study from the DNB highlighted that consumers' potential usage of a digital euro depends on the interest rate offered and the public's need for security and privacy (Bijlsma et al., 2021).

For the digital euro to stand out, it must offer clear advantages that go beyond existing options. Privacy, accessibility, cost-effectiveness, reliability and user convenience are areas where it could differentiate itself. By addressing these areas, the digital euro could potentially become an alternative payment method for the general public.

3.4 Conflicting Interests

The development and implementation of the digital euro face several conflicting interests and dilemmas among stakeholders. These challenges stem from the diverse priorities and expectations of institutions, market stakeholders and the general public. This section identifies and examines the areas where such conflicts emerge, based on the identified motivations and stakeholder analysis.

3.4.1 Preserving Financial Stability vs. Encouraging Adoption

A significant dilemma lies in designing a digital euro that supports financial stability while encouraging its adoption among the public. Commercial banks, for example, have expressed concerns about disintermediation, where large-scale transfers from bank deposits to digital euros

could disrupt their traditional business models. To mitigate this, holding limits and other restrictions are being considered. However, such constraints might reduce the digital euro's appeal to consumers, potentially limiting its uptake and effectiveness as a widely adopted payment solution.

3.4.2 Privacy vs. Traceability

The general public and consumer advocacy groups advocate for high levels of privacy in digital euro transactions, particularly for offline payments. They emphasise the need for cash-like anonymity to protect user data and ensure fairness. On the other hand, regulatory authorities require sufficient traceability to prevent illegal activities such as money laundering and tax evasion. Balancing these conflicting demands might be a challenge in the design and regulatory framework of the digital euro.

3.4.3 Offline Functionality vs. Security

Ensuring offline functionality is viewed as a key feature of the digital euro to mimic the accessibility of cash, especially in areas with limited internet connectivity or during system outages. However, implementing offline functionality raises security and technical concerns, such as risks of fraud, double spending and counterfeit digital euros. Balancing these risks while ensuring the usability of the digital euro in offline scenarios is a significant design challenge.

3.4.4 Public Good vs. Private Profit

As a public good, the digital euro is intended to serve societal interests, such as accessibility and inclusivity, while complementing existing payment systems. However, PSPs and commercial banks who both will be intermediaries in the digital euro ecosystem, are profit-driven entities. This raises a dilemma about how to incentivise these private actors to distribute and manage the digital euro without compromising its status as a public good.

3.4.5 Cost-Effectiveness vs. Legal Tender Obligations

Businesses and retailers have highlighted concerns about the potential costs of upgrading payment infrastructure to support the digital euro, particularly if adoption rates are low. However, if the digital euro would get legal tender status, thereby ensuring universal acceptance, it might impose undue financial and administrative burdens on businesses, particularly small and medium-sized enterprises. Balancing cost-effectiveness with regulatory requirements could therefore be a challenge.

3.5 Conclusion

This chapter addressed **Sub-question 1:**

What are the goals of the Eurosystem and stakeholders regarding the digital euro?

Through an analysis of the ECB's problem identification, motivations and stakeholder perspectives, several key goals and interests have been identified. The ECB's primary motivations for the digital euro are rooted in preserving monetary sovereignty, adapting to the decline of cash usage and fostering financial inclusion. The rise of private currencies, particularly stablecoins and the dependency on non-European payment providers have further emphasised the need for a digital euro to ensure strategic autonomy and payment resilience. Additionally, the ECB envisions the digital euro as a modern, inclusive and privacy-conscious payment system that complements cash and existing payment solutions.

The chapter also explored the diverse priorities of stakeholders. EU policymakers and national central banks aim to balance economic stability with the goals of financial inclusion and competition. Market stakeholders, such as commercial banks, PSPs and fintech companies, view

the digital euro both as an opportunity for innovation and a potential challenge to traditional business models. Businesses and retailers would be open to adopting the digital euro if it reduces costs, improves efficiency and aligns with consumer demand, provided it does not impose significant infrastructure or regulatory burdens. Consumer interest groups advocate for privacy, accessibility and fairness. The conflicting interests among stakeholders, as discussed in Section 3.4, highlight the dilemmas in designing a digital euro that satisfies all parties. Especially the trade-off between preserving financial stability and encouraging adoption seems highly relevant and complex.

4. Design and Design Space

Chapter 4 examines the design and design space of the digital euro. It begins by defining the design space in terms of fundamental and variable features that shape the digital euro's functionality and adaptability. Following this, the chapter presents the most-likely digital euro design based on ECB and EC proposals. It outlines the technical, functional, regulatory and monetary aspects of the design, highlighting areas that are well-defined and those still under discussion. To further explore the possibilities within the design space, two alternative designs are explored: a privacy-focused digital cash option and an incentivised onboarding approach. These alternatives emphasise different priorities and illustrate the trade-offs inherent in achieving the goals of the digital euro. Then, the chapter evaluates existing digital payment solutions on the requirements identified in 4.2. The chapter concludes with an evaluation of the different designs that were discussed during the chapter and tries to answer sub-questions 2, 3 and 4.

Clarification of design terminology

This chapter introduces several terms to structure the exploration of the digital euro's design. To aid understanding, these terms are defined as follows:

- *Design Features*: The building blocks of the digital euro system. These include both fundamental features, which are indispensable for the digital euro to function as a central bank digital currency and variable features, which allow for customisation to address technical, functional, regulatory and monetary needs.
- *Functions:* The specific roles or purposes that design features are intended to fulfil. Each design feature is directly associated with one or more functions critical to the digital euro's operation. For example, privacy design serves functions such as securing personal data and enhancing user trust.
- *Options:* The potential methods or ways to implement specific design features or fulfil their associated functions. These options represent practical approaches for achieving the desired outcomes of a feature or function. In the institutional morphological chart, options are presented in columns, corresponding to each feature or function listed in the first column.
- *Requirements:* High-level objectives that outline what the digital euro must achieve to meet stakeholder needs and policy goals. Requirements generally indicate what the digital euro must do (e.g., enhance financial inclusion, ensure compliance with regulatory frameworks) rather than specific features it must have. These are used to evaluate how well different design options align with the overarching goals of the digital euro.

4.1 Determining the Design Space

The design space encompasses all possible configurations and features that can define a product or system. For scoping purposes, in the case of the digital euro, we divide the design space in fundamental and variable features.

4.1.1 Fundamental design features

The fundamental features consists of design features that if removed, it would compromise the digital euro's ability to function as a legitimate and effective CBDC in the Eurozone, thereby changing its fundamental characteristics and purpose. Bjerg (2017) introduces a definition of CBDCs. They are electronically registered, on the balance sheet of a central bank and are universally accessible. Following this definition, Bjerg fits CBDC into a Venn diagram to compare it with three existing forms of money, as shown in figure 6. Here is shown that CBDC forms a unique combination of the three existing forms of money.

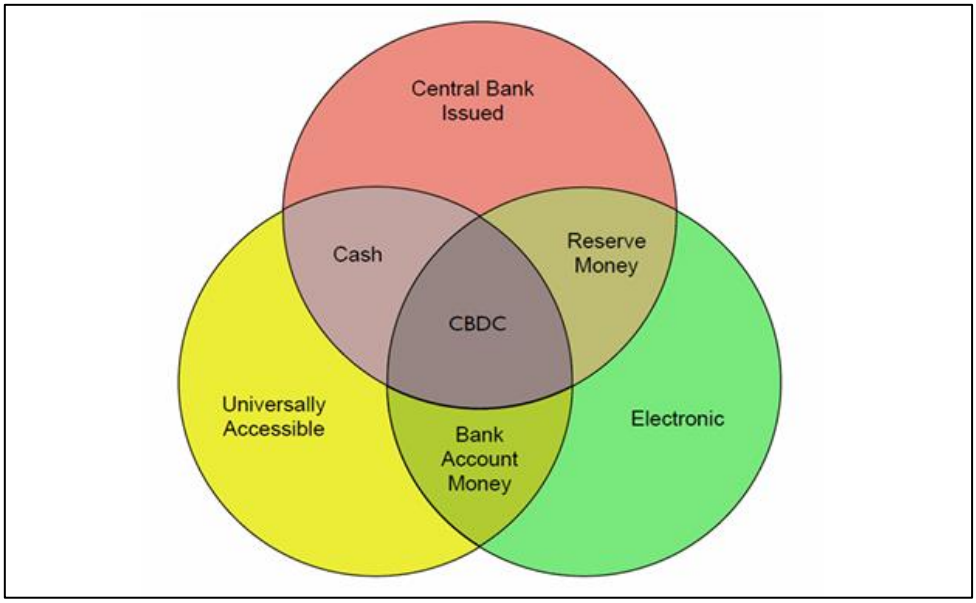

Figure 6: The features of CBDC (Bjerg, 2017)

To narrow the scope of the design space, the definition of Bjerg (2017) is altered based on the specific case of the digital euro. When proposing alternative digital euro designs, these designs must at least have these fundamental features:

1. **Suitability for digital transactions:** The digital euro must be capable of facilitating card, online and other digital payments, as this is essential to its function as a central bank digital currency (CBDC). While Bjerg (2017) identifies the "electronic" nature of a CBDC as a defining characteristic, the context of the digital euro necessitates a broader focus on digital transactions to emphasise its primary function as a payment instrument.
2. **Issuance by the ECB:** The digital euro must be issued by the ECB to ensure its legitimacy as an official CBDC within the Eurosystem. This makes the digital euro a direct liability of the ECB, similar to physical euro notes and coins. It guarantees that it is backed by the stability and credibility of the central bank. In this way a digital euro would be a digital counterpart to physical euro notes and coins.
3. **Currency parity:** The digital euro must maintain a one-to-one parity with the physical euro to ensure consistency and stability in its valuation. This feature establishes the digital euro as

a direct digital counterpart to the physical euro, reinforcing its role as public money. While Bjerg's (2017) definition of CBDCs does not explicitly include currency parity, it is a necessary characteristic in the context of the digital euro. One of the drivers for its development was the rise of private stablecoins, which aim to maintain a stable value by pegging to fiat currencies, including the euro. For the digital euro to provide a viable public alternative and support monetary sovereignty, it must reliably maintain the same value as a physical euro.

4. **Universal access in the Eurozone:** Universal access to the digital euro is essential to ensure it serves as public money within the jurisdiction of the ECB. This characteristic aligns with the fundamental role of central banks in providing accessible money to all users within their mandate.

4.1.2 Variable design features

Variable design features provide flexibility in defining the operational and functional aspects of the digital euro without compromising its fundamental characteristics. These features allow for customisation based on technical capabilities, regulatory requirements, user needs and monetary policy objectives. Divided into four categories, technical, functional, regulatory and monetary, these features represent the key design considerations shaping how the digital euro could function within the Eurozone and interact with the existing financial ecosystem.

4.1.2.1 Technical Design

The technical design of the digital euro defines the underlying architecture and operational mechanisms necessary for its implementation. This includes decisions on the system structure, privacy features and infrastructure.

Account or token based: The digital euro's technical design includes a decision between an account-based or token-based system, each with implications for privacy, security and operational mechanisms. In an account-based system, digital euros are linked to user accounts managed by intermediaries, such as banks. A token-based system treats the digital euro as a bearer instrument, where ownership is determined by possession of the digital token. In a token-based model, the digital euro functions as a digital unit of value that users can transfer directly to one another. Similar to physical cash, the token itself embodies the value it represents and can be exchanged without the need for an intermediary (Kramer, 2024).

Privacy design: Designing the digital euro requires addressing varying levels of privacy to balance user trust, data protection compliance and operational considerations. Payment digitisation often produces transaction data that can be shared and utilized by counterparties, raising concerns about user privacy in comparison to cash-based transactions (Auer et al., 2022). Privacy levels for the digital euro could range from pseudonymous transactions, where user identities are not directly tied to transactions but can still be traced, to fully anonymous transactions resembling cash or combinations in the form of hybrid models. However, it can be complicated to achieve high levels of privacy while complying with regulations (e.g. Know Your Customer (KYC) and Anti-Money Laundering (AML)) (Darbha & Arora, 2020)

Technical infrastructure: Developing a secure and scalable (digital) infrastructure is key for the digital euro. The choice of infrastructure is dependent on the needs for fast transactions, energy efficiency and integration with existing payment systems. The technical infrastructure also covers the type of banking system that will be used to settle transactions. Decisions regarding the underlying technology, such as centralised systems or distributed ledger technologies, will influence the digital euro's resilience and functionality. Furthermore, it will be needed to determine the roles of public and private actors in managing this infrastructure.

4.1.2.2 Functional Design

The functional design of the digital euro focuses on its practical applications and user interaction. This section explores features that define the digital euro's usability in various contexts, where efficiency, accessibility and adaptability are of importance.

Business users and payments: A consideration in the functional design of the digital euro is determining the range of users who will have access to it. While the general public is expected to be the primary user group, extending access to businesses could expand the digital euro's applicability. For businesses, access to the digital euro might streamline transactions, lower costs associated with intermediaries and improve efficiency in payment processing. However, enabling business-to-business (B2B) payments could introduce additional complexities.

Conditional payments & programmable money: Whether the digital euro could be 'programmable' will have great consequences for its uses. A programmable digital euro, similar to vouchers, would enable transactions to occur under specific conditions, allowing it to be used for targeted purposes defined by those conditions. Conditional payments allow transactions to be executed automatically when predefined conditions are met, such as recurring payments or pay-per-use services.

Offline capability: Offline capability has been identified by potential users as one of the features that could distinguish the digital euro from existing payment solutions (Kantar Public, 2023). It refers to the ability of users to conduct digital euro transactions without an active internet connection. This design feature is particularly relevant for ensuring the digital euro's usability in areas with limited connectivity or during emergencies. It is also seen as a way to enhance privacy. Various approaches to implementing offline capability include hardware solutions, such as secure chips in payment cards and software options like encrypted smartphone applications. Each option involves trade-offs in security and usability. Addressing challenges like preventing double spending and ensuring system synchronisation could be difficult.

User interface and interaction: Determining how users will interact with the digital euro is a relevant design feature. This includes deciding whether, for example, transactions will be conducted through mobile applications, QR codes, NFC technology or physical cards. The design should aim to provide a balance of convenience, security and accessibility to meet the needs of a diverse range of users with varying levels of technological proficiency.

4.1.2.3 Regulatory Design

Regulatory design focuses on the legal and compliance framework necessary for the digital euro's implementation and operation. This includes considerations such as legal tender status, user accessibility, adherence to EU regulations like AML/KYC/Counter Terrorism Financing (CTF) measures and the distribution mechanisms for the digital euro.

Legal tender: The design feature of legal tender is related to whether the digital euro will be recognized as an official form of money, comparable to physical cash and coins. According to Article 128(1) of the Treaty on the Functioning of the European Union , the ECB is authorized to issue banknotes and coins as legal tender. However, the traditional interpretation of legal tender has been confined to physical cash, raising questions about how a digital euro could align with these definitions (Mooij, 2023). If the digital euro is granted legal tender status, it would mean that it must be universally accepted for all debts, public charges and taxes within the Eurozone. This would enhance its usability and ensure its equivalence to cash. However, the shift to include digital currency as legal tender also presents complexities. For example there are debates about whether the digital euro could have features such as remuneration, which may conflict with traditional notions of legal tender (Mooij, 2023)

Accessibility (Geographical scope) The accessibility of the digital euro refers to defining which individuals, businesses and entities will be allowed to use it. This design feature directly affects its scope and user base. Determining accessibility involves considering whether the digital euro will be restricted to residents within the Eurozone, extended to international users or made universally accessible. It will be up to legislators to determine who can eventually use a digital euro.

Financial crime regulation: Ensuring the digital euro adheres to EU regulations for AML, KYC and CTF is an important design feature. This involves determining the frameworks and operational structures to prevent financial crime, while also maintain user trust and privacy. Decisions must address how compliance responsibilities will be allocated between intermediaries. It should also specify how the digital euro will integrate with existing regulatory systems.

Distribution channels: The distribution of the digital euro is a significant design feature, involving decisions about how it will be delivered to end users and the roles of public and private actors in this process. Potential options include direct distribution by the ECB and national central banks, or leveraging private sector intermediaries such as commercial banks, fintech firms, or digital wallet providers. These distribution models align with the retail CBDC architectures outlined by Auer & Böhme (2021) (see figure 2 in Chapter 1.1.1), which classify CBDC systems into three categories: direct, hybrid and intermediated. Each architecture defines a different role for the private sector, ranging from no involvement in single-tier models to active participation in two-tier systems for onboarding users and processing payments. Determining the appropriate distribution channel will shape how the digital euro interacts with the existing financial ecosystem and its accessibility to users.

4.1.2.4 Monetary Design

The monetary design of the digital euro focuses on how it will function within the broader monetary system and its potential impact on financial stability, monetary policy and consumer behaviour. This includes considerations such as remuneration, holding limits and integration with existing monetary tools.

Renumeration: Deciding whether to offer interest on digital euro holdings is a significant aspect of its monetary design, as it directly affects its attractiveness compared to other financial assets. The options for remuneration include a fixed interest rate, which could also be set to zero, tiered interest rates that vary depending on the amount held, or variable interest rates linked to specific economic conditions. Introducing remuneration could encourage adoption by making the digital euro more appealing to users, as noted by Bijlsma et al. (2021). However, it also raises considerations about its role as a store of value and its interaction with traditional bank deposits, which could have implications for financial stability (Laguna De Paz, 2023).

Holding limits: Holding limits involve implementing caps on the amount of digital euro that individuals or entities can hold. This design feature is primarily aimed at mitigating risks to financial stability, such as large-scale withdrawals from commercial banks that could disrupt the banking system. By setting limits, the digital euro would act more as a payment instrument rather than a savings tool. However, holding limits might reduce its attractiveness to consumers, as they may perceive it as less flexible compared to traditional bank accounts or other digital payment options.

Monetary policy functionality: The design of the digital euro could impact how the ECB executes and adjusts monetary policy. By integrating the digital euro with existing tools, the ECB may have new ways for influencing liquidity, consumption and investment. For instance, a study from the

Bank of Canada (Bhattarai et al., 2024) highlights how CBDCs, depending on their substitutability with deposits and whether they bear interest, can magnify or mitigate the effects of traditional monetary policy shocks. Design considerations include whether the digital euro will serve as an active instrument for monetary policy (e.g., via interest rate adjustments) or as a complementary liquidity mechanism. Its ability to amplify or smooth the effects of policy changes will depend on structural decisions, such as its interaction with reserve systems and its integration into broader economic models.

Pricing model for the digital euro: The design feature of the pricing model for the digital euro involves deciding how costs and revenues related to its usage and distribution will be managed. It encompasses decisions on whether fees should be charged, who bears the costs and how revenue is distributed among stakeholders. Different approaches could be adopted, depending on policy goals and market dynamics. There are several approaches possible for this. One approach could offer basic digital euro services free to individuals, with merchants paying regulated fees similar to current payment systems. Alternatively, a tiered structure could allow fees for value-added services while keeping basic transactions free. Another option involves subsidising private intermediaries to lower costs or establishing fee caps to protect consumers and merchants from excessive charges.

4.1.3 Conclusion Design Space

In conclusion, the design space of the digital euro includes both fundamental and variable features. The fundamental features, such as transaction suitability, ECB issuance and currency parity, are essential for maintaining the digital euro's core functions and legitimacy.

Variable features, divided into technical, functional, regulatory and monetary categories, offer flexibility to adapt the digital euro to different needs and regulatory environments. These include considerations like privacy design, offline capability, legal tender status and monetary policy tools. This framework allows for thoughtful exploration of how the digital euro can be effectively designed for the Eurosystem.

On the next page, table 1 summarises section 4.1 by giving an overview of the identified digital euro design features:

Table 1: Overview of digital euro design features

Category	Design feature	Description
Fundamental	Suitability for digital transactions	Ensures the digital euro facilitates various payment methods
	Issuance by the ECB	Guarantees the digital euro's legitimacy as a central bank liability
	Currency parity	Maintains a one-to-one value with the physical euro
	Universal access in the Eurozone	Providing inclusive public digital money for all users within its jurisdiction.
Technical	Account or token-based	Defines the ownership structure
	Privacy design	Determines the balance between anonymity and compliance with regulations
	Technical infrastructure	Specifies the technological foundations, including centralised or distributed systems
Functional	Business users and payments	Decides whether businesses will have access and its implications for payment ecosystems
	Conditional & programmable money	Explores features like recurring payments and conditional transactions
	Offline capability	Determines the availability of making transactions without an internet connection
	User interface and interaction	Defines the channels and devices through which users engage with the digital euro
Regulatory	Legal tender	Determines whether the digital euro is recognized as a full equivalent to cash
	Accessibility	Defines who can access the digital euro, including Eurozone residents and international users
	Financial crime regulation	Ensures compliance with AML, KYC and CTF regulations
	Distribution channels	Determines whether distribution is direct, hybrid or intermediated using private entities
Monetary	Renumeration	Considers offering interest to make the digital euro more attractive
	Holding limits	Considers holding caps to prevent risks to financial stability
	Monetary policy functionality	Explores integration with existing monetary tools to influence economic activity
	Pricing model	Defines costs and revenue allocation for users and intermediaries

4.2 Digital euro design requirements

In the design science process, requirements serve as the bridge between the identification of problems and the development of solutions. For the definition of requirements, see the introduction of Chapter 4.

4.2.1 ECB requirements

In 2020, the ECB outlined a set of design requirements for the digital euro (ECB, 2020), providing a framework for addressing both scenario-specific and general considerations. These requirements aim to ensure the digital euro fulfils its intended purpose while adhering to technical, functional and regulatory standards. The requirements were developed in response to potential scenarios that could drive the digital euro's issuance and are categorised into two types: scenario-specific requirements, which address particular contexts and general requirements, which are applicable across all scenarios. A full list of these requirements is given in Appendix B. For this design study, not all ECB requirements were included, but only those for which the scenario is relevant and in line with the ECB's current intentions. The requirements that were included are shown below and have been renumbered.

One of the scenario-specific requirements, **R1**: **Cash-like features**, highlights the importance of replicating the key attributes of cash to address the decline in its usage. This includes offline usability, privacy protection and accessibility.

Other scenario-specific requirements include **R2**: **Enhanced digital efficiency**, which emphasises the need for the digital euro to leverage state-of-the-art technology to ensure fast, cost-effective and user-friendly transactions. The digital euro should also integrate well with private payment systems to maximize usability. Additionally, **R3**: **Backup system** addresses the need for a reliable payment alternative that can function even during disruptions to existing payment systems, thereby improving the resilience of our payment ecosystem.

From a general perspective, **R4**: **Controlled circulation** focuses on ensuring the digital euro remains a practical payment tool rather than an investment asset, minimising risks to financial stability. **R5: Compliance with regulatory frameworks** underscores the importance of meeting EU regulations to build trust and ensure secure adoption. Furthermore, **R6**: **Easy accessibility** throughout the Eurozone ensures that the digital euro will be available to all residents, including those without traditional banking access, while **R7**: **Conditional use by non-euro area residents** establishes clear guidelines to prevent risks like volatile capital flows and exchange rate fluctuations.

4.2.2 Requirements derived from the stakeholder analysis (Chapter 3)

Building on the ECB's requirements, additional insights from stakeholder analysis in Chapter 3 have informed a complementary set of requirements to address broader societal, economic and strategic goals. The requirements marked with an asterisk have been drafted by the author and added to the ECB requirements. These are as follows:

R8*: Promoting Strategic Autonomy: The digital euro should reduce reliance on foreign payment providers and ensure payment resilience in the face of geopolitical risks or external disruptions. This aligns with the ECB's concern about Europe's dependency on non-European providers.

R9*: Cost-Effective Design for Businesses and Consumers: Ensuring low transaction costs for businesses and consumers can improve adoption while addressing concerns from merchants and retailers about infrastructure upgrades.

R10*: Inclusivity for Underserved Populations: Financial inclusion was a recurring theme, particularly in regions with low banking penetration. The digital euro must be accessible to underserved populations while remaining simple to use.

R11*: Enhancing Privacy: The digital euro should prioritise user privacy by incorporating robust safeguards against the misuse of transactional data. This includes offering features that try to achieve the anonymity of cash transactions while adhering to necessary compliance measures.

R12*: Clear advantages over existing options: For the digital euro to stand out to consumers, it must provide clear advantages beyond those offered by existing payment solutions. The digital euro must demonstrate why it is necessary and valuable within the existing financial ecosystem.

4.2.3 Requirements overview

To summarize the most important requirements, table 2 provides an overview that includes both ECB-derived and stakeholder-informed requirements. It includes the requirement, a description of the requirement and the source (and actor from Chapter 3 if applicable).

Table 2: Overview of design requirements for the digital euro

Requirement	Description	Source
R1: Cash-like features	The digital euro should replicate important features of cash	Scenario-Specific, ECB (2020)
R2: Enhanced digital efficiency	The digital euro should use modern technology to ensure fast, user-friendly, and cost-effective transactions	Scenario-Specific, ECB (2020)
R3: Backup system	The digital euro should offer a reliable alternative payment option that remains functional even during disruptions in other payment systems.	Scenario-Specific, ECB (2020)
R4: Controlled circulation	The digital euro should be designed to prevent excessive use as an investment, ensuring it remains a practical payment tool.	General, ECB (2020)
R5: Compliance with regulatory framework	The digital euro must meet all applicable EU regulations to ensure trust and secure adoption.	General, ECB (2020)
R6: Easy accessibility throughout the Eurozone	The digital euro should be available to everyone in the Eurozone, including people without access to traditional banking.	General, ECB (2020)
R7: Conditional use by non-euro area residents	The digital euro should have clear rules for use by non-Eurozone residents.	General, ECB (2020)
R8*: Prompting strategic autonomy	The digital euro should reduce reliance on foreign payment providers to strengthen Europe's financial independence and resilience.	Chapter 3 (EC, ECB)
R9*: Cost-effective for businesses and consumers	The digital euro should keep transaction costs low to encourage adoption and avoid extra expenses for businesses or consumers.	Chapter 3 (Businesses, Retailers, general public)

R10*: Inclusive	The digital euro should be accessible and easy to use, especially for people who are currently excluded from the financial system.	Chapter 3 (EC, ECB, consumer interest groups)
R11*: Enhancing privacy	The digital euro should protect user privacy by limiting how transaction data is collected and used, while still meeting legal requirements.	Chapter 3 (General public, consumer interest groups)
R12*: Clear advantages over existing options	For the digital euro to stand out to consumers, it must provide clear advantages beyond those offered by existing payment solutions.	Chapter 3 (General public)

In section 4.7 Design evaluation, these requirements are used to evaluate different digital euro designs and existing payment solutions.

4.3 Institutional morphological chart creation

The institutional morphological chart created in this chapter is an adaptation of the traditional morphological chart used in engineering design (such as outlined by Dym et al. (2014)). While the traditional chart primarily focuses on technical products by mapping functions to potential means of implementation, the institutional morphological chart broadens this approach to cover both institutional and technical considerations. In this institutional adaptation, the term "options" is used instead of "means" to better fit the broader focus of the chart. While "means" often refers to specific methods and solutions in engineering, "options" reflects a wider range of possibilities suited to both institutional and technical considerations. Besides, the institutional chart allows for multiple options to be chosen for one function or feature. This adaptation allows the chart to address the complexities of a CBDC, including stakeholder dynamics, regulatory requirements and societal objectives. The chart organises design alternatives, breaking down complex systems into simpler parts, making it easier to evaluate the digital euro's design.

4.3.1 Design features and functions

In this section functions will be established for the corresponding design features section 4.1 concluded with. For the definition of a function in this context see the introduction of Chapter 4. To summarise the relationship between design features and their functions, Table 3 provides an overview. This overview highlights how these features and functions together address both fundamental and variable needs for the digital euro design. The principal functions also form the basis of the institutional morphological chart in the next section.

Table 3: Design features and corresponding functions

Design Feature	Function 1	Function 2	Function 3
Suitability for transactions	Facilitate card, online and digital payments		
Issuance by the ECB	Issue the digital euro	Maintain monetary integrity	
Currency parity	Ensure value consistency		
Universal access in Eurozone	Provide easy access	Standardize usage across jurisdiction	
Account or token based	Determine the mode of digital euro access		
Privacy design	Secure personal data	Enhance user trust	Protect data
Technical infrastructure	Facilitate/Settle transactions	Collect data	Enable scalability
Business users and payments	Provide business to business transactions		
Conditional payments & programmable money	Customize financial transactions	Support smart contracts	Enable conditional transactions
Offline capability	Facilitate offline transactions	Provide for topping up the offline wallet/environment	Provide for the transfer of digital euros from the offline to the online environment
User interface and interaction	Provide user-friendly usage of digital euro interface	Support transaction methods	Facilitate a customer support system
Legal tender	Mandate universal acceptance	Standardize usage across jurisdiction	
Accessibility	Define who can use the digital euro	Facilitate inclusive onboarding	Implement verification mechanisms
Financial crime regulation	Monitor and ensure compliance	Verify user identity	
Distribution channels	Establish distribution networks	Define stakeholder distribution roles	
Renumeration	Incentivise digital euro holding	Renumerate the digital euro	
Holding limits	Control digital euro money supply	Prevent bank runs	
Monetary policy functionality	Adjust Monetary Supply	Control inflation	Crisis Response
Pricing model for the digital euro	Establish fee structures	Manage profits and costs	

The functions highlighted in green represent the principal functions selected for using in the institutional morphological chart in 4.3.2.

The highlighted functions were chosen because they are either the most critical for fulfilling the digital euro's primary objectives or because they encompass aspects of other functions associated with the same design feature. This focus ensures that the chart remains both manageable and effective in addressing the most pressing design considerations. For instance, in the design feature Privacy Design, "Secure personal data" is chosen as the primary function because it serves as the foundation for enhancing user trust and protecting data. Without securing data, the other related functions cannot be meaningfully achieved. Similarly, for Offline Capability, "Facilitate offline transactions" captures the essential purpose of this feature, while also supporting additional functionalities such as wallet funding and transitions between offline and online environments.

When determining the principal functions for the institutional morphological chart, it is important to select those that provide flexibility and allow for broader exploration of potential design solutions. For example, the function "Mandate universal acceptance" under Legal Tender highlights the obligation for businesses and individuals to accept the digital euro as a valid form of payment, ensuring its integration into the broader financial ecosystem. However, this function is inherently narrow in scope, as the associated options would likely converge on the concept of legal tender itself. In contrast, selecting "Standardize usage across jurisdictions" as the principal function provides greater flexibility in exploring design options. This broader function allows for the consideration of various options, including legal tender, but also other mechanisms that promote consistency and interoperability across regions. By prioritising "Standardize usage across jurisdictions," the design process remains open to a wider range of potential solutions, enabling a more comprehensive evaluation of the digital euro's legal and functional integration.

It is not practical to include all identified functions in the institutional morphological chart because doing so would overcomplicate the design exploration process (Dym et al., 2014) and dilute the focus on critical system attributes. By narrowing the focus to principal functions, the chart remains actionable, enabling a clearer comparison of design alternatives. A broader scope could also introduce redundancy, as many secondary functions are inherently supported by the primary ones.

4.3.2 Institutional morphological chart

For an explanation about the institutional morphological chart see the introduction of 4.3. To generate ideas and populate the chart, a combination of brainstorming and literature review was employed. As recommended by Johannesson & Perjons (2014), brainstorming sessions were used to find potential options for achieving the principal functions. This was complemented by a review of existing literature, following the guidelines of Dym et al. (2014). Sources included general literature on CBDCs, Literature specific to the digital euro, such as ECB reports and focus groups and related academic research and industry insights.

The institutional morphological chart, including a description of the options, can be found in Appendix C. It consists of the principal functions identified in section 4.3.1. The chart underscores the complexity and multidimensionality of the digital euro’s design. By including diverse options for the functions, it provides a framework for generating design alternatives. However, careful consideration of trade-offs, stakeholder priorities and practical feasibility is of high importance for selecting the most appropriate options. In the next sections, the institutional morphological chart will be used to map alternative and the current digital euro designs.

4.4 Current digital euro design

Although there is not one clear report that states the exact digital euro design, the current digital euro design by the ECB and EC can be outlined by combining several publications from their side. This includes ECB reports and presentations and the legislative proposals the EC did on the establishment of the digital euro, the legal tender of the (digital) euro and the provision of digital euro services in non-Eurozone member states of the EU. Table 4 gives an overview of the sources that outline the current digital euro design:

Table 4: Sources that outline the current digital euro design

Source title	Author & Date	Design aspects informed
Report on a digital euro	ECB (2020)	Objectives and requirements
Core, optional and value-added services for the digital euro	Euro Retail Payments Board (2022)	Customized transactions
A stocktake on the digital euro – Summary report	ECB (2023b)	Technical, functional, monetary
Compensation model for the digital euro	Euro Retail Payments Board (2023)	Fee structures, profits and costs
Progress on the investigation phase of a digital euro – second report	ECB (2022b)	Distribution and settlement model, funding and defunding
Progress on the investigation phase of a digital euro – third report	ECB (2023d)	Transaction methods, conditional payments, User interaction
Proposal for a regulation on the establishment of the digital euro	European Commission (2023)	Definitions, regulatory aspects, responsibilities, distribution, functionalities, technical features, privacy, AML
Proposal for a regulation on the provision of digital euro services by PSPs incorporated in Member States whose currency is not the euro	European Commission (2023)	Accessiblity for EU Member States outside the Eurozone
Proposal for a regulation on the legal tender of euro banknotes and coins	European Commission (2023)	Legal tender
Progress on the preparation phase of a digital euro – first progress report	ECB (2024c)	Privacy, fraud detection, offline digital euro, holding limits, compensation model, user experience
Digital euro – Risk and Fraud management	ECB (2024b)	Transactions monitoring, risk & fraud management
State of play on offline digital euro	ECB (2024e)	Offline digital euro
Update on workstream on the methodology for the calibration of holding limits	ECB (2024f)	Holding limits
Update on the work of the digital euro scheme's Rulebook Development Group	Rulebook Development Group (2024)	Distribution model, digital euro accounts, functions, liquidity management, high-level architecture

4.4.1 Most-likely digital euro design

The most-likely design of the digital euro, as envisioned by the ECB and EC, emerges from multiple publications and legislative proposals that are shown in table 4. In this section the most-likely digital euro design will be discussed. The section concludes with an institutional morphological chart that gives an overview of this design.

4.4.1.1 Technical design

The digital euro is expected to follow a centralised, account-based model, with the ECB maintaining full control over the central ledger used for settlement. In this setup, the Eurosystem would also provide complementary centralised services accessible to PSPs who would interact with the system to distribute the digital euro and provide related services to end-users. The proposed architecture by the ECB, as illustrated in Figure 7, represents a centralised structure where settlement processes remain under the ECB's direct control while allowing PSPs to operate within the system to deliver end-user services.

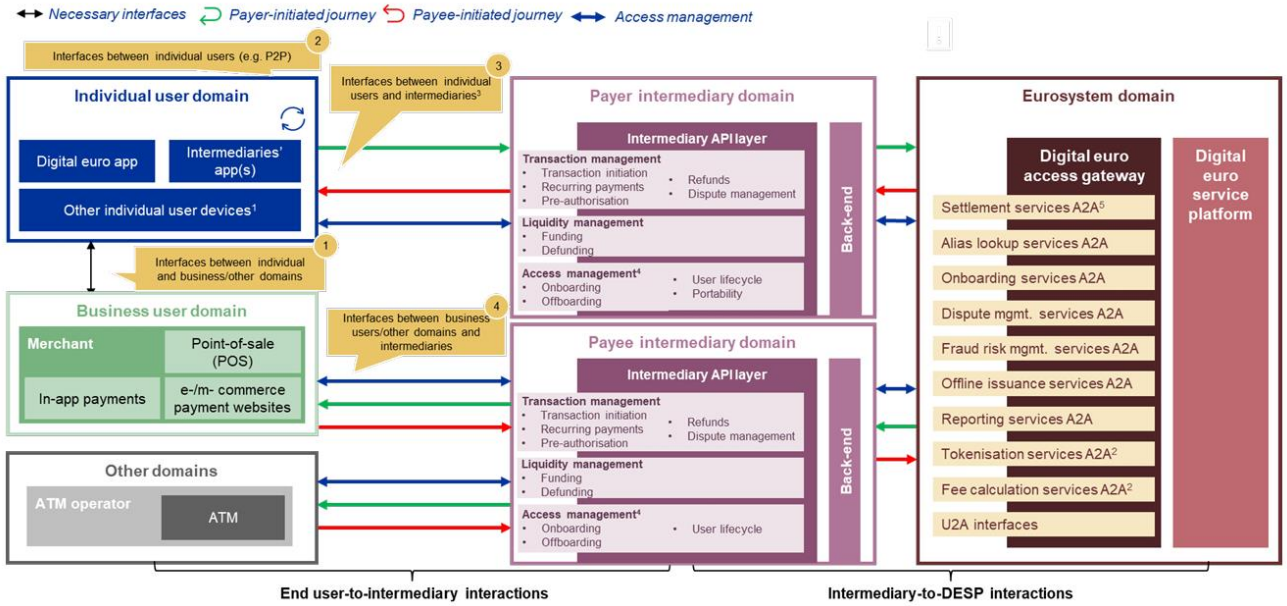

Figure 7: High-level architecture Digital euro ecosystem (Rulebook Development Group, 2024)

4.4.1.2 Functional design

The ECB's current proposal describes the digital euro as a non-programmable currency. However, the possibility of conditional payments may be made available by market participants as a so called 'value-added service'. The ECB will provide basic digital euro services for free. Market participants will be able to create these value-added services to provide additional use cases which they can monetize. The choice of technologies for Point Of Sale (POS) payments, such as NFC, QR codes, mobile applications, or cards, has not yet been made.

For user interaction, the digital euro is likely to adopt approaches aligned with existing payment systems in use within the Eurozone. POS transactions are expected to involve payee-initiated transactions where users can tap a card or device to make payments. or online and e-commerce payments, users would scan a QR code with their mobile device when making payments from a different device, similar to the iDeal system. If using the same device, the transaction would redirect the user to an application for validation and confirmation of the payment. For basic usage, the ECB will design the digital euro app where users can manage their digital euro account. This app can be used by PSPs that do not have enough resources to create their own app. PSPs can also interact with users through their own applications, using the digital euro API. The legislative proposal also says that front-end services of the digital euro wallet shall be interoperable with the European Digital Identity Wallet,

For offline payments, the ECB is considering both mobile devices and physical smart cards to make the payments. Funding of the offline wallet should be made available via online deposits as well

as using an ATM. The ECB is looking for a component provider to develop an offline, hardware bearer payment instrument. It has to be an end-to-end solution that enables the ability to pay offline, with no third party involved in the transaction, with instant and final settlement, as well as consecutive payments and the ability to pay in proximity in P2P or POS scenarios. Therefore, a successful development of the offline capability will probably have these functionalities and characteristics.

4.4.1.3 Regulatory design

The EC has proposed that the digital euro shall have legal tender status. This options that the digital euro entails mandatory acceptance. However, there will be exceptions to the obligation to accept the digital euro, mainly for small companies.

PSPs are expected to play a central role in ensuring compliance with regulatory requirements such as AML and CTF checks, consistent with existing EU directives. For offline transactions, data storage will be limited to funding and defunding activities, with no transaction data retained by PSPs or the Eurosystem, except for what is required to prevent forgery.

In this system, PSPs would be responsible for onboarding users, providing services, initiating and validating payments and managing post-settlement processes. The Eurosystem would oversee settlement operations via its central ledger. Privacy considerations are central to the regulatory design. The Eurosystem would not store personally identifiable information and data access would be limited to pseudonymised information necessary for fulfilling regulatory obligations. As the controllers of personal data, PSPs will be responsible for pseudonymising the personal data so that any communicated data with the ECB / National Central Banks is not directly identifiable. The ECB will use a general fraud detection tool to assist PSPs in detecting fraud. This could be executed by the ECB themselves or by providers of support services designated by the ECB.

Offline payments would ensure transaction anonymity, with no data shared beyond what is required to prevent forgery. Funding and defunding data of the offline wallet will be processed by PSPs. For online transactions, data processing would comply with GDPR and AML/CTF rules, with PSPs limited to accessing the information required to perform their regulatory and operational duties.

The distribution of the digital euro is proposed to extend beyond eurozone residents. It would include individuals who previously resided in the eurozone, visitors and those in non-euro Member States or third countries, contingent upon specific agreements between the ECB and relevant national central banks. Cross-currency payments involving the digital euro would similarly require prior arrangements with non-euro central banks or third-country authorities.

4.4.1.4 Monetary design

Monetary design proposals indicate that the digital euro is being developed as a means of payment, not as a monetary policy tool. The ECB is not planning on using any tools that would directly incentivise usage of the digital euro. The ECB proposes a non-remunerated design, meaning the digital euro would not bear interest. In the legislative proposal the ECB is assigned with the task to develop instruments to limit the use of the digital euro as a store of value. The ECB wants to fulfil this task by implementing holding limits. The current idea is that individuals will be allowed to hold up to €3.000, while businesses are expected to have a holding limit of zero. The ECB proposes that businesses will be allowed to pay their customers (B2C) in digital euros, but whether they will be able to make business-to-business payments is not clear.

To minimize the impact the banking system, the digital euro will feature a (reverse) waterfall mechanism that integrates digital euro accounts with linked commercial bank accounts. When a payment causes a digital euro balance to exceed the holding limit, the excess will be automatically

transferred to the linked commercial bank account (waterfall functionality). Conversely, if there are insufficient funds in the digital euro account for a payment, the shortfall will be automatically covered from the linked bank account (reverse waterfall functionality). Users can enable or disable these features and set custom thresholds for automatic transfers. Without a linked bank account or enabled waterfall functionality, users would need to manually manage their digital euro balances to stay within the holding limit

In the current design, the digital euro will be free for basic use by private individuals. PSPs distributing the digital euro would receive incentives comparable to those associated with existing electronic payment systems. The Eurosystem will bear its own costs related to the production and issuance of the digital euro, PSPs will manage their own distribution costs, but will not be charged by the Eurosystem for settlement processing

4.4.1.5 Institutional morphological chart most-likely digital euro design

It is important to note that the proposed design choices for the digital euro, as outlined by the ECB and EC, are still subject to approval by the European Parliament and Council. While the designs reflect the ECB's vision, they are not final and could undergo changes during the legislative process. This underscores the significance of this study, as the design process remains ongoing and new insights or priorities may influence the final implementation.

To summarise the current proposals, Table 5 presents an institutional morphological chart showing the features of the most-likely digital euro design. The specific options proposed by the ECB are highlighted in green:

Table 5: Institutional morphological chart for the most-likely digital euro design as proposed by the ECB and EC

Design Function / Feature	Option 1	Option 2	Option 3	Option 4	Option 5
Facilitate payments	Facilitate card, online and digital payments				
Issue digital euro	Issued by ECB				
Ensure value consistency	Currency parity to euro				
Determine the mode of digital euro access	Account-based	Token-based			
Data processed by who	PSP	ECB	Provider of support services	Distributed Ledger	
Secure personal data	Make data anonymous	Make data pseudonymous	Apply zero knowledge proof		
Facilitate/Settle transactions	Centralised	Decentralised	Blockchain		
Provide business to business transactions	Allow uncapped B2B payments	Allow capped B2B payments	Allow B2C payments		
Customize financial transactions	Smart contracts	User-defined rules			
Facilitate offline transactions	Hardware wallets	Preloaded smart cards	NFC	Bluetooth transactions	Card-to-card with a bridge device
Provide offline wallet (de)funding	ATM integration	Online deposit (de)funding	Bank branch services	Cash-in Cash-out kiosks	POS terminal
Provide user-friendly usage of digital euro interface	Digital euro app	Digital euro API/SDK	Smart device compatibility	Multilingual support	
Support transaction methods	Card payments	Tap-to-pay	QR code payments	Mobile wallet integration	
Standardize usage across jurisdiction	Legal tender status	Centralised oversight	Common technical standard		
Define who can use the digital euro	Natural and legal persons residing or established in a euro country	Visitor Access	Legal status	Economic activity	Bilateral agreements with non-euro countries
Monitor and ensure compliance	ECB general fraud detection and prevention mechanism	Sanctions screening by PSPs	Transaction monitoring by PSPs	Criminal background check	

Verify user identity	No verification mechanisms	Biometric verification	European digital identity	Proof of identity (passport, ID)	
Define stakeholder distribution roles	Distributed by PSPs	Distributed directly by ECB	Distributed by National Central Banks	Distributed via selected financial institutions	
Incentivise digital euro holding	Rewards program	Promotional offers	Tax benefits	Integration with government services	None
Renumerate the digital euro	No interest on digital euro holdings	Flat rate monthly set by ECB	Fixed margin below ECB Deposit rate	Reverse tiered interest rates	Transaction-based bonuses
Control digital euro money supply	Fixed holding limit	Transaction limit	Issuance control	ECB Buy/sell programs of digital euro	(Reverse) waterfall method
Prevent bank runs	Funding restrictions during distressed periods	Additional liquidity support mechanisms for commercial banks	Real time monitoring and alerts		
Adjust Monetary Supply	Adjust digital euro interest rate	Adjust holding limits			
Establish fee structures	Pricing up to the market	Flat regulated rate per transaction	Percentage-based fees	Zero fees for basic transactions, higher fees for bigger transactions	Maximum rates set by regulation
Manage profits and costs	ECB bears own cost on infrastructure and settling	PSP bear their own distribution cost	PSPs get charged for using digital euro infrastructure	ECB is not allowed to make profits on digital euro operations	Public-private partnership were both parties have investments in the infrastructure

The options highlighted in green present the choices for the most-likely digital euro design as proposed by the ECB and EC

4.5 Exploring alternative digital euro designs

This section presents two conceptual designs for the digital euro, developed using the chart in Appendix C. These designs are intended to explore the design space, stimulating innovation and creativity rather than offering fully validated solutions. Each alternative highlights different priorities, such as enhancing privacy or incentivising user adoption and underscores the potential trade-offs involved.

These proposals are exploratory and require further research to assess their feasibility, effectiveness and compliance. They aim to inspire discussion and innovation in the development of the digital euro while complementing the ECB's objectives of financial stability and usability. The filled in institutional morphological charts for these designs can be found in Appendix D.

4.5.1 Alternative design 1: Privacy-focused digital cash alternative

This alternative design envisions the digital euro as a privacy-focused digital cash alternative, prioritising user privacy while using a centralised infrastructure. It aims to replicate the anonymity and ease of use of physical cash while incorporating safeguards like holding limits and transaction caps to mitigate risks to the banking sector and limit the potential for large-scale misuse. Designed for small-scale, everyday transactions, it aligns with the ECB's objectives of complementing existing payment systems without significant disruption to the financial ecosystem.

The design uses a centralised account-based system with enhanced privacy through pseudonymisation. During onboarding, users complete a one-time KYC process where their identity is verified and a pseudonymous identifier is generated. This pseudonym is used for all transactions a user makes. As a consequence, personal identities are no longer directly coupled to transaction data. Real identities should be securely stored in a separate database accessible only under specific legal or regulatory conditions. This structure should reduce the need for stringent AML/CTF requirements for these kind of transactions. It would be similar to how cash works with limited traceability for small-scale use.

Transactions are processed via a centralised ledger managed by the ECB. Holding limits (e.g., €3000) and transaction caps (e.g., €250 per transaction) ensure the digital euro remains a complement to cash rather than a significant store of value and also limits its potential for misuse. Regulators should be able to access the real identities behind pseudonyms only when necessary, which would give improved privacy for everyday transactions, while allowing compliance when required. Offline payments are supported through secure hardware wallets and NFC technology, enabling transactions without internet connectivity, similar to the ECB's design. Hardware wallets could provide a secure way to store digital euros and would be somewhat similar to cash. Offline wallets could be funded through ATMs or PSP applications.

The digital euro is issued by the ECB and distributed through PSPs, which handle onboarding, pseudonymised transactions and account management. PSPs would only access user identity data when they are legally required to do so. This would provide more privacy compared to the current ECB design. By combining pseudonymisation with holding limits and transaction caps, the design addresses privacy concerns. Instead of granting the digital euro legal tender status, this design would rely on centralised oversight for being compliant. This approach avoids the regulatory challenges associated with legal tender. Adoption could be driven by the system's privacy and usability benefits instead. However, further research is needed to validate the feasibility of the design, especially regarding the management of pseudonymised data and on achieving regulatory compliance.

In summary, alternative Design 1 seeks to give users increased privacy by replicating the characteristics of cash in a digital format. It might offer a practical solution for small-scale, everyday transactions while addressing the privacy limitations of existing digital payment systems.

4.5.2 Alternative design 2: Incentivised onboarding and usage

This alternative design builds on the ECB's proposed digital euro framework but adds user incentives to encourage wider adoption. Unlike the ECB's design, which does not include remuneration or bonuses, this approach introduces features to promote onboarding and increase familiarity with the system. The goal is to ensure the digital euro is widely used and recognized, making it more effective as a backup payment option during disruptions in private systems.

The core design remains an account-based system, with PSPs handling data processing and managing pseudonymised transaction data to balance privacy and regulatory compliance. Transactions are settled centrally by the ECB. Offline payments will be enabled through NFC technology and possibly physical smart cards as well, allowing users to make payments without an internet connection.

The main difference is the inclusion of user incentives. Holdings of digital euros would earn a small positive interest rate, set below the ECB's deposit rate (can even be set below savings rates offered by commercial banks) to prevent large withdrawals from commercial banks. Additionally, new users would receive a one-time sign-up bonus in digital euros to encourage adoption. These incentives aim to attract more users and ensure they are onboarded and familiar with the system. This could improve the digital euro's utility as an everyday payment option, but especially as a backup system. In scenarios where our current payment systems are down, being onboarded already would mean that you could directly make use of the digital euro and that you are already familiar with the system, which could be seen as a benefit.

PSPs would continue to oversee transaction monitoring to ensure compliance with AML and CTF rules, as in the ECB's design. The introduction of incentives would require careful consideration to avoid unintended effects, such as excessive use of the digital euro as a store of value, which could impact financial stability. Additionally, they carry the risk of being perceived as unfair competition and could lead to legal challenges.

In summary, alternative design 2 retains much of the ECB's proposed structure but introduces interest on holdings and onboarding bonuses to encourage early adoption. These additions could help establish a larger user base and improve the digital euro's reliability as an alternative payment method during system outages. Further testing is needed to evaluate the impact of these incentives on user behaviour and the broader financial system.

4.6 Review of existing alternatives

When considering the main functionalities of a digital euro as previously described, it can be said that it is mainly designed as a means of payment. This section evaluates existing payment methods to assess their similarities and differences compared to the digital euro, focusing on how they align with its objectives.

Cash money: Physical currency used for face-to-face transactions. Similar to a digital euro, cash is issued by central banks, provides privacy in transactions and holds legal tender status. However, cash lacks digital functionality and programmability, limiting its use in the digital economy.

Commercial bank money: Digital money created and stored in commercial banks, used for electronic transactions. Like the digital euro, it is widely accepted and suitable for both physical and online payments. However, commercial bank money is not always accessible for international transactions and excludes certain underbanked populations (Zamora-Pérez, 2022). Additionally, it is subject to credit risk for amounts exceeding deposit insurance limits.

Credit cards: Payment cards that provide a line of credit for transactions, repayable later. Credit cards are similar to the digital euro in their wide acceptance for online and offline transactions. However, they differ significantly as they involve borrowing, potential interest costs and are not issued by central banks.

Tokenized commercial bank money: A representation of commercial bank money as digital tokens, often implemented using blockchain technology. This approach shares similarities with the digital euro in enhancing digital transaction efficiency, such as enabling instant settlement and

improved security. However, it is dependent on the financial health of commercial banks and requires extensive coordination to function as a pan-European solution. Besides, most tokenized commercial bank money schemes are still in development.

Cryptocurrencies: Decentralised digital currencies like Bitcoin and Ethereum operate independently of a central authority. Similar to the digital euro in terms of digital use and potential for online transactions, cryptocurrencies provide high levels of privacy. However, they are highly volatile and lack the stable value and legal tender status that a digital euro would have.

Stablecoins: Cryptocurrencies designed to maintain a stable value by pegging their worth to other assets, such as fiat currencies. Like the digital euro, stablecoins offer digital convenience and aim to preserve value stability, providing transaction benefits similar to tokenized commercial bank money. However, stablecoins are issued by private entities regulated under the Markets in Crypto-Assets (MiCA) framework, not by central banks and therefore do not carry the same risk-free status as the digital euro.

Prepaid cards: Cards preloaded with a specific amount of money in advance. Like the digital euro, prepaid cards can be used for digital transactions and are widely accepted. It could be similar to an offline digital euro. However, unlike the digital euro, they are limited by the pre-loaded amount and often lack the flexibility of a fully-fledged digital currency. They also do not directly offer programmability or the security of being issued by a central bank.

Mobile Payment platforms (Apple pay, Google Wallet) : These platforms facilitate secure and efficient transactions using NFC and tokenisation to ensure user privacy and security. Similarly, the digital euro is expected to utilize tokenisation to enhance transaction security. Both offer convenience for online and in-store payments. However, unlike the digital euro, which is directly issued by the central bank, mobile payment platforms rely on existing banking infrastructure for funding, linking them to traditional financial systems. Besides, these kinds of solutions are often not created by companies in the EU, conflicting with the strategic autonomy objective of the ECB.

P2P payment systems (Tikkie, Venmo etc) : Platforms that facilitate direct money transfers between individuals. Similar to a digital euro in enabling digital transfers, these platforms are dependent on existing bank accounts and do not provide universal accessibility across the eurozone or the central bank backing of a digital euro.

iDeal / European Payments Initiative: A popular payment method in the Netherlands that allows direct online payments from a user's bank account to the merchant's bank account. Similar to the digital euro in that it is designed for digital transactions and is widely accepted within the region. IDeal is currently dependent on the banking system, is not available throughout the whole eurozone and does not offer the potential benefits of central bank issuance. However, the European Payments Initiative (EPI), a consortium of 16 European banks and PSPs is introducing *wero*, a European equivalent of iDeal, which would be available throughout Europe (Wero, 2024). The goal of wero is to provide a unified digital payment system that is interoperable throughout the eurozone, reducing fragmentation in the European payments market. Like the digital euro, wero aligns with the objective of strategic autonomy in the EU, aiming to reduce reliance on external payment providers such as Visa, Mastercard and big-tech companies. However, one of the major challenges for wero is achieving full pan-European coverage, which requires extensive coordination and collaboration across all eurozone countries. Currently, the consortium includes only 16 banks, which does not represent the entire eurozone banking system. To fulfil its ambition as a truly pan-European solution, EPI would need to expand its membership significantly, integrate with existing national payment systems and ensure interoperability with diverse financial institutions across the region.

This preliminary analysis of existing payment alternatives illustrates how each has certain functionalities that (partly) overlap with the proposed digital euro. Among these, the European Payments Initiative and its proposed wero platform stand out as the most relevant for further evaluation. EPI shares several objectives with the digital euro, which would make it interesting to compare it do a digital euro in the evaluation section.

4.7 Design evaluation

In this section, the current digital euro design, two alternative designs and the existing alternative wero from EPI will be evaluated using the requirements from section 4.2. Table 6 gives an overview in to what extent each alternative fulfils the requirements.

Table 6: Evaluation of digital euro designs and the European Payments Initiative alternative

Requirement	**ECB Design**	**Alternative 1:** *Privacy focused digital cash*	**Alternative 2:** *Incentivised onboarding*	**EPI** *wero*
R1: Cash-like features	●●○	●●●	●●○	●○○
R2: Enhanced digital efficiency	●●●	●●○	●●●	●●●
R3: Backup system	●●○	●●○	●●●	●●○
R4: Controlled circulation	●●●	●●●	●●○	●○○
R5: Compliance with regulatory framework	●●●	●●○	●●○	●●●
R6: Easy accessibility throughout the Eurozone	●●●	●●○	●●●	●●○
R7: Conditional use by non-euro area residents	●●●	●○○	●●●	●○○
R8: Prompting strategic autonomy	●●●	●●●	●●●	●●●
R9: Cost-effective for businesses and consumers	●●●	●●●	●●○	●●○
R10: Inclusive	●●●	●●○	●●●	●●○
R11: Enhancing privacy	●●○	●●●	●●○	●○○
R12: Clear advantages over existing options	●●○	●●●	●●●	●●●

Legend: ●●● (High): Fully meets the requirement.
●●○ (Moderate): Partly meets the requirement or has trade-offs.
●○○ (Low): Does not meet the requirement effectively.

Each score is based on an assessment by the author on how specific features or options within the designs address the goals and criteria underlying each requirement. The following section provides reasoning:

ECB's most-likely design: The ECB's design performs well across most requirements. It scores high for accessibility (R6) and inclusivity (R10) due to its integration with PSPs and the provision of a basic application, which ensures availability to users across the eurozone. The account-based and central system architecture allows for efficient handling of digital payments (R2) and could support robust functionality as a backup system (R3). However, it is unclear whether this infrastructure will be completely independent from the payment systems currently in place. It is also unclear whether onboarding would still be possible during an outage of existing payment systems, therefore R2 has only two points.

Although the design aims to provide a cash-like digital euro in an offline form, the funding and defunding of this offline wallet will not be anonymous. In addition, the ECB can still access offline transaction data to prevent forgery of offline digital euro's. Therefore it may enhance the privacy of payment methods, but to what extent is questionable, especially when comparing it to cash. The ECB's digital euro design does not provide clear advantages over existing options because it largely replicates functionalities already available in commercial bank money and other digital payment systems. Without strong incentives for adoption, such as enhanced privacy, lower costs, or significant technological advantages, its value proposition as a truly distinct payment method may remain limited.

Alternative 1: Privacy-focused digital cash: Alternative 1 performs strongly in privacy (R11) and replicating cash-like features (R1). It offers a digital payment option closer aligned with the characteristics of physical cash. The inclusion of holding limits and transaction caps shift its use to a payment tool rather than an investment, resulting in a high score for controlled circulation (R4).

However, its score for enhanced digital efficiency (R2) is limited to two points. While the design supports smaller everyday transactions, the transaction cap restricts its use for larger payments, reducing its versatility. Compliance with regulatory requirements (R5) also scores two points due to potential challenges in aligning pseudonymisation with AML/CTF rules. Conditional use by non-euro area residents (R7) scores one point, as the design focuses on transactions within the eurozone and does not provide onboarding options for non-EU residents.

Alternative 2: Incentivised onboarding: Alternative 2 scores highly for providing clear advantages over existing options (R12) through remuneration and promotional offers. These features distinguish it from cash and other payment methods by incentivising onboarding and encouraging active use. By attracting a broader user base, the digital euro's utility as a backup system (R3) is enhanced, as more people would already be familiar with the system in case of disruptions to other payment infrastructures.

However, certain features present potential challenges. Promotional offers, such as sign-up bonuses, could be perceived as unfair competition, particularly by commercial banks. Similarly, the remuneration of holdings, while limited to a small positive interest rate, could still raise concerns about its impact on the broader financial system, although holding limits are in place to mitigate significant outflows from commercial banks.

EPI (wero): EPI performs well in enhanced digital efficiency (R2) by offering a (potentially) pan-European payment method that supports instant settling and fast transactions across multiple use cases. However, it does not replicate cash-like features (R1), as it lacks anonymity and offline functionality, making it more like a digital payment platform than a cash substitute.

Controlled circulation (R4) is not met since the ECB cannot directly control the circulation of digital money not directly issued by them. Accessibility (R6) and inclusivity (R10) score moderately, as it requires a bank account, limiting its reach to the underbanked population. Privacy (R11) is also not improved compared to existing commercial bank systems, offering standard protections but no enhancements. A key challenge for EPI is achieving full eurozone coverage. Unlike a digital euro issued by the ECB, which would automatically apply across the eurozone, EPI depends on voluntary participation by financial institutions. Currently, only 16 banks are members, which limits its scope and interoperability. Expanding membership and coordination would be necessary for broader adoption.

Overall, the ECB's design offers strong inclusivity but lacks differentiation. Alternative 1 excels in privacy but sacrifices some accessibility, while Alternative 2 provides clear adoption benefits at the cost of added complexity. EPI delivers pan-European efficiency but struggles with limited scope and a lack of unique features, highlighting the need for broader coordination and refinement. These contrasts underscore the trade-offs inherent in designing a digital euro that balances accessibility, privacy, efficiency and innovation.

4.8 Conclusion

This chapter explored the design space of the digital euro, gave an overview of the current digital euro design as proposed by the ECB and EC, explored alternative designs and evaluated existing digital payment solutions in relation to the objectives of the digital euro. Below, the three sub-questions guiding this analysis are addressed:

Sub-question 2: *What are the key design aspects of the digital euro, and to what extent are design alternatives of the digital euro yet to be determined?*

The key design aspects of the digital euro are its suitability for digital transactions, issuance by the ECB, currency parity with the euro and universal accessibility within the Eurozone. These fundamental features ensure the digital euro functions as proper public money while aligning with the ECB's broader policy goals. Variable features, such as privacy design, offline capability and user interaction, remain flexible, allowing for different configurations to meet user needs and regulatory requirements. Section 4,1 gives an overview of the design aspects of the digital euro. While the ECB's design outlines several core features, such as its centralised account-based system, issuance by the ECB and non-remunerated monetary structure, some technical, functional, regulatory and monetary design choices are still open. For example whether businesses could use the digital euro and how holding limits will be set. These undecided features will play an important role in shaping the digital euro's usability, privacy and adoption. This also underscores the importance of ongoing research and evaluation on the digital euro's design.

Sub-question 3: *What are alternative designs of the digital euro?*

Two alternative designs were proposed to explore different priorities. Alternative 1, a privacy-focused digital cash option, tries to achieve private transactions through an enhanced pseudonymisation structure. To offset unwanted effects on financial stability, it incorporates holding limits and transaction caps. This design tries to replicates the characteristics of cash but introduces trade-offs in regulatory compliance and broader accessibility. Alternative 2, an incentivised onboarding approach, is based on the design as proposed by the ECB, but adds remuneration and promotional offers to encourage adoption. This makes the digital euro more attractive to users and enhances its readiness as a backup system. However, these features present challenges, such as the potential for unfair competition and impacts on the broader financial system. These alternative designs were developed as exploratory concepts to analyse the

possibilities within the digital euro's design space and to highlight the potential trade-offs associated with different priorities, such as privacy, usability and incentivisation.

Sub-question 4: *Are there existing digital payment solutions that can achieve similar goals to those of the digital euro?*

Existing payment solutions, such as cash, commercial bank money and mobile payment platforms, partially overlap with the goals of the digital euro. Among them, the European Payments Initiative and its proposed wero platform stand out as the most relevant comparison. EPI aims to create a pan-European payment solution with instant settlement capabilities, aligning with the strategic autonomy objectives of the ECB. However, EPI lacks the privacy, cash-like features and universal accessibility that a central bank-issued digital euro would provide. Its reliance on voluntary bank participation to reach full Eurozone coverage highlights the coordination challenges it may face.

The chapter demonstrates that while the ECB's proposed design lays a solid foundation, its ability to differentiate itself from existing solutions may remain limited. Alternative designs could offer pathways to enhance privacy and incentivise adoption but come with distinct challenges. Existing solutions like EPI illustrate overlap with the digital euro's objectives but lack features unique to a central bank digital currency.

5. Discrete Choice Experiment

This chapter outlines the setup of the discrete choice experiment to investigate consumer preferences for the digital euro

5.1 Importance of consumer adoption

The success of the digital euro depends significantly on consumer adoption. Previous CBDC implementations have demonstrated that even technically feasible and well-intentioned projects can fail without broad public engagement. Dowd (2024) highlights the cases of Finland and Ecuador, where CBDC initiatives were terminated due to poor uptake, while ongoing projects in countries such as Nigeria, the Bahamas and China face limited usage despite considerable government efforts to promote adoption. In these cases, the primary issue was the absence of clear and tangible benefits for consumers, raising concerns about the ability of CBDCs to transform payment systems or achieve their stated objectives.

For the ECB, striking a balance between protecting financial stability and driving consumer adoption is important. Restrictive design choices, while deemed necessary for financial stability by the ECB, risk making the digital euro less appealing to consumers. Without sufficient adoption, the digital euro is unlikely to fulfil its goals of improving payment efficiency, boosting financial inclusion and enhancing Europe's monetary sovereignty. As Bofinger and Haas (2023) note, the unique value of central bank money may be difficult to communicate to the public, especially in light of existing deposit insurance systems, further complicating efforts to encourage adoption.

Existing studies on the digital euro also emphasise the importance of public interest and adoption in achieving the ECB's objectives. Tronnier and Kakkar (2021) argue that while a digital euro could bring advantages, such as building synergies with existing payment systems and enhancing monetary policy, its success will largely depend on whether citizens are willing to adopt this new form of digital currency. Dowd (2024) similarly states that CBDCs often fail to offer significant advantages over existing alternatives, leaving consumers with little incentive to switch.

These insights highlight the importance of consumer adoption in the digital euro's design and implementation. Without clear benefits that are appreciated by the public, the digital euro may struggle to reach significant usage levels. This underscores the need for additional research into consumer preferences to identify the design features and attributes that could drive adoption. The DCE introduced in this chapter is designed to address this gap, providing empirical insights into the factors that influence public willingness to adopt the digital euro.

5.2 Design attributes in the choice model

In this thesis, the attributes will be drawn from the design features identified during the initial phase of research, Chapter 2.2.1.1 explains how the attributes should be selected for the experiment.

5.2.1 Attribute selection

The following section provides a review of literature related to CBDC and consumer adoption that serves as a basis for understanding which attributes are likely to influence consumer behaviour.

Trust, risk and innovativeness have consistently been identified as key determinants of behavioural intention in digital payment adoption (Patil et al., 2018). Research by Fairweather et al. (2024) in the Australian CBDC context highlights that attributes like account fees, data access and issuer preference can shape consumer choices. Their findings suggest that privacy is a particularly important consideration, as many users value anonymity and have strong opinions

about who should access their transaction data. Conversely, they found limited consumer concern over whether the money is issued by a central bank or a commercial bank when privacy and other factors are held constant. Since the digital euro would have free of charge basic usage for consumers, account fees are not relevant for this experiment.

Bijlsma et al. (2021) demonstrated the importance of attributes like interest rates, security and privacy in steering CBDC adoption. Similarly, Leon et al. (2024) simulated the adoption of a retail CBDC using an agent-based model and found that attractive design features, such as remuneration, can foster adoption, especially in environments with strong competition from existing digital payment solutions. Offline suitability, explored in the focus group by Kantar Public (2023), is another attribute unique to CBDCs. While participants found offline functionality innovative and useful in specific scenarios, they did not expect to use it very often.

Based on these studies, the DCE in this thesis focuses on attributes that directly impact the user experience and are meaningful to consumers, such as privacy, ease of use and incentives. These attributes are also actionable for policymakers, as they can be adjusted in the design process to influence adoption. In contrast, attributes related to back-end infrastructure or technical details, which are less visible or relevant to the average user, are excluded to ensure the experiment focuses on the most impactful factors.

5.2.1.1 Selected Attributes and Rationale

Below is an overview of the attributes that will be included in the DCE, along with the rationale for their inclusion:

Issuer of Money (Included): This attribute reflects whether the digital euro is issued by a central bank or a commercial bank. As the issuer is a defining characteristic of CBDCs, consumer sentiment towards the government or central banks versus private banks could potentially influence adoption.

Wallet Holding Limit (Included): The holding limit for digital euros affects perceived usability. A low limit may restrict adoption by reducing the currency's functionality for larger transactions. There is limited research available on how consumers valuate these holding limits in the context of the digital euro.

Privacy – Who Can Access Transaction Data? (Included): Privacy is consistently cited as a critical factor in CBDC adoption (Bijlsma et al., 2021; Fairweather et al., 2024). Gaining insights into how privacy preferences are formed in the specific context of the digital euro could provide valuable information for adoption.

Interest Rate Received on Online Holdings (Included): As demonstrated by Bijlsma et al. (2021) and Leon et al. (2024), remuneration, even at modest rates, can influence adoption by making the digital euro more attractive than competing payment methods.

Offline Suitability (Included): The ability to use the digital euro offline is a feature unique to CBDCs, making it interesting to analyse its perceived importance. While offline payments are seen as innovative, their relevance for daily transactions is less clear (Kantar Public, 2023).

5.2.1.2 Excluded Attributes and Rationale

Several attributes were considered but excluded based on their limited relevance or adjustability in the context of consumer adoption:

- **Availability of the Digital Euro:** Excluded because geographical availability, such as whether it extends beyond the Eurozone, is less relevant for Dutch consumers.

- **Available Transactions:** Excluded as features like P2P payments, online transactions and POS payments are already standard across digital payment methods.
- **Conditional Payments/Budget Management**: Excluded since these functionalities are not unique to CBDCs and can be achieved with private solutions.
- **Payment Instrument/Method:** Excluded as decisions about instruments (e.g., cards, smartphones, QR codes) are likely to follow established and efficient practices.
- **Transaction Time:** Excluded because current digital transactions are already fast and this is unlikely to influence adoption significantly.
- **Prone to Physical Theft:** Excluded because ensuring offline holdings are theft-proof may not be technically feasible or adjustable in design.
- **Funding Method:** Excluded due to its limited relevance, as future designs will likely offer multiple convenient options for account funding.

5.2.2 Attribute levels

This section discusses how attribute levels were selected and assigned to their corresponding attributes.

5.2.2.1 Issuer of money

The two levels reflect two distinct issuance models:

- **Level 0:** *Commercial Bank:* This reflects a scenario where the digital euro-like asset is issued by commercial banks, comparable to digital tokens or assets. While this scenario deviates from a true CBDC, it serves as a relevant alternative for comparison.

- **Level 1:** *European/National Central Bank:* Represents the issuance by the ECB, as expected for the digital euro. This allows for testing if the central bank's involvement adds perceived utility.

Including these levels enables us to examine whether people value the unique public backing and safety associated with central bank issuance over commercial bank issuance.

5.2.2.2 Wallet holding limit

Four levels were chosen based on the existing proposal and practical considerations:

- **Level 0:** *€0, No Limit:* Represents no holding restrictions. This is included to test whether the introduction of a holding limit impacts perceived utility.

- **Level 1:** *€9000 Holding Limit:* In the Netherlands, 95% of the households have a disposable monthly income of €9000 or less (CBS, 2022b). Having a holding limit of €9000 would therefore enable a large group of households to receive their salary on their digital euro account (provided that they would spend and distribute their funds afterwards so that the balance becomes zero before receiving the next portion of income).

- **Level 2:** *€6000 Holding Limit:* This level represents a middle ground between €3000 and €9000 and is approximately twice the average monthly expenditure of Dutch households (CBS, 2022a). It allows for flexibility in managing regular expenses and savings while testing whether a more generous holding limit influences perceived utility.

- **Level 3:** *€3000 Holding Limit:* This holding limit is currently seen as the proposed holding limit by the ECB (as for example stated by Panetta & Bindseil (2020)). As a reference, the currently proposed limit by the ECB is about the same amount that a Dutch household on average spends per month (CBS, 2022a).

This range allows for equidistant testing and exploration of whether different holding limits significantly affect consumer preferences.

5.2.2.3 Privacy – Who could access the transaction data?

Four privacy levels reflect varying degrees of transparency and anonymity:

- **Level 0:** *Anonymous, Only Payer and Payee:* Reflects a cash-like level of privacy, with no data shared beyond the transaction parties.
- **Level 1:** *Personal Data Shared with PSPs of Payer and Payee:* Reflects a level of privacy similar to current bank accounts, where PSPs have access to data.
- **Level 2:** *Personal Data Shared with PSPs and Pseudonymised with ECB:* Reflects the current proposed design for online payments, which balances privacy and regulatory compliance by pseudonymising user data.
- **Level 3:** *Personal Data Shared with PSPs and ECB:* Reflects a more centralised approach where data is also available to the ECB. This allows for testing whether pseudonymising the data before sharing it with the ECB makes a difference in utility for consumers.

This structure allows testing of privacy preferences, from cash-like anonymity to varying levels of shared access.

5.2.2.4 Interest rate received on online holdings

The interest rate attribute includes four levels that reflect different scenarios based on the ECB's plans and current market conditions. These levels were chosen by looking at the average savings account interest rate in the Netherlands (around 1.5% at the end of 2024, as shown on Independer (2024)) and creating clear and meaningful differences to see how consumers might respond.

- **Level 0:** *No Interest:* Reflects the ECB's proposed non-remunerated design, serving as a baseline scenario.
- **Level 1:** *1.0% Interest:* Represents a rate slightly below the average savings account rate.
- **Level 2:** *2.0% Interest:* Represents a mid-level rate, offering a moderate divergence from current savings rates.
- **Level 3:** *3.0% Interest:* Reflects a high incentive rate, offering a significant benefit compared to commercial savings accounts.

These levels were deliberately chosen to cover a wide range of interest rate scenarios, from no remuneration to highly incentivised rates, enabling an analysis of whether and how remuneration affects consumer preferences.

5.2.2.5 Offline suitability

Two levels capture the availability of offline payments:

- **Level 0:** *Only Online:* Reflects the standard functionality of existing digital payment solutions.
- **Level 1***: Offline and Online:* Represents the unique capability of the digital euro to function without an internet connection.

These levels enable the exploration of whether offline functionality adds utility compared to existing online-only payment methods.

5.2.3 Overview of attributes and levels

Table 7 provides an overview of the attributes and their corresponding levels that will be included in the discrete choice experiment:

Table 7: Overview of attributes and corresponding levels included in the discrete choice experiment

Attribute	Level 0	Level 1	Level 2	Level 3
Issuer of money	Commercial bank	European / National Central Bank		
Wallet holding limit	[€0] no limit	[€9000] holding limit	[€6000] holding limit	[€3000] holding limit
Privacy – Who could access the transaction data?	Anonymous, only the payer and payee	Personal data is shared with PSPs of payer and payee	Personal data is shared with PSPs and pseudonymised with ECB	Personal data is shared with PSPs and ECB
Interest rate received on online holdings	No interest	1,0% interest	2,0% interest	3,0% interest
Offline suitability	Only online	Offline and online		

5.3 Model specification and experimental design

This section outlines the approach taken to design the DCE, covering the model specification and the construction of the experimental design.

5.3.1 Model specification

The DCM used in this study is designed to estimate consumer preferences for the digital euro based on the attributes and levels identified earlier. To maintain simplicity and feasibility, the model assumes that the effects of the attributes are independent, with no interaction effects included. While interaction effects could provide more detailed insights, accounting for them would require a full factorial design (Lancsar & Louviere, 2008). One could for example expect that a high interest rate on digital euro holdings would provide less utility when there is holding limit present. However, this is not feasible in this case, as the combination of two attributes with two levels and three attributes with four levels would result in $2^2 * 4^3 = 256$ unique alternatives, creating an unmanageable number of choice tasks.

The choice task in this DCE is designed to assess consumer preferences for digital euro accounts compared to their current bank accounts. Each choice task presents respondents with three options: two unlabelled digital euro account alternatives and one base alternative representing their current bank account. The two digital euro account alternatives vary in attribute levels, while the base alternative remains consistent across all choice sets.

Respondents are first asked to select their most preferred option among the three choices. Then, they are asked to select their second most preferred option from the remaining two alternatives. The inclusion of the base alternative enables the estimation of the potential market share for digital euro accounts by comparing the likelihood of choosing the new accounts over their current bank account. By making sure that a respondent also always states their preference between the

two digital euro options, the trade-offs being made for this choice can also be studied. This will give insights in the importance of the attributes and their levels.

5.3.2 Experimental design

As described in chapter 2.2.1, the experiment was constructed using a orthogonal fractional factorial design. Basic plans are published experimental designs that meet that requirements for these orthogonal fractional factorial designs (Molin, 2017). Therefore, to determine the amount of choice tasks needed, basic plan 3 was used (see Appendix E1 for Basic Plan 3). Basic Plan 3 supports a design with three attributes having four levels and two attributes having two levels, resulting in a total of 16 choice sets.

The experimental design with 16 choice sets was then created using Ngene software, which optimises the distribution of attribute levels across the sets to maintain orthogonality and attribute level balance. The syntax used for creating the design can be found in Appendix E2.

To reduce the number of choices respondents needed to make during the experiment, the 16 choice sets were divided into two blocks of eight tasks each. Each respondent is randomly assigned one block, ensuring that the full range of attribute and level combinations is still covered across the sample. This approach limits respondent burden, as they only need to complete eight choice tasks instead of 16.

The complete experimental design is presented in Appendix E3. After the design was created, it was reviewed for dominant alternatives. Dominant alternatives are options within a choice set that are clearly superior to the other alternative. For this study, dominance was evaluated based on the following criteria: for *Wallet Holding Limit*, a higher limit is superior (with no limit being the best option); for *Privacy*, greater anonymity is preferred; for *Interest Rate*, higher rates are better; and for *Offline Suitability*, options that support both online and offline payments are preferred over online-only options. For the *Issuer of Money*, no clear superiority exists between levels, so dominance was only identified when the issuers for both alternatives were the same.

Using this method, it lead to the discovery of 2 dominant alternatives, one in block 1 and one in block 2. Both of these choice sets were then removed. By removing choice sets from the experimental design, correlations are introduced within alternatives. Appendix E4 shows these correlations. Since the within-alternative correlations were of limited size, no trouble would be caused once the parameters would be estimated.

Using these criteria, two dominant choice sets were identified—one in Block 1 and one in Block 2. Both choice sets were removed from the design. Removing these choice sets introduced limited correlations within alternatives, which are shown in Appendix E4. Since the resulting within-alternative correlations were minor, they are not expected to impact the reliability of the parameter estimates. Therefore, this design can be used for the experiment. The final design is shown in Appendix E5.

5.4 Survey structure

The survey for this study was created using Qualtrics, which offers tools to efficiently manage experimental designs and respondent interactions. A template for DCEs created by Weber (2021) was used to ensure a clear and structured implementation of the experiment in Qualtrics. To ensure equal representation of the experimental design's blocks, respondents were randomly assigned to one of the two blocks of choice tasks. Qualtrics was configured to balance the distribution, ensuring that both blocks were selected approximately an equal number of times. Additionally, the order in which the choice tasks were presented was randomised for each respondent to minimise potential order effects, as described in Section 2.2.1.

The survey began with an introduction and opening statement, which provided respondents with context about the research and ensured informed participation. The full opening statement can be found in Appendix E6. Following this, the first question asked respondents to provide their age. Any respondent under the age of 18 was automatically redirected to the end of the survey, ensuring compliance with ethical research guidelines.

Demographic questions were then presented, covering gender, educational level and household income. These questions were phrased in Dutch as follows:

- Q1: Hoe oud bent u? (What is your age?)
- Q2: Wat is uw geslacht? (What is your gender?)
- Q3: Wat is de hoogste opleiding die u heeft afgerond? (What is the highest level of education you have completed?)
- Q4: Wat is uw totale jaarlijkse huishoudelijke (bruto) inkomen? (What is your total annual household (gross) income?)

After answering the demographic questions, respondents were provided with an introduction to the digital euro and the choice experiment, explaining its purpose and how to approach the tasks. This explanation is included in Appendix E7.

The core of the survey consisted of seven choice tasks (per block), where respondents were presented with three options: two digital euro account alternatives and their current bank account (base alternative). They were required to select their first preference among the three options and then their second preference from the remaining two. Qualtrics enforced the selection of two distinct choices, ensuring that respondents could not inadvertently choose the same option twice, making the process clear and "foolproof." The survey concluded with a message to thank the respondents for participating and the email address of the researcher for any questions.

Figure 8 demonstrates an example of a choice task in Qualtrics, where respondents compare two digital euro account options and their current bank account. The decision to leave the "Uw huidige rekening" (Your current account) column empty was deliberate. Instead of providing average information, such as an interest rate of 1.5%, which might confuse respondents if it did not match their exact bank details, the empty column allows participants to reflect on their own bank account conditions. This approach aligns with real-life decision-making, where individuals are not typically presented with a detailed comparison of their current account when considering new financial products. By including an empty column, it still emphasises the option to retain the current account, making it a thoughtful choice in the experiment. Including this empty column visually reinforces that the current account is part of the choice set

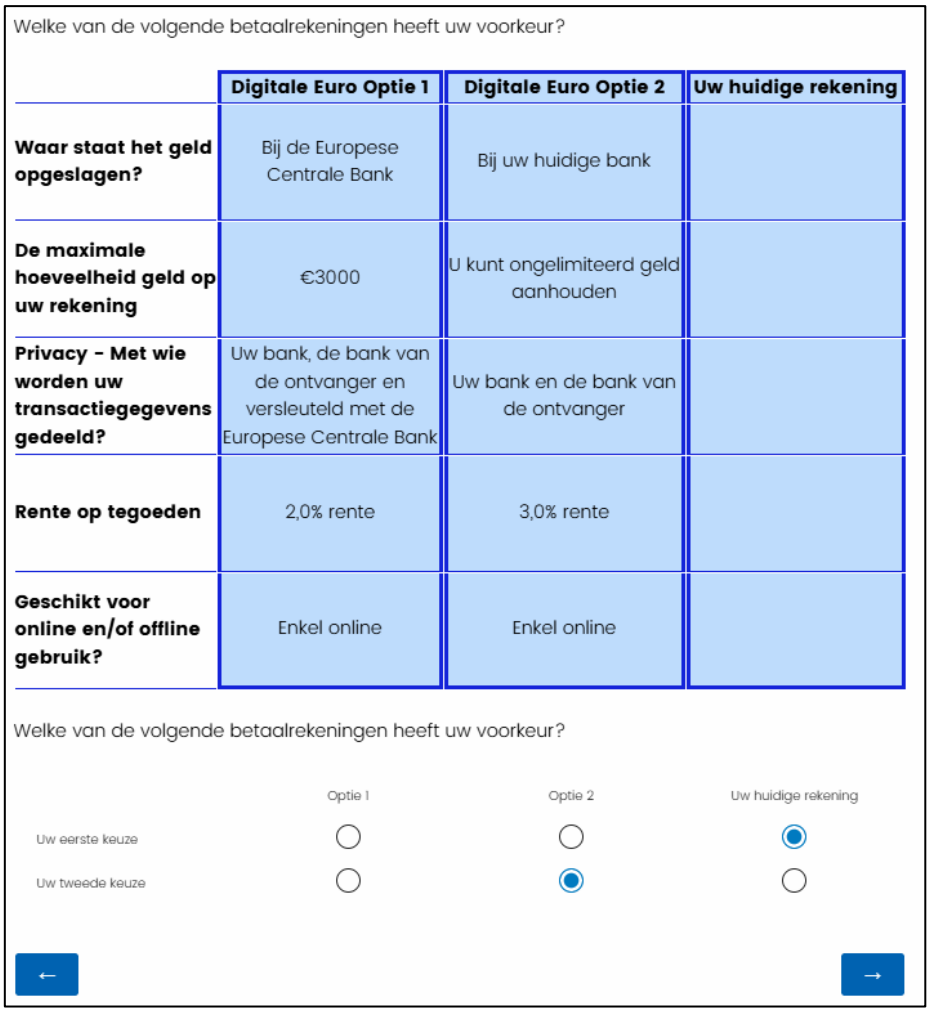

Figure 8: Example of a choice task during the survey in Qualtrics

5.5 Pilot test

A pilot test was conducted to ensure the survey and choice experiment were clear, functional and user-friendly. The pilot aimed to validate aspects such as the time required to complete the survey, the clarity of the questions, the visual presentation of the interface and whether all elements fit properly on various screen sizes.

During the pilot, it was observed that some respondents selected the same option twice in the choice task, which was not the intention for this survey. To address this, the survey was adjusted in Qualtrics to enforce the selection of two different options. Additionally, based on feedback from pilot participants, the survey language was simplified to make the questions easier to understand. The time it takes to complete the survey, as estimated in the opening statement, was updated based on the average completion times observed during the pilot.

5.6 Survey distribution

The survey was distributed using convenience sampling. It was shared via LinkedIn and WhatsApp groups to reach potential respondents. It was accessible from December 23, 2024, to January 12, 2025. Efforts were made to target a broad population to ensure diverse input, however, reaching a representative sample proved to be challenge. These limitations and their implications for the study's findings will be further addressed in the discussion chapter.

6. Experiment Results

Chapter 6 presents the results of the DCE and their interpretation, addressing how different design attributes influence consumer preferences and adoption of the digital euro. Section 6.1 explains the data preprocessing process, followed by 6.2 describes the demographic characteristics of the sample. In 6.3, the choice model is further specified and estimated, section 6.4 shows the results. The chapter concludes with 6.5, here sub-question 5 and 6 are answered.

6.1 Data preprocessing

The collected survey data was exported from Qualtrics in CSV format. The dataset initially contained responses where each row represented one respondent and each column represented a question or choice task (the wide format). However, when using the Apollo package (a package for discrete choice modelling) in R, the data needs to be transformed into a long format, where each row represents a single choice task. This transformation, along with other preprocessing steps, was performed in Python using the pandas package.

The preprocessing steps included the following:

1. **Removal of Redundant Columns**: Columns unimportant for the choice experiment, such as start date, end date, status and completion status, were removed from the dataset to simplify processing.
2. **Reshaping Data into Long Format:** The data was reshaped so that each row corresponded to a single choice task.
3. **Handling Missing or Invalid Data:** Rows containing missing values (NaN) in any of the choice variables were removed to ensure the dataset only included complete responses. Additionally, rows where respondents selected the same option for both their first and second preferences were deleted. Although Qualtrics was set up to prevent this, this step implemented just to be sure.
4. **Merging with Experimental Design:** The reshaped dataset was merged with the experimental design based on the block and choice task number, so that each row includes the attribute levels corresponding to the presented alternatives.
5. **Encoding Choice Variables**: Choice variables (e.g., 'Optie 1', 'Optie 2', 'Uw huidige rekening') were converted into numerical variables named first_pref and second_pref. For these variables, a value of 1 indicates that Option 1 was chosen, 2 indicates Option 2 and 3 indicates that the base alternative (current bank account) was selected.
6. **Handling the Holding Limit Attribute:** For the holding limit attribute, the level representing no holding limit (in essence a holding limit of infinity) was treated as a separate variable. A dummy variable (no_holding_limit) was created, which equals 1 when the alternative has no holding limit and 0 otherwise. This allows for the assumption of a linear relationship between the €3000–€9000 holding limits while estimating the effect of no holding limit separately, as the no holding limit is expected to give the most utitlity.

Once the preprocessing steps were completed, the dataset was prepared for further analysis in R.

6.2 Demographic characteristics of respondents

A total of 56 individuals initiated the survey by answering at least one question. Among them, 53 respondents completed the demographic questions and were assigned to a block of choice tasks. Of these respondents, 48 individuals filled in at least one choice task and were therefore included in the analysis for descriptive statistics.

The distribution of participants between the two blocks was relatively balanced, with 25 respondents completing Block 1 and 23 completing Block 2. After removing one outlier with an unreasonably high completion time of 19.771 seconds, the average time required to complete the survey was approximately 6,5 minutes. The shortest recorded completion time was 1 minute and 42 seconds, which seems fast, but reasonable for someone who for example was already familiar with the concept of the survey by participating in the pilot.

6.2.1 Demographic characteristics of respondents

Table 8 presents the demographic characteristics of the respondents.

Table 8: Demographic characteristics of respondents

Individual level variable	Category	N	Percentage
Age	18-24	23	51,1%
	25-34	16	35,6%
	35-44	1	2,2%
	45-54	5	11,1%
	55 or older	3	6,7%
Gender	Male	40	83,3%
	Female	8	16,7%
Education level	No diploma	1	2,1%
	High-school 1, middle-level applied education*	1	2,1%
	High school 2, middle-level applied education 2**	12	25,0%
	Higher education bachelor (hbo/wo)	18	37,5%
	Higher education masters (hbo/wo)	15	31,3%
	PhD degree	1	2,1%
Household income	€0 - €24.999	19	39,6%
	€25.00 - €49.999	15	31,3%
	€50.000 - €89.999	5	10,4%
	€90.000 - €129.999	2	4,2%
	€130.000 - €149.999	2	4,2%
	More than €150.000	3	6,3%
	Prefer not to answer	2	4,2%

* Educational level in in Dutch: vmbo ; havo/vwo year 1-3 & mbo 1

** Educational level in Dutch: havo, vwo & mbo 2-4

The majority of participants are aged between 18 and 34, with 51.1% in the 18-24 age range and 35.6% in the 25-34 age range. The remaining age groups (35 years and older) accounts for a smaller proportion of respondents, indicating a relatively young sample overall.

In terms of gender, 83.3% of the respondents are male, while 16.7% are female. Regarding education levels, the largest group of participants (37.5%) hold a bachelor's degree, followed by

31.3% with a master's degree. A smaller proportion of respondents have completed middle-level applied education (25%), while only a few have a PhD degree or no formal diploma.

Household income is distributed across a wide range, with the largest group (39.6%) reporting an income of €0 - €24.999. Approximately 31.3% of respondents earns between €25.000 and €49.999, while higher income brackets are less represented. A small proportion (4.2%) chose not to disclose their income.

The sample characteristics suggest that the respondents are predominantly young, male and highly educated, which limits the representativeness of the data relative to the broader Dutch population. The overrepresentation of younger age groups and males may influence the findings, as these demographic factors are likely associated with different preferences and familiarity with digital innovations. Similarly, the high level of education in the sample might skew the results toward individuals with greater awareness or understanding of digital currencies. This limits the generalizability of the findings. These limitations will be further addressed in the discussion chapter.

6.3 Choice Model Estimation

This section describes the estimation of consumer preferences using the exploded logit model with the Apollo package in R. Utility functions were specified for each alternative in the choice sets, capturing the systematic components of utility based on the attributes. The estimation process is divided into two parts: model specification, which defines the utility functions and variable coding for the alternatives and model estimation, which presents the observed choice data and evaluates the model using measures of fit metrics.

6.3.1 Model specification

To estimate the Exploded Logit model, utility functions for each alternative in the choice sets were specified. These utility functions represent the systematic part of the utility derived from each alternative, based on the attributes presented in the discrete choice experiment.

In this study, the choice sets included three alternatives: two digital euro account options and a baseline alternative representing the respondent's current bank account. The utility functions for each alternative were formulated as follows:

$$V_j = a_{DigEuro} + \beta_{holdlim} * holdim_j/1000 + \beta_{holdlim_0} * holdlim_{0,j} + \sum_{i=0}^{3}(\beta_{privacy,i} * privacy_{j,i}) + \beta_{interest} * interest_j + \sum_{i=0}^{1}(\beta_{offline,i} * offline_{j,i}) + \sum_{i=0}^{1}(\beta_{Issuer,i} * issuer_{j,i})$$

Here, j (=1,2) represents the digital euro account alternatives. The base utility for digital euro accounts is represented by $a_{DigEuro}$, the β's represent the parameters for the corresponding attributes. Note that $\beta_{privcacy,3}$, $\beta_{offline,0}$, $\beta_{issuer,0}$ are fixed to zero to prevent perfect multicollinearity. For interpretability, the holding limit variable has been scaled by dividing it by 1000, so the coefficient represents the change in utility associated with a €1.000 increase in the holding limit.

The base alternative is coded as j=3 and has the following systematic utility:

$$V_3 = 0$$

Table 9 gives an overview of how the variables are coded:

Table 9: Overview of variable coding

Attribute	Variable	Level 0	Level 1	Level 2	Level 3
Issuer of money	issuer	Commercial bank	European / National Central Bank		
Wallet holding limit	holdlim	[€0] no limit	[€9000] holding limit	[€6000] holding limit	[€3000] holding limit
Privacy – Who could access the transaction data?	privacy	Anonymous, only the payer and payee	Personal data is shared with PSPs of payer and payee	Personal data is shared with PSPs and pseudonymised with ECB	Personal data is shared with PSPs and ECB
Interest rate received on online holdings	interest	No interest	1,0% interest	2,0% interest	3,0% interest
Offline suitability	offline	Only online	Offline and online		

6.3.2 Model estimation

The analysis was conducted using the Apollo package in R, which is specifically designed for estimating DCMs. The model syntax can be found in Appendix F.

The specified exploded logit model assumes homogeneous preferences. This means that all respondents are assumed to share identical preference parameters for the utility components (Beggs et al., 1981). This provides general insights into population-level preferences, but ignores heterogeneity in preferences across individuals. This limitation is a trade-off for simplifying the analysis and focusing on general trends in consumer choice.

Table 10 provides an overview of the respondents' first and second preference choices across the three alternatives: two digital euro account options and the baseline alternative representing the current bank account. The first preference data shows that the current bank account was selected most frequently (54%), while digital euro alternatives were chosen less often, with 25% and 21% of first preference choices. The second preference data highlights the remaining rankings after the first choice, with digital euro alternatives being selected more often than the baseline option in the second rank. However, here the current bank account option is still chosen 57% of the time when available.

Table 10: Overview of first and second preference choices

		Dig Eur alt 1	Dig Eur alt 2	Current bank account (3)
First preference	Times available	322	322	322
	Times chosen	66	81	175
	Percentage chosen overall	21%	25%	54%
Second preference	Times available	256	241	147
	Times chosen	112	126	84
	Percentage chosen overall	35%	39%	26%
	Percentage chosen when available	44%	52%	57%

The model fit metrics for the estimated exploded logit model are shown in Table 11. These metrics assess how well the model explains the observed choice behaviour. The maximum log-likelihood (-490.7) reflects the best fit achieved under the model's assumptions. The adjusted ρ^2 value of 13.4% indicates how much of the variance in the ranking data is explained, accounting for the number of parameters. The AIC (999.4) and BIC (1033.4) measure the balance between model fit and complexity, with lower values indicating better performance. While these metrics are most meaningful when compared to alternative models, they are included here for transparency and to provide a general indication of the model's suitability for analysing the choice data.

Table 11: Model fit metrics for the exploded logit model

Fit Metric	**Result**
Maximum Log-likelihood	-490,7
Adjusted ρ^2	13,4%
AIC	999,4
BIC	1033,4

6.4 Model results

The parameter estimates from the exploded logit model provide insights into how various attributes influence consumer preferences for digital euro accounts. Each parameter represents the marginal utility derived from a unit change in the corresponding attribute. A positive sign indicates an increase in utility (and thus preference), while a negative sign suggests a decrease. For dummy variables, the interpretation is relative to the reference category, which is assigned a parameter of zero. For example, in the privacy attribute, where β_privacy_3 serves as the reference category (data shared with PSPs and ECB), the coefficients for β_privacy_0, β_privacy_1 and β_privacy_2 reflect the change in utility compared to this baseline. Similarly, for other categorical variables, the coefficients show how each level compares to the reference level in terms of its contribution to the utility of the alternative. Table 12 presents the parameter estimates, robust standard errors and t-statistics for the model:

Table 12: Exploded logit model parameter estimates

Parameter	**Estimate**	**Robust s.e.**	**Robust t-stat**
β holdlim	0,15	0,03	5,13*
β holdim_0	1,63	0,30	5,42*
β privacy_0	0,63	0,18	-3,47*
β privacy_1	0,10	0,17	0,58
β privacy_2	0,38	0,15	-2,57**
β interest	0,45	0,08	5,40*
β offline_1	0,48	0,16	3,04*
β issuer_ECB	-0,14	0,12	-1,17
α Digital Euro constant	-2,88	0,44	-5,72*

**, ** denotes significance at the 1% and 5% level respectively, using a critical t-value of 2,576 and 1,96*

6.4.1 Interpretation of estimation results

The estimation results presented in this section should be understood in the context of the sample characteristics described earlier. The respondents in this study are predominantly young, male and highly educated, which may influence their preferences and attitudes toward the digital euro. As a result, the findings reflect the views of this specific group and may not fully represent the broader Dutch population.

Wallet Holding Limit (β holdlim, β holdlim_0): The positive and significant coefficient for β holdlim suggests that higher holding limits increase utility. However, having no holding limit (β holdlim_0) provides the most utility out of the surveyed options, confirming the expectation that unrestricted access is preferred. The parameter estimates for the wallet holding limit provide a clear picture of how different levels of holding limits influence utility. For the range of €3000 to €9000, utility increases by 0,149 per €1000. For a holding limit of €3000, the utility is 0,447, for €6000 and €9000 it increases respectively to 0,894 and 1,341.

Interestingly, the utility associated with having no holding limit, as captured by the variable β holdim_0, is equivalent to a holding limit of approximately €10,940. This hints at diminishing marginal utility around this point, as a holding limit of €10,940 offers the same utility as having no limit at all. However, this is an extrapolation beyond the attribute level range presented in the survey, so it should be interpreted with caution.

Privacy (β privacy_0, β privacy_1, β privacy_2): The parameter estimates for privacy provide insights into how different levels of data sharing influence utility. Privacy Level 3, where data is shared with PSPs and the ECB without pseudonymisation, serves as the reference category and is associated with the lowest perceived utility. Positive coefficients for other privacy levels indicate an increase in utility as fewer parties gain access to transaction data compared to Privacy Level 3.

Privacy Level 0, offering full anonymity (e.g., only the payer and payee have access to transaction data), has the highest positive and significant coefficient. This reflects a clear preference for this option when compared to Privacy Level 3. The result suggests that respondents place significant value on privacy. Privacy Level 1, where data is shared with the PSPs of both the payer and the payee, has a positive but not statistically significant coefficient. This reflects a small improvement in utility compared to Privacy Level 3, although the result is insignificant. Privacy Level 2, where data is shared with PSPs and pseudonymised with the ECB, reflects the ECB's current proposal. The coefficient is positive and significant, indicating a clear preference over Privacy Level 3. Interestingly, while this level involves sharing data with an additional party (the ECB), the coefficient is higher than for Privacy Level 1 where data is not being shared with the ECB.

The lack of significance for Privacy Level 1 and its lower coefficient compared to Privacy Level 2 suggest that the way privacy options are communicated might impact perceptions. While Privacy Level 1 was explained only briefly as involving data sharing with PSPs, the more detailed description of pseudonymisation for Level 2 in the survey explanation may have shaped respondents' views, potentially making it appear more privacy-friendly than it actually is. This highlights the importance of clear and balanced communication when presenting privacy-related attributes, as the framing of pseudonymisation can presumably influence user preferences.

Interest Rate (β interest): The coefficient for β_interest is positive and statistically significant at the 1% level, indicating that higher interest rates increase the utility of the digital euro account. This result aligns with economic intuition, as consumers of course tend to prefer better returns on their balances. The magnitude of the coefficient (0,45) suggests that for every 1 percentage point increase in the interest rate offered on the digital euro account, the utility of the alternative increases by 0,45.

Offline Suitability (β offline_1): The parameter estimate for β_offline_1 is positive (0,48) and statistically significant at the 1% level, suggesting that offering both offline and online payment functionality increases the utility of the digital euro, compared to offering only online payment functionality. This finding aligns with the idea that consumers value the ability to use the digital euro in scenarios where online connectivity is unavailable, such as during technical disruptions or in areas with poor internet coverage.

Issuer of Money (β issuer_ECB): The parameter estimate for β_issuer_ECB is -0,14, with a robust standard error of 0,12 and a t-statistic of -1,17. This indicates that the effect is not statistically significant. This suggests that who would issue a digital euro , the ECB or a commercial bank, does not have a significant impact on consumer utility in this study.

The slightly negative but non-significant coefficient raises questions about how the role of the issuer is perceived by consumers. One possible explanation is that, in a stable financial environment such as the Netherlands, the perceived safety advantage of central bank-issued money may not add significant utility. With strong regulatory frameworks and deposit guarantee schemes already in place, consumers may feel equally secure using money issued by commercial banks or the ECB. Another possibility is that the lack of a significant preference for an ECB-issued digital euro reflects varying levels of trust in public institutions. Some consumers may have a neutral or cautious attitude toward governmental entities, including the ECB, which could contribute to the slightly negative coefficient. However, this remains speculative and would require further investigation.

Digital Euro Constant (α): The parameter estimate for the digital euro constant (α_DigEuro) is -2,88, with a robust t-statistic of -5,72, indicating a statistically significant negative effect. This constant shows the baseline preference for the digital euro compared to respondents' current bank accounts, before considering any specific attributes of the digital euro.

The negative value suggests that, on average, people prefer their current bank accounts over the digital euro accounts. Several potential factors could potentially contribute to this baseline aversion to the digital euro. First, familiarity and trust in existing banking relationships might lead consumers to view their current bank accounts as safer or more reliable. Second, a lack of understanding or clarity about the digital euro concept might contribute to consumer reluctance, particularly if respondents are uncertain about how the digital euro would function or its benefits over existing bank accounts.

Heterogeneity in the sample: To explore whether preferences for digital euro design attributes vary across demographic groups, parameter estimates were analysed for subsets of the sample based on gender, income, education level and age. The full analysis can be found in Appendix F2

Overall, the results indicate that the key attributes driving adoption, such as holding limits, interest rates and offline functionality, are valued similarly across demographic groups, as shown by the consistent signs of most coefficients across subsets. While differences in coefficient magnitudes suggest potential variations in how these attributes contribute to adoption, these variations should be interpreted cautiously due to the small sample sizes in some of the subsets.

6.4.2 Results in comparison with other studies

The results of this study are compared with findings from other research on CBDCs that focus on privacy, interest rates, offline functionality and adoption. These comparisons provide additional context for the findings and highlight similarities and differences across studies.

Privacy concerns

This study found that a decrease in privacy has a significant negative effect on the utility of a digital euro account. Privacy Level 2 (data shared with PSPs and pseudonymised with ECB) and Privacy Level 3 (data shared with PSPs and the ECB without pseudonymisation) have significant positive coefficients, indicating a clear preference for higher privacy protections. However, Privacy Level 1 (data shared with PSPs) showed no significant effect compared to level 3, suggesting that the perceived privacy impact of pseudonymisation may be overstated or unclear to respondents.
These findings are consistent with Tronnier et al. (2022), who found that privacy concerns significantly affect willingness to adopt a digital euro in Germany. Tronnier et al. also emphasised the importance of trust in the issuer and transparency in data handling, which may influence perceptions of privacy in pseudonymised systems. Both this study and our results highlight the need for clear communication about privacy safeguards in the design and presentation of CBDCs.

Interest rates

The results of this study indicate that higher interest rates increase the utility of digital euro accounts, with a coefficient of 0.45, which is significant at the 1% level. This means that for every 1 percentage point increase in interest, utility increases by 0.45 units. These results are consistent with Bijlsma et al. (2021), who found that higher interest rates on CBDCs positively impact adoption intentions and deposit amounts. Both studies underline the importance of financial incentives, though Bijlsma et al. note that the relative advantage of interest rates compared to traditional accounts might be more influential than the absolute rate level.

Offline functionality

The results indicate that the availability of offline payment functionality has a significant positive impact on utility, as evidenced by a coefficient of 0.48. This finding suggests that consumers appreciate the ability to use digital euro accounts in situations where internet access is unavailable, as this was explained in the explanation section of the survey. This aligns with findings from Kantar Public (2023), where offline payments were identified as the most innovative feature of a digital wallet. However, Kantar Public also highlighted that while participants found offline functionality useful for specific scenarios, they did not expect to use it frequently in their daily lives. This may indicate that offline payments are perceived as a "safety net" rather than a core feature of regular usage.

Adoption and issuer

The findings of this study suggest that the issuer of the digital euro—whether the ECB or a commercial bank—does not have a significant impact on consumer utility. These results are consistent with the findings of Fairweather et al. (2024), who conducted a DCE on CBDC adoption in Australia. Their study similarly found that Australians do not seem to value the added safety of a claim on their central bank over a claim on a commercial bank. This was attributed to the public already perceiving commercial bank deposits as a safe form of money. Additionally, Fairweather et al. noted that attitudes toward government involvement in financial services might also influence perceptions of central bank issuance.

In both studies, the lack of a significant preference for central bank issuance may reflect the stability of the existing financial system. In contexts where commercial banks are viewed as reliable and where deposit guarantee schemes provide a strong safety net, the safety advantage of a central bank-issued digital currency may not be that relevant consumers.

6.4.3 Market shares for digital euro designs

To better understand consumer preferences, market shares are calculated for different digital euro designs by evaluating the utility of various attribute combinations. All parameter estimates are included in these calculations, even if they are not statistically significant. This ensures that the analysis captures all aspects of consumer preferences reflected in the model, providing a more complete picture of how different designs might perform.

For this analysis, there are only two alternatives in each scenario: the digital euro account and the current bank account. This allows the use of the standard logit model function to calculate the market share of the digital euro alternative:

$$P_j = \frac{e^{V_j}}{e^{V_j} + e^{V_b}} = \frac{e^{V_j}}{e^{V_j} + e^{0}}$$

Here, P_j is the probability of choosing digital euro alternative j, V_j is the utility of the digital euro alternative and V_b is the utility of the current bank account, which is fixed to zero.

6.4.3.1 Digital euro alternative with the same attribute levels as the current bank account

Let's first look into the utility of a digital euro alternative that has the same attribute levels as the base alternative (current bank account) would have. This alternative would have the following attribute levels:

- *Issuer of money*: Commercial bank (level 0)
- *Wallet holding limit*: [€0] no limit
- *Privacy – who could access the transaction data*: Personal data is shared with PSPs of payer and payee (level 1)
- *Interest rate received on online holdings:* [1,5%]
- *Offline suitability:* Only online (level 0)

Therefore, this alternative would have the following utility level:

V = -0,475

Since the utility of the current bank account is fixed to 0, this -0,475 utility can be seen as the as the negative base preference for a digital euro bank account compared to a commercial bank account. This difference in utility is caused by all utility bringing attributes that are missing in this experiment.

If this alternative were to be introduced, it would, according to our model and data, get a market share of 38%.

6.4.3.2 Digital euro alternative as proposed by the ECB

This section evaluates the utility and market share of the digital euro design based on the ECB's proposed attributes, as outlined in Chapter 4. This digital euro alternative would have the following attribute levels:

- *Issuer of money*: ECB (level 1)
- *Wallet holding limit*: [€3000]
- *Privacy – who could access the transaction data*: Personal data is shared with PSPs and pseudonymised with ECB (level 2)
- *Interest rate received on online holdings:* 0%, No interest
- *Offline suitability:* Offline and online (level 1)

Therefore, this alternative would have the following utility level:

$V_{DigitalEuro}$ = -1,713

If this alternative were to be introduced, it would, according to our model and data, get a market share of 15,3%.

The estimated market share of 15,3% for the ECB's proposed digital euro design reflects relatively low potential adoption compared to the current bank account (100-15,3=84,7%). This indicates that the proposed design may not align closely with consumer preferences in the Netherlands.

To give this 15,3% estimated market share some context, we can compare it with the market share of other payment methods. However, it is important to note that this data reflects actual payment methods used for transactions, whereas this study focuses on the stated preferences of consumers regarding their likelihood of opening a digital euro account. It remains unclear whether the introduction of a digital euro would primarily reduce card or cash usage. It is also worth noting that individuals who open a digital euro account for specific use cases, such as offline payments, may continue relying on their regular bank accounts for other purposes, such as e-commerce transactions. As such, these numbers are not directly comparable but can still offer some context.

In 2023, 80% of POS transactions in the Netherlands were made using cards or phones linked to bank accounts (5,61 billion transactions), while 20% were in cash (1,4 billion) (Betaalvereniging Nederland, 2023). For e-commerce, iDeal accounted for 71% of online transactions in 2022 (Banken.nl, 2022), with 1,36 billion transactions recorded in 2023 (Betaalvereniging Nederland, 2023). For P2P payments, 350 million transactions were made electronically (for example by iDeal or direct transfers), compared to 228 million in cash (Betaalvereniging Nederland, 2023).

Should the EPI's WERO platform replicate iDeal's success (which is not unthinkable because they acquired iDeal), it could continue to dominate the online and P2P payments market, especially if its reach will become pan-European. If you would assume that the digital euro were to achieve a 15,3% market share in terms of transaction volume (which would be very high if stated adoption is 15,3%), it would be used in hundreds of millions of payments. However, this would still represent a relatively small portion of the total payment system compared to current dominant solutions like card payments or iDeal.

6.4.3.3 Alternatives on the digital euro design as proposed by the ECB

This section explores how varying individual attributes of the digital euro design proposed by the ECB affects its estimated market share. Using the base design from 6.4.3.2 (referred to as the ECB proposal), attributes are systematically varied one level at a time while keeping all others constant. Table 13 summarises the results of these variations, showing the utility and corresponding market share for each alternative, along with the change in market share compared to the ECB proposal.

Table 13: Estimated utility and market share of digital euro design variations compared to the ECB's proposal

Attribute	Variation	Utility	Market share (%)	Change from base (% point)
Base design	ECB proposal	-1,713	15,3	-
Issuer	Commercial bank (level 0)	-1.573	17,2	+1,9
Holding limit	€6000	-1.266	22,0	+6,7
	€9000	-0.819	30,6	+15,3
	No limit	-0.530	37,1	+21,8
Privacy level	Full anonymity (level 0	-1.473	18,6	+3,3
	PSPs only (level 1)	-2.003	11,9	-3,4
	PSPs + ECB (level 3)	-2.103	10,9	-4,4
Interest Rate	1%	-1.263	22	+6,7
	1,5%	-1.038	26,2	+10,9
Offline suitability	Only online (level 0)	-2.193	10,0	-5,3

The relevance of this analysis lies in its ability to directly compare the market share impacts of specific design choices for the digital euro. While the parameter signs in table 12 already indicate whether a design feature increases or decreases utility, this table provides a clearer understanding of the magnitude of these effects and their direct influence on market share.

The base design (ECB Proposal), with a utility of -1,713 and an estimated market share of 15,3%, serves as the benchmark for this analysis. Changing the issuer to a commercial bank slightly increases market share to 17,2% (+1,9%). While this attribute does not have a significant influence on preferences, it suggests a marginal preference for commercial bank issuance in this specific design. However, this is not really something that the ECB can incorporate into their design, as one of the fundamental aspects of a CBDC is that it is being issued by a central bank.

Increasing holding limits consistently yields the largest gains in market share. For instance, raising the limit to €6000 results in a 6,7 percentage point increase in market share, comparable to offering a 1% interest rate. Further increasing the limit to €9000 yields a 15,3 percentage point increase, significantly surpassing the 10,9 percentage point increase achieved by a 1,5% interest rate. This finding suggests that consumers value having unrestricted balances as well as receiving a financial incentive to use the digital euro.

When comparing privacy levels to holding limits and interest rates, it becomes clear that while privacy is important, its impact on market share is generally smaller. For example, offering full anonymity (Privacy Level 0) increases market share by 3,3 percentage points, which is significantly less than the gains achieved by increasing holding limits to €6000 or adding a relatively low interest rate of 1%. This relatively smaller impact of privacy might be explained by the unexpectedly high parameter estimate for Privacy Level 2 (see 6.4.1 for the explanation), which is present in the base design.

The importance of offline functionality also becomes evident in preventing market share losses. Not making offline payments available reduces market share by 5,3 percentage points. This indicates that offline functionality, while presumably not the primary driver of adoption, is still important for maintaining the appeal of the digital euro. To prevent the market share of the ECB's proposed design from dropping further, it would be important to ensure that offline payments are well implemented and clearly communicated when the digital euro is introduced.

6.5 Conclusion

The results of this study provide insights into how different design attributes influence consumer preferences and adoption of the digital euro, addressing Sub-question 5 and Sub-question 6. It is important to note that these findings are based on a sample that is predominantly young, male and highly educated, and may not fully represent the broader population. As such, the results should be interpreted with caution and in the context of the study's sample characteristics.

Sub-question 5: *How do different design attributes influence consumer preferences and adoption of the digital euro?*

The analysis shows that consumer preferences are influenced by holding limits, interest rates, privacy protections and offline functionality. The ECB's current proposed digital euro design is estimated to have a market share of 15,3%. Increasing holding limits consistently increases market share, with the removal of limits entirely providing the largest impact out of the tested options. Renumeration in the form of an interest rate also plays a role, with a modest rate of 1% resulting in a 6,7% increases in market share compared to the alternative as proposed by the ECB. Privacy protections affect preferences, though their impact is generally smaller compared to holding limits and interest rates. Offering full anonymity improves market share, but the relatively high utility derived for 'sharing data with PSPs and pseudonymised with ECB' compared to an alternative where data is just being shared with PSPs suggests that consumer perceptions of privacy may be influenced by how these options are communicated. Offline functionality increases market share by 5,3 percentage points, emphasising its value in the digital euro's design. Whether or not a digital euro would be issued by the ECB (compared to a commercial bank) does not seem to significantly affect consumer preferences. The analysis of demographic subsets suggests that key attributes like holding limits, interest rates and offline functionality are consistently valued across groups, though differences in magnitude were observed and would require further research to draw more definitive conclusions.

Sub-question 6: *Which design attributes are most important for consumer adoption of the digital euro?*

Out of all the options considered in the choice experiment, holding limits are identified as the most influential attribute for adoption, followed closely by interest rates. Privacy protections, while still relevant, have a smaller effect. Offline functionality also contributes significantly to the digital euro's appeal. The issuer variable has insignificant influence on adoption. This reflects that consumers are indifferent to whether the digital euro is issued by a central or commercial bank under the conditions tested in this study.

In conclusion, holding limits, interest rates, privacy levels and availability of making offline payments are found to have significant effects on consumer preferences for digital euro accounts. The issuer variable does not show significant results, suggesting that whether the digital euro is issued by the ECB or a commercial bank is less relevant to consumers when choosing between the current bank account and a digital euro account.

7. Recommendations

This chapter combines the findings from previous chapters to answer:

Sub-question 7: *"Based on consumer preferences, how should the ECB incorporate these insights into the further design and finalization of the digital euro?"*

The digital euro is an initiative by the ECB to modernize public money while addressing strategic objectives such as financial inclusion, resilience and European sovereignty in payments. As explored throughout this thesis, its success will likely depend on how its design aligns with the preferences of consumers and stakeholders, and its ability to balance usability with broader policy goals. Drawing on the interests of stakeholders (Chapter 3), the design space analysis (Chapter 4) and the DCE (Chapter 5 & 6), this chapter provides recommendations to guide the ECB in aligning the digital euro's design with consumer preferences while considering broader policy objectives.

Recommendation 1: *Prioritise flexibility in holding limits*

The current proposed holding limit of €3,000 is viewed as restrictive and may reduce the attractiveness of the digital euro. Increasing the limit, for example to €6,000, could significantly improve its appeal to potential users while maintaining limited impacts on the financial system. The results indicate that higher limits are strongly associated with increased adoption potential, making flexibility in holding limits a key factor in the digital euro's design. Therefore, the ECB is recommended to increase the holding limit as much as is feasible within the constraints of financial stability to make the digital euro more attractive to consumers.

Recommendation 2: *Explore financial incentives*

The DCE results highlight the value consumers place on financial incentives, such as earning interest on their holdings. However, offering interest might have broader implications for the monetary system. Therefore, alternative incentives that could have a similar effect on perceived utility, but may have smaller effects on the broader system, should also be considered. As discussed in Chapter 4, the ECB could explore mechanisms like sign-on bonuses or rewards programs to encourage adoption without directly impacting monetary policy. Additionally, collaborating with private partners, such as PSPs and fintech companies that support the digital euro, could help deliver complementary services that strengthen its value proposition and make it more appealing to consumers.

Recommendation 3: *Improve communication*

Effective communication could be very important in addressing consumer concerns and enhancing the perceived value of the digital euro. The results in Chapter 6 suggest that consumer' perceptions of certain attributes, such as privacy protections, might be shaped not only by the objective level of the feature but also by how it is communicated. Although this remains a plausible interpretation rather than a confirmed finding, it underscores the importance of clear and transparent communication. Providing detailed information about what data the ECB will process and whether it will be anonymous or pseudonymised or not, could help build trust and positively influence consumer preferences. Similarly, the limiting nature of holding limits could potentially be partially mitigated by clearly explaining how waterfall mechanisms ensure that users can still pay and receive payments, regardless of their current account balance. For offline payments, the ECB should clearly communicate the level of anonymity these transactions will provide once the technology is finalised, particularly as the offline digital euro has been described as having "cash-like" features.

Recommendation 4: *Focus on the unique use cases of the digital euro*

The ECB should emphasise the unique benefits and use cases of the digital euro to encourage adoption. Highlighting abstract goals, such as enhancing Europe's strategic autonomy, is unlikely to persuade individuals to use it. Instead, the ECB must clearly provide the practical advantages of the digital euro over existing payment methods. Competing solutions, such as the Wero platform from the European Payments Initiative, already aim to address pan-European payment needs, which could reduce the perceived necessity of the digital euro. Moreover, the findings from the DCE reveal that the issuer dimension does not significantly influence consumer preferences. The ECB may have hoped that consumers would value the 'increased' safety of CBDC, but the results suggest that this aspect might not play a significant role in their preferences. As such, the ECB must present a compelling case for why the digital euro is necessary and actively communicate this message to the public to avoid the risk of it becoming another failed CBDC project.

8. Conclusion & Discussion

The digital euro is a retail CBDC being designed by the ECB to provide a secure, efficient and inclusive digital payment option alongside physical cash. It aims to address challenges like declining cash use, dependence on non-European payment providers and private digital currencies. To mitigate risks to financial stability, features like holding limits and no remuneration are proposed. However, its success relies on aligning with consumer preferences to drive adoption. While much research on CBDCs focuses on technical and macroeconomic aspects, consumer preferences are not extensively explored, especially for the digital euro. This thesis fills that gap by examining how design features like holding limits, remuneration and privacy affect consumer adoption. The central research question is:

What design choices can the ECB make to enhance consumer adoption of the digital euro?

The research question is addressed through an approach consisting of two phases, combing design science research and discrete choice modelling. In the first phase, design science research explored the digital euro's design space by mapping the most important objectives and attributes. In the second phase, discrete choice modelling was used to empirically assess preferences of Dutch consumers through a discrete choice experiment.

Stakeholder objectives and the role of banks

The analysis of stakeholder objectives revealed that the ECB's primary goals for the digital euro include preserving monetary sovereignty, ensuring payment resilience and promoting financial inclusion. These objectives are driven by challenges such as the decline in cash usage, dependence on non-European payment providers and the rise of private digital currencies like stablecoins. Other stakeholders, such as commercial banks, PSPs, businesses and consumer groups, have diverse priorities, ranging from protecting current business models for banks to emphasising privacy and accessibility for consumers. Especially the trade-off between preserving financial stability and encouraging adoption seems highly relevant and complex.

Currently, it appears that the ECB has prioritised preserving financial stability, potentially at the expense of the digital euro's attractiveness to consumers. This prioritisation may be influenced by the structure of the digital euro project, which has actively involved market participants, such as banks, in the design process. While it makes sense for banks to be involved to some extent, given their role in the financial ecosystem, the level of their involvement raises questions about whether their influence on the design has been too significant. As important players in the payment system and potential competitors to the digital euro, their prominent role may have steered design choices in ways that protect their interests but limit the digital euro's potential to serve as an attractive alternative.

Digital euro design and alternatives

The exploration of the design space identified fundamental features of the digital euro, such as suitability for digital transactions, issuance by the ECB, currency parity with the euro and universal accessibility, aligning it with the ECB's policy goals as proper public money. Variable design features, including privacy levels, user interaction and holding limits, remain flexible and open to refinement. Next to mapping the ECB's current design proposal, two alternative designs were proposed to explore different priorities. A privacy-focused digital cash option prioritised enhanced privacy protections while introducing trade-offs in regulatory compliance and accessibility. Another alternative, using an incentivised onboarding approach, incorporated remuneration and promotional offers to encourage adoption, though this could present risks to financial stability and competition. These alternatives illustrate the potential trade-offs involved in tailoring the digital euro to meet different objectives.

While these alternative designs provide valuable insights into the design space, they have not been rigorously validated and were primarily intended as exploratory concepts rather than fully implementable solutions. While they could provide insights into the design space, further research is needed to assess their technical and regulatory feasibility. Similarly, the technical feasibility of the offline digital euro is not validated in thesis, but assumed to be present, although the ECB is still looking to develop this component.

Comparison with existing payment systems and differentiation challenges

The comparison with existing payment solutions revealed that while the digital euro shares some objectives with systems like the European Payments Initiative, it also offers unique features, such as the potential for anonymous offline payments and universal accessibility. However, the extent to which the digital euro can differentiate itself remains uncertain. Although the design aims to provide a cash-like digital euro in offline form, the funding and defunding of offline wallets would not be anonymous and offline transaction data could still be accessible to the ECB to prevent forgery. While this may enhance privacy compared to some digital payment methods, it falls short of replicating the anonymity of cash.

Furthermore, the proposed design largely replicates functionalities already available through commercial bank money and existing digital payment systems. Without offering clear advantages, such as significantly enhanced privacy, lower costs, or unique technological innovations, the digital euro risks being perceived as redundant. Past CBDC implementations in countries like Sweden and Nigeria highlight that technical feasibility alone is insufficient. Clear benefits that align with consumer expectations are critical for adoption. Restrictive design choices, such as the absence of remuneration and strict holding limits, though aimed at preserving financial stability, may reduce the digital euro's appeal.

Future research could explore whether the goals of the digital euro project, such as financial inclusion, payment resilience and strategic autonomy, could be better addressed through specific, targeted solutions rather than a single CBDC. For instance, projects like the European Payments Initiative or improving instant payment systems could tackle certain objectives without the need for a completely new digital currency. Examining whether a more focused approach might work better than trying to meet all goals with one solution could provide valuable insights for the ECB and enrich the CBDC literature.

Consumer preferences and adoption

The discrete choice experiment provided empirical insights into how specific attributes influence adoption. Out of the attributes and levels varied in the experiment, holding limits emerged as the most significant driver of preferences. Removing limits entirely provided the largest impact on adoption, while increasing the limit from €3000 to €6,000 or €9,000 also improved market share. Interest rates were found to play an important role in influencing consumer adoption, with remuneration options increasing the appeal of the digital euro compared to a non-remunerated design. An improvement in privacy protection has a smaller but still notable impact on preferences. The suitability for offline payments also contributed significantly to the utility of the digital euro accounts. The issuer variable is not significant, suggesting that whether the digital euro is issued by the ECB or a commercial bank is less relevant to consumers when choosing between the current bank account and a digital euro account. Additionally, the model outcomes showed a baseline preference for current bank accounts over the digital euro.

The derived market share for the ECB's current digital euro proposal, based on the model, was estimated at 15.3%. For context, competing payment systems such as cards and iDeal currently dominate the market, with over 70% share in POS and e-commerce transactions, while cash still accounts for around 20% of POS payments. These numbers reflect actual transaction volumes,

whereas the 15.3% market share represents stated preferences for adopting a digital euro account. The actual share in transaction volume could be lower, as individuals might use the digital euro selectively, such as for offline payments, while continuing to use existing accounts for other purposes. The ECB has never stated a target adoption rate.

To assess the robustness of preferences for digital euro design attributes across demographic groups, parameter estimates were analysed for subsets of the sample. Overall, the results suggest that key attributes such as holding limits, interest rates and offline functionality are consistently valued across groups, though differences in the magnitudes of preferences may exist.

These findings align with prior research. Tronnier et al. (2022) highlight the importance of privacy safeguards, showing significant negative effects on utility when data sharing increases. Both studies emphasise the need for transparent communication to build trust. Bijlsma et al. (2021) found that higher interest rates positively influence adoption and deposit levels. Both studies highlight the role of financial incentives in making CBDCs more attractive to consumers, though Bijlsma et al. note that relative advantages compared to traditional accounts may play an even greater role. The positive impact of offline functionality on adoption matches findings from a focus group by Kantar Public (2023), which identified offline payments as valuable but often viewed as a backup rather than a primary feature. Finally, the insignificant effect of the issuer variable in this study is consistent with Fairweather et al. (2024), who found that Australians did not value the added safety of a central bank-issued CBDC over one issued by commercial banks.

These findings are subject to several limitations. The representativeness of the survey sample is a significant limitation that likely affects the generalisability of the findings. The sample primarily consisted of young, male and highly educated respondents, which does not reflect the broader Dutch population. Moreover, the survey was distributed electronically and relied on convenience sampling, potentially excluding demographics less likely to engage with digital surveys, such as older individuals. As a result, certain consumer perspectives may be underrepresented. Additionally, this study only captures preferences within the Netherlands, a country with a high level of digital payment adoption. Preferences in other Eurozone countries with differing payment behaviours and less developed financial infrastructures could vary significantly.

Furthermore, respondents' opinions may change as the digital euro gains publicity and the ECB's proposal becomes more concrete. The stated preferences in this study reflect current perceptions and may not align with future attitudes. Additionally, stated preferences may not fully translate into real-world actions, meaning actual adoption could differ from these findings.

Finally, the study did not estimate interaction effects between holding limits and interest rates, which likely influence consumer preferences. For example, remuneration may be less appealing with lower holding limits, while higher limits could enhance the attractiveness of earning interest on larger balances.

Future studies could aim to address the limitations identified in this research. Larger and more diverse samples that capture a broader demographic range, both within the Netherlands and across other Eurozone countries, would provide more generalisable insights. Another interesting path would be to investigate consumer preferences in countries where cash usage is still more prevalent. This could provide a broader understanding of how cultural and economic differences affect CBDC adoption. Such studies would complement this thesis by exploring preferences in contexts where digital payment infrastructure is less developed and cash remains a dominant payment method. It would be interesting to compare the results to the findings of this study.

Additionally, future research could analyse the implications of increasing holding limits under varying adoption scenarios. This would provide valuable insights into the potential trade-offs

between encouraging adoption and preserving financial stability, especially as higher holding limits could lead to significant changes in deposit outflow from commercial banks to the digital euro.

8.1 Recommendations

This thesis provides several recommendations to enhance the digital euro's appeal and adoption potential, while considering broader policy goals.

Flexibility in holding limits: The current proposed holding limit of €3,000 is viewed as restrictive and may reduce the attractiveness of the digital euro. Increasing the limit, for example, to €6,000, could significantly improve its appeal to potential users while maintaining limited impacts on the financial system. Therefore, the ECB is recommended to increase the holding limit as much as is feasible within the constraints of financial stability to make the digital euro more attractive to consumers.

Explore Financial Incentives to drive adoption: Consumers value financial incentives like remuneration on holdings. While paying interest could have broader monetary implications, alternative mechanisms such as sign-on bonuses or rewards programs could achieve similar effects. Collaborations with PSPs or fintech companies could also enhance the digital euro's appeal by delivering complementary services.

Improve Communication: Effective communication could be very important to address consumer concerns and enhancing the perceived value of the digital euro. Consumer perceptions of certain attributes, such as privacy protections, might be shaped not only by the objective level of the feature but also by how it is communicated. Although this remains a plausible interpretation rather than a confirmed finding, it underlines the importance of clear and transparent messaging. Transparency about privacy mechanisms and the level of anonymity in offline transactions could positively influence perceptions and trust in the digital euro.

Emphasise Unique Use Cases: The ECB should emphasise the unique benefits and use cases of the digital euro to encourage adoption. Highlighting abstract goals, such as enhancing Europe's strategic autonomy, is unlikely to persuade individuals to use it. Instead, the ECB must clearly provide the practical advantages of the digital euro over existing payment methods. Competing solutions, such as the Wero platform from the European Payments Initiative, already aim to address pan-European payment needs, which could reduce the perceived necessity of the digital euro. As such, the ECB must present a compelling case for why the digital euro is necessary and actively communicate this message to the public to avoid the risk of it becoming another failed CBDC project.

To finalise, while the digital euro holds potential to address objectives such as financial inclusion and payment resilience, it is important to consider whether these goals could also be achieved through enhancements to existing systems like the instant payment infrastructures or promising projects like the European Payments Initiative. Policymakers must carefully evaluate whether the digital euro offers unique and essential benefits, or if refining current systems could achieve similar outcomes with fewer complexities and risks.

8.2 Societal relevance

By introducing a CBDC, the ECB aims to improve the resilience of the payment system, promote financial inclusion and reduce reliance on private payment providers. The design and implementation of the digital euro have implications for consumers and businesses, making the development of this currency a topic of societal relevance. A successful digital euro could provide benefits such as greater accessibility to digital payments, increased competition in the payments market and strengthened monetary sovereignty within the Eurozone. It could provide Europe's citizens with a proper digital public payment alternative.

However, challenges remain regarding consumer adoption and the potential impact on financial stability. If the digital euro is perceived as unattractive or redundant by the public, adoption may fall short of expectations, raising questions about its value and effectiveness. Additionally, balancing features that appeal to consumers with safeguards that preserve financial stability presents a complex trade-off.

This thesis contributes to addressing these challenges by identifying what consumers value in a digital euro and evaluating how design features, such as holding limits, remuneration and privacy protections, influence adoption. The findings suggest that consumer preferences should play a more central role in the design process to make sure that the digital euro is both appealing and practical to consumers. A digital euro that is not widely adopted may fail to justify the costs of its implementation. Therefore, it is very important to make sure that the digital euro becomes an attractive and competitive payment method if it is introduced. For example, the proposed holding limit of €3.000, while intended to mitigate financial stability risks, may act as a barrier to adoption by limiting the digital euro's utility for consumers. An increase to €6.000 could already have a significant positive effect on the adoption rate. This thesis highlights the importance of designing a digital euro that not only meets regulatory and policy objectives but also addresses the needs of the public and thereby tries to contribute to society.

8.3 Scientific relevance

This thesis contributes to the growing body of research on CBDCs by offering insights into the relationship between design features and consumer adoption. One of its main contributions is the quantification of the effects of holding limits on consumer preferences for a payment method. To the best of the researcher's knowledge, this is the first study to empirically evaluate how holding limits impact adoption rates. This is relevant since the implementation of these limits is currently being proposed by the ECB for the digital euro to mitigate risks to financial stability. However, they reduce the attractiveness of a CBDC as well.

The methodological approach of this thesis also contributes to scientific research by combining design science research with discrete choice modelling in a two-phased approach. Design science research was used to map the digital euro's design space and structure the exploration of its features, while discrete choice modelling provided an empirical framework to assess consumer preferences. This combination offers a replicable and structured way to explore design trade-offs and quantify consumer adoption potential, not only for the digital euro, but possibly also for other innovative systems.

This research also gives insights in the governance of design processes, in this case in the context of the digital euro. The involvement of commercial banks in the design process, through working groups and consultations, likely had a great impact on the features of the proposed digital euro. While banks' input is valuable given their expertise and role in the financial and payment system, banks also act as potential competitors to a retail CBDC. Their influence may have contributed to the inclusion of restrictive features, such as holding limits and the absence of remuneration, which

aim to minimize risks to traditional banking models, but reduce the digital euro's attractiveness. This shows the importance of balancing stakeholder involvement to make sure that competing interests do not negatively impact the overall objectives of a project. Future initiatives should better address potential conflicts of interest and seek to provide a more balanced representation of stakeholders.

Finally, this thesis builds on earlier studies on CBDC adoption, such as Fairweather et al. (2024), who have employed a discrete choice experiment to assess consumer preferences for retail CBDCs in Australia. There is no application of this methodology to the digital euro so far. This thesis expands the scope by applying DCEs to assess Dutch consumers' preferences, while incorporating the specific design considerations and regulatory environment of the digital euro project.

8.4 Fit to CoSEM program

This master thesis fits well within the CoSEM program because the topic concerns a design issue within a complex system. A potential introduction of the digital euro can be seen as an innovation within our current money and payment infrastructure, where certain rules and legislation apply and where both private actors (banks, citizens) and public actors (ECB, EU Commission and Parliament, national central banks) play a role.

The thesis tackles a multidisciplinary design issue in a complex system. It combines technical, legal, economic and organizational perspectives to assess the digital euro design and its fit within the greater financial system. For example, the thesis includes an analysis of the legislative frameworks that are proposed for the implementation of the digital euro. It reviews literature on the macroeconomic impact of CBDCs and looks at the technical side, such as data privacy mechanisms and different CBDC architectures. By researching consumer preferences, the social context of the system is taken into account, which is of great importance for this specific complex system.

Additionally, design science research and discrete choice modelling were used, which are both approaches/techniques that were taught during the CoSEM program. Since the digital euro is digital in its nature, it connects well with the CoSEM I&C Track.

8.5 Personal reflection

When I spoke to fellow students or friends about the topic of my thesis, I often received the same reaction: "But we already have digital euros—what's in my bank account then?" This frequently led me to explain the difference between public and private money. At the same time, this gave me the insight that the way a digital euro is presented—the "front end"—is extremely important. People's perception of the digital euro significantly influences whether they would use it. The goals the ECB is pursuing with the digital euro seem less important to potential users than practical aspects, like the €3000 holding limit or the absence of interest. That's why I emphasised the importance of consumer adoption in my thesis.

I also learned how challenging it is to design (within) complex systems in a real-world case. There are so many different interests and countless ways to approach specific issues. Even when a decision appears to have been made, things can shift within a month. It can take years for an idea to move from concept to implementation. Additionally, I found it fascinating to see that some banks, which were initially very critical of CBDCs and the digital euro (as seen in older blog posts), now seem to support the idea. This shift is clearly linked to their involvement in designing the digital euro. In my view, the balance has been somewhat lost. Speaking personally, I see little added value in a digital euro compared to how I currently manage my payments. I do not see much reason to open a digital euro account, except for curiosity about its design. That being said, I can imagine that in less developed countries, a well-functioning digital payment system might offer

significant benefits, though I have limited insight into that context. I hope the ECB continues to research the success potential of this project and the relevance of the goals it aims to achieve. Ideally, this will lead to the right decision on whether or not to implement the digital euro.

The design process of the digital euro also demonstrates the importance of governance and steering in shaping the final product (even though the digital euro is not yet finalized). Who has a seat at the table matters. I would advise the ECB or other policymakers to focus on designing from the user's perspective. Particularly when it comes to tools that consumers are expected to use in their daily lives, high-level objectives are less compelling to potential new users than concrete, tangible benefits for them.

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Appendix A: Power Interest Matrix

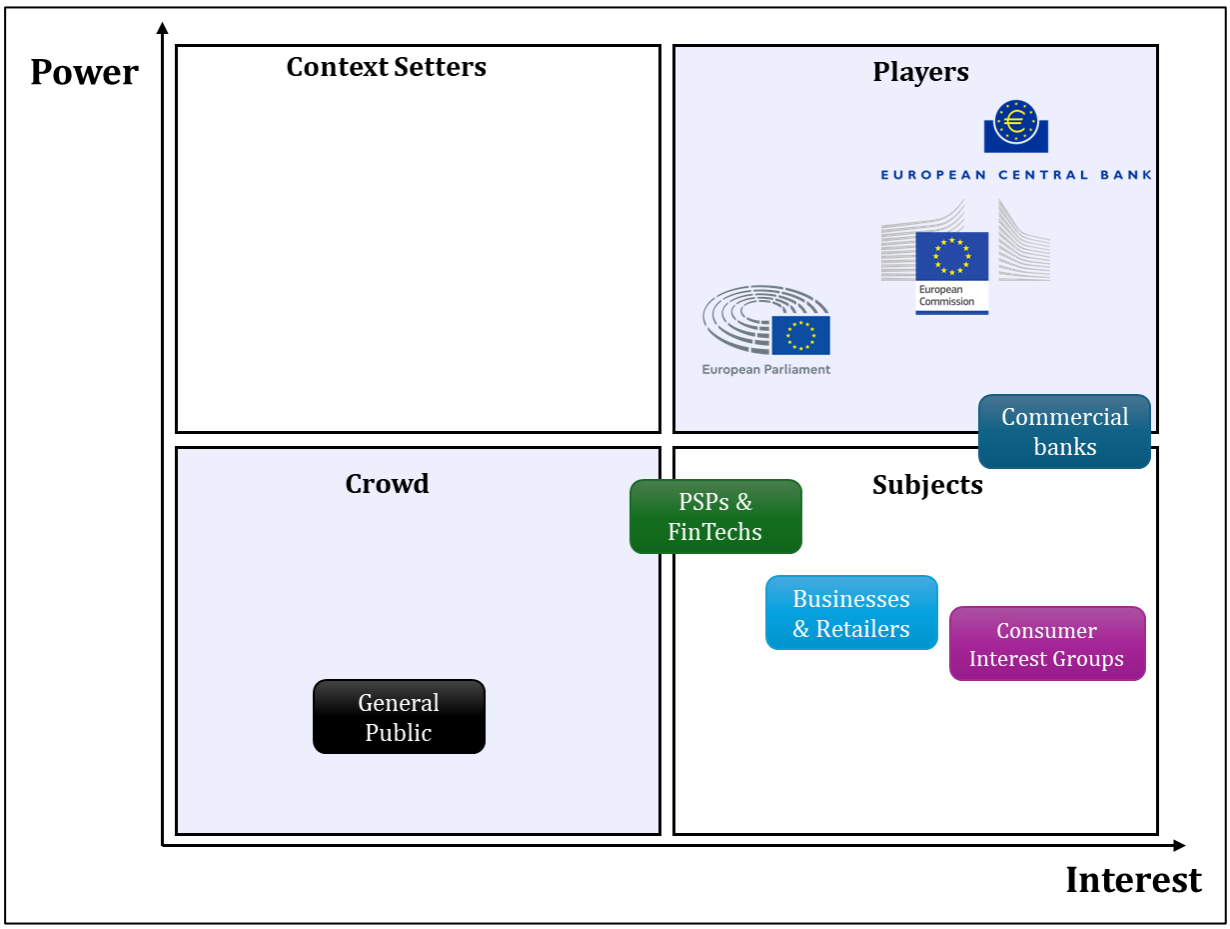

Figure 9: Power-Interest matrix for digital euro stakeholders

The power-interest matrix in figure 9 provides a structured overview of the diverse stakeholders involved in the development and implementation of the digital euro. The ECB, as the problem owner, holds significant power and interest. It is responsible for the technical design and implementation of the digital euro, addressing key features such as privacy, offline functionality and distribution. Alongside the ECB, the European Commission plays a role in developing the legislative framework, ensuring that the digital euro aligns with EU legal and operational standards. The European Parliament and the Council of the European Union provide oversight and approval, representing the broader interests of EU citizens and member states.

Among market stakeholders, commercial banks hold a unique position with relatively higher influence compared to other actors such as PSPs and FinTech companies. The current design of the digital euro, with measures like holding limits and safeguards to mitigate disintermediation risks, reflects the success of commercial banks in lobbying for a framework that prioritizes financial stability and minimizes disruption to their business models. PSPs and fintech companies, while active participants in the project, have more limited influence but see opportunities to develop services and adapt to new revenue streams within the digital euro ecosystem.

The general public, represented by consumer interest groups, has high interest but limited power in shaping the digital euro. Their concerns are primarily conveyed through advocacy groups.

While these groups lack decision-making authority, they ensure that the digital euro addresses societal needs, an essential factor for widespread acceptance.

The matrix underscores the need for balanced collaboration. The ECB and EC must work closely to align the technical and regulatory aspects of the digital euro, while engaging with market stakeholders to address concerns about stability and business models.

Appendix B: Design requirements Digital Euro Report

The ECB, in its 2020 report on the digital euro (ECB, 2020), outlined a comprehensive set of design requirements to guide its development. These requirements are categorized into scenario-specific requirements, addressing specific use cases and general requirements, applicable across all scenarios. By considering potential drivers for issuing the digital euro, such as the decline of cash or the need for enhanced monetary policy tools, the ECB derived key characteristics that the digital euro should meet to fulfil its objectives. Table 14 gives an overview of these design requirements from the digital euro report.

Table 14: Design requirements from the digital euro report (ECB, 2020)

Type of characteristic	Description
Scenario-specific requirements	**R1:** Enhanced digital efficiency (if launched to support digitalisation): The digital euro should keep pace with state-of-the-art technology at all times in order to best address the needs of the market as regards, among other attributes, usability, convenience, speed, cost efficiency and programmability. It should be made available through standard interoperable front-end solutions throughout the entire euro area and should be interoperable with private payment solutions.
	R2: Cash-like features (if aiming to tackle a decline in the acceptance of cash): To match the key distinctive features of cash, a digital euro aiming to tackle a decline in the acceptance of cash should permit offline payments. Moreover, a digital euro should be easy for vulnerable groups to use, free of charge for basic use by payers and should protect privacy. It should have a strong European branding.
	R3: Competitive features (if introduced to limit the uptake of forms of money that are not denominated in euro and/or not appropriately supervised): The digital euro should have features which are at the technological frontier. It should offer the basis for providing functionalities that are at least as attractive as those of the payment solutions available in foreign currencies or through unregulated entities.
	R4: Monetary policy option: If considered to be a tool for improving the transmission of monetary policy, the digital euro should be remunerated at interest rate(s) that the central bank can modify over time.
	R5: Back-up system: If aiming to improve the overall resilience of the payment system, the digital euro should be widely available and transacted via resilient channels that are separate from those of other payment services and can withstand extreme events.
	R6: International use (if introduced to increase the international role of the euro): The digital euro should be potentially accessible outside the euro area in a way that is consistent with the objectives of the Eurosystem and convenient to non-euro area residents.
	R7a: Cost saving (if launched for cost efficiency): The design of the digital euro should achieve a reduction in the cost of the current payments ecosystem.
	R7b: Environmentally friendly (if launched for environmental reasons): The design of the digital euro should be based on

	technological solutions that minimize its ecological footprint and improve that of the current payments ecosystem.
General Requirements	**R8:** Ability to control the amount of digital euro in circulation: The digital euro should be an attractive means of payment, but should be designed so as to avoid its use as a form of investment and the associated risk of large shifts from private money (for example bank deposits) to digital euro.
	R9: Cooperation with market participants: A project to introduce a digital euro should be carried out in line with best practices in IT project management. The digital euro should then be made available on an equal basis in all euro countries through supervised intermediaries, which could leverage their existing customer-facing services and avoid the costly duplication of processes.
	R10: Compliance with the regulatory framework: Although central bank liabilities are not subject to regulation and oversight, in issuing the digital euro the Eurosystem should still aim at complying with regulatory standards, including in the area of payments.
	R11: Safety and efficiency in the fulfilment of the Eurosystem's goals: The digital euro should be designed in a safe and efficient way. Its project and operating costs should be estimated and compared with the expected benefits, considering alternative solutions in any future scenario. The provision of non-core services should be left to supervised private entities.
	R12: Easy accessibility throughout the euro area. The digital euro should be made available through standardized front-end solutions throughout the entire euro area and should be interoperable with private payment solutions. It should be easily accessible by anyone, including citizens who currently do not participate in the financial system (for example, those who do not have an account at a commercial bank), and should be easy to use. The digital euro would need to co-exist with cash.
	R13: Conditional use by non-euro area residents: The design of the digital euro should include specific conditions for access and use by non-euro area residents, to ensure that it does not contribute to excessively volatile capital flows or exchange rates. Such conditions could take the form, for instance, of limits or adequate remuneration policies for holdings of digital euro of non-euro area residents.
	R14: Cyber resilience: Digital euro services will need to be highly resilient to cyber threats and capable of providing a high level of protection to the financial ecosystem from cyberattacks. In the event of successful attacks, the recovery time should be short and the integrity of the data protected.

Appendix C: Institutional Morphological Chart

Table 15: Institutional morphological chart for the digital euro design

Design Function / Feature	Option 1	Option 2	Option 3	Option 4	Option 5
Facilitate payments	Facilitate card, online and digital payments				
Issue digital euro	Issued by ECB				
Ensure value consistency	Currency parity to euro				
Determine the mode of digital euro access*	Account-based	Token-based			
Data processed by who*	PSP	ECB	Provider of support services	Distributed Ledger	
Secure personal data*	Make data anonymous	Make data pseudonymous	Apply zero knowledge proof		
Facilitate/Settle transactions *	Centralised	Decentralised	Blockchain		
Provide business to business transactions*	Allow uncapped B2B payments	Allow capped B2B payments	Allow B2C payments		
Customize financial transactions*	Smart contracts	User-defined rules			
Facilitate offline transactions*	Hardware wallets	Preloaded smart cards	NFC	Bluetooth transactions	Card-to-card with a bridge device
Provide offline wallet (de)funding	ATM integration	Online deposit (de)funding	Bank branch services	Cash-in Cash-out kiosks	POS terminal
Provide user-friendly usage of digital euro interface	Digital euro app	Digital euro API/SDK	Smart device compatibility	Multilingual support	
Support transaction methods	Card payments	Tap-to-pay	QR code payments	Mobile wallet integration	
Standardize usage across jurisdiction*	Legal tender status	Centralised oversight	Common technical standard		

Define who can use the digital euro*	Natural and legal persons residing or established in a euro country	Visitor Access	Legal status	Economic activity	Bilateral agreements with non-euro countries
Monitor and ensure compliance	ECB general fraud detection and prevention mechanism	Sanctions screening by PSPs	Transaction monitoring by PSPs	Criminal background check	
Verify user identity	No verification mechanisms	Biometric verification	European digital identity	Proof of identity (passport, ID)	
Define stakeholder distribution roles*	Distributed by PSPs	Distributed directly by ECB	Distributed by National Central Banks	Distributed via selected financial institutions	
Incentivise digital euro holding*	Rewards program	Promotional offers	Tax benefits	Integration with government services	None
Renumerate the digital euro*	No interest on digital euro holdings	Flat rate monthly set by ECB	Fixed margin below ECB Deposit rate	Reverse tiered interest rates	Transaction-based bonuses
Control digital euro money supply*	Fixed holding limit	Transaction limit	Issuance control	ECB Buy/sell programs of digital euro	(Reverse) waterfall method
Prevent bank runs*	Funding restrictions during distressed periods	Additional liquidity support mechanisms for commercial banks	Real time monitoring and alerts		
Adjust Monetary Supply	Adjust digital euro interest rate	Adjust holding limits			
Establish fee structures*	Pricing up to the market	Flat regulated rate per transaction	Percentage-based fees	Zero fees for basic transactions, higher fees for bigger transactions	Maximum rates set by regulation
Manage profits and costs*	ECB bears own cost on infrastructure and settling	PSP bear their own distribution cost	PSPs get charged for using digital euro infrastructure	ECB is not allowed to make profits on digital euro operations	Public-private partnership were both parties have investments in the infrastructure

Table 15 presents the institutional morphological chart for the digital euro design, which maps the principal functions identified in Section 4.3.1 to a range of potential options that could achieve them. Certain functions are marked with an asterisk ('*') to indicate those requiring additional explanation:

Determine the mode of digital euro access

Account-Based: In this model, the digital euro is linked to user accounts managed by intermediaries, such as banks or payment service providers. Ownership and transaction validation are tied to personal identity. This offers a relatively high traceability and makes compliance with regulations such as AML and KYC easier, but may reduce user privacy. Account-based systems align with the systems that are currently used a lot, making them easier to integrate (Urbinati et al., 2021). Putting features like renumeration and holding limits in place is easier to do using an account-based system (Urbinati et al., 2021).

Token-Based: This approach treats the digital euro as a bearer instrument, where ownership is determined by possession rather than account linkage. A token-based system could offer variable levels of privacy and would make the possibility to make the digital euro 'programmable' easier (Urbinati et al., 2021). However, it could pose challenges to preventing fraud and maintaining compliance with AML standards (Urbinati et al., 2021). Another challenge for token-based systems could be that the rate of transactions might not be high enough to facilitate payments on a European scale. Using tokens would also make it more difficult to renumerate the digital euro and apply holding limits.

Data processed by who

PSPs: In this case PSPs would be the party to provide accounts to digital euro users. To facilitate that users can make transactions, they would have to process and manage transaction data, which they would probably do in a similar manner to private payment systems. This approach could use infrastructure that these payment providers currently are using.

ECB: In this case the ECB would process all the transactions and its corresponding data. Centralised processing gives the ECB direct oversight and control. However, this option requires the ECB to develop and maintain extensive infrastructure, which could strain resources and increase operational complexity.

Provider of Support Services: In the case that third parties will be used to provide support services regarding the transactions, they would also gain access to the personal data that the digital euro transactions would generate.

Distributed Ledger: With a distributed ledger, the transactions are processed across multiple decentralised nodes. These nodes all keep track of the ledger where the transaction data is stored. DLT could offer a secure and transparent basis, but it may pose challenges related to coordination, scalability and potential inefficiencies in transaction validation (Kramer, 2024).

Secure personal data

Make Data Anonymous: Data would be made fully anonymous what would result in the highest privacy possible. At the same time this would make it very hard to comply with regulations regarding financial crime.

Make Data Pseudonymous: Under this model, users' identities are not directly tied to transactions but can be disclosed under specific circumstances, for example for legal investigations. In this way data is initially de-identified but could be re-identified if ought to be needed by the ECB.

Apply Zero-Knowledge Proof:
Zero-knowledge proof is a cryptographic technique that allows one party to confirm a transaction's validity to others without sharing any sensitive information (Wang & Kogan, 2018). However, implementing zero-knowledge proofs in large-scale systems like a digital euro presents challenges, including high computational demands, integration with regulatory requirements and ensuring scalability and public trust (Gross et al., 2021).

Facilitate/Settle transactions

Centralised: In a centralised model, transactions are processed through a single central system. The ECB could for example be the one that oversees this central ledger. A centralised approach goes well together with an account-based system, which forms a proven highly performing infrastructure (Urbinati et al., 2021).

Decentralised: Decentralised processing distributes transaction validation across multiple nodes, reducing dependence on any single entity. A distributed ledger is an example of a decentralised system, but there are different possibilities as well.

Blockchain: Blockchain technology uses distributed ledger systems to record transactions in a decentralised way. However, blockchain systems often face challenges in scalability and energy efficiency, particularly when managing large volumes of transactions in real time (Sanka & Cheung, 2021).

Provide business-to-business transactions

Allow Uncapped B2B Payments: Unrestricted B2B transactions enable businesses to transfer any amount. This would increase the usability of a digital euro promote adoption among businesses. However, this approach may lead to (excessive) fund outflows from commercial banks, which could potentially destabilise the financial ecosystem according to the ECB (2023b).

Allow Capped B2B Payments: Introducing transaction limits for B2B payments could help control the potential risks that allowing business users to use the digital euro would bring. This approach however may also hinder businesses and possibly keep them away from using a digital euro.

Allow B2C Payments: In this version businesses would only be allowed to pay their consumers with digital euros, for example in the case of a refund. This feature would limit the effect on outflow of funding from banks.

Customize financial transactions

Smart Contracts: Smart contracts are digital contracts which are programmed to execute transactions automatically when specific conditions are met. Smart contracts are typically used in combination with blockchain technology.

User-Defined Rules: This approach gives users the possibility to establish their own payment conditions, such as setting spending limits or defining payment schedules. Personalising your payments could be appealing to users (Kantar Public, 2023).

Facilitate offline transactions

Hardware Wallets: Hardware wallets are physical devices designed for storing currencies. Hardware wallets would be relatively secure against cyber threats due to the absence of an internet connectivity. However, they would also be prone to being lost or stolen. Also, carrying a physical hardware wallet could be perceived as inconvenient.

Preloaded Smart Cards: A Physical card that is preloaded with digital euros. It could provide a feasible method for offline and in-store payments. They might appeal to users who prefer tangible payment methods, such as those less familiar with digital technology. However, it would require regular reloading and could be seen as less convenient to digital alternatives.

NFC: NFC technology allows users to perform contactless offline transactions by tapping or bringing devices close together. NFC-based payments are considered by the ECB for point-of-sale (POS) and P2P payments (ECB, 2023a).

Bluetooth Transactions: P2P or POS payments could be facilitated using Bluetooth connections.

Card-to-Card with a Bridge Device: These devices could facilitate offline transactions and are currently being considered by the ECB (ECB, 2024e). Although this method would assumably be technically relatively simple to implement, it can be expected that users would find it highly inconvenient to carry such a device when making payments.

Standardize usage across jurisdiction

Legal Tender Status: Granting the digital euro legal tender status would mandate its acceptance across all Eurozone jurisdictions for public and private transactions. Currently cash is the only form of legal tender in the Eurozone. However, implementing legal tender status requires alignment with existing regulatory frameworks, which could have some consequences for other design features (Mooij, 2023).

Centralised Oversight: A single regulatory authority, such as the ECB, would oversee compliance with legal and technical standards across jurisdictions. This would ensure uniform application of rules.

Common Technical Standard: Refers to establishing one single set of rules that are followed throughout the Eurozone on technical standards as well as legal frameworks.

Define who can use the digital euro

Natural and Legal Persons Residing or Established in a Euro Country: Access is granted to individuals and businesses residing or legally established within the Eurozone.

Visitor Access: Temporary access for tourists and non-residents when visiting a Eurozone country allows the digital euro to function as a convenient payment option for short-term visitors.

Legal Status: Users must provide legal European identification, like a passport, to be eligible.

Economic Activity: Access to the digital euro could be granted to foreign entities based on their involvement in specific types of economic activities within the Eurozone.

Bilateral Agreements with Non-Euro Countries: International access can be established through specific agreements with non-Eurozone countries.

Define stakeholder distribution roles

Distributed by PSPs: Under this model, PSPs manage the distribution of the digital euro. PSPs could make use of their existing customer bases, infrastructure and expertise in retail payments. This structure maintains the two-tier banking system. In this model, the ECB focuses on oversight rather than operational retail activities, which is in line with recommendations for intermediated CBDC models (Auer et al., 2022).

Distributed Directly by ECB: In this model, the ECB takes full control over issuing and managing the digital euro. It would use a single-tier direct CBDC architecture where users interact directly with the ECB for accessing and transacting with digital euros (Auer et al., 2022).

Distributed by National Central Banks: Similar to the model where the ECB distributes the digital euro, but now distribution takes place decentralised throughout the Eurozone.

Distributed via Selected Financial Institutions: This is a hybrid model where both private and public parties involved in the distribution process. In this case, the ECB would select a certain amount of financial institutions that will distribute the digital euro.

Incentivise digital euro holding

Rewards Program: A non-monetary incentive model where users receive benefits such as loyalty points or discounts for holding the digital euro.

Promotional Offers: Short-term incentives, like bonus digital euros for early adopters, can encourage people to open accounts and boost adoption during the rollout. While these offers may have less impact on financial stability, they could be expensive for the Eurosystem to implement.

Tax Benefits: Users would receive fiscal benefits, such as reduced taxes or deductions for digital euro holdings. However, this approach might create challenges, such as unfair competition between payment systems and added complexity for tax authorities.

Integration with Government Services: Providing public services like allowance payments and subsidies to be paid in digital euros could encourage people to open a digital euro account.

None: No explicit activities would be performed to incentivise the holding of digital euros. This would be similar to cash and avoids potential conflicts related to unfair competition that could arise with private payment methods.

Renumerate the digital euro

No Interest on Digital Euro Holdings: This option positions the digital euro strictly as a payment instrument, discouraging its use as a savings or investment tool. The digital euro would not be used as a monetary policy tool and would maintain parity with cash.

Flat Rate Monthly Set by ECB: Users receive a predefined remuneration at a fixed rate, which is set by the ECB. They could for example base it on their rate on the deposit facility.

Fixed Margin Below ECB Deposit Rate: Digital euro holders would receive an interest on their holdings consisting of a fixed margin below the ECB deposit rate.

Reverse Tiered Interest Rates: This structure rewards smaller holdings with higher interest rates and reduces the effective interest rate for larger amounts. This could be used to disincentivise large digital euro holdings.

Transaction-based bonuses: Transaction-based bonuses could serve as an additional means of remuneration for the digital euro. In this approach, users would receive small rewards for completing a certain number of transactions. This incentivises active use of the digital euro as a payment method.

Control digital euro money supply

Fixed Holding Limit: This approach involves setting a maximum amount of digital euro that users can hold. Fixed holding limits can prevent users from saving a certain amount of digital euros, which could otherwise lead to disintermediation of commercial banks.

Transaction Limit: A cap on the value or frequency of transactions can be implemented to reduce the risk of excessive usage.

Issuance Control: Issuance control means the ECB would decide how much digital euro to create and release into the economy. This allows the ECB to make sure there isn't too much or too little digital euro in circulation..

ECB Buy/Sell Programs of Digital Euro: This method allows the ECB to intervene in the digital euro market by buying or selling digital euros, similar to open market operations, to manage supply and demand.

(Reverse) Waterfall Method: This mechanism ensures that when digital euro balances exceed a specific threshold, excess funds are automatically redirected to a linked commercial bank account. In a reversed way, the reverse waterfall method would automatically fund the digital euro account from the connected commercial bank account if there is not enough balance to do a transaction. This method decreases the amount of money present in the digital euro and shifts its focus to a payment method.

Prevent bank runs

Funding Restrictions During Distressed Periods: This measure involves temporary limitations on digital euro deposits during periods of financial instability. It aims to prevent panic-induced bank runs by controlling the outflows to the digital euro system.

Additional Liquidity Support Mechanisms for Commercial Banks: This option can offer targeted support to commercial banks that face liquidity issues as a result of conversion of banks' excess reserves to CBDC deposits. If banks would get access to long-term central bank lending facilities, the ECB could stabilize those banks to make sure they can still fulfil their credit provision (Fegatelli, 2022). This mechanism would help to prevent that banks will get disintermediated.

Real-Time Monitoring and Alerts: Due to the digital nature and instant settlement of digital euro transactions, real-time monitoring systems could be in place to enable quick detection of unusual withdrawal patterns or stress signals.

Establish fee structures

Pricing Up to the Market: In this approach, transaction fees are left to be determined by market dynamics. There could be multiple types of transaction fees, depending on the distribution model the digital euro will use. If for example PSPs are distributing the digital euro, they could charge merchants for their digital euro services (Euro Retail Payments Board, 2023). This approach would allow these private intermediaries to set the rates they charge.

Flat Regulated Rate Per Transaction: This would entail a single, fixed per-transaction fee for merchants that is set by the ECB. A fixed fee has the benefits of predictability and equality throughout the Eurozone. It would make it simpler for businesses to estimate their costs making it simpler for users to estimate costs and would possibly drive SMEs to support the digital euro (Merchant Payments Coalition Europe, 2024).

Percentage-Based Fees: This would entail that transaction fees are calculated a a proportion of the total transaction amount, resulting that larger transactions would have larger transaction fees. However, according to the Merchant Payments Coalition Europe (2024), costs associated with processing transactions are not related to the value of the transaction.

Zero Fees for Basic Transactions, Higher Fees for Bigger Transactions: This model eliminates fees for small transactions, while larger transactions incur higher fees to subsidize the system's costs. This option could incentivise the use and offering of digital euro as a payment method for people's day to day transactions.

Maximum Rates Set by Regulation: This approach involves setting a maximum on the fees that can be charged for digital euro transactions. With this option, the legislator can make sure that the costs remain affordable and to some extent consistent across providers. This would also prevent PSPs from exploiting the legal tender status of the digital euro by setting excessively high transaction fees, knowing that merchants are obligated to accept this form of payment (Euro Retail Payments Board, 2023).

Manage profits and costs

ECB Bears Own Cost on Infrastructure and Settling: In this model, the ECB funds infrastructure and settlement costs themselves, which would be in line with the digital euro's role as a public money. The ECB also bears the costs related to cash money.

PSPs Bear Their Own Distribution Cost: With this option, PSPs would cover the costs associated with distributing the digital euro to users. This reduces financial pressure on the ECB and incentivises the PSPs to efficiently setup their payment operations.

PSPs Get Charged for Using Digital Euro Infrastructure: Intermediaries pay usage fees for accessing ECB-managed infrastructure. This model would allow the ECB to recover operational costs while maintaining control over the system's core components.

ECB Is Not Allowed to Make Profits on Digital Euro Operations: This approach ensures the ECB operates solely for public benefit, focusing on accessibility and inclusivity rather than revenue generation. It aligns with the Eurosystem's goals but limits financial flexibility for covering costs.

Public-Private Partnership Where Both Parties Have Investments in the Infrastructure: Costs and benefits are shared between public institutions and private parties. While this model spreads financial responsibility, it may require complex governance structures to align stakeholder interests.

Appendix D: Alternative digital euro designs

Table 16: Alternative digital euro design 1: Privacy-focused digital cash

Design Function / Feature	Option 1	Option 2	Option 3	Option 4	Option 5
Facilitate payments	Facilitate card, online and digital payments				
Issue digital euro	Issued by ECB				
Ensure value consistency	Currency parity to euro				
Determine the mode of digital euro access	Account-based	Token-based			
Data processed by who	PSP	ECB	Provider of support services	Distributed Ledger	
*Secure personal data**	Make data anonymous	Make data pseudonymous	Apply zero knowledge proof		
Facilitate/Settle transactions	Centralised	Decentralised	Blockchain		
Provide business to business transactions	Allow uncapped B2B payments	Allow capped B2B payments	Allow B2C payments		
Customize financial transactions	Smart contracts	User-defined rules			
Facilitate offline transactions	Hardware wallets	Preloaded smart cards	NFC	Bluetooth transactions	Card-to-card with a bridge device
Provide offline wallet (de)funding	ATM integration	Online deposit (de)funding	Bank branch services	Cash-in Cash-out kiosks	POS terminal
Provide user-friendly usage of digital euro interface	Digital euro app	Digital euro API/SDK	Smart device compatibility	Multilingual support	
Support transaction methods	Card payments	Tap-to-pay	QR code payments	Mobile wallet integration	

Standardize usage across jurisdiction	Legal tender status	Centralised oversight	Common technical standard		
Define who can use the digital euro	Natural and legal persons residing or established in a euro country	Visitor Access	Legal status	Economic activity	Bilateral agreements with non-euro countries
Monitor and ensure compliance	ECB general fraud detection and prevention mechanism	Sanctions screening by PSPs	Transaction monitoring by PSPs	Criminal background check	
Verify user identity	No verification mechanisms	Biometric verification	European digital identity	Proof of identity (passport, ID)	
Define stakeholder distribution roles	Distributed by PSPs	Distributed directly by ECB	Distributed by National Central Banks	Distributed via selected financial institutions	
Incentivise digital euro holding	Rewards program	Promotional offers	Tax benefits	Integration with government services	None
Renumerate the digital euro	No interest on digital euro holdings	Flat rate monthly set by ECB	Fixed margin below ECB Deposit rate	Reverse tiered interest rates	Transaction-based bonuses
Control digital euro money supply	Fixed holding limit	Transaction limit	Issuance control	ECB Buy/sell programs of digital euro	(Reverse) waterfall method
Prevent bank runs	Funding restrictions during distressed periods	Additional liquidity support mechanisms for commercial banks	Real time monitoring and alerts		
Adjust Monetary Supply	Adjust digital euro interest rate	Adjust holding limits			
Establish fee structures	Pricing up to the market	Flat regulated rate per transaction	Percentage-based fees	Zero fees for basic transactions, higher fees for bigger transactions	Maximum rates set by regulation
Manage profits and costs	ECB bears own cost on infrastructure and settling	PSP bear their own distribution cost	PSPs get charged for using digital euro infrastructure	ECB is not allowed to make profits on digital euro operations	Public-private partnership were both parties have investments in the infrastructure

Table 17: Alternative digital euro design 2: Incentivised onboarding and usage

Design Function / Feature	Option 1	Option 2	Option 3	Option 4	Option 5
Facilitate payments	Facilitate card, online and digital payments				
Issue digital euro	Issued by ECB				
Ensure value consistency	Currency parity to euro				
Determine the mode of digital euro access	Account-based	Token-based			
Data processed by who	PSP	ECB	Provider of support services	Distributed Ledger	
*Secure personal data**	Make data anonymous	Make data pseudonymous	Apply zero knowledge proof		
Facilitate/Settle transactions	Centralised	Decentralised	Blockchain		
Provide business to business transactions	Allow uncapped B2B payments	Allow capped B2B payments	Allow B2C payments		
Customize financial transactions	Smart contracts	User-defined rules			
Facilitate offline transactions	Hardware wallets	Preloaded smart cards	NFC	Bluetooth transactions	Card-to-card with a bridge device
Provide offline wallet (de)funding	ATM integration	Online deposit (de)funding	Bank branch services	Cash-in Cash-out kiosks	POS terminal
Provide user-friendly usage of digital euro interface	Digital euro app	Digital euro API/SDK	Smart device compatibility	Multilingual support	
Support transaction methods	Card payments	Tap-to-pay	QR code payments	Mobile wallet integration	

Standardize usage across jurisdiction	Legal tender status	Centralised oversight	Common technical standard		
Define who can use the digital euro	Natural and legal persons residing or established in a euro country	Visitor Access	Legal status	Economic activity	Bilateral agreements with non-euro countries
Monitor and ensure compliance	ECB general fraud detection and prevention mechanism	Sanctions screening by PSPs	Transaction monitoring by PSPs	Criminal background check	
Verify user identity	No verification mechanisms	Biometric verification	European digital identity	Proof of identity (passport, ID)	
Define stakeholder distribution roles	Distributed by PSPs	Distributed directly by ECB	Distributed by National Central Banks	Distributed via selected financial institutions	
Incentivise digital euro holding	Rewards program	Promotional offers	Tax benefits	Integration with government services	None
Renumerate the digital euro	No interest on digital euro holdings	Flat rate monthly set by ECB	Fixed margin below ECB Deposit rate	Reverse tiered interest rates	Transaction-based bonuses
Control digital euro money supply	Fixed holding limit	Transaction limit	Issuance control	ECB Buy/sell programs of digital euro	(Reverse) waterfall method
Prevent bank runs	Funding restrictions during distressed periods	Additional liquidity support mechanisms for commercial banks	Real time monitoring and alerts		
Adjust Monetary Supply	Adjust digital euro interest rate	Adjust holding limits			
Establish fee structures	Pricing up to the market	Flat regulated rate per transaction	Percentage-based fees	Zero fees for basic transactions, higher fees for bigger transactions	Maximum rates set by regulation
Manage profits and costs	ECB bears own cost on infrastructure and settling	PSP bear their own distribution cost	PSPs get charged for using digital euro infrastructure	ECB is not allowed to make profits on digital euro operations	Public-private partnership were both parties have investments in the infrastructure

Appendix E: Discrete choice experiment

E1: Basic Plan 3

BASIC PLAN 3: 4^5; 3^5; 2^{15}; 16 trials

```
 1 2 3 4 5    1 2 3 4  5   0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1
 * * * * *    * * * *  *   1 2 3 4 5 6 7 8 9 0 1 2 3 4 5

 0 0 0 0 0    0 0 0 0  0   0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 1 1 2 3    0 1 1 2  1   0 0 0 0 1 1 0 1 1 1 0 1 1 1 0
 0 2 2 3 1    0 2 2 1  1   0 0 0 1 0 1 1 0 1 1 1 0 0 1 1
 0 3 3 1 2    0 1 1 1  2   0 0 0 1 1 0 1 1 0 0 1 1 1 0 1
 1 0 1 1 1    1 0 1 1  1   0 1 1 0 0 0 0 1 1 0 1 1 0 1 1
 1 1 0 3 2    1 1 0 1  2   0 1 1 0 1 1 0 0 0 1 1 0 1 0 1
 1 2 3 2 0    1 2 1 2  0   0 1 1 1 0 1 1 1 0 1 0 1 0 0 0
 1 3 2 0 3    1 1 2 0  1   0 1 1 1 1 0 1 0 1 0 0 0 1 1 0
 2 0 2 2 2    2 0 2 2  2   1 0 1 0 0 0 1 0 1 1 0 1 1 0 1
 2 1 3 0 1    2 1 1 0  1   1 0 1 0 1 1 1 1 0 0 0 0 0 1 1
 2 2 0 1 3    2 2 0 1  1   1 0 1 1 0 1 0 0 0 0 1 1 1 1 0
 2 3 1 3 0    2 1 1 1  0   1 0 1 1 1 0 0 1 1 1 1 0 0 0 0
 3 0 3 3 3    1 0 1 1  1   1 1 0 0 0 0 1 1 0 1 1 0 1 1 0
 3 1 2 1 0    1 1 2 1  0   1 1 0 0 1 1 1 0 1 0 1 1 0 0 0
 3 2 1 0 2    1 2 1 0  2   1 1 0 1 0 1 0 1 1 0 0 0 1 0 1
 3 3 0 2 1    1 1 0 2  1   1 1 0 1 1 0 0 0 0 1 0 1 0 1 1

1-  0 0 0   2-  0 0 0   3-  0 0 0   4-  1 1 1   5-  1 1 1
*-  1 2 3   *-  4 5 6   *-  7 8 9   *-  0 1 2   *-  3 4 5
```

BASIC PLAN 3: 4^5; 3^5; 2^{15}; 16 trials

The first line, the title, provides the following information:

- **n^t**: n = number of levels per attribute, t = number of attributes
  - 4^5: a maximum of 5 attributes that each have 4 levels
- **4^5; 3^5** : semicolon means **or**: So you either select 5 attributes with 4 levels **or** 5 attributes with 3 levels, but you are not allowed to select them together**!**
- **16 trials**: 16 profiles

Figure 10: Basic Plan 3, Source: (Molin, 2017)

E2: NGENE syntax

---

design

;alts = alt1, alt2

;rows = 16

;block = 2

;orth = seq

;model:

U(alt1) = b_holdlim * holdlim[0,9000,6000,3000] + b_privacy * privacy[0,1,2,3] + b_interest * interest[0,1,2,3] + b_issuer * issuer[0,1] + b_offline * offline[0,1]/

U(alt2) = b_holdlim * holdlim + b_privacy * privacy + b_interest * interest + b_issuer * issuer + b_offline * offline $

E3: Experimental design

Choice situation	alt1.holdlim	alt1.privacy	alt1.interest	alt1.issuer	alt1.offline	alt2.holdlim	alt2.privacy	alt2.interest	alt2.issuer	alt2.offline	Block
1	0	2	2	1	1	0	3	1	1	1	2
2	3000	2	2	1	0	0	1	3	0	0	2
3	6000	3	2	0	0	9000	0	3	1	0	2
4	6000	2	1	0	0	6000	1	0	1	1	2
5	3000	0	0	0	1	6000	2	1	0	0	1
6	9000	1	0	1	0	0	2	2	1	1	1
7	0	1	3	0	0	6000	0	3	1	1	1
8	9000	2	1	0	1	3000	3	1	1	0	1
9	6000	1	0	1	1	3000	0	0	0	1	2
10	9000	0	3	1	0	3000	2	2	1	0	1
11	9000	3	2	0	1	3000	1	3	0	1	2
12	3000	3	1	1	0	9000	3	2	0	1	1
13	3000	1	3	0	1	0	0	0	0	0	1
14	0	3	1	1	1	9000	2	1	0	1	1
15	6000	0	3	1	1	9000	1	0	1	0	2
16	0	0	0	0	0	6000	3	2	0	0	2

Figure 11: Experimental design with dominant alternatives marked in grey

The figure above shows the experimental design created using the NGENE script. Both choice situation 1 and 10 contain a dominant alternative. Both rows were removed before continuing with the experiment. For the coding method of the levels, see section 5.2.3 Overview of attributes and levels.

E4: Correlations after removal of dominant alternatives

Table 18: Correlation matrix between alternatives after removal of dominant alternatives

	alt1.holdlim	alt1.privacy	alt1.interest	alt1.issuer	alt1.offline	alt2holdlim	alt2.privacy	alt2.interest	alt.issuer	alt2.offline
alt1.holdlim	1									
alt1.privacy	0.183	1								
alt1.interest	-0.092	0.124	1							
alt1.issuer	0	0.074	-0.149	1						
alt1.offline	0.204	-0.128	0.064	0	1					
alt2holdlim	-0.337	0.165	0.046	0.019	-0.064	1				
alt2.privacy	-0.031	0.008	-.568*	0.112	-0.064	0.162	1			
alt2.interest	-0.086	0.38	0.136	-0.122	-.545*	-0.027	0.027	1		
alt.issuer	0.412	-0.055	0.242	-0.167	-0.289	0.149	-0.149	0	1	
alt2.offline	0.068	0.384	-0.193	0.289	-0.143	0.064	-0.064	0.061	0	1

Due to the removal of choice sets 1 and 10, small correlations are introduced within and between alternatives. According to Molin (2023), only within alternative correlations could be problematic However, since the maximum absolute correlation found within alternatives is 0,18, which is below the magnitude of 0,3 which is considered very little, if any (Calkins, 2005), we can continue with this setup.

E5: Final experimental design

Table 19: Final experimental design

Choice task	Block	alt1.holdlim	alt1.privacy	alt1.interest	alt1.issuer	alt1.offline	alt2.holdlim	alt2.privacy	alt2.interest	alt2.issuer	alt2.offline
2	2	3000	2	2	1	0	0	1	3	0	0
3	2	6000	3	2	0	0	9000	0	3	1	0
4	2	6000	2	1	0	0	6000	1	0	1	1
5	1	3000	0	0	0	1	6000	2	1	0	0
6	1	9000	1	0	1	0	0	2	2	1	1
7	1	0	1	3	0	0	6000	0	3	1	1
8	1	9000	2	1	0	1	3000	3	1	1	0
9	2	6000	1	0	1	1	3000	0	0	0	1
10	2	9000	3	2	0	1	3000	1	3	0	1
11	1	3000	3	1	1	0	9000	3	2	0	1
12	1	3000	1	3	0	1	0	0	0	0	0
13	1	0	3	1	1	1	9000	2	1	0	1
14	2	6000	0	3	1	1	9000	1	0	1	0
15	2	0	0	0	0	0	6000	3	2	0	0

Note that the numbering of choice tasks has been changed, but the contents of the design have not been changed.

E6: Survey opening statement

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd ‘Consumentenvoorkeuren bij het ontwerpen van een digitale euro’.

Dit onderzoek wordt uitgevoerd door Levi van Kersen van de TU Delft.

Het doel van dit onderzoek is om inzicht te krijgen in de voorkeuren van consumenten met betrekking tot verschillende ontwerpeigenschappen van een mogelijke digitale euro. Het onderzoek zal ongeveer 10 minuten in beslag nemen. De data zal gebruikt worden om een inschatting te maken van het mogelijke gebruik van de digitale euro en om de waarde van verschillende ontwerpeigenschappen vast te stellen. De data zal worden gebruikt voor academische doeleinden in de vorm van een masterscriptie. U wordt gevraagd om deel te nemen aan een enquête, waarbij u keuzes zult maken tussen verschillende soorten digitale euro-rekeningen en een reguliere bankrekening.

Zoals bij elke online activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico’s door ervoor te zorgen dat de enquête anoniem is. Alleen algemene demografische informatie (leeftijdsgroep, geslacht, etc.) wordt verzameld om heridentificatie te voorkomen. Alleen geaggregeerde resultaten en conclusies worden openbaar gemaakt in de MSc-thesis, die wordt gepubliceerd in de TU Delft Research Repository. Persoonsgegevens worden vernietigd na voltooiing van de MSc-thesis.

Uw deelname aan dit onderzoek is volledig vrijwillig, en **u kunt zich elk moment terugtrekken zonder reden op te geven**. U bent vrij om vragen niet te beantwoorden.

Voor vragen of klachten over dit onderzoek kunt u contact opnemen met:

Uitvoerende onderzoeker
Levi van Kersen

Verantwoordelijk onderzoeker
Sander Renes

Door verder te klikken naar de online enquête, geeft u aan dat u akkoord gaat met deelname aan dit onderzoek onder de bovengenoemde voorwaarden.

E7: Survey choice experiment context and explanation

Wat is een digitale euro?

De Europese Centrale Bank (ECB) werkt samen met nationale centrale banken aan de digitale euro. De digitale euro is een betaalmiddel dat wordt uitgegeven en beheerd door de ECB, waardoor de waarde altijd gelijk is aan die van gewone euro's. De digitale euro moet een extra optie bieden voor veilige en gemakkelijke betalingen.

Hoe werkt het keuze-experiment?

In dit onderzoek vragen we u om verschillende bankrekeningen te vergelijken, waaronder digitale euro-rekeningen. Bij elke keuze krijgt u drie opties voorgelegd: twee opties die verschillende digitale euro-rekeningen weergeven en één optie die uw huidige bankrekening voorstelt. U wordt eerst gevraagd om de rekening te kiezen die u het meest prefereert. Daarna maakt u een tweede keuze tussen de twee overgebleven rekeningen.

Elke rekening heeft verschillende eigenschapen zoals:

Waar staat het geld opgeslagen?
Dit geeft aan of uw geld wordt bewaard bij uw huidige bank of bij de Europese Centrale Bank.

De maximale hoeveelheid geld op uw rekening?
De ECB wil een limiet stellen aan hoeveel digitale euro's een persoon kan hebben op hun rekening. Als u een gewone bankrekening heeft gekoppeld aan uw digitale euro-rekening, worden bedragen boven de limiet automatisch doorgestuurd naar deze gekoppelde rekening. Als er geen gekoppelde rekening is, zal een transactie die de limiet overschrijdt niet worden uitgevoerd.

Privacy - Met wie worden uw transactiegegevens gedeeld?
Dit laat zien wie mogelijk toegang heeft tot uw transactiegegevens. Dit kan variëren van volledige anonimiteit, waarbij alleen de betaler en ontvanger de gegevens zien, tot het delen van gegevens met uw bank, de bank van de ontvanger en de Europese Centrale Bank. Een andere mogelijkheid is dat de gegevens versleuteld gedeeld worden met de ECB. Dit betekent dat uw gegevens niet direct naar een persoon te herleiden zijn, maar indien noodzakelijk voor naleving van wet- en regelgeving, kan dit alsnog worden gedaan

Rente op tegoeden
Dit geeft aan of en hoeveel rente u ontvangt op uw saldo van digitale euro's.

Geschikt voor online en/of offline gebruik?
Bij sommige digitale euro-rekeningen kunt u betalingen doen zonder een internetverbinding, vergelijkbaar met het gebruik van contant geld. Dit betekent dat u met de digitale euro kunt betalen, zelfs als u en de ontvanger geen internettoegang hebben. Dit offline gebruik is vooral ontworpen voor betalingen van persoon tot persoon of in winkels, zonder dat de transactie via een bank verloopt.

Appendix F: Discrete choice model estimation

F1: Syntax in R for estimating the Exploded Logit model

```
# Initialise code
apollo_initialise()
# Set core controls
apollo_control = list(
  modelName  = "EL",
  modelDescr = "Exploded logit model",
  indivID    = "ResponseId"  )
database = read.csv("INSERT FILE LOCATION")
# Vector of parameters, including any that are kept fixed in estimation
apollo_beta = c(
  BETA_holdlim   = 0,
  BETA_holdlim_0 = 0,   # Dummy for holding limit of 0
  BETA_privacy_0 = 0,   # Privacy dummy for level 0
  BETA_privacy_1 = 0,   # Privacy dummy for level 1
  BETA_privacy_2 = 0,   # Privacy dummy for level 2
  BETA_privacy_3 = 0,   # Privacy dummy for level 3
  BETA_interest = 0, #
  BETA_offline_0 = 0,
  BETA_offline_1 = 0,
  BETA_issuer_RB = 0,
  BETA_issuer_ECB = 0,
  DigEuro_constant = 0  )
apollo_fixed = c("BETA_privacy_3", "BETA_offline_0", "BETA_issuer_RB")
apollo_inputs = apollo_validateInputs()
apollo_probabilities=function(apollo_beta, apollo_inputs, functionality="es
timate"){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))
  ### Create list of probabilities P
  P = list()

  ### List of utilities: these must use the same names as in el_settings, o
rder is irrelevant
  V = list()
  V[["alt1"]] =    DigEuro_constant + alt1.holdlim * BETA_holdlim/1000 +
           (alt1.holdlim_0 == 1) * BETA_holdlim_0 +
                   (alt1.privacy == 0) * BETA_privacy_0 +
                   (alt1.privacy == 1) * BETA_privacy_1 +
                   (alt1.privacy == 2)* BETA_privacy_2 +
                   (alt1.privacy == 3)* BETA_privacy_3 +
                  alt1.interest * BETA_interest +
           (alt1.offline == 0) * BETA_offline_0 +
           (alt1.offline == 1) * BETA_offline_1 +
                   (alt1.issuer == 0) * BETA_issuer_RB +
                   (alt1.issuer == 1) * BETA_issuer_ECB



### Continues on the next page
```

```
  V[["alt2"]] =     DigEuro_constant + alt2.holdlim * BETA_holdlim/1000 +
            (alt2.holdlim_0 == 1) * BETA_holdlim_0 +
                    (alt2.privacy == 0) * BETA_privacy_0 +
                    (alt2.privacy == 1) * BETA_privacy_1 +
                    (alt2.privacy == 2)* BETA_privacy_2 +
                    (alt2.privacy == 3)* BETA_privacy_3 +
                   alt2.interest * BETA_interest +
            (alt2.offline == 0) * BETA_offline_0 +
            (alt2.offline == 1) * BETA_offline_1 +
                    (alt2.issuer == 0) * BETA_issuer_RB +
                    (alt2.issuer == 1) * BETA_issuer_ECB

  V[["alt3"]] =( 0 )

  ### Define settings for exploded logit
  el_settings = list(
    alternatives = c(alt1=1, alt2=2, alt3=3),
    avail        = list(alt1=1, alt2=1, alt3=1),
    choiceVars   = list(first_pref, second_pref),
    utilities    = V
  )

  ### Compute exploded logit probabilities
  P[["model"]]=apollo_el(el_settings, functionality)

  ### Take product across observation for same individual
  P = apollo_panelProd(P, apollo_inputs, functionality)

  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}

model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities, ap
ollo_inputs)

apollo_modelOutput(model)
```

F2: Testing for heterogeneity in the sample

Table 20: Parameter estimates for different subsets of the sample

Parameter	Full Sample	Male	Female	Low Income	Middle Income	High Income	Low edu	High edu	Age 45+
β holdlim	0,15***	0,15***	0,15***	0,21***	0,13***	0,11***	0,10**	0,17***	0,09**
β holdim_0	1,63***	1,76***	1,09	2,29***	1,53***	0,69	1,05***	1,86***	0,30
β privacy_0	0,63***	0,61***	0,80	0,73*	0,66***	0,48	0,49	0,66***	0,41
β privacy_1	0,10	0,01	0,60	0,20	-0,03	0,19	-0,05	0,13	0,46
β privacy_2	0,38**	0,40**	0,31	0,49*	0,44**	-0,08	0,38	0,36**	0,16
β interest	0,45***	0,50***	0,27**	0,56***	0,42***	0,31***	0,37**	0,47***	0,19
β offline_1	0,48***	0,40**	1,08**	0,36	0,50**	0,69**	0,67*	0,41**	0,88***
β issuer_ECB	-0,14	-0,18	0,04	-0,16	-0,13	-0,13	-0,36*	-0,06	0,02
α Digital Euro constant	-2,88***	-2,81***	-3,66***	-3,70***	-2,49***	-2,04	-2,18**	-3,14***	-2,89*

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

This table presents parameter estimates for the discrete choice model across various subsets of the sample, categorized by demographic characteristics. The purpose of this analysis is to examine whether preferences for digital euro design attributes do vary across different demographic groups. The following subsets were created:

- **Gender**: Separate models were run for male and female respondents.
- **Income**: Subsets were based on household income: low (≤€24.999), middle (€24.999≤€89.999) and high income (≥€90,000).
- **Education Level**: Divided into lower education (up to high school and vocational education) and higher education (bachelor's degree or higher).
- **Age**: A subset for respondents aged 45 and older was analysed separately.

Some subsets, such as high-income, older respondents and females, have limited sample sizes, which could affect the significance and validity of parameters. The coefficients for the holding limits, interest rates, offline functionality and digital euro constant all seem to be relatively consistent across the subsets, with no differences in signs.

The privacy levels generally have positive coefficients, suggesting a gain in utility compared to the reference category (data sharing with PSPs and ECB, the lowest privacy level). However, there are a few exceptions. For Privacy Level 1 (data shared only with PSPs), the middle-income and lower-education groups show negative but non-significant coefficients. Similarly, Privacy Level 2 (PSPs and pseudonymised sharing with ECB) has a negative coefficient for the high-income group, though this result is also not statistically significant. These variations may indicate that certain groups perceive privacy differently, but the lack of statistical significance limits the strength of these findings.

For the issuer variable, most subsets have a preference for commercial banks as issuers. However, the female and age 45+ groups show a positive coefficient for the ECB as the issuer. These

coefficients are not statistically significant and both groups contain relatively few respondents, which may affect the robustness of these results.

Overall, the consistent signs for most parameters across subsets suggest that the key attributes driving adoption, are valued similarly across demographic groups. Differences in coefficient magnitudes may reflect variations in how these attributes contribute to adoption. However, due to the small sample sizes in some subsets, these differences should be interpreted cautiously and would require further research to draw more definitive conclusions.