Demystifying consumers' adoption of a digital euro in the euro area: a households' structural (behavioural) finance approach and a financial-stability perspective[1]

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Abstract

A central-bank digital currency is a step forward for central banks in the context of technological advancements in the financial world. This study examines households' digital-euro adoption process in the euro area. It adopts a novel and simple approach to estimate the upper bounds of the short-term adoption rate in the euro area. Among the quantitative methods employed, the most significant are unsupervised machine-learning algorithms (clustering techniques), non-parametric statistical methods, and an econometric vector autoregressive model. The results show that this process may be slower and less extensive than may be expected, and it is unlikely to considerably impact the economy and society immediately after its introduction. The model indicates that, in the best-case scenario, the maximum retail digital euro's adoption rate at the euro-area level is less than 4% of the euro-area banks' total liabilities and approximately 17% of its quarterly gross domestic product. The findings are critical for the domain as policymakers could use them to adjust their impact studies over the banking sector and real economy. Additionally, this study proposes a new hypothesis regarding the parity of funding sources for digital-euro accounts (cash reserves-to-deposits ratio). It concludes that in a scenario in which all holders of digital euros reach the maximum limit of € 3000, the impact on the euro area's financial stability would be slightly less significant than what is quantified in the existing specialized literature.

Keywords: digital-euro demand, behaviour finance, households' structural finance, financial stability

JEL Codes: C38, D85, D91, E42, E58, G51

1. Introduction

Although the concept of a central bank-issued digital currency is relatively new, it has sparked intense interest among central banks and researchers. According to Auer et al. (2023), this digital asset issued by a central bank is at least in the exploration and research phase for numerous central banks, including the European Central Bank (ECB, 2023a). The ECB launched the second phase of the digital-euro project in November 2023, focusing on investigating the architecture and design of the digital euro. In 2023, the regulatory process for the digital-euro project was initiated at the European level. However, these processes are challenging, and the issuing of this currency by a central bank entails potential advantages and risks. According to the Bank for International Settlements (Kosse and Mattei, 2023), among a central bank's motives for issuing a central-bank digital currency (CBDC) and the potential advantages of this action could be the streamlining and increased security of the payment methods available to European households, enhancement of digital financial inclusion (Auer, Frost, et al., 2022), reduction of the informal economy, and beneficial macroeconomic and monetary effects (Das et al., 2023). The most significant risk is the potential shift in bank deposits from commercial banks to digital-currency holdings (Ahnert et al., 2022), which could reduce bank liquidity. Reduced liquidity in the banking sector could lead to financial disintermediation and a scenario in which banks might be compelled to resort to riskier and costlier funding sources (Hoffmann et al., 2023).

The macro-financial effects (Ahnert et al., 2022) of central bank-issued digital currencies have been intensively studied, starting from the premise of widespread adoption by consumers. These studies have explored scenarios in which digital-currency holdings are either remunerated or have no imposed limits, as well as those in which the digital currency is interest-free, or its holdings are limited to a certain amount. However, all impact studies on issuing a digital currency in various scenarios should consider households' potential maximum adoption levels,

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Abbreviations: European Central Bank (ECB); central-bank digital currency (CBDC); standard vector autoregressive (SVAR); principal component analysis (PCA); highest take-up cluster (HTC); medium highest take-up cluster (MHTC); medium lowest take-up cluster (MLTC); lowest take-up cluster (LTC); fuzzy K-means (FKM); Gaussian mixture model (GMM); Partitioning around medoids (PAM).

which must be further explored. These estimated upper bounds or upper-bound intervals should represent the focal points of any study on the consequences of issuing a digital euro.

Throughout this study, I refer only to the retail digital euro, in which case only households can hold digital euros. The adoption of the digital euro by Europeans will be a challenging process. Taking the example of Revolut, which offers products comparable to the functionalities of the digital euro and operates with low or no fees for consumers in payments to merchants and instant person-to-person (P2P) transfers, the period it took to reach 20 million users (from 0.1 million in 2016) was seven years.

According to the latest ECB communications, to preserve and safeguard the euro area's financial stability, holdings of the digital euro will be capped, and the digital euro will not bear interest (ECB, 2023b, 2023c). The issuance of the digital currency in the euro area may have a limited effect on term deposits in a scenario in which remuneration is equal to or near zero, especially in an environment characterized by high interest rates. Moreover, a bank run toward holdings of the digital euro is unlikely, even in a crisis such as the sovereign-debt crisis of 2009–2012 (Azzone and Barucci, 2023). In addition, I find that a random economic downturn or upturn does not change household saving behaviour in Germany, France, Italy, and Spain. However, stress in the banking sector could lead to bank runs or flights for safety episodes (as in the United States (US) in March 2023). In the event of a migration of deposits to digital-euro holdings, financial intermediation decreases by a percentage lower than that associated with transferred deposits, as customers remaining in the commercial banking sector are more optimistic about this sector's stability (Muñoz and Soons, 2023).

However, as with any financial product, success depends on the population's acceptance and assimilation of the digital euro. Another significant challenge to the success of the digital euro is the engagement level of banks and merchants in the digital-currency ecosystem.

The scenario used in the present study involves the cumulative fulfilment of the following highly plausible conditions: i) the digital euro will not be remunerated; ii) the holding limit will be no more than € 3000; iii) negligible stress in the banking sector; and iv) the adoption will be such that at least one of the two functionalities (payments to merchants and money transfer) is used, with the store-of-value function being implicit.

In the following lines, remarks are provided regarding the remuneration associated with the holdings of digital euros and the limits that may or will be imposed. Establishing a limit on holdings can be considered a macroprudential countercyclical measure aimed at maintaining liquidity in the banking sector at comfortable levels, especially in a crisis and in its aftermath. It can demonstrate its benefits during periods of stress in the banking sector, primarily by preventing the outflow of overnight deposits as term deposits are guaranteed up to an amount that significantly exceeds the potential limit of digital-euro holdings. Potential remuneration, which could positively contribute to the efficiency of monetary-policy transmission (Das et al., 2023), may lead to both the migration of deposits (both term and overnight) to holdings of digital euros (in regular and crisis periods) and a loss of incentive for banks to participate in the distribution of digital euros, as the withdrawal of deposits harms their interests. Two essential factors would alter the dynamics of a bank run: remuneration and holding limits (Adalid et al., 2022).

The estimated maximum adoption rate was calculated for the short term. Medium- and long-term numbers largely depend on herding effects and the signs of the network effects created among consumers, credit institutions, and merchants (Martens, 2021). The estimation is a point-in-time figure because CBDC issuance and adoption have no history. Instead, approaches based on the probable profile of a digital-euro holder and their digital financial behaviour were adopted. Individuals with the profile necessary to adopt the digital-euro for transfers between individuals and payments to merchants were considered. Given that digital-euro holdings will not bear interest, and, as shown in Subsection 7.1 of this study, a key determinant of household deposit creation in three of the largest European economies is the interest, it can be concluded that banked individuals from these countries, in the absence of a financial crisis, will not turn to digital-euro holdings solely to benefit from the store-of-value function, with some exceptions, to a small extent. However, some voluntarily unbanked individuals may turn to digital-euro holdings if they trust the central bank more than private financial institutions (OMFIF, 2020). Therefore, the calculated share of digital-euro holdings in the euro area's quarterly gross domestic product (GDP) includes also all unbanked customers. Proving a high appetite for payments and transfers is necessary; however, more is required to achieve many digital-euro holders' goal. Several other reasons may cause an individual with the required profile not to adopt the digital euro or at least not to adopt it for the entire threshold of € 3000: possible perceived low privacy of digital-euro holdings; lack of trust in the ECB and dissatisfaction with how high inflation has been addressed in recent years, mostly in countries where social trust is low (Angino et al., 2022); the inconvenience of migrating from a commercial financial institution to the central bank; the perception that digital banking services and their associated software applications better serve their needs than the digital euro; the limited success of the digital euro in a consumer's social circle; and a limited number of merchants offering the digital euro as a payment option (Tan, 2023) and thus creating the premises for triggering adverse network

externalities. Depending on the digital euro's privacy level, individuals who promote it and are part of the informal economy may or may not adopt it. It might also be difficult to convince Eurosceptic citizens of the euro area to embrace and be part of this European project. A probable reason those fitting the profile of a digital-euro holder with high financial capacity might not initially adopt the digital euro for the maximum limit of € 3000 could be that, initially, as is customary with the launch of a new product, consumer appetite for it in large quantities could be low. If the product were to meet the needs and requirements of the consumer, they would then be willing to use more significant amounts. Once again, crisis and non-crisis periods must be clearly distinguished. An example is the COVID-19 pandemic, which eventually led individuals to purchase a range of products in quantities far exceeding their consumption needs. Up until that point, no excesses had been recorded in this regard.

Consumers respond positively to specific essential characteristics that a digital currency must possess; the likelihood of adopting a digital currency increases if it helps manage household budgets and provides high confidentiality, offers a range of essential banking services for users, and brings financial gains (Bijlsma et al., 2024; Li, 2023).

Although the goal was to facilitate the distribution of the digital euro at the time of issuance, on February 26, 2024[2], the Council of the European Union (EU) issued a press release stating that it had adopted a proposed regulation that would make instant payments fully available in euros to consumers and businesses in the EU and European Economic Area (EEA) countries. Instant payments would be processed through the TARGET Instant Payment Settlement, which Eurosystem launched in November 2018. All payment-service providers would be required to provide instant payment services to their clients, with different deadlines for non-euro-area providers (33 months for receiving instant credit transfers in euros and 39 months for sending instant credit transfers in euros).

Facilitating instant payments is an advantage in the distribution of the digital euro. However, if banks waived transfer fees between individuals and fees for merchants, the commercial banking sector would become an even stronger competitor of the central bank in the field of payments and money transfers.

Because of the waterfall principle on which the digital euro operates, if the number of holders remains relatively constant, the ratio of the maximum sum associated with all holdings at the euro-area level (presuming that any initial holding is € 3000) to the sum of overnight deposits remains constant, if not on a decreasing path. This is possible because when a transfer in digital euros is made or a payment is made to a merchant, the amount exceeding € 3000 from the digital-euro account of the recipient of the transfer, or the amount paid to the merchant, will return to the current account of the transfer recipient's or merchant's commercial bank.

National-level surveys support the aforementioned results for some euro-area member states. My research results are valid for 2022, as all data were collected during this timeframe (2021 being the reference year). However, it is important to mention that these numbers could and will be recalculated as newer data become available.

The estimates were checked for robustness using payment and digital-finance behaviour data through multivariate/univariate clustering techniques and statistical correlations/comparisons/validations using an index that quantified the propensity to hold and use cash.

From the perspective of the adoption level of the digital euro for payments or money-transfer purposes, the euro-area countries were clustered as follows, from the highest to the lowest take-up level: 1. North and Northwest; 2. Western and Baltic states; 3. Central and East; and 4. South. Moreover, a vector autoregressive (VAR) model was used to analyze the sensitivity of consumers to changes in interest rates on on-term deposits in Germany, France, Italy, and Spain, which account for approximately 75% of the euro-area population over 15 years old. It emerged that a crucial determinant for consumers from Germany, France, and Italy to create a term deposit was a change in the interest rate (the variables were adjusted for seasonality, and the trend was removed); this points to the fact that in the most likely scenario of issuing an interest-free digital euro, bank liabilities, which might be the main financial source to transition to digital-euro holdings, would be the population's funds in current bank accounts (overnight deposits) and cash holdings, to a very small extent. In addition, I hypothesize and demonstrate in Section 7 that, almost exclusively, overnight deposits would be massively used to open digital-euro accounts.

One of this study's primary hypotheses is that the capacity to adopt the digital euro is more important than the intention (measured through various surveys), particularly the maximum amount, which represents the holding limit calculated by Adalid et al. (2022) or Meller et al. (2023). All the surveys conducted thus far at the level of euro-area countries have shown that the level of adoption intention is lower than that calculated in this study through the measurement of adoption capacity. Adoption capacity itself was measured using specific parameters of digital financial inclusion and digital behavioural finance. This study will show that the results obtained overestimate the real level of population adoption of the digital euro, which is conducive to financial stability. If

[2] https://www.consilium.europa.eu/en/press/press-releases/2024/02/26/council-adopts-regulation-on-instant-payments/

the study's results underestimated the real level of adoption, the calculated holding limit would exceed the banking sector's capacity to cope with a high level of digital-euro adoption.
The second part of the study (Subsection 7) focuses on the potential funding sources for digital-euro accounts within the euro area. To find a realistic ratio, I examined the variation in the share of cash reserves and cash in circulation within the total of the population's most essential and liquid financial assets. Additionally, I graphically and statistically argued, using non-parametric methods, the hypothesis that regardless of geopolitical events, the presence or absence of economic and financial crises, phases of business and financial cycles, financial digital revolution, level of inflation, and interest rates on term deposits, people's propensity to hold cash reserves had not decreased, and the fluctuation of overnight or term deposits had predominantly occurred between these two types of assets. According to Adalid et al. (2022) and Petracco Giudici and Di Girolamo (2023), the ratio of cash reserves to deposits as funding sources for digital-euro accounts is approximately 40:60. More specifically, the authors estimate that individuals in the euro area will adopt the retail digital euro (amounting to approximately € 1 trillion) by withdrawing 50% from their cash reserves (approximately € 380 billion), with the remaining € 620 billion coming from deposits, thus creating a ratio of approximately 40:60 (cash reserves:deposits). In Subsections 7.2 and 7.3, I show that this ratio tends more toward 10:90.
When an unprecedented event is about to occur, we must work with various hypotheses and assumptions that make sense from economic and financial perspectives.
These two variables—the maximum potential adoption level and number of deposits that would be transformed into digital-euro holdings—represent the two focal elements based on which the holding limit can be quantified so that the euro area's financial stability remains unaffected.

2. Broad literature review concerning the adoption process of the retail digital euro

According to a survey conducted by the Official Monetary and Financial Institutions Forum (OMFIF, 2023), for two-thirds of the respondents (central banks from developed countries), the most significant concern regarding digital currencies is households' possible lack of interest in this type of asset. A series of surveys were conducted at the national level within euro-area member states, such as the Netherlands (2023), Austria (2023), Germany (Deutsche Bundesbank, 2021), Spain (Bank of Spain, 2023), and at the euro-area level (Eurobarometer). However, only one study has attempted to estimate the boundaries of the potential demand for the digital euro at the euro-area level (Gross and Letizia, 2023). Another study assessed the take-up of the digital euro, but only in Spain (León et al., 2023). The central assumption in Gross and Letizia's (2023) study was that no limit on holdings was imposed. They employed a utility function and Nash-equilibrium model to estimate potential demand and calculate an adoption interval from cash-like take-up to deposit-like take-up edges. Gross and Letizia split the holdings into deposit-like (used primarily for the store-of-value function, in which case the digital euro will bear interest close to or equal to the ECB's policy rate) and cash-like (used to pay merchants or for P2P transfers). They estimate an upper bound of 20% of the broad money in the euro area if the take-ups were more deposit-like. If the digital euro were perceived only as a cash-like instrument, the lower boundary of demand would be 1% of the broad money in the euro area. Furthermore, Nocciola and Zamora-Perez (2024) try to quantify transactional demand for CBDC; however, they do not estimate any minimum or maximum boundaries.
The digital euro serves three fundamental functions: i) payment to merchants, ii) fund transfers between individuals, and iii) store of value. It is essential to distinguish between the public's interest at regular times (the absence of financial turmoil/stress) and appetite for the digital euro during and in the aftermath of turbulence in the banking sector.
Considering that the digital euro is unlikely to bear interest, the public is unlikely to perceive this asset as an investment. Therefore, those who adopt the digital euro are presumed to do so to benefit from all three fundamental functions, or at least not solely from the value-storage function in a period that is not characterized by financial stress. However, the upper-boundary interval was estimated to range from a level associated with the absence of a financial crisis to one associated with turmoil in the banking sector.
Meller and Soons (2023) estimate a generally applicable limit for digital-euro holdings at € 3000. Imposing this limit would not affect the euro area's financial stability, and liquidity outflows from the banking sector would be manageable. The scenario used in this study (as well as in the study of Adalid et al. (2022)) involves the entire population of the euro area adopting the digital euro, with each person reaching this holding limit. However, even the authors acknowledge that it is very unlikely for the adoption rate to reach 100%.
According to Burlon et al. (2022), "the optimal amount of CBDC in circulation for the euro area lies between 15% and 45% of quarterly GDP in equilibrium, with the steady-state impact of CBDC on bank lending and valuations likely to be moderate under this range of values." In other words, for beneficial economic effects, it would be ideal for the digital euro to record an adoption rate (as an amount) of at least 15% of the euro area's quarterly GDP but no more than 45%.

Examining the implications of heuristic factors, cognitive biases (ACAPS, 2016), emotions, and financial behaviour in general (Ricciardi and Simon, 2000; Kahneman, 2011) has gained increasing prominence in the last few decades. The notion that individuals' financial decisions are entirely rational and that these decisions best serve consumers' interests has been discarded (Shabarisha, 2015). Emotional, cognitive, and behavioural aspects are significant in all elements leading to financial decision-making (Cavalheiro et al., 2012). Typically, investors must be made aware of their behavioural biases. If things were different (being aware of their behavioural biases), financial decisions would be much more rational, and the utility and gains resulting from these decisions would be higher (Dervishaj, 2021). Conceptual analyses show that investors' use of various heuristics tends to minimize risks and maximize gains, often leading to systematic judgment errors (Ayaa et al., 2022). Research also indicates that national cultural aspects affect individuals' risk-taking behaviour (Weber, 2014).

The list of cognitive biases identified at the individual level is substantial (Ehrlinger et al., 2016). To these biases, the herd effect is added, or the externality sign of the networks created between the providers and consumers of a product. Specifically, if the network effect is positive, it results in the retention of existing consumers and attraction of others. If the network effect is negative, existing individuals may leave, and attracting new individuals to the consumer network is less likely (De Giorgi et al., 2020; Liebowitz and Margolis, 1994). Therefore, the degree of adoption of the digital euro immediately after its launch and in the short term is crucial for the success of this currency in the medium and long term through the prism of the network (León et al., 2023, p. 20) and herd effects. The latter are more pronounced within the euro area during and immediately after a crisis (Mobarek et al., 2014). However, it is essential to clearly distinguish between herd effects in crises and during regular periods. Recently, online social-networking platforms have become significant catalysts of the herding effect (such as in the US banking crisis in March 2023).

It has been documented that family networks become increasingly important in periods characterized by financial distress, and retail customers consider weaker and less direct social relationships (Atmaca et al., 2020). Vital work in behavioural finance shows that poverty affects cognitive functions related to financial decision-making, creating a loop effect and perpetuating a state of pronounced financial deprivation (Mani et al., 2013). This study is supported by numbers related to the euro area regarding the proportion of people at risk of poverty or social exclusion. In 2015, this proportion was 23% of the euro area's total population, while in 2021, the proportion was approximately 22%. The decrease in this value by a mere one percentage point in six years indicates an extremely high financial-wealth inertia of individuals in this socio-economic cluster. This category of individuals is unlikely to have the capacity to adopt the digital euro up to € 3000.

This section aims to raise awareness among readers and policymakers that, despite the unquestionable advantages of the digital euro compared to private-sector competition (risk-free, free to use, facilitating instant payments to merchants, and P2P transfers, online and offline), it may not be the first choice for consumers. For example, cognitive biases[3] such as overconfidence or conservatism, among many others, could cause a person to take excessive risks (in search of high yields), assuming that these risks could be managed, thus placing their financial resources in risky and highly volatile investments such as crypto assets, or not to follow new and innovative ideas. Additionally, I must re-iterate the importance of the herding effect and level of adoption of the digital euro at issuance and immediately thereafter (to create positive network effects). The importance of social networks for the adoption of the digital euro is also highlighted by Nocciola and Zamora-Perez (2024).

As far as my knowledge extends, this is the first research work that has provided validated upper boundaries for the retail interest-free and capped digital euro adoption by the euro area households. These findings are significant as they shed light on the potential adoption of digital euro. Moreover, this paper introduces a new and sound ratio between sources that could fuel the digital euro account, further enriching our understanding of digital currency adoption.

3. Data and methodologies

The primary data sources used in this study were the World Bank (WB, FINDEX) and Eurostat (ES) indicators, ECB (deposits and interest data), World Economics (WE) public databases, and the European Commission's (2022) Eurobarometer (E). Several critical indicators for this study were disseminated for the first time starting in 2022 (for the reference year 2021 by Eurostat), while others were published at a frequency of three years (WB indicators). To ensure the consistency and comparability of the results, data primarily from 2021 were extensively used, most of which were collected in 2022. The lack of data for some indicators from the WB for Luxembourg led to its exclusion from all samples.

Only in the case of data not included in calculating and validating the digital-euro adoption rate are 2022 and 2023 the last years with data (e.g., the VAR model used to identify whether the random interest-rate change was an

[3] https://www.lineex.es/en/cognitive-biases/

essential determinant of the creation of household term deposits). Based on point-in-time data, this analysis likely represents the *status quo* as of mid-2022. To identify the ratio between cash and deposits as funding sources for digital-euro accounts, data on overnight and term deposits of the population in the eurozone, covering the period from 2003 to March 2024, were used.

This study does not focus on a single or central empirical methodology. It rather represents a visual journey underpinned by a variety of calculation methods and empirics, for which functions or scripts from R or Python libraries were predominantly used. Behind all the charts in this study lie several empirics, formulas, and functions. Throughout the study, the following main calculation methods were used: i) composite indices to reduce complex phenomena to a single number (the calculation of composite indices was conducted following the most important guidelines, methodologies, and studies in the field) (Becker et al., 2019; Environmental Systems Research Institute, 2023; Mazziotta and Pareto, 2013; Organization for Economic Co-operation and Development (OECD), 2008); ii) multivariate and univariate clustering through various methods and using different settings and distances between data points; iii) non-parametric statistical methods to compare various distributions or validate a series of results; and iv) an autoregressive vector to test the hypothesis that a random interest-rate change is a significant determinant of households' creation of term deposits. When data with different measurement scales were used for the same operation, they were normalized using the same scale of values. The difference between the maximum and indicator values was considered in the MinMax methodology for all indicators with a negative meaning.

4. Digital-euro holder's profile: Introducing the MinMax methodology

The adoption of a digital euro is conditioned by willingness and capability. Individuals who have yet to use digital payment methods or are financially deprived are unlikely to adopt the digital euro shortly after its issuance. Building on this idea, I have outlined the profile of individuals who would have the capacity and propensity to adopt the digital euro at the time of its issuance. The holder of the digital euro is profiled by conditioning the choice of an eligible person on the cumulative fulfilment of seven essential characteristics (Figures 1 and 2).

These seven characteristics refer to digital financial inclusion, payment habits, and the capacity to withstand adverse financial events. Furthermore, considering the percentage of individuals meeting each of the seven characteristics in seven distinct sets, where each percentage represents the number of individuals in the set, I used the valid mathematical assumption that the maximum obtained by the intersection of the seven sets is, in fact, the set with the most negligible percentage. In other words, in this situation, the maximum number of individuals satisfying all seven criteria that could be found in all seven sets would in fact be represented by all the individuals in the set with the most negligible associated percentage. The probability computed for the result of this intersection, using sets and probability theories and taking the percentages as probabilities, was less than 1%. At the end of this procedure, the results from Table 1 (Figure 3) were obtained, where the cells highlighted in light blue represent the maximum result of the intersection of the seven datasets for each country. Next, I multiplied this result (referred to as MinMax) for each country by the number of individuals over 15 years old and the maximum value of the digital-euro holding of € 3000. Thus, I obtained a result of approximately € 578 billion or 3.92% (Table 2, i.e., UB2 – Upper Boundaries 2) of the total liabilities of credit institutions in the euro area (deposits held by banks at other banks in the euro area were excluded), which is estimated to be the maximum level of digital-euro adoption in stress-free periods in the financial sector. The MinMax methodology is illustrated as follows. Imagine that we have seven factories (*X1, X2....X7*) that produce different quantities of partially different electronic components, and that some are similar. Each factory's total quantity of components equals the number of individuals in the sets corresponding to the seven MinMax indicators. We also have a factory (*Y*) that purchases and assembles these electronic components to produce personal computers. This factory will purchase an equal number of identical electronic components from each of the seven factories. The maximum number of electronic components purchased from each factory will be, at most, equal to the total number of electronic components produced by one of the seven factories with the lowest production. The term, MinMax, is not new; it is found in game theory, linear algebra, and functional analysis, known as the min-max theorem, variational theorem, or Courant–Fischer–Weyl min-max principle[4]. The idea of applying this methodology arose from studying Lozano et al.'s (2013) research paper titled "Cooperative Game Theory Approach to Allocating Benefits of Horizontal Cooperation," although the methodology in the current study is only tangentially related to that proposed by Lozano et al. (2013). Profiling the target audience is a common practice in marketing, merchandising, and even in the creation process for financial products and services. These practices often contribute to the market success of the products and services offered to the population. Essentially, this process identifies individuals with the same characteristics, with the same purchasing habits, or within the same group in terms of financial capacity.

[4] https://en.wikipedia.org/wiki/Min-max_theorem

(1) *MinMax = max (A∩B∩C∩D∩E∩F∩G) = min (A, B, C, D, E, F, G)*

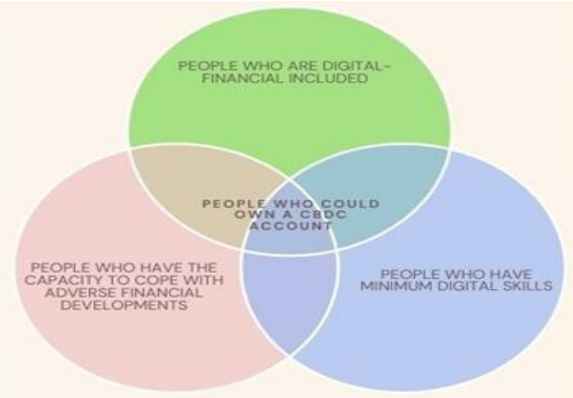


Figure 1. Venn diagram for CBDC holders

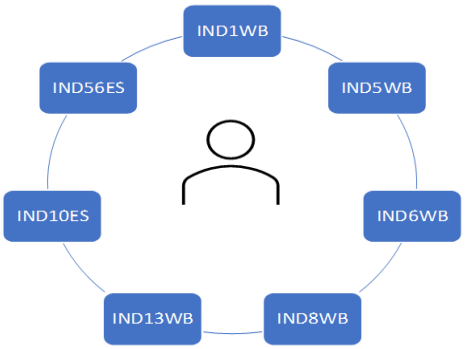


Figure 2. Adopter's profile – 7 essential characteristics (MinMax indicators).

List of the 7 essential characteristics

(A) IND5WB - Used a mobile phone or the Internet to check account balance (% with a financial-institution account, age 15+)

(B) IND6WB - Use a mobile phone or the Internet to make payments, buy things, or to send or receive money using a financial-institution account (% age 15+)

(C) IND8WB - Store money using a financial institution or a mobile money account (% with an account, age 15+)

(D) IND56ES - Individuals with minimum digital skills

(E) IND1WB - Financial-institution account (% age 15+)

(F) IND10ES - Have the ability to face unexpected financial expenses

(G) IND13WB - Made a digital payment (% age 15+)

This value (€ 578 billion) is nearly half the maximum threshold of the digital-euro adoption level, which, according to Adalid et al. (2022) and Meller and Soons (2023), does not lead to financial disintermediation in the euro area. Adalid et al. (2022) use approximately €1 trillion to calculate the impact on the euro area's banking sector. They conclude that this level is benign for the sector. As we will see further in this study, the MinMax result in the case of France was replaced with that for Lithuania. In the event of widespread stress in the euro area's banking sector, only the indicator, IND8WB (*Store money using a financial institution or a mobile money account (% with an account, age 15+)*), was considered, premised on the idea that a massive bank run in this situation would be highly likely. In this case, the maximum demand for the digital euro would be 5.15% (UB6) of credit institutions' total liabilities in the euro area.

	IND5 WB	IND6 WB	IND8 WB	IND56 ES	IND1 WB	IND10 ES	IND13 WB	%MAX TAKE-UP 3T= MIN (INTERSECT_IND)	CENSUS 2021 OVER 15	No. MAX INDIV. TAKE-UP 3T ED	MAX TAKE-UP 3T ED AMOUNT
AT	0,64	0,65	0,89	0,98	1,00	0,81	0,99	0,64	7.673.412	4.914.750	14.744.248.689
BE	0,84	0,78	0,92	0,97	0,99	0,78	0,97	0,78	9.619.330	7.474.219	22.422.658.230
CY	0,64	0,56	0,62	0,97	0,93	0,57	0,79	0,56	775.010	437.265	1.311.793.668
DE	0,62	0,61	0,92	0,96	1,00	0,68	0,99	0,61	71.630.189	43.880.814	131.642.441.385
EE	0,92	0,85	0,95	0,98	0,99	0,73	0,98	0,73	1.114.032	812.129	2.436.387.984
ES	0,76	0,64	0,84	0,98	0,98	0,67	0,97	0,64	40.687.137	26.100.134	78.300.401.224
FI	0,94	0,90	0,98	1,00	1,00	0,77	0,98	0,77	4.672.932	3.574.793	10.724.378.940
FR	0,72	0,55	0,83	0,99	0,99	0,72	0,98	0,55	55.994.788	30.641.888	91.925.663.865
GR	0,73	0,65	0,73	0,98	0,95	0,54	0,88	0,54	8.910.114	4.784.731	14.354.193.573
HR	0,61	0,42	0,84	1,00	0,92	0,54	0,75	0,42	3.319.417	1.402.331	4.206.993.481
IE	0,76	0,71	0,90	0,98	1,00	0,70	0,98	0,70	4.000.000	2.812.000	8.436.000.000
IT	0,74	0,59	0,86	0,96	0,97	0,67	0,93	0,59	51.540.338	30.328.277	90.984.830.205
LT	0,77	0,67	0,90	0,97	0,94	0,64	0,83	0,64	2.393.690	1.522.387	4.567.160.520
LV	0,82	0,76	0,75	0,98	0,97	0,58	0,93	0,58	1.590.245	927.113	2.781.338.505
MT	0,67	0,61	0,90	0,99	0,96	0,84	0,86	0,61	451.746	273.359	820.077.826
NL	0,88	0,80	0,87	1,00	1,00	0,85	0,98	0,80	14.763.684	11.789.245	35.367.735.621
PT	0,59	0,50	0,72	0,97	0,93	0,69	0,87	0,50	9.011.878	4.473.350	13.420.048.756
SI	0,68	0,58	0,72	0,97	0,99	0,75	0,94	0,58	1.791.246	1.042.650	3.127.950.896
SK	0,83	0,71	0,82	0,98	0,96	0,73	0,93	0,71	4.581.860	3.258.585	9.775.754.068

Table 1. MinMax indicators' values and calculations

	% of the euro area quarterly GDP (as of June 2022)	% of total deposit liabilities in the euro area (as of June 2022)	% of households' overnight deposits (as of June 2022)
MinMax (FR max of cluster 2) (UB1 – UB3)	17,37%	3,92%	10,39%
MinMax + Unbanked (UB4)	17,78%	N.A.	N.A.
Value storage (UB5 – UB7)	22,85%	5,15%	13,67%
Value storage + Unbanked (UB8)	23,26%	N.A.	N.A.

Note: UB = upper boundaries; UB1 – UB3 = (UB1, UB2, UB3)

Table 2. Take-up upper boundaries as % of the euro area's quarterly GDP, total deposit liabilities, and households' overnight deposits

Figure 3. Word-cloud visualization of the MinMax results (as a percentage of the total population over 15)

5. Intermediary steps before checking for robustness

5.1. Measuring the euro-area households' financial capacity, digital financial inclusion, and digital skills

According to the WB's definition, financial inclusion means that individuals and businesses can access useful and affordable financial products and services that meet their needs—transactions, payments, savings, credit, and insurance—and are delivered responsibly and sustainably. I have added a digital dimension to this definition. Ultimately, digital financial inclusion refers to access to financial services and products through digital means.
Financial capacity means households' capacity to cope with adverse financial developments.
For an individual to adopt a central bank-issued digital currency, especially close to the holding limit, as theoretical principles but not entirely restricted, they must possess a minimum level of digital skills and literacy, be familiar with such financial products, not be in a situation of material and financial deprivation, and they must favour modern digital-payment and money-transfer means.
Not only do researchers believe that digital financial inclusion can increase the likelihood of adopting a central bank-issued digital currency and vice versa, either in tandem with other tools (Auer, Banka, et al., 2022) or independently, primarily through the attraction of unbanked individuals (Tan, 2023), but it can also lead to and boost economic growth (Daud and Ahmad, 2023; Khera et al., 2021; Shen et al., 2021). The composite index measures digital financial inclusion, financial capability, and digital skills (CARIX3T – CBDC Adoption Readiness Index, where 3T means the trinity of the three main functionalities of the digital euro). Indicators composing CARIX3T are presented in Table 3.
The scarce, scattered, and heterogeneous landscape of digital financial inclusion represents a major challenge to massive and homogenous retail digital-euro adoption.

IND5WB	Positive	Used a mobile phone or the Internet to check account balance (% with a financial-institution account, age 15+)
IND2ES	Positive	Population by educational attainment level, tertiary education (Levels 5-8), from 15 to 64 years
IND57ES	Positive	Internet banking use, percentage of all individuals
IND6WB	Positive	Use a mobile phone or the Internet to make payments, buy things, or send or receive money using a financial-institution account (% age 15+)
IND10WB	Positive	Saved any money (% age 15+)
IND56ES	Negative	Individuals with no overall digital skills
IND1WB	Positive	Financial-institution account (% age 15+)
IND10ES	Negative	Inability to face unexpected financial expenses
IND9WB	Positive	Own a mobile phone (% age 15+)
IND1ES	Negative	Proportion of population aged 65 years and older
IND17WB	Positive	Worried about not having sufficient money for monthly expenses or bills: not worried at all (% age 15+)
IND18WB	Negative	Most worrying financial issue: money to pay for monthly expenses or bills (% age 15+)
IND13WB	Positive	Made a digital payment (% age 15+)
IND4WB	Positive	Owns a debit or credit card (% age 15+)
IND55ES	Positive	Individuals with above basic overall digital skills
IND19WB	Positive	Raising emergency funds in 30 days: possible and not difficult at all (% age 15+)
IND8WB	Positive	Store money using a financial-institution or a mobile money account (% with an account, age 15+)
IND12WB	Positive	Saved at a financial institution or using a mobile money account (% age 15+)
IND21WB	Positive	Main source of emergency funds in 30 days: savings (% age 15+)
IND25ES	Positive	Last Internet use: in the last 12 months
IND41ES	Positive	Individuals who downloaded or installed software or apps
IND42ES	Positive	Individuals who changed the settings of software, app, or device

Table 3. Indicators for measuring the digital financial inclusion/financial capacity/digital skills of the euro area's households (CARIX3T)

5.2. Quantifying the propensity to hold and use cash in the euro area

To compare the MinMax results and to include an indicator regarding the population's propensity to hold and use cash in the euro area in a final index on the level of euro-area digital-euro adoption capacity, separately by state, a composite index, the cash propensity index (CPIX), was computed. Indicators such as the number of non-cash

payments per capita (negative impact on the CPIX), number of cash withdrawals per card (positive effect), utility payment using cash only (% of the total population, positive impact), received wages in cash only (% of the total population, positive impact) and receives a public-sector pension in cash only (% of the total population, positive effect) were used for the CPIX calculation (values with reference year 2021). The indicators were pre-processed (scaled) using the minimum-maximum method and the index was aggregated using the weighted geometric mean[5] (Figure 4). For the euro area, there are available data on the currency in circulation in each member state, which could consistently improve the accuracy of the composite index, but I decided not to use these data for two reasons: i) the data do not include only cash in circulation, and ii) money circulates inside the euro area (i.e., business and recreational tourism) or outside the euro area (leaving the euro area as remittances). In addition, my decision was made because the currency in circulation in each member state is not only a matter of appetite for holding and using cash. It depends greatly on macroeconomic factors such as GDP growth, inflation, and average income. Moreover, cash in circulation it is also a measure of enterprises' appetite for holding and using cash while the retail digital euro it is meant to be held only by households.

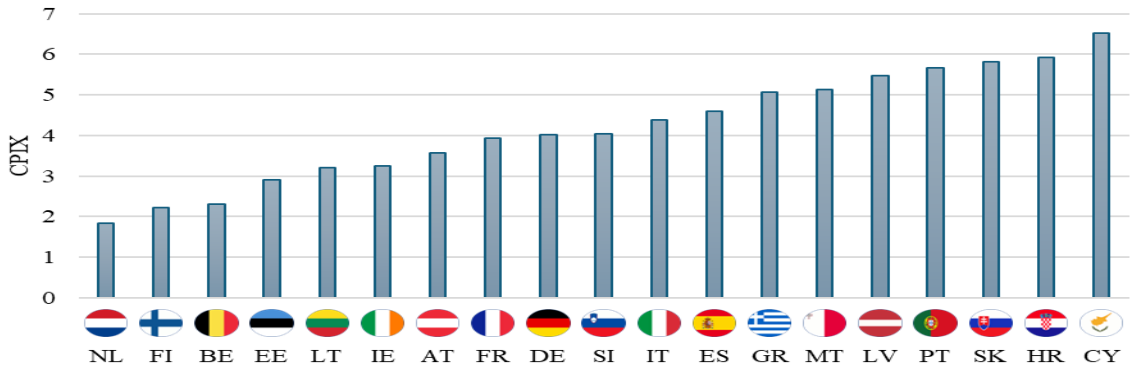


Figure 4. Propensity to hold and use cash in the euro area (mid-2022 status quo)

5.3. Calculating the CBDC Adoption European Scoreboard (CAES)

The next step is to construct a composite index that measures the potential level of adoption of the digital euro. According to the literature, multiple scaling methodologies (percentiles, ranks, min-max, z-score, etc.) can be applied to the indicators included in the composite-index calculation. Aggregation can be achieved through multiplicative methods (the most common are the geometric or exponential mean) and compensatory methods (sum or arithmetic mean). For additive processes (compensatory), an indicator with a value that negatively affects the composite index at least partially cancels out one that contributes positively to the composite-index value. However, multiplicative aggregation behaves differently, requiring multiple indicators with positive effects on the composite index to offset an indicator with a value that negatively affects the final composite index.

From the preprocessing perspective, using a preprocessing method that maintains the initial distance between raw values is preferable. The only drawback of the minimum-maximum preprocessing method is that it does not manage extreme values. It was not of interest in this study to allocate equal distances between states using a percentile or rank-type preprocessing method. Therefore, no methods for managing extreme values (such as winsorizing or trimming) were applied after preprocessing.

The most significant disadvantage of a composite index is that the results are difficult to interpret, and the level of adoption of an observation (such as a country) can be quantified only relative to other observations in the sample. However, calculating this composite index is only a preparatory step for the next level of the study: multivariate clustering.

The CAES contains indicators related to the following: financial capacity; information and communications technology (ICT) skills; social, digital, and financial inclusion; income inequality; social inequality; the level of libertarianism in society; the intention to adopt the digital euro (Google Trend Index as a proxy for interest or Eurobarometer survey responses); the level of competition (the dimension of financial technology-sector (fintech-sector) development); the level of aging in society; the informal-economy dimension; the financial-burden level; a measure of financial wealth; and proxies for risk tolerance (Table 4).

[5] https://en.wikipedia.org/wiki/Weighted_geometric_mean

Inequality Index WE	World Economics	IWE	P	2
Age Dependency Ratio WE	World Economics	ADRWE	N	1
Informal Economy WE	World Economics	IEWE	N	2
Fintech Dimension McKinsey	McKinsey	FDM	P	3
Social Index WE	World Economics	SIWE	P	2
Proxy Risk Tolerance 1	Eurobarometer	PRT1	N	2
Proxy Risk Tolerance 2	Eurostat	PRT2	P	2
Human Freedom Index - HFI				
Personal Freedom Index - PFI	World Economics	Libertarian Index - LIX	N	3
Economic Freedom Index - EFI				
Tend To Trust The Central Bank	ECB	TTCB	P	2
Net Income PPS ES	Eurostat	NIPPS	P	2
CBDC 5 years Google EU	Google Trends Index	C5YGEU	P	3
Eurobarometer Not Interested In Digital Euro	Eurobarometer	ENIDE	N	3
CBDC Adoption Capacity 3T	Own calculations	CARIX3T	P	5
Cash Propensity Index	Own calculations	CPIX	N	3
Median Age WE	World Economics	MAWE	N	1
Poverty and Social Exclusion Risk ES	Eurostat	PSEES	N	2
Financial Assets/Financial Liabilities (Financial Burden)	Eurostat	FAFL	P	2
Financial Assets Per Capita over 15	Eurostat	FAPCO15	P	2

Note: FDM has the highest value for countries in which the fintech sector is less developed; consequently, considering that where the financial technology (fintech) sector is more developed, the competition is higher for CBDC, this indicator positively impacts the composite index; PRT1 is calculated as the ratio of the weight of the population who invested in crypto assets to that of the population who invested in equities; PRT2 is the ratio of the weight of the population who made on-term deposits to that of the population who invested in equities; C5YGEU is the Google Trend Index for the last five years for searching the term "CBDC" on google.com.

Table 4. CAES indicators

The results are interpreted as follows. For example, comparing Finland with Malta, the three most probable situations are as follows: either the per-capita number of holdings over 15 years will be considerably higher in Finland, and the average values of holdings in the cases of Malta and Finland are relatively close, or the per-capita number of holdings over 15 years will be relatively similar in Finland and Malta while the average values of holdings will be significantly different in favour of Finland. The third possibility is that both the number of per-capita holdings and the dimension of holdings are higher in Finland.

The CAES was calculated using five different (composite index specific) methods (with different preprocessing and aggregation methods) and the specific-to-business area method of the multi-criteria analysis (MCA). However, the CAES MMGM (preprocessing through the minimum-maximum method and aggregation through the weighted geometric mean) was used further, as shown in Figure 5.

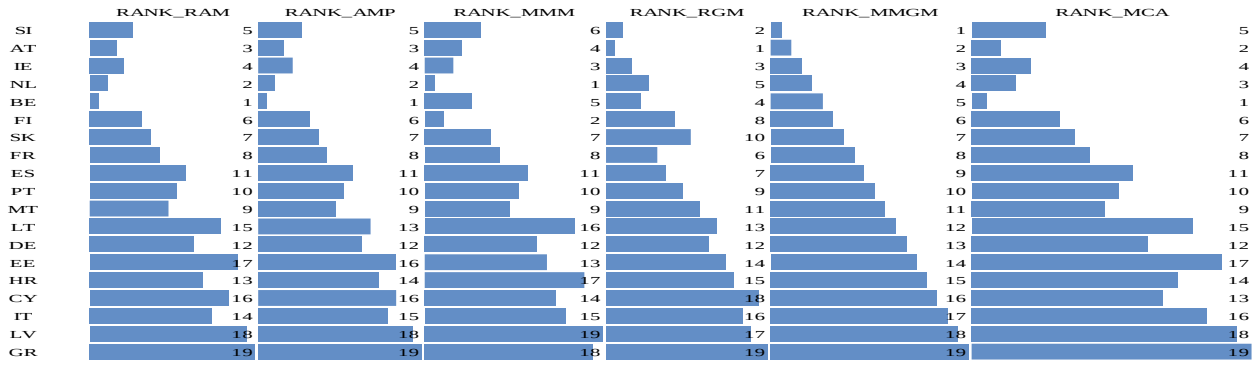


Figure 5. Countries' rankings according to CAES (calculated in six different ways)
Note: RAM – ranking preprocessing, arithmetic mean aggregating; AMP – percentile preprocessing, arithmetic mean aggregating; MMM – minimum-maximum preprocessing, arithmetic mean aggregating; RGM – ranking preprocessing, geometric mean aggregating; MMGM – minimum-maximum preprocessing, geometric mean aggregating; MCA – multicriteria analysis.

A double-stability test of the results was also conducted, indicating the range of results from the best to the worst ranking for each country, resulting in two distributions. Descriptive statistics were computed for these distributions, indicating that by allocating unequal weights, there were minor differences between the composite-index values for the different aggregation and preprocessing methods (Tables 5 and 6).

Trial unequal weights - equal weights stability checks (MMGM)			
Unequal weights		*Equal weights*	
Indicator	**Value**	**Indicator**	**Value**
Mean	3,263157895	Mean	3,736842105
Median	3	Median	3
Mode	3	Mode	4
Standard Deviation	1,726978906	Standard Deviation	2,376788339
Sample Variance	2,98245614	Sample Variance	5,649122807
Range	6	Range	9
Minimum	1	Minimum	1
Minimum Counts	3	Minimum Counts	2
Maximum	7	Maximum	10
Maximum Counts	2	Maximum Counts	1
Sum	62	Sum	71

Table 5. CAES – stability/robustness checks version 1

Final unequal weights - equal weights stability checks (MMGM)			
Unequal weights		*Equal weights*	
Indicator	**Value**	**Indicator**	**Value**
Mean	3,052631579	Mean	3,315789474
Median	3	Median	3
Mode	4	Mode	4
Standard Deviation	1,470966584	Standard Deviation	1,916380604
Sample Variance	2,16374269	Sample Variance	3,67251462
Range	5	Range	6
Minimum	1	Minimum	1
Minimum Counts	4	Minimum Counts	4
Maximum	6	Maximum	7
Maximum Counts	1	Maximum Counts	2
Sum	58	Sum	63

Table 6. CAES – stability/robustness checks version 2

According to the literature and guidelines on building composite indices (OECD, 2008), a principal component analysis (PCA, Abdi and Williams, 2010) should be performed to aggregate the indicators into sub-indices to be included in the CAES calculation. However, this procedure should only be applied if there are significant correlations among the indicators (i.e., Pearson's R is significant and exceeds 0.636 in several cases). The correlation matrix for the CAES indicators was not sufficient for performing PCA.

Through the expert-judgment method, indicator weighting was performed using hierarchical weighting, meaning that, depending on an indicator's importance in calculating the final composite index, a certain weight was allocated; the less critical the indicator, the smaller the weight.

Interestingly, Slovenia ranks first according to the CAES MMGM and OECD 2020 rankings on financial literacy. According to a Eurobarometer survey[6], Slovenia reported the highest proportion of the population closely following the topic of the "digital euro."

6. Robustness checks for MinMax results

MinMax is based on the hypothesis that a holder of 3000 digital euros must cumulatively meet a series of conditions. As this is merely a hypothesis and not a quantitatively measurable phenomenon, the results obtained from this methodology must be checked for robustness. Therefore, I first compare how euro-area member states cluster based on the MinMax results, with their clustering based on the degree of usage of financial products with functionalities similar to those of the digital euro, as well as adoption capacity (CAES). Thus, the discriminatory

[6] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6162

capacity of a univariate clustering method, which uses a single variable to group data, is evaluated in comparison to multivariate clustering methods, which use multiple variables, utilizing data related to the use of private financial products with functionalities similar to those of the digital euro. In the second validation stage, the distribution of the MinMax results is compared with that of the CPIX results to verify mirror image, complementarity (Rosl and Seitz, 2022), and substitutability (the latter being studied by Reimers et al., 2020) hypotheses. Additionally, for several countries (Germany, Spain, the Netherlands, and Austria), a comparison between the MinMax results and the proportion of the population expressing interest in holding a digital-euro account (as indicated in survey responses) is conducted. These proportions are significantly lower in all these countries than the corresponding MinMax results. This aspect is conducive to the euro area's financial stability, as it indicates that if the holding limit were calculated based on the MinMax results, it would have a more proper calibrated value. If the MinMax value underestimated potential demand, the holding limit would be higher than the banking sector could accommodate. This discrepancy could lead to significant challenges for financial stability. Specifically, an underestimated demand reflected by the MinMax value implies that more people might want to hold digital euros than initially anticipated. Consequently, if the holding limit is set based on this underestimated demand, it might allow for a greater accumulation of digital euros than the banking sector can support without adverse effects. This scenario could result in excessive outflows from traditional bank deposits to digital-euro holdings, potentially leading to liquidity shortages in the banking sector. These liquidity shortages could force banks to sell off assets at unfavourable prices, potentially triggering a financial crisis or amplifying existing financial instability. Therefore, it is crucial to accurately calibrate, as much as possible, the holding limit. This calibration should be based on as much as possible realistic demand assessments to prevent excessive strain on the banking sector and maintain financial stability.

6.1. Validating through clustering techniques

In this section, a comparison of the MinMax results with digital financial behaviour was initiated using CAES and data on the usage of three functionalities, such as those of the digital euro: the per-capita number of payments through credit transfers, per-capita number of card payments, and the percentage of people who had Internet banking activities in 2021 whose degree of usage was characterized by very high scarcity and heterogeneity at the euro-area level (Figure 6). For the first two functionalities, indicators related to sums paid or transferred were not used because this aspect is more related to financial well-being than to the appetite for modern means of payment or transfers. Subsequently, multivariate clustering procedures were employed (using six different methodologies as a concept and setting (Kassambara, 2017)) for functionalities such as those of the digital euro and CAES (Figures 7–12), and univariate clustering was performed using the MinMax data (Table 7 and Figure 13).

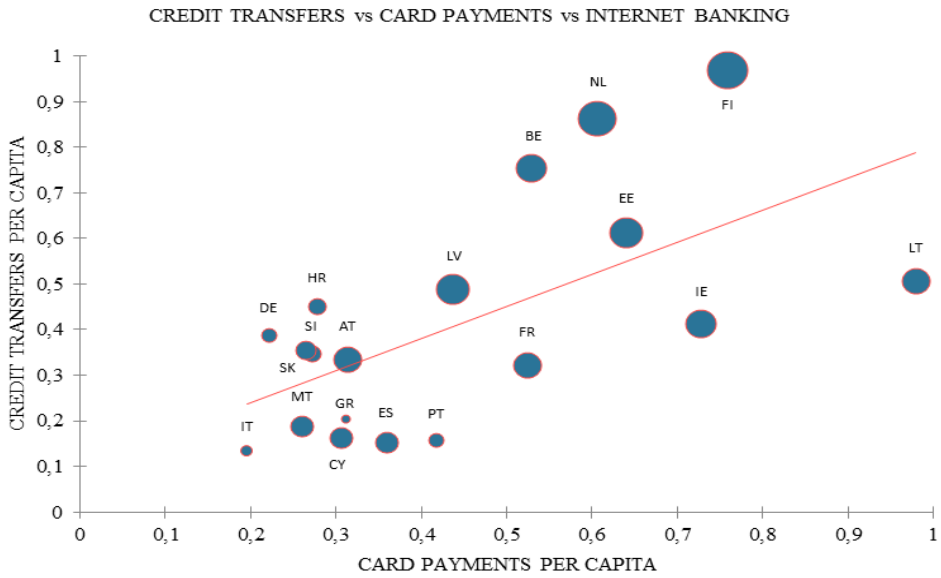
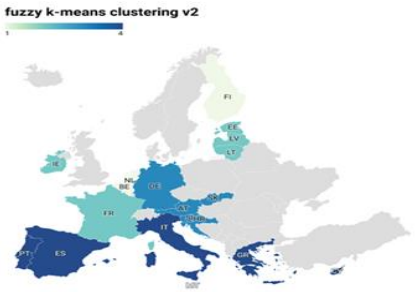
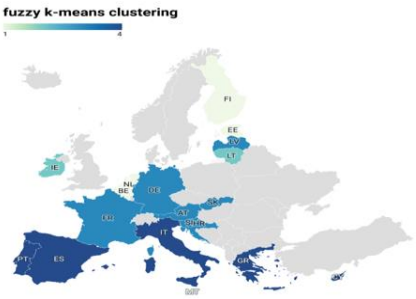
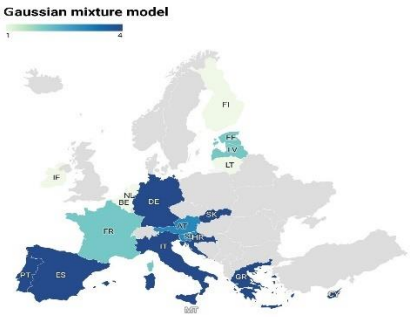
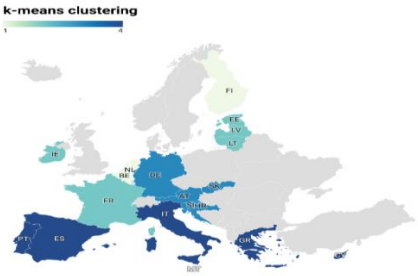


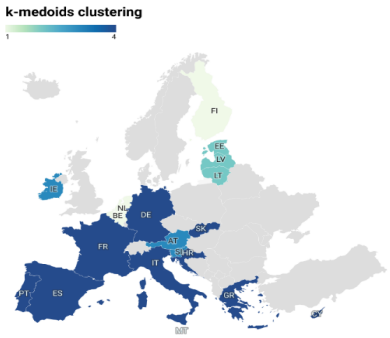
Figure 6. The 3D plotting of credit transfers per capita vs. card payments per capita vs. Internet banking usage (as % of total population)
Note: The size of the dots is given by Internet-banking usage

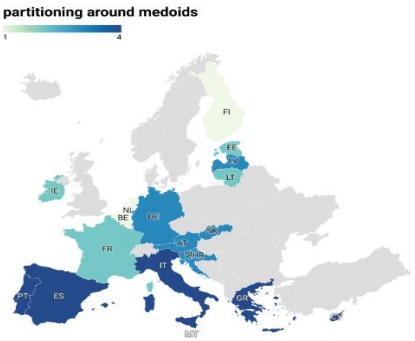












Figures 7–12. Multivariate clustering using CAES, card payments per capita, Internet-banking usage, and credit transfers per capita[7]

Univariate clustering

1	2	3	4
Belgium	**Austria**	Germany	Cyprus
Estonia	**Spain**	**France**	Greece
Finland	Lithuania	**Italy**	Croatia
Ireland		Latvia	Portugal
Netherlands		**Malta**	
Slovakia		Slovenia	

Table 7. Cluster allocation - univariate clustering with MinMax

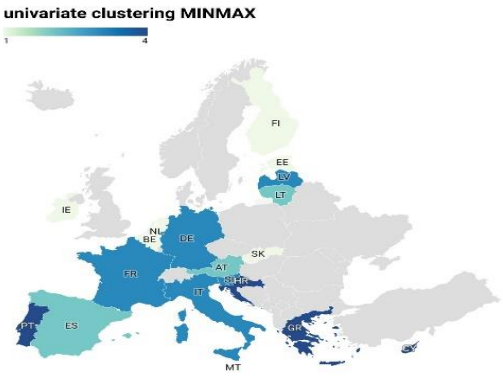


Figure 13. Univariate clustering with MinMax values

After multivariate clustering, Table 8, Figures 14–17, and Figure 30 were created (HTC = highest take-up cluster; MHTC = medium highest take-up cluster; MLTC = medium lowest take-up cluster; and LTC = lowest take-up cluster). For example, in the case of Germany and France, which fall into two and three different clusters, respectively, depending on the methodology, high social, cultural, economic, and ethnic diversity is likely to

[7] Except for the fuzzy k-means clustering version 2, which uses the Jaccard-distance metric, and the Gaussian-mixture model, which does not use any specific metric, all other multivariate clustering methods employ the Euclidean-distance metric

contribute substantially to the scattering between clusters (Figures 18–26, 27–29). I hypothesize that this uncertain positioning of some states within a single cluster is because these states are characterized by a very high degree of heterogeneity in their structure. For example, it is well known in France that the north is more financially potent, while cash payments are favoured in the south. For Germany and France, the average of the clustering indicators did not decisively lean toward one of the clusters. Based on these premises, I created Table 8 and Figures 14–17 and 30. The problem of averages in statistics can be well explained by the following example: We could have sweltering summers and freezing winters, but on average, throughout the year, the temperature does not change significantly. Typically, the averages hide significant structural heterogeneity.

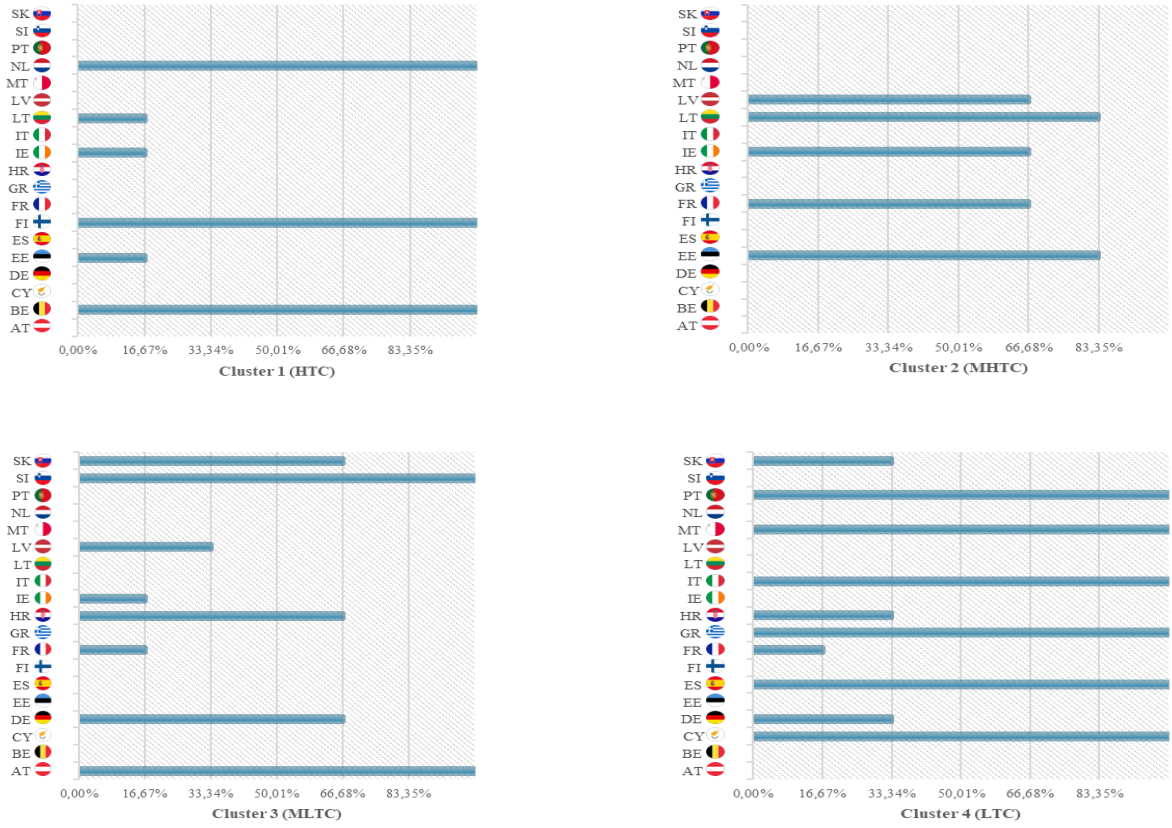
	k-means	fkm v1	gmm	pam	fkm v2	k-medoids
AT	3	3	3	3	3	3
BE	1	1	1	1	1	1
CY	4	4	4	4	4	4
DE	3	3	4	3	3	4
EE	2	1	2	2	2	2
ES	4	4	4	4	4	4
FI	1	1	1	1	1	1
FR	2	3	2	2	2	4
GR	4	4	4	4	4	4
HR	3	3	4	3	3	4
IE	2	2	1	2	2	3
IT	4	4	4	4	4	4
LT	2	2	1	2	2	2
LV	2	3	2	3	2	2
MT	4	4	4	4	4	4
NL	1	1	1	1	1	1
PT	4	4	4	4	4	4
SI	3	3	3	3	3	3
SK	3	3	4	3	3	4

	Cluster 1 (HTC)	Cluster 2 (MHTC)	Cluster 3 (MLTC)	Cluster 4 (LTC)
AT	0	0	6	0
BE	6	0	0	0
CY	0	0	0	6
DE	0	0	4	2
EE	1	5	0	0
ES	0	0	0	6
FI	6	0	0	0
FR	0	4	1	1
GR	0	0	0	6
HR	0	0	4	2
IE	1	4	1	0
IT	0	0	0	6
LT	1	5	0	0
LV	0	4	2	0
MT	0	0	0	6
NL	6	0	0	0
PT	0	0	0	6
SI	0	0	6	0
SK	0	0	4	2

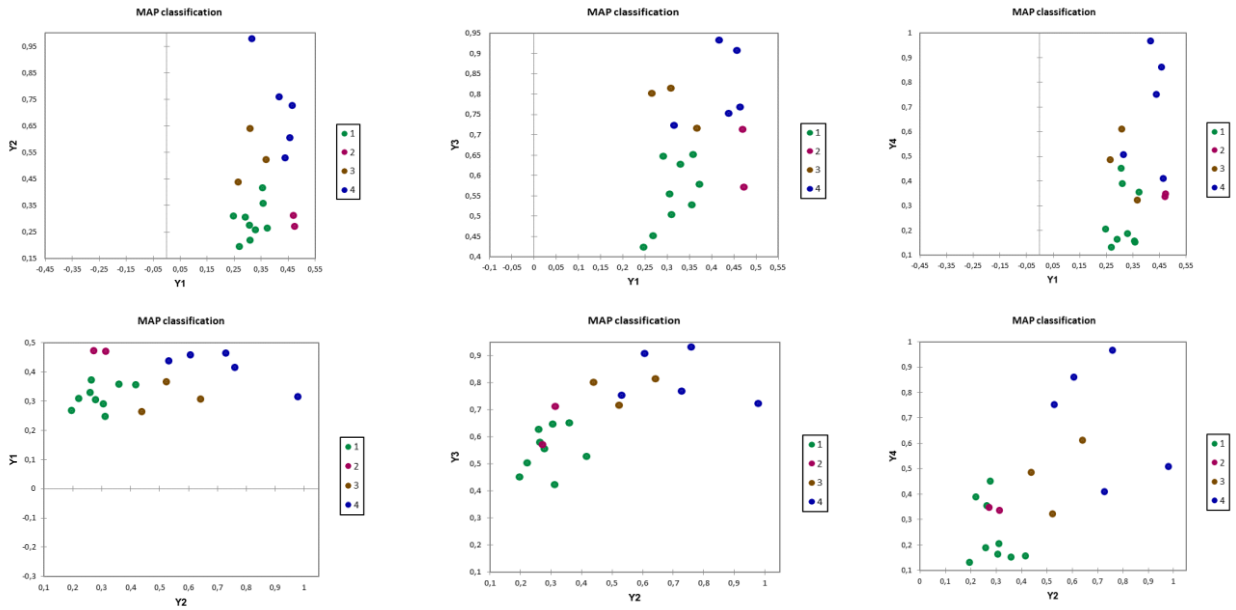
	Cluster 1	Cluster 2	Cluster 3	Cluster 4
AT	0,00%	0,00%	100,00%	0,00%
BE	100,00%	0,00%	0,00%	0,00%
CY	0,00%	0,00%	0,00%	100,00%
DE	0,00%	0,00%	66,67%	33,33%
EE	16,67%	83,33%	0,00%	0,00%
ES	0,00%	0,00%	0,00%	100,00%
FI	100,00%	0,00%	0,00%	0,00%
FR	0,00%	66,67%	16,67%	16,67%
GR	0,00%	0,00%	0,00%	100,00%
HR	0,00%	0,00%	66,67%	33,33%
IE	16,67%	66,67%	16,67%	0,00%
IT	0,00%	0,00%	0,00%	100,00%
LT	16,67%	83,33%	0,00%	0,00%
LV	0,00%	66,67%	33,33%	0,00%
MT	0,00%	0,00%	0,00%	100,00%
NL	100,00%	0,00%	0,00%	0,00%
PT	0,00%	0,00%	0,00%	100,00%
SI	0,00%	0,00%	100,00%	0,00%
SK	0,00%	0,00%	66,67%	33,33%

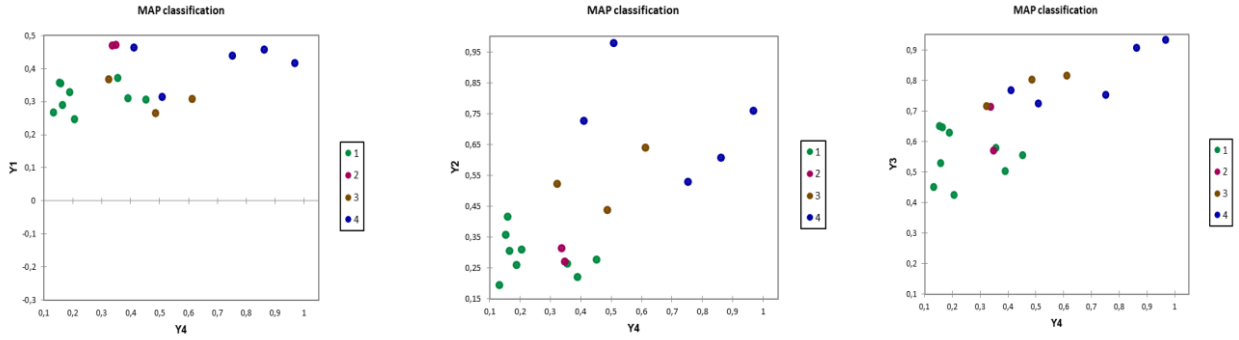
	Cluster 1	Cluster 2	Cluster 3	Cluster 4
AT			7.673.412	
BE	9.619.330			
CY				775.010
DE			47.753.459	23.876.730
EE	185.672	928.360		
ES				40.687.137
FI	4.672.932			
FR		37.329.859	9.332.465	9.332.465
GR				8.910.114
HR			2.212.945	1.106.472
IE	666.667	2.666.667	666.667	
IT				51.540.338
LT	398.948	1.994.742		
LV		1.060.163	530.082	
MT				451.746
NL	14.763.684			
PT				9.011.878
SI			1.791.246	
SK			3.054.573	1.527.287
	10%	**15%**	**25%**	**50%**

Table 8. Cluster allocation for 6 different multivariate clustering methods
Note: The percentages highlighted in blue above represent the weights of the total population in the HTC (Cluster 1), MHTC (Cluster 2), MLTC (Cluster 3), and LTC clusters (Cluster 4). HTC = highest take-up cluster; MHTC = medium highest take-up cluster; MLTC = medium lowest take-up cluster; and LTC = lowest take-up cluster

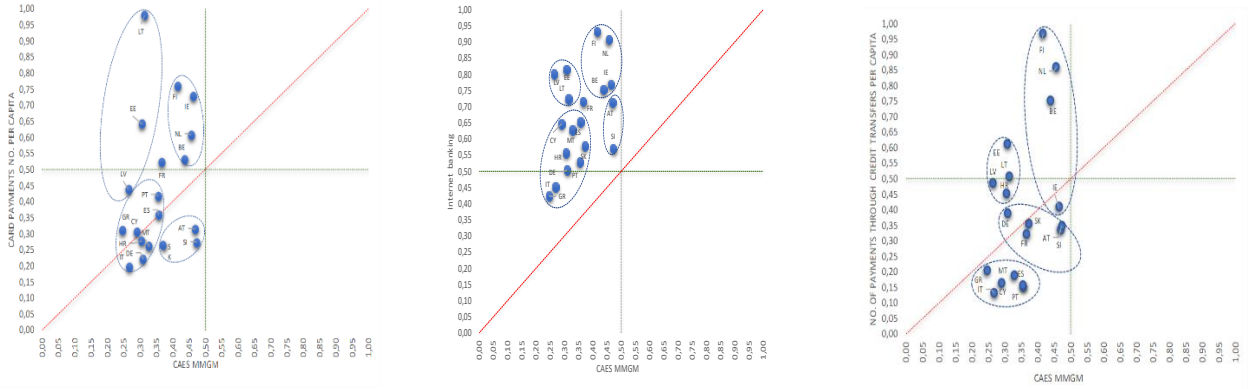


Figures 14–17. Graphical representations of the third quadrant of Table 8





Figures 18–26. MAP classification – part of the Gaussian mixture model (Y1, Y2, Y3, and Y4 represent CAES, per-capita card payments, Internet banking usage, and payments through credit transfers per capita, respectively); cluster numbering is different than cluster numbering from Table 8



Figures 27–29. Visual clustering of CAES vs. card payments per capita, Internet banking, and credit transfers per capita

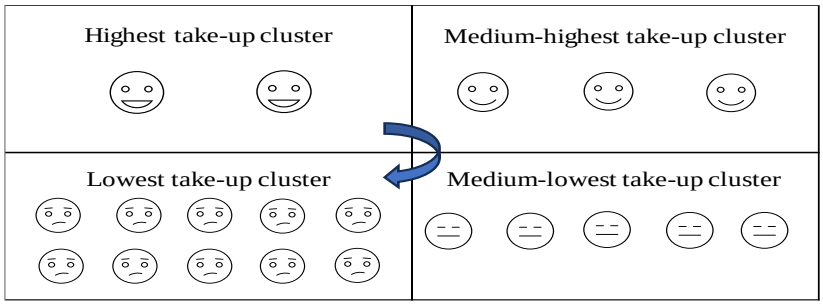


Figure 30. Graphical representation of the 4th quadrant from Table 8

In the first quadrant of Table 8, I allocate each state to a cluster based on the clustering method used (for example, states with the highest usage of financial products with functionalities similar to those of the digital euro are in Cluster 1). In the second quadrant, I list the number of times a state appears in one of the clusters numbered from 1 to 4. In the third quadrant, I show the proportion of a state's appearances in one of the clusters numbered from 1 to 4. In the fourth quadrant, I multiply the proportions from the third quadrant by the population over 15 years of age in each state.

We can observe that MinMax partially overestimates (in the case of Slovakia, Austria, Spain, Italy, and Malta), meaning that, in univariate clustering, some states fall into clusters higher than those predominantly characterizing them after applying the six multivariate clustering procedures, except for France. One reason for the imperfect fit between univariate and multivariate clustering might be that in the former, the data used are qualitative, obtained from surveys (whose accuracy depends heavily on the statistical representativeness of the sample), and avoiding biased responses is difficult when surveying with a certain margin of error. In contrast, the data in the latter are primarily quantitative.

As previously mentioned, univariate clustering partially overestimates compared to multivariate clustering, except in France's case. If univariate clustering had vastly underestimated this, it would have been negative, meaning that the upper limit of the digital-euro adoption calculated using the MinMax data would have been higher than that initially obtained in Section 4. In the case of France, to ensure that the MinMax results were overestimated, the highest MinMax result was allocated, which belongs to a country in the MHTC cluster, Lithuania. Although

natural compensation might have occurred between overestimates and France's underestimation, the country was artificially upgraded to the second cluster.
In conclusion, the findings of this section validate the MinMax results. In addition, MinMax does not underestimate the actual level of digital-euro adoption.

6.2. Validating through comparisons with CPIX

The MinMax results and CPIX values should be mirror images because I hypothesize that they should be both substitutable and complementary. Thus, the higher a country's appetite for holding and using cash, the lower the level of digital-euro adoption, and vice versa. If this hypothesis is confirmed, the MinMax results will be validated again as primarily correct. Kotkowski and Polasik (2021), with their comprehensive research, have provided strong support for the mirror image principle. Their findings show that the divide between cash users and users of modern digital payment and transfer means has become more evident during the pandemic, with only a small proportion of the population using both, thereby filling to some extent the gap between the two types of individuals.
First, Figures 31 and 32 were plotted to confirm the initial hypothesis. Next, I excluded Slovakia from the sample and created Figure 33. Thereafter, I calculated a Pearson's R (Figure 34) of approximately -0.9, which shows that the two distributions are strongly negatively correlated, although correlation does not imply causality. The substitutability and complementarity hypotheses and mirror-image principle between MinMax and CPIX were used. Thus, the higher the CPIX, the lower the potential level of digital-currency adoption. In the case of the euro area, after the first two graphs were created, Slovakia was excluded. Subsequently, Pearson's R coefficient was calculated as close to 0.91 (for the euro area).
The data collected by the WB are published every 3 years. Therefore, the calculations could be repeated once the data for 2024 were published in 2025. The sample contained 19 states. However, the Pearson's R coefficient (for 18 countries; the outlier, Slovakia, was excluded) seems to indicate a robust negative correlation between MinMax and the CPIX (a composite index of the inclination toward holding and using cash). As Figure 32 shows, the countries are remarkably close to the trend line, indicating that the initial assumptions of substitutivity and complementarity are rather correct than false. Slovakia appears to exhibit a high propensity for cash and a relatively high MinMax value. This suggests that despite the potential benefits of the digital euro, such as high privacy standards and instant payments, there may be cultural or economic factors in Slovakia that make the population more inclined toward cash transactions. We also might think that the relatively high MinMax value in the case of Slovakia might occur due to sampling issues.
Subsequently, I applied a series of non-parametric tests to the distributions, excluding Slovakia. The application of the two-sample Kolmogorov-Smirnov and Mann-Whitney tests, Fisher's F-test, and Wilcoxon signed-rank test (Figures 35–38) verifies that the two samples followed the same distribution, the distributions were almost identical, and the ratio of one sample's variance to that of the other was equal to 1. The two distributions were normalized using a scale of 0 to 100. Table 9 indicates that the two distributions have similar statistical properties.
With the MinMax results validated using the two different methods, it should be noted that the approximately € 578 billion previously calculated as the maximum limit of the digital-euro adoption level in the absence of a crisis in the banking sector is difficult to achieve for the following reasons: (F1) the potential perceived poor privacy of digital-euro holdings, which could keep libertarians away (there might be individuals who were not convinced that the design features of the digital euro would not infringe their fundamental rights and would meet their privacy needs); (F2) lack of trust in the central bank; (F3) dissatisfaction with how high inflation has been addressed in recent years, mostly in countries where social trust is low; (F4) the inconvenience of migrating from a commercial payment- and transfer-service provider to the central bank; (F5) the perception that digital financial private services and their associated software applications better serve consumers' needs than the digital euro; (F6) limited success of the digital euro in a consumer's social circle; (F7) limited number of merchants offering the digital euro as a payment option; (F8) Euroscepticism reached a worrying level in the past several years; (F9) the maximum probability associated with the MinMax results is the result of (2) formula; (F10) not all individuals with the requisite profile have the financial capacity to hold € 3000, as shown above; and (F11) MinMax overvalues in the case of some countries in the euro area.

(2) $P_{max}(A \cap B \cap C \cap D \cap E \cap F \cap G) = min\{P(A), P(B), P(C), P(D), P(E), P(F), P(G)\}$

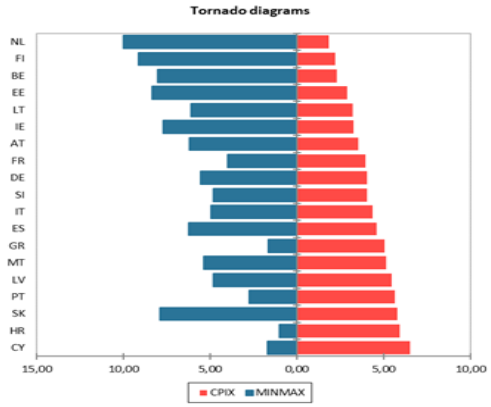


Figure 31. Tornado diagram: CPIX vs. MinMax

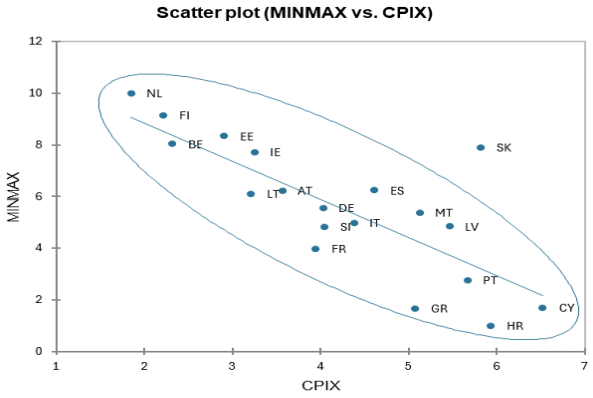


Figure 32. MinMax vs. CPIX

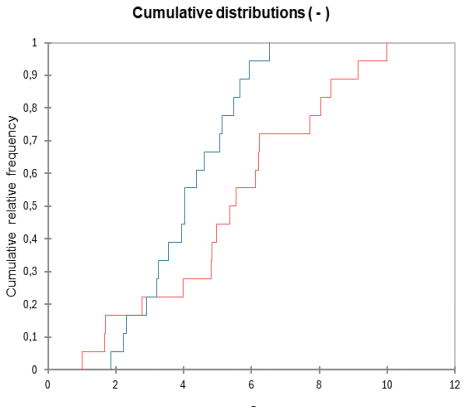


Figure 33. Two-sample Kolmogorov-Smirnov test / Two-tailed test (without SK)

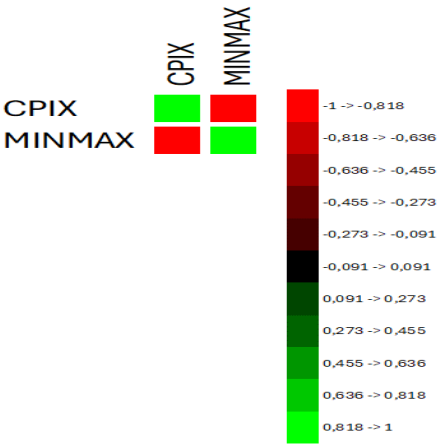


Figure 34. Pearson's correlation between CPIX and MinMax (without SK)

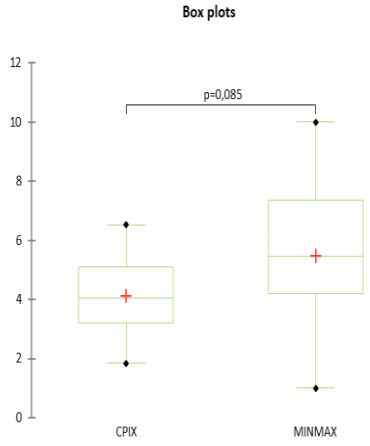


Figure 35. Mann-Whitney test / Two-tailed test (without SK)

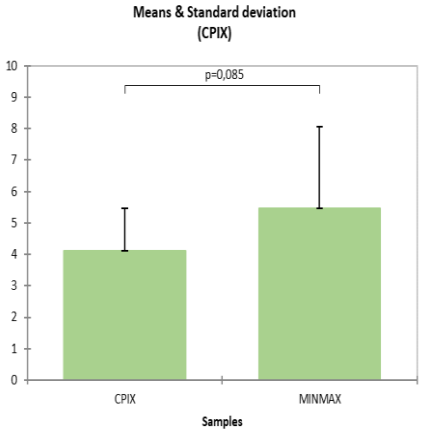


Figure 36. Mann-Whitney test / Two-tailed test (without SK)

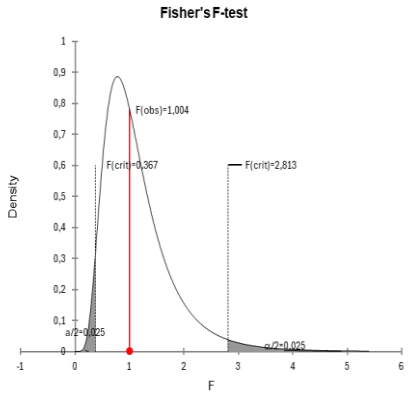


Figure 37. Fisher's F-test / Two-tailed test (without SK)

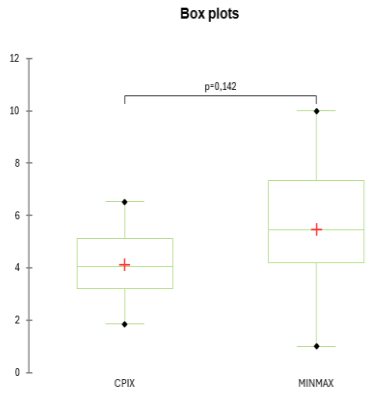


Figure 38. Wilcoxon signed-rank test / Two-tailed test (without SK)

The fact that only some countries are extremely close to the trendline (Figure 32) or scattered around it does not necessarily mean that something must be fixed. There might be cases in practice in which some member states' citizens prove to have a high/low appetite for cash, imperfectly correlated with the usage of digital solutions for payments and money transfers. Nevertheless, there may also be other reasons for this kind of deviation from the trendline: using qualitative data with a certain margin of error due to both a minor/major lack of sampling representativity and biased and unrealistic survey answers; some indicators are averages, while others are weights; composite indices are not the perfect instrument (although they might be the only one applicable in some cases) to measure a compounded phenomenon; etc. The imperfect mirroring of these two distributions may also be due to a small proportion of the population that uses both cash and modern digital payment and transfer methods.

Descriptive statistics (Quantitative data):

Statistic	CPIX	MINMAX
Minimum	0,000	0,000
Maximum	100,000	100,000
Range	100,000	100,000
1st Quartile	29,244	35,493
Median	46,776	49,565
3rd Quartile	69,911	70,508
Sum	873,224	894,053
Mean	48,512	49,670
Variance (n)	789,088	786,752
Variance (n-1)	835,505	833,031
Standard deviation (n)	28,091	28,049
Standard deviation (n-1)	28,905	28,862
Variation coefficient (n)	0,579	0,565
Variation coefficient (n-1)	0,596	0,581
Skewness (Pearson)	0,010	-0,092
Skewness (Fisher)	0,011	-0,101
Skewness (Bowley)	0,138	0,196
Kurtosis (Pearson)	-0,957	-0,796
Kurtosis (Fisher)	-0,863	-0,647
Standard error of the mean	6,813	6,803
Lower bound on mean (95%)	34,138	35,317
Upper bound on mean (95%)	62,887	64,023
Standard error of the variance	286,576	285,727
Lower bound on variance (95%)	470,457	469,065
Upper bound on variance (95%)	1877,740	1872,182
Standard error (Skewness (Fisher))	0,536	0,536
Standard error (Kurtosis (Fisher))	1,038	1,038
Mean absolute deviation	23,444	22,364
Median absolute deviation	22,812	20,711

Table 9. Descriptive statistics: CPIX vs. MinMax (scaled values ranging from 0 to 100)

It is important to note that testing the principles of mirror image, complementarity, and substitutability in the case of CPIX and MinMax was a multi-iterative, dynamic, and bidirectional process aimed at selecting the appropriate seven indicators used to calculate MinMax. In other words, a multi-iterative fitting process was applied, terminating when the above principles were met. For example, in the first iteration, a series of indicators were chosen, partially different from the final indicators, and after applying the MinMax procedure, it was found that the three principles/hypotheses were not satisfied. In the next iteration, some of the indicators were changed, and compliance with the three principles was checked again. Ultimately, the 7 indicators presented in Section 4 were retained. To find out how much depositors qualify for adopting a digital euro, we can repeat the MinMax methodology by using fewer criteria than the original MinMax. In the case of Romania, coincidence or not, it revealed that MinMax applied on depositors is approximately equal to the result of the original MinMax (as number of individuals).

7. Digital-euro account funding sources

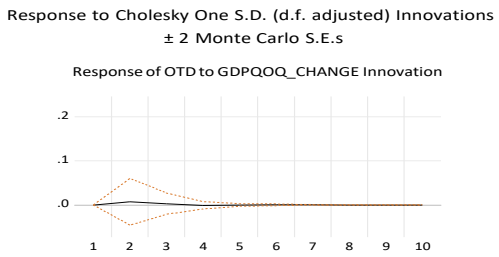
7.1. Consumers' sensitivity to on-term deposits interest-rate change

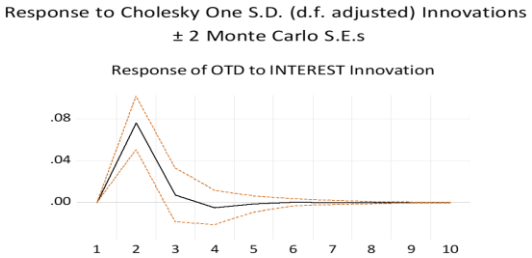
In this sub-section, I determine the dimension of on-term deposit-demand elasticity related to interest rates.
The population holds bank savings accounts typically for several underlying reasons: i) as a precautionary measure to have a safety net in the case of income reduction or job loss; ii) as an investment for obtaining returns and protecting against high inflation; and iii) for security, such as migrating from a troubled bank to an institution perceived as more robust. These three drivers are not mutually exclusive, and a consumer could have in mind all three when opening an on-term deposit. This section focuses on the second category as I attempt to determine whether term deposits are substitutable by holdings of digital euros under the condition that the latter will likely not be remunerated. In this regard, I conducted a standard vector autoregressive (SVAR) analysis for the four largest economies in the euro area, which also account for the most significant population (approximately 75% of the total population over 15 years old in the euro area). The idea behind including only these four countries in the model is that, if the digital euro were widely adopted in these four countries (Germany, France, Italy, and Spain), its success across the entire euro area would then be almost guaranteed. In the previous sections, we observed that the potential level of digital-euro adoption in three of the four countries was relatively low. However, in this subsection and the following, I attempt to determine which money forms (cash, overnight deposits, and on-term deposits) could be subject to migration to digital euros, and whether on-term bank-depositing behaviour is less or more pronounced in periods of economic crisis or during regular periods. This last question seeks to answer whether on-term deposits could migrate to digital-euro holdings during and in the aftermath of an economic downturn.
Researchers have concluded that the probability of bank savings increases with the interest rate and tends toward zero at shallow interest-rate levels (Felici et al., 2023). Additionally, Fredriksson and Staal (2021) provide robust evidence of the positive effect of lagged savings interest on bank savings, while a decrease in the interest rate leads to a decline in the level of new deposits (Kharazi et al., 2022). In the case of the Netherlands, which is not included in our model but is ranked among the top five economies in Europe, studies indicate that relocating deposits from one bank to another significantly depends on differences in bank interest rates (Gerritsen et al., 2017).
In the SVAR model, I include newly constituted on-term deposits (quarterly frequency), quarterly economic growth compared to that of the same quarter of the previous year (GDP at market prices, chain-linked volumes), and the interest rate on newly constituted term deposits (quarterly frequency). The data cover nearly 20 years, until Q1, 2023. Focusing only on the second savings category, I do not include a dummy variable that lags the financial crisis. Regarding this last variable, the literature has consistently documented that a financial crisis generates flight-to-safety or bank-run episodes, as discussed in the next section. In a preliminary VAR, I use the population's quantitative inflation expectations. The results show that this variable is not statistically significant and does not impact random increases or decreases in new deposits in the four countries.
The first step was to standardize the data; the next was to test for stationarity. Following the stationarity test, I found that only the GDP series was stationary. I then attempted to make the data series stationary through the Box-Cox transformation and first-difference method. Even after applying these two procedures, the data series for new deposits and the associated interest rate remained non-stationary. I used a third method: adjusting for seasonality and removing the trend. This resulted in a random, stationary data series.
After applying the lag-length criteria test, I found that the lag order should be 1 (one) for all four countries. I then estimated the SVAR model and conducted the VAR Granger causality/block exogeneity Wald test. I also conducted robustness tests on the model and the results did not indicate any issues related to its robustness.

The results lead to the following main conclusions (Figures 39–46): i) Germans are the most sensitive to changes in the interest rate. Variations in economic activity do not influence Germans' on-term bank-saving behaviour (this latter conclusion is valid for all the states included in the model). ii) The French and Italians are less sensitive to changes in the interest rate than Germans. iii) Spaniards are not influenced by the interest-rate level in the decision-making process for bank savings. This SVAR captures the short-term relationship between the level of new deposits, interest rate (the reaction of the former to the latter's random swings), and variation in economic activity. A vector error-correction model is more appropriate for observing long-term relationships.

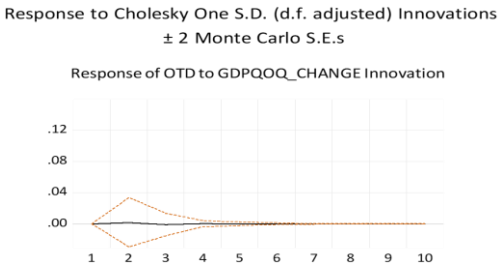
The VAR results indicate another aspect. The model disentangles the savings behaviours of citizens from the four member states. Thus, Spaniards do not necessarily invest in excess financial resources to create new bank deposits. Most likely, they save it as a precautionary measure or for security, suggesting that even when issuing a non-interest-bearing digital euro, this asset could prove attractive to Spanish citizens during regular periods and especially during financial crises. For the French and Italians, compared to Spaniards, issuing a non-interest-bearing digital euro might lead to less pronounced migration behaviour (by moving resources meant to be turned into on-term deposits) away from the commercial banking sector toward digital-euro holdings. However, Germans perceive savings primarily as a form of investment; thus, only if the digital euro were to bear interest could it attract on-term depositors from the banking sector.

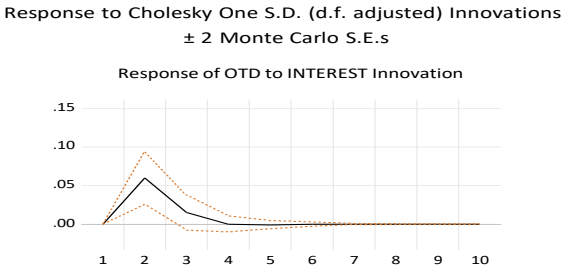
Other conclusions in this section are as follows: 1) German consumers will likely adopt the digital euro by transferring financial resources from current accounts. 2) The French and Italians will adopt the digital euro by shifting funds from current accounts initially meant to be spent, transferred, or stored, especially, and to a lesser extent, by shifting money from current accounts, which generally would be transformed into term deposits. 3) In the case of Spaniards, any of the money from current accounts, which generally would be transformed into term deposits, or funds from current accounts used to purchase goods and services or for any other purposes (such as a store of value), could be the source for fueling a digital-euro account.



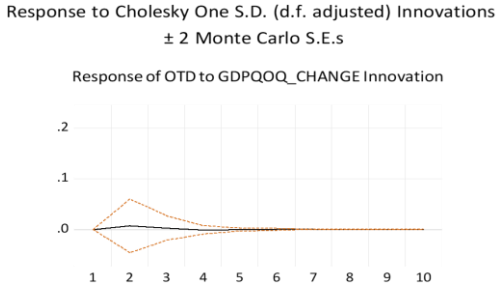


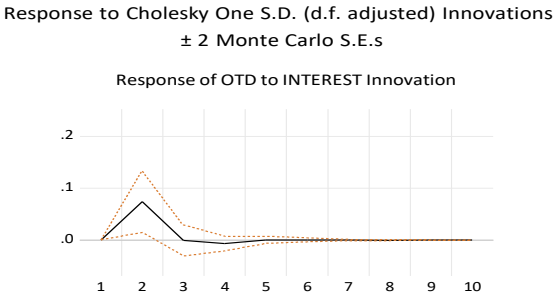
Figures 39,40. Impulse-response function for Germany



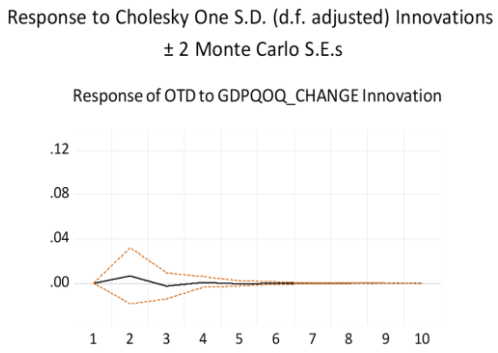


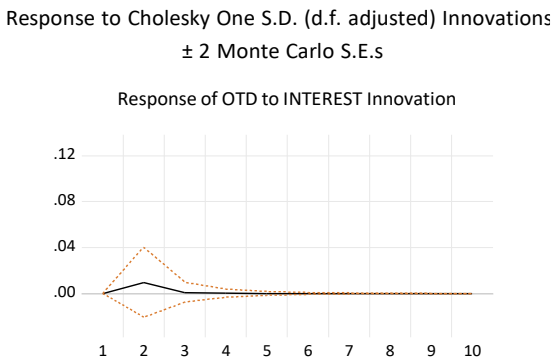
Figures 41,42. Impulse-response function for France





Figures 43,44. Impulse-response function for Italy





Figures 45,46. Impulse-response function for Spain

The adoption of the digital euro could pose significant challenges for banks. If the population were to withdraw money from current accounts initially meant only to be stored, rather than withdrawing money from current accounts, which, in the absence of the digital euro, would turn into term deposits, banks would face more problems. Current accounts represent the cheapest source of funding for credit institutions. Banks would need to find alternative funding sources to replace a maximum of € 578 billion in a scenario in which all digital-euro holdings were sourced from current accounts.

It is important to note that low sensitivity to random variations of interest rates on term deposits would not necessarily lead to liquidating term deposits before maturity to migrate toward digital-euro holdings. Instead, a low sensitivity to interest-rate variations could lead to a dissaving phenomenon. Specifically, individuals who do not save to gain financial benefits will save less in term deposits than before the issuance of the digital euro or will not renew their term deposits. In conclusion, it is not term deposits that may be subject to migration toward digital-euro holdings; however, overnight deposits will shift to digital-euro holdings (which contain three types of money: money stored without the purpose of being transferred or spent, dissaved money, and money meant to be spent or transferred). These last ideas align with the assumption from Adalid et al. (2022), who hypothesize that overnight deposits would be substituted by digital euro holdings and not on-term deposits. In Subsection 7.2, I examine if and to what extent cash reserves will migrate, at least partially, toward digital-euro holdings.

From a credit institution's perspective, the highest impact would come from moving funds from current accounts initially intended only for storing value without an agreed-upon maturity. This study aims to measure the potential level of adoption of the digital euro and sources of funding for digital-euro holdings. Therefore, estimating banks' costs may represent another study's purpose and scope.

7.2. The (in)flexibility and volatility of cash reserves and currency in circulation over time

Although the openness of the population and companies in the eurozone to using digital means of payment and transfer, as well as the transactions behind e-commerce, have increasingly digitalized, cash in circulation has followed an upward trend, a development supported by the evolution of its main economic and financial determinants (Figure 47).

Theoretically, the increase in cash reserves as a proportion of households' total financial assets in the euro area can be attributed to several key factors. During periods of economic uncertainty, such as financial crises or recessions, households tend to increase their cash holdings as a precautionary measure. This behaviour was particularly noticeable during and after the 2008 financial crisis and the COVID-19 pandemic. The European Central Bank (ECB) has played a pivotal role in the increase of cash reserves. By maintaining low or negative interest rates for an extended period, the ECB has effectively reduced the opportunity cost of holding cash, thereby making it more appealing for households to allocate a larger portion of their assets to cash reserves. Households may prefer liquidity to access funds for unexpected expenses or investment opportunities easily. This preference for liquidity directly increases the weight of cash in their total financial assets, as they allocate a larger portion of their assets to cash to ensure immediate access to funds. Changes in household income and savings rates impact cash reserves. Perceptions of inflation or deflation can influence household behaviour. During deflationary periods, households might hold more cash, expecting prices to fall. Conversely, during inflationary periods, they might hold less cash to avoid losing purchasing power. Low inflation rates in the euro area have often supported higher cash holdings. Cultural attitudes toward savings and spending also play a significant role in the increase of cash reserves. In some euro area countries, there may be a stronger tradition of saving in cash, which impacts the overall trend and highlights the diversity within the euro area. These factors, collectively and individually, have influenced the rising weight of cash reserves in households' total financial assets in the euro area.

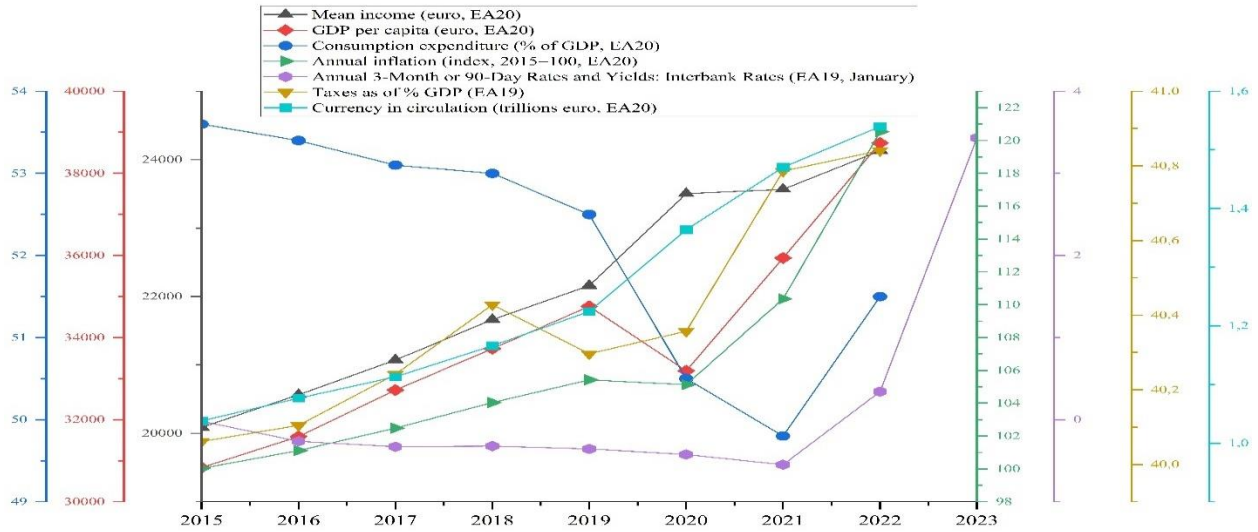


Figure 47. Currency in circulation and its main economic and financial determinants

According to the specialized literature, a strong positive correlation exists between the level of the informal economy and that of cash holding and usage (Reimers et al., 2020). Among the most commonly used methods to estimate the level of the informal economy in a country is the currency-demand approach (Feld and Schneider, 2010; Schneider and Enste, 2000), which is based on the premise that cash transactions account for the bulk of informal transactions (e.g., Johnson et al., 1998; Schneider, 1997). A growing body of literature claims that cash supports the shadow economy (Andrews et al., 2011; Riccardi and Levi, 2017; Schneider, 2017). A bidirectional relationship exists between cash and the informal economy in the sense that these two concepts reinforce each other, and disrupting this cycle can be achieved through the adoption of digital-payment and transfer methods by those who currently prefer cash.

Figure 48 illustrates that, despite the exponential growth of the digital financial phenomenon over the years, the informal economy has only marginally decreased, with a few exceptions in small states, from 2000 to 2022. This persistent presence of the informal economy, despite the significant growth in digital transactions, underscores the crucial and urgent need for effective measures to disrupt the cash-informal economy circle.

Despite the exponential growth in digital payments and transfers, the data present a surprising trend. Figures 49–51 reveal that cash in circulation or the population's cash reserves have either insignificantly fluctuated or have increased. The proportion of cash reserves in the population's total financial assets has trended upward from 2012 to 2022, a period associated with the digital financial revolution. This unexpected increase in cash reserves within the aggregate of cash reserves and the population's term and overnight deposits is a significant finding that challenges the conventional understanding and piques our curiosity.

"Cash is by far the most popular payment method in Europe. It is so high partly due to the fact that in uncertain times, cash is perceived as particularly familiar and secure. Cash remains highly valued, reflected in the strong majority favouring cash in the next five to ten years."[8]

Even with the introduction of cash payment limits in most states of the euro area[9], the propensity of consumers to hold and use cash has not decreased. This lack of change in behaviour raises questions about the effectiveness of these measures in reducing tax evasion. Additionally, the legislative package aimed at regulating cash as a legal tender[10] continues to support its high usage.

All these aspects clearly indicate that the transition of financial operations to the digital environment has been supported not by transferring cash into current accounts (or not withdrawing from automated teller machines (ATMs)) but by using excess money from current accounts.

[8] https://www.bearingpoint.com/en/about-us/news-and-media/press-releases/survey-cash-is-number-one-in-europe/

[9] https://www.evz.de/en/shopping-internet/cash-payment-limitations.html

[10] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13429-Clarifying-the-legal-tender-status-of-euro-banknotes-and-coins_en

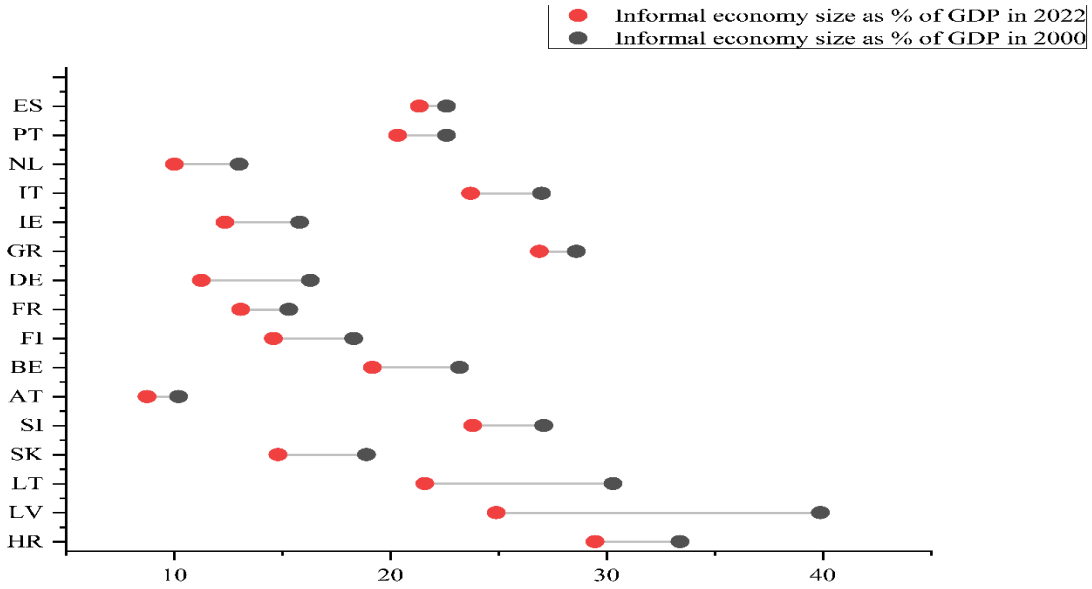


Figure 48. The size of the informal economy, 2000 vs. 2022[11]

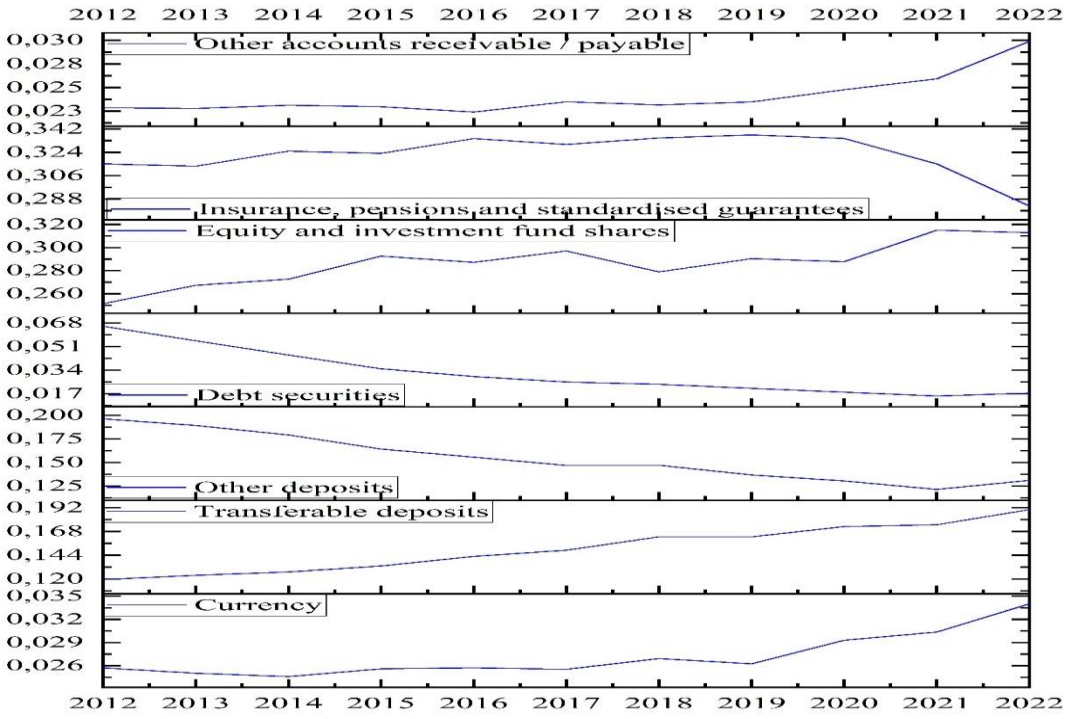


Figure 49. The evolution of weights of the main households' financial assets in total

[11] https://www.researchgate.net/publication/253147023_Size_and_Measurement_of_the_Informal_Economy_in_110_Countries_Around_the_World

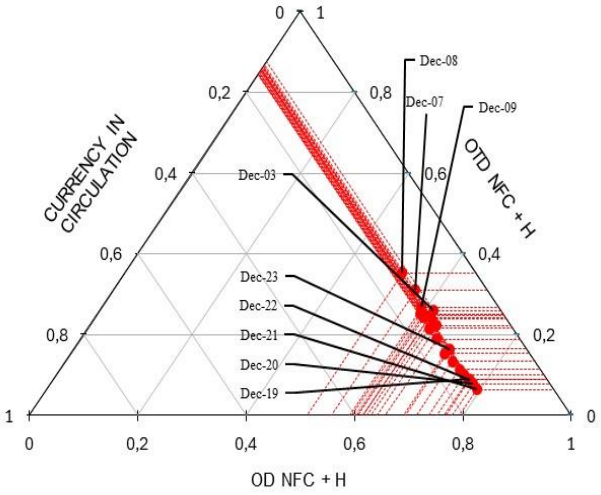


Figure 50. Ternary chart of currency in circulation, on-term deposits (non-financial companies plus households), and overnight deposits (non-financial companies plus households)

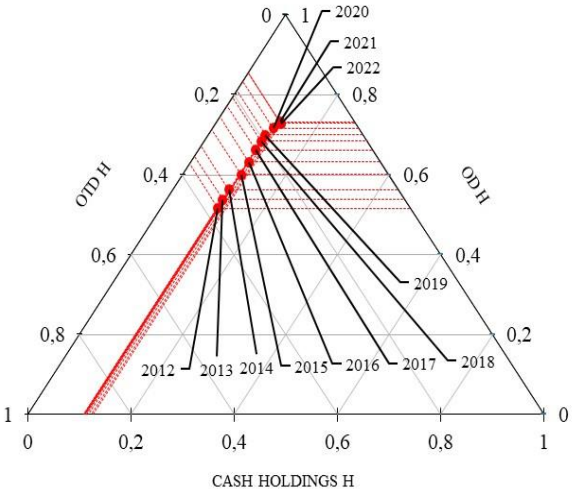


Figure 51. Ternary chart of households' cash reserves, households' on-term deposits, and households' overnight deposits

7.3. A two or three players game?

The next step in this section's analysis was to test the hypothesis that consumers in the euro area did not reduce their cash reserves to create term deposits in the context of a high-interest-rate environment or to fund current accounts to support the exponential growth in the number of digital payments and transfers. However, funding current accounts or creating term deposits was a two-way interplay between these elements, except for situations unrelated to reducing cash reserves.

My research, spanning over 20 years of monthly series of term and overnight deposits, has led to significant findings. I calculated the monthly variations, resulting in two distributions with over 250 data pairs. By creating a scatter plot and an ellipse to encompass the respective pairs (with a Fisher confidence interval of 97%), I identified a series of pairs placed outside the ellipse. These pairs correspond to June 2005 and the beginnings/ends of years during the 2005–2009 period. According to Grimaldi (2010), during this period, financial stress in the euro area was detected at a level higher than the long-term average, which generated atypical (dis)saving behaviour from euro-area consumers. These findings are backed by the increased volatility of the on-term deposits in the period 2005-2009 (Figure 73), and are crucial in understanding euro-area consumers' financial behaviour and highlighting the importance of my research.

The next step was to exclude these outlier pairs and treat these series of pairs as two simple distributions, not as time series, due to breaks in them. Table 10 and Figure 52 show that between the monthly variations of term deposits and the monthly variations of overnight deposits, a second-order polynomial relationship is created (the best fit without risking to overfit; the scatterplot of residuals and predicted values does not follow any pattern/trendline) with an adjusted R squared of 0.73. A quadratic relationship between an independent variable, *x*, and a dependent variable, *y*, implies that the relationship can be described by a quadratic function, which includes a squared term. This results in a parabolic curve when plotted, indicating that the rate of change of *y* with respect to *x* is not constant but varies in a quadratic manner. The value of R squared adjusted signifies that the variation in overnight deposits explains 73% of the variation in term deposits. The fact that the adjusted R squared adjusted is not higher does not necessarily mean that people used part of their cash reserves to fund current accounts or to constitute term deposits. Given the points mentioned above regarding cash reserves, several explanations for the adjusted R-squared level may include the following: i) high cross-correlation after 2009 (albeit on a decreasing path), even when comparing *od(t)* with *odt(t)*, *odt(t-1)...odt(-12)*, and *odt(t+1)*, *odt(t+2)...odt(t+12)*, and vice versa, where $t = 0$; ii) excess amounts generated by income growth above the long-term average are not automatically converted into term deposits; iii) liquidation of term deposits and direct transformation into cash without passing through current accounts; and iv) the influence of other several exogenous factors such as sale or realization of fixed (real estate) or financial (private pensions, insurance, equities and shares, and debt securities) assets and their direct conversion into term or overnight deposits. Most of these operations largely depend on the phases of the economic and financial cycles.

	p-value	R^2 adj.	MSE	RMSE	AIC	AICC
Quadratic equation (second order)	<0,0001	0,73	0,000	0,005	-2528	-2528

otd mom change = 0,009086 - 2,216 * *od mom change* + 65,32 * *od mom change*^2

Table 10. Robustness indicators of the quadratic equation where monthly changes in households' on-term deposits are the endogenous variable and monthly changes in households' overnight deposits are the endogenous variable

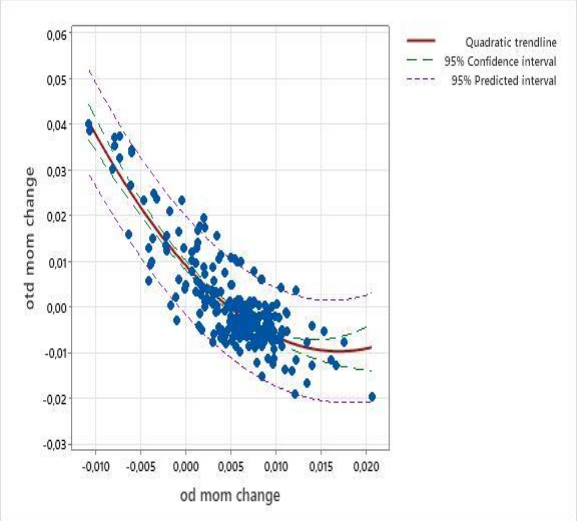


Figure 52. Visualizing the quadratic equation specified in Table 10

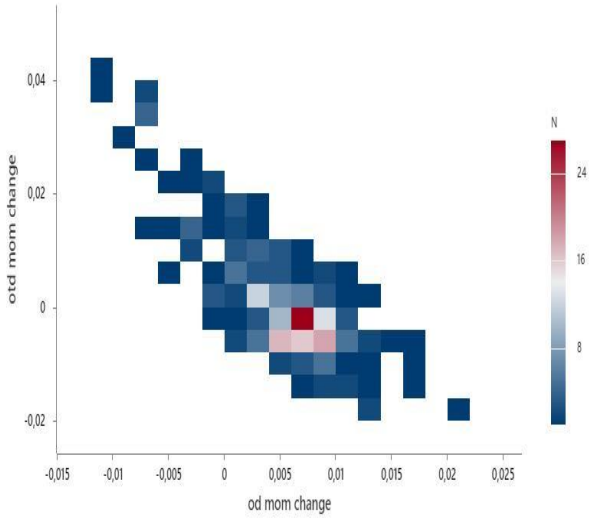


Figure 53. Binned scatterplot for od MoM changes vs. otd MoM changes

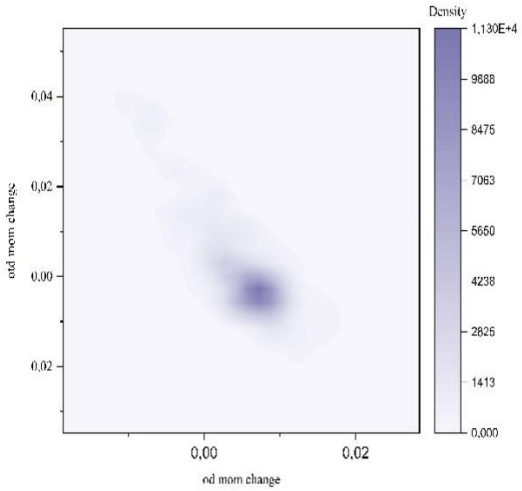


Figure 54. 2D Kernel density for od MoM changes vs. otd MoM changes

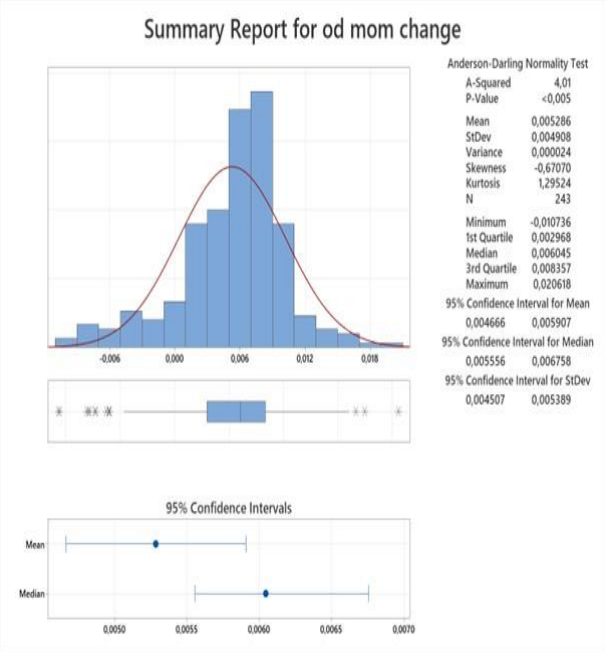


Figure 55. Summary statistics and histogram for overnight deposits Distribution of MoM changes

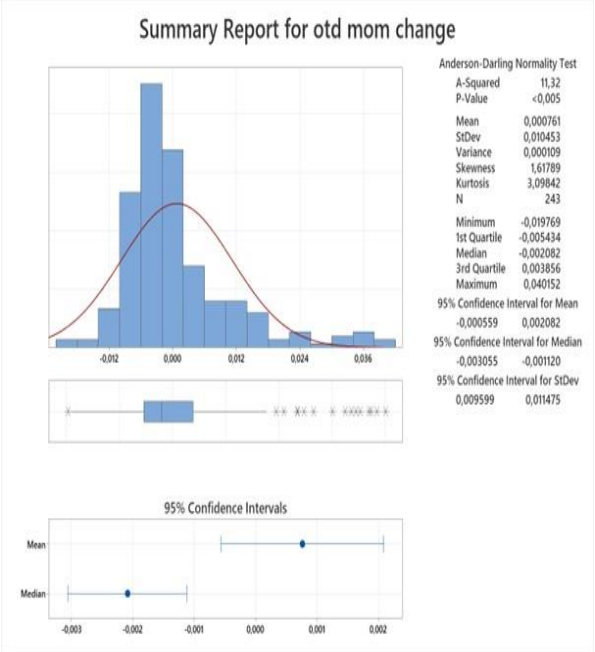


Figure 56. Summary statistics and histogram for on-term deposits Distribution of MoM changes

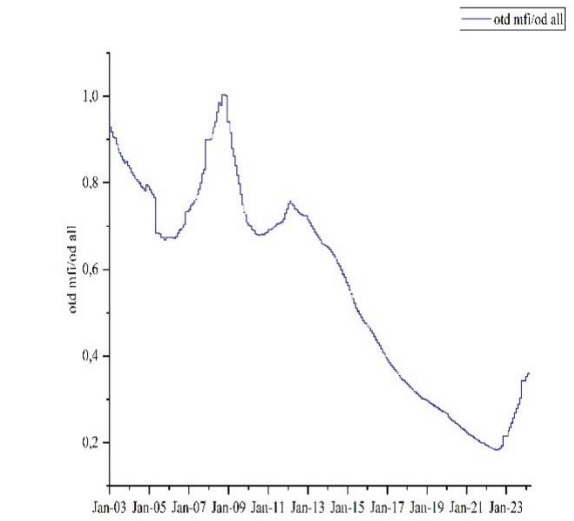


Figure 57. On-term deposits/Overnight deposits ratio

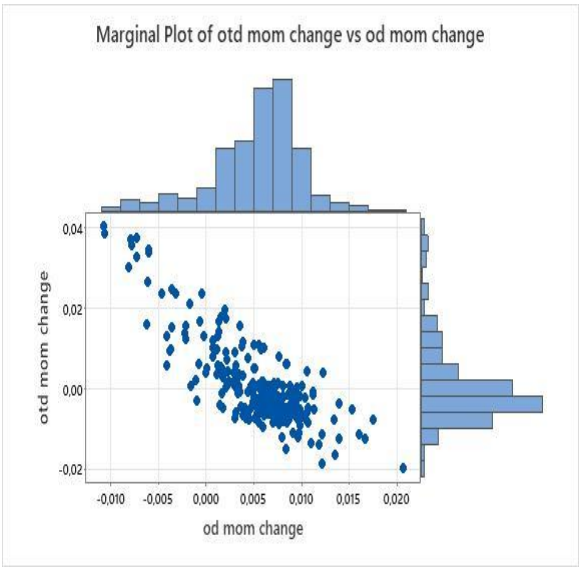


Figure 58. Scatterplot for overnight deposits; MoM changes versus on-term deposits; MoM changes plus marginal histograms

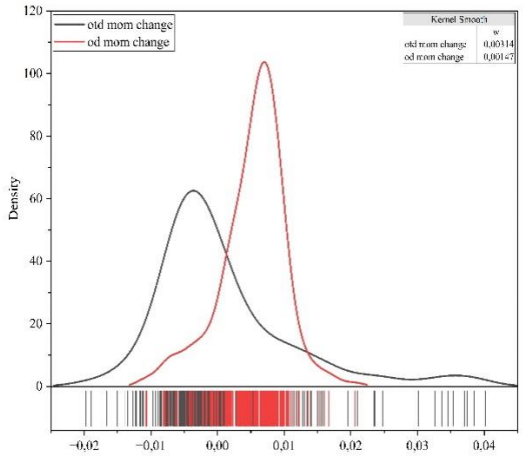


Figure 59. Distributions plus rugged chart

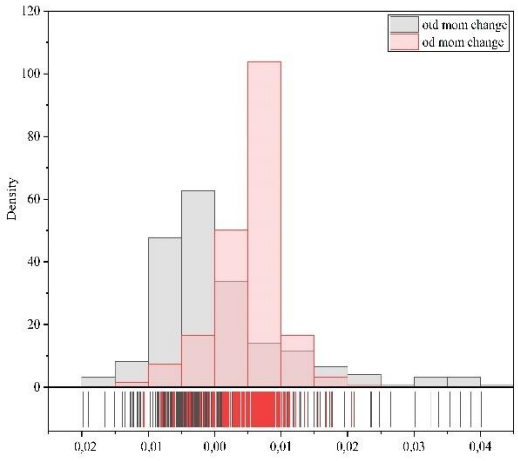


Figure 60. Overlapping histograms plus rugged chart

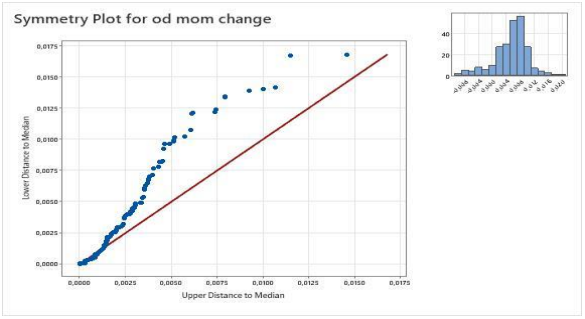


Figure 61. Symmetry plot for overnight deposits; MoM changes

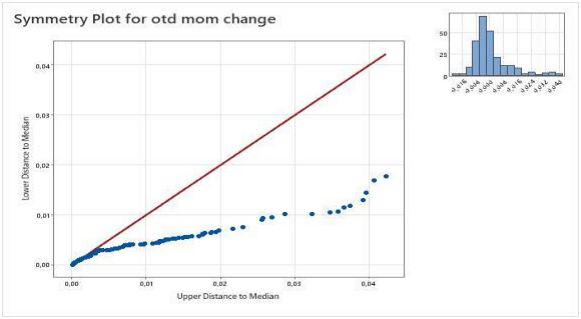


Figure 62. Symmetry plot for on-term deposits; MoM changes

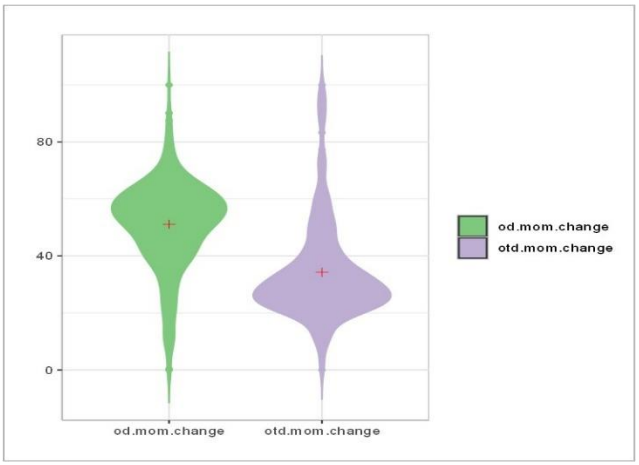


Figure 63. Violin plots for overnight deposits and on-term deposits; MoM changes

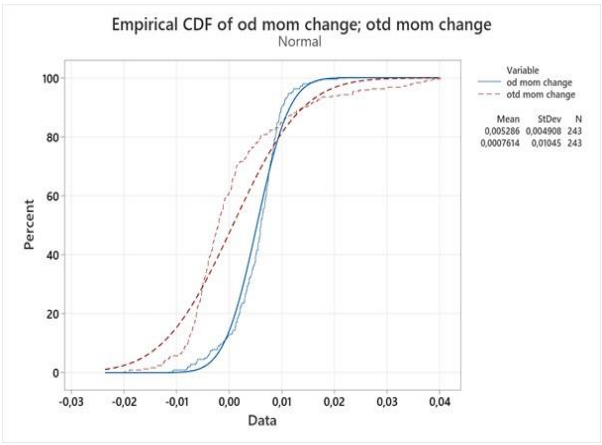


Figure 64. Empirical CDF of overnight deposits and on-term deposits; MoM changes

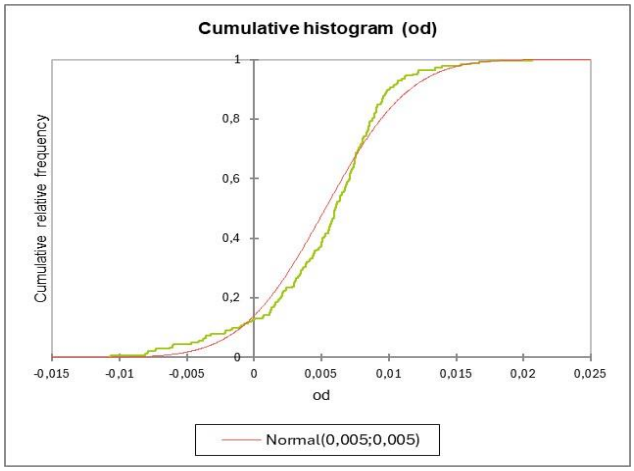


Figure 65. Cumulative histogram of overnight deposits; distribution of MoM changes

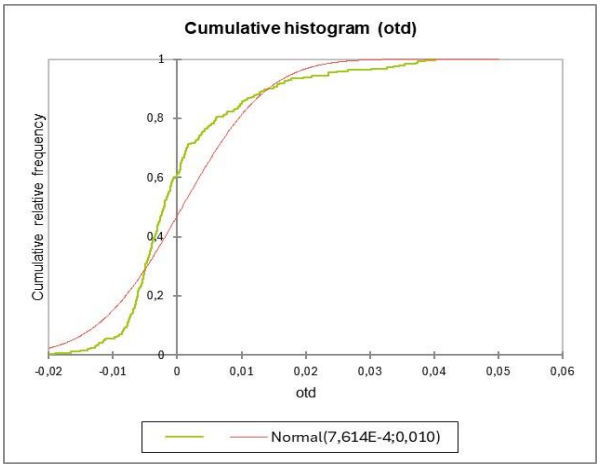


Figure 66. Cumulative histogram of on-term deposits; distribution of MoM changes

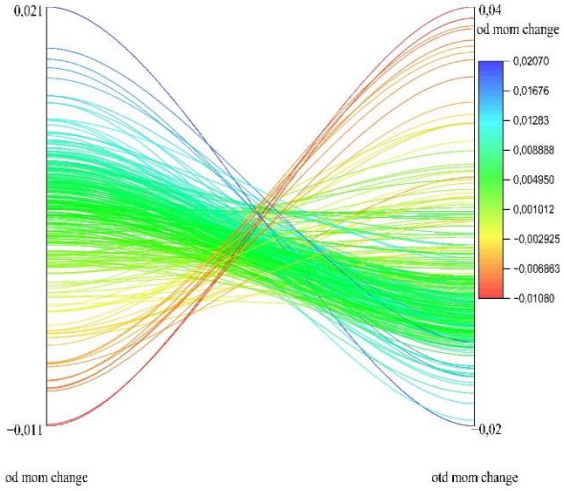


Figure 67. Parallel plot where the color is set after overnight deposits; value of MoM changes

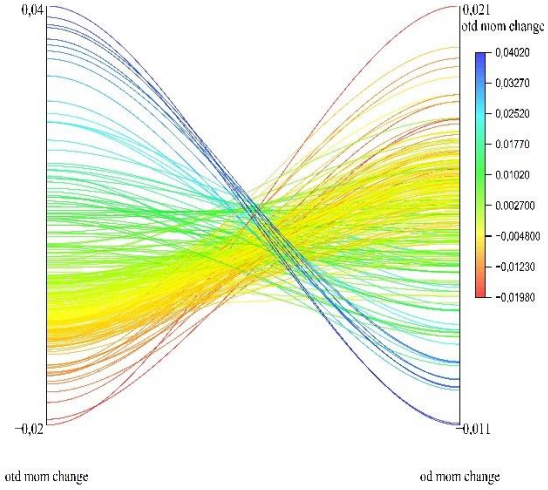


Figure 68. Parallel plot where the color is set after on-term deposits; value of MoM changes

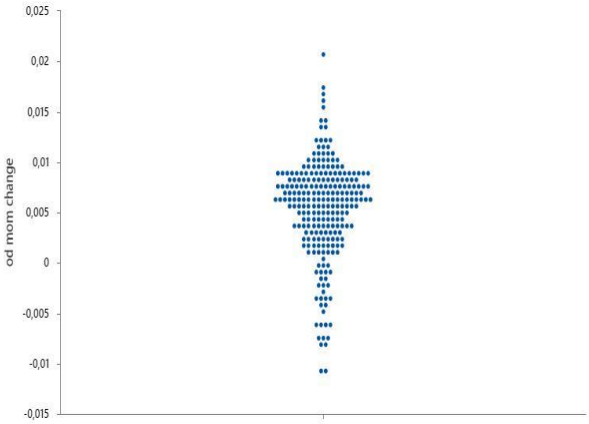


Figure 69. Individual values plot for overnight deposits; MoM changes

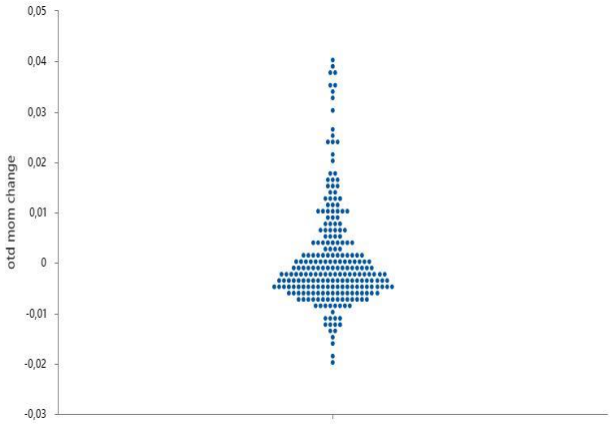
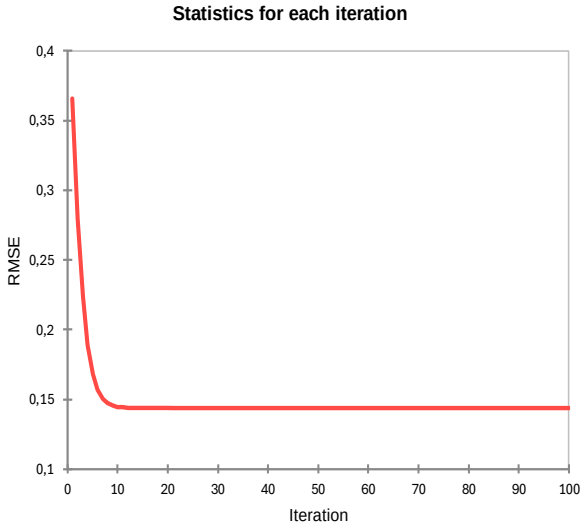


Figure 70. Individual values plot for on-term deposits; MoM changes



Any variable is important enough to predict the response variable

Figure 71. Prediction power of overnight deposits; MoM changes for on-term deposits; MoM changes (an Extreme Gradient Boosting exercise)

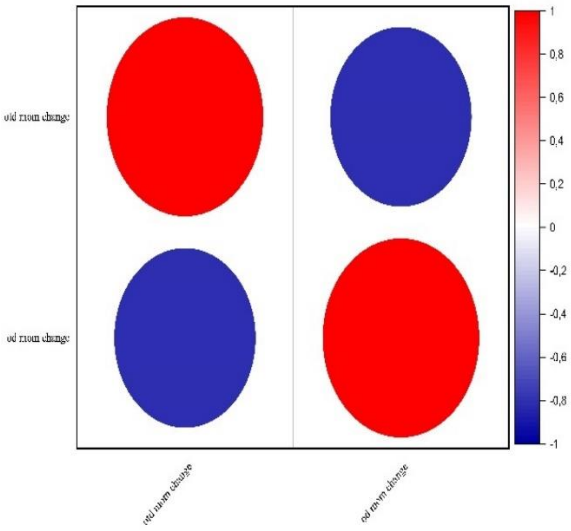


Figure 72. Pearson's correlation between on-term deposits MoM changes and overnight deposits MoM changes

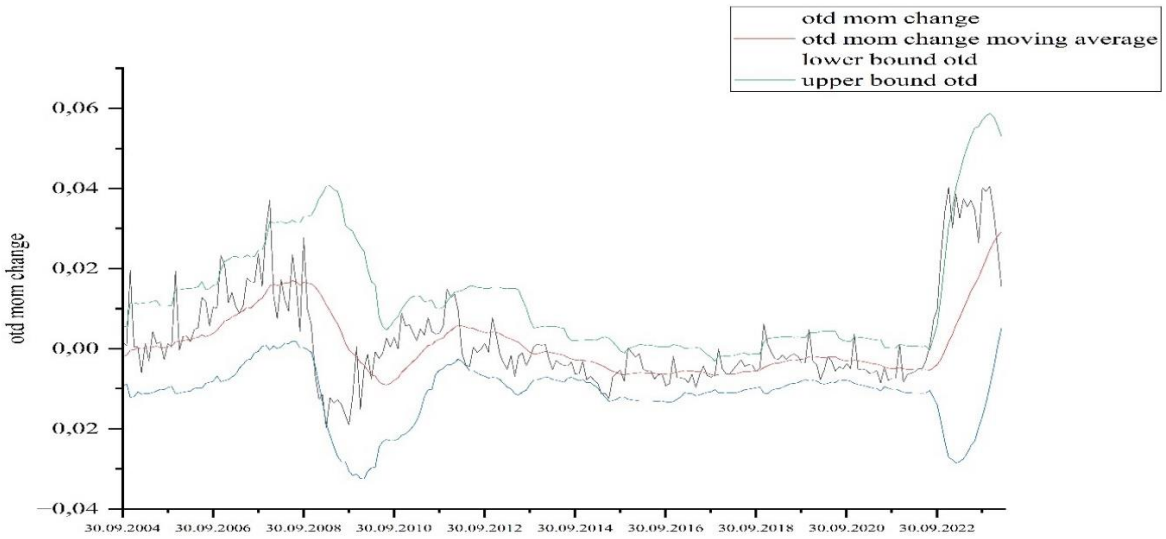


Figure 73. Bollinger bands plot for on-term deposits monthly changes

Considering the ratio from Figure 57 and Figures 55–56, 58–66, 69–70, and 72, it is obvious that the distributions of monthly changes in overnight deposits and on-term deposits are mirrored and highly negatively correlated. Additionally, Figures 53–54 and 67–68 exhibit a high concentration of instances where funds are, in several cases, shifting from on-term to overnight deposits.

Figures 53–70 and 72 statistically support the previously stated hypothesis that the variations in the two elements (term and overnight deposits) strongly and negatively influence each other. Moreover, Figure 71 shows that by using variations in overnight deposits as an explanatory variable in an Extreme Gradient Boosting (EGB) model, we can predict the evolution of monthly variations in term deposits. All this evidence leaves no room for other interpretation than the aforementioned ones. It is evident that despite the digital financial revolution, periods characterised by high interest rates and inflation (where the appetite for holding significant cash reserves is higher

than the need to counter inflation), geopolitical events (where, due to geopolitical risks and the potential for their expansion within the euro area, people may prefer to maintain substantial cash reserves to support high mobility), high consumerism, and changes in the propensity to save, people not only did not reduce their cash reserves, they even increased them. Most likely, in people's perception, the main difference between the retail digital euro and private digital means of transfer or payment is and will be, from the consumer's perspective, that the former is the central bank's liability, and the introduction of the digital euro will not lead to the households' cash reserves reduction. Meanwhile, the money for transactions in the latter category (private money) is a liability of private financial institutions. Digital money already exists. The main novelty lies in the fact that a new provider is now entering the market. For these reasons above, I suppose that, despite the advantages of the digital euro in meeting essential consumer criteria—high privacy standards, the ability to make payments throughout the euro area, and instant payments and transfers—most probably, we would not be witnessing an immediate significant downward change in people's propensity to hold cash reserves. Moreover, the scenario in which people would reduce the number and amount of cash withdrawals from ATMs is unlikely, given the low elasticity of cash in circulation in the euro area during the analysed period. However, with its clear benefits over commercial payment and money transfer solutions, the digital euro holds a promising future. Its adoption is expected to be 'heterogeneous and sparse' across euro-area countries, meaning that it will not be uniformly or densely adopted, but rather in a varied and scattered manner. Nonetheless, it is a step toward increasing digital financial inclusion.

7.4. Theoretical considerations on cash reserves, overnight deposits and on-term deposits

7.4.1. Is there any chance for the cash reserves to decrease in the short and medium term?

There is a chance that the weight of cash reserves in households' total financial assets in the euro area will decrease. This could occur due to several potential developments:

A. *Rising Interest Rates* - If the European Central Bank (ECB) increases interest rates, savings account returns, and low-risk investments will improve. This could incentivize households to shift some of their cash reserves into interest-bearing accounts or other financial instruments, reducing the proportion of cash in their total assets.

B. *Economic Stability and Growth* - As economic conditions stabilize and grow more favourable, households might feel more confident in investing in higher-risk assets such as stocks, bonds, or real estate, which typically offer higher returns compared to cash. This would reduce the relative weight of cash in their financial portfolios.

C. *Inflationary Pressures* - In a scenario where inflation rises significantly, households might reduce their cash holdings to avoid the erosion of purchasing power. Instead, they might invest in assets protecting against inflation, such as commodities or inflation-linked bonds.

D. *Improved Financial Literacy and Investment Options* - As financial literacy improves and more investment options become accessible to households, individuals might diversify their portfolios beyond cash. Enhanced access to financial markets through digital platforms and lower costs for investment products can also encourage this shift.

E. *Policy Incentives* - Governments and financial institutions might introduce policies or incentives to encourage households to invest their cash reserves. For example, tax benefits for investing in retirement accounts or other long-term savings instruments can make these options more attractive.

F. *Technological Advancements* - Advances in financial technology (fintech) can make it easier for households to manage their finances and invest in a broader range of assets. Automation and robo-advisors can provide tailored investment advice, reducing the reliance on cash holdings.

G. *Reduction in Economic Uncertainty* - As uncertainties related to global events (e.g., geopolitical tensions, pandemics) decrease, households may feel less need to hold large cash reserves as a precautionary measure and may instead seek higher returns through investments.

While these factors could decrease the weight of cash reserves in household financial assets, the actual impact will depend on the interplay of these elements and the broader economic and financial environment. One serious issue is that all these factors are not directly linked to a particular type of event such as issuing the digital euro. A dilemma for the policymakers is that keeping low nominal interest rates would boost credit activity and consequently the economic growth, but low interest rates would favour increasing cash reserves (Shirai and Sugandi, 2019).

7.4.2. What exactly determines the swings of households' overnight and on-term deposits in the euro area?

The swings in households' overnight deposits and term deposits in the euro area are influenced by several key factors.

A. *Interest Rate Environment*

Overnight Deposits: Typically, these deposits have very low or no interest rates. When central banks, like the European Central Bank (ECB), set low or negative interest rates, households might prefer to keep funds in more accessible overnight deposits rather than committing to longer-term deposits with similarly low returns.

Term Deposits: Higher interest rates can make term deposits more attractive. When the ECB raises interest rates, banks usually offer higher rates on term deposits to attract funds.

B. *Economic Uncertainty and Confidence*

Overnight Deposits: In times of economic uncertainty, households might prefer the liquidity and safety of overnight deposits. Economic crises, political instability, or health emergencies like the COVID-19 pandemic can lead to increased holdings in overnight deposits.

Term Deposits: During periods of robust economic stability and confidence, households may be more willing to lock their money in term deposits for higher returns, reducing their overnight deposits.

C. *Inflation Expectations*

Overnight Deposits: In low inflation or deflationary environments, households may keep more funds in overnight deposits, expecting that prices will not rise quickly. High inflation, conversely, might lead to less cash being kept in overnight deposits as households seek assets that better preserve purchasing power.

Term Deposits: If households expect higher inflation, they might be less inclined to use term deposits unless these deposits offer interest rates that outpace inflation.

D. *Financial Market Performance*

Overnight Deposits: Poor performance in financial markets can lead households to move their money to safer overnight deposits.

Term Deposits: Conversely, a strong performance in stocks or bonds might reduce overnight and term deposits as households seek higher returns in these markets, reflecting the influence of market dynamics on deposit behaviour.

E. *Availability and Access to Credit*

Overnight Deposits: Easier access to credit might reduce the need for large overnight deposits as a liquidity buffer.

Term Deposits: Tight credit conditions might make households more cautious, increasing their liquidity preference and reducing term deposits.

F. *Changes in Household Income and Spending*

Overnight Deposits: Fluctuations in household income, such as bonuses or seasonal earnings, can temporarily boost overnight deposits. Similarly, periods of high spending, like holidays, can reduce these deposits.

Term Deposits: Consistently higher income might allow households to set aside more money in term deposits.

G. *Policy and Regulatory Changes*

Changes in banking regulations, deposit insurance limits, and tax treatment of interest earnings can also influence household preferences between overnight and term deposits.

H. *Technological Advancements*

Digital banking and fintech innovations are reshaping the financial landscape, making it easier for households to manage their funds and potentially shifting preferences between overnight and term deposits based on ease of access and management.

I. *Behavioural Factors*

Personal preferences, risk tolerance, and financial literacy influence whether households prefer the safety and liquidity of overnight deposits or the higher returns (with reduced liquidity) of term deposits.

These factors interact in complex ways, leading to the observed fluctuations in households' overnight and term deposits in the euro area.

Households' choices between overnight and term deposits in the euro area are multifaceted, influenced by a complex interplay of economic conditions, interest rates, inflation expectations, financial market performance, income stability, credit availability, regulatory changes, technological advancements, and behavioural factors. Each of these factors can shift household preferences, leading to fluctuations in the balances of overnight and term deposits.

7.4.3. Which sources fuel households' overnight and on-term deposits in the euro area?

The money that fuels households' overnight and term deposits in the euro area primarily comes from various sources of household income and financial activities. These sources include:

A. *Wages and Salaries*

Overnight deposits: For instance, regular pay checks are often initially deposited into checking or current accounts, which are types of overnight deposits that offer immediate access to funds for daily expenses and short-term savings. Similarly, term deposits, which are often used for long-term savings, include accounts like fixed deposits or time deposits.

These accounts offer immediate access to funds for daily expenses and short-term savings, providing you with the flexibility to manage your finances effectively.

Term Deposits: Excess income from wages and salaries not needed for immediate expenses may be moved into term deposits, offering the potential for higher interest and returns on idle money.

B. *Self-Employment and Business Income*

Overnight deposits: Income from self-employment or small businesses is usually deposited into accessible accounts for ease of use and liquidity, which refers to the ease with which an asset can be converted into cash without affecting its market price. This ensures that funds are readily available for business operations or personal use.

Term Deposits: Surplus business profits can be placed into term deposits to earn returns on idle funds.

C. *Investment Income*

Overnight Deposits: Dividends, interest from bonds, and other investment returns may be temporarily held in overnight deposits before being reinvested or used for expenses.

Term Deposits: Part of the investment income may be allocated to term deposits for secure, interest-earning storage.

D. *Rental and Property Income*

Overnight Deposits: Rental income from properties is often initially deposited into accessible accounts for easy management and payment of property-related expenses.

Term Deposits: Excess rental income that is not needed immediately can be moved into term deposits for better interest rates.

E. *Government Transfers and Benefits*

Overnight Deposits: Payments from government programs, such as pensions, unemployment benefits, and social security, are typically deposited into checking or savings accounts.

Term Deposits: Any portion of these funds not required for immediate use can be placed into term deposits to generate interest.

F. *Savings and Inheritances*

Overnight Deposits: Inheritances or accumulated savings may initially be placed in overnight deposits for liquidity.

Term Deposits: Larger sums from inheritances or long-term savings are often moved to term deposits for higher returns over a fixed period.

G. *Sale of Assets*

Overnight Deposits: Proceeds from selling assets, such as real estate, vehicles, or securities, may be temporarily held in overnight deposits.

Term Deposits: If the funds from asset sales are not needed immediately, they may be shifted to term deposits for better yields.

H. *Loans and Credit*

Overnight Deposits: Funds borrowed through personal loans, home equity loans, or lines of credit can temporarily boost overnight deposits before being used for their intended purposes.

Term Deposits: While less common, some households may place borrowed funds in term deposits to arbitrage interest rates if the cost of borrowing is lower than the interest earned on the deposit.

Various income sources fuel households' overnight and term deposits in the euro area, including wages, business income, investment returns, rental income, government benefits, savings, inheritances, and asset sales. These funds are initially deposited into easily accessible overnight accounts for liquidity and day-to-day use. Surplus

funds, not needed immediately, are often transferred into term deposits to take advantage of higher interest rates and to earn returns on idle money.

7.4.4. Will the digital euro (replace cash) issuance lead to reducing the cash reserves?

The issuance of a digital euro has the potential to reduce the cash reserves held by households, but the extent of this impact will depend on several factors:

A. *Convenience and Accessibility* - If the digital euro is designed to be highly convenient and accessible, it could encourage households to shift from holding physical cash to digital currency. The ease of use, security, and integration with existing financial systems would be crucial in this transition.
B. *Trust and Adoption*: The level of trust households have in the digital euro will significantly influence its adoption. Effective communication and demonstration of the security and reliability of the digital euro by the European Central Bank (ECB) and other authorities can boost confidence and encourage its use over physical cash.
C. *Incentives and Benefits*: If the ECB or governments provide incentives for using the digital euro, such as lower transaction fees, rewards programs, or better integration with financial services, households might be more inclined to reduce their cash holdings in favour of the digital currency.
D. *Economic Behaviour and Preferences*: Households' behaviour and preferences regarding savings and spending will influence the impact of the digital euro. Those who prefer the tangible nature of cash or are concerned about privacy might be slower to adopt the digital euro, while tech-savvy individuals may embrace it more quickly.
E. *Monetary Policy and Interest Rates*: The introduction of the digital euro might be accompanied by changes in monetary policy or interest rates that could affect the attractiveness of holding cash versus digital currency. For example, if the digital euro offers interest or other benefits that physical cash does not, it could encourage households to transition to the digital format.
F. *Regulatory Framework*: The regulatory environment surrounding the digital euro will also play a role. Clear regulations ensuring digital euro transactions' safety, security, and privacy will be critical in gaining public trust and encouraging its use.
G. *Integration with Payment Systems*: Seamless integration of the digital euro with existing payment systems and platforms will be essential for widespread adoption. If the digital euro can be easily used for everyday transactions, online purchases, and transfers, it will be more attractive to households.

However, these factors would have a significant effect only after a period of observation of the digital euro (once issued) by households. Consequently, these factors will be observed in the aftermath of the issuance before adopting the retail digital euro.

7.5. What are the main conclusions of this section?

Section 7 highlights two key points: i) Between on-term deposits and overnight deposits, the latter is more likely to migrate to digital euro holdings. ii) Cash reserves are likely to be transformed into digital euro holdings only to a very small extent. Therefore, considering that no type of event or phenomenon (economic, political, or financial) has been sufficiently disruptive for the population’s cash reserves, the most likely ratio of cash reserves to deposits as sources of funding for digital-euro holdings will tend more toward 10:90 in the aftermath of the digital euro issuance.

8. Facts and shorts

8.1. Bank run and flight to safety

Goedde-Menke et al. (2014) document that a financial crisis triggers a bank run, and the risk of this phenomenon is higher immediately following a financial crisis than during it. The existence of a CBDC exacerbates bank panic; however, the optimal option is to coexist with these panics because the cost of eliminating them would be higher (Williamson, 2022). An analysis of the banking crisis in the US in the spring of 2023 and other financial crises concluded that during a period of stress in the banking sector, there was a re-allocation of deposits by households to placements in institutions considered more robust or to cash (Caglio et al., 2023; Gerritsen et al., 2017; Sandri et al., 2023). This means that individuals’ savings are highly likely to migrate to digital-currency holdings during a financial crisis or in its aftermath. The herding effect is significant during bank panic, as depositors tend to withdraw their savings from a bank when they observe other individuals' similar movements (Kiss, 2018); a more

pronounced exacerbation effect occurs in the case of uninsured deposits, particularly against the backdrop of the contemporary wider spread of negative news through online social-networking platforms (Cookson et al., 2023).

8.2. Various correlations

Correlation does not imply causality. However, a series of associations was visible among some of the indicators used to calculate the CAES composite index, MinMax, and the population weights from the Eurobarometer related to the three financial-literacy scores (Low FinLit, Medium FinLit, and High FinLit, Table 11).
To adopt the digital euro, a risk-free and non-remunerative asset, Europeans must have a low risk tolerance to avoid allocating their financial resources to riskier assets with high associated returns but extremely volatile (such as crypto-assets). It has been documented that, regardless of academic profile, the higher the level of financial education, the greater the risk tolerance. Moreover, individuals relying more on intuition than financial knowledge tend to take higher risks (Gustafsson and Omark, 2015). Molina-García et al. (2023) demonstrate that financial literacy positively determines the risks that individuals take. Both financial education and financial-asset returns are associated with a higher level of risk tolerance, with the latter having a more significant impact (Hermansson and Jonsson, 2021). A strong negative relationship was identified between per-capita income and risk tolerance (Vieider et al., 2012). This latter statement is supported by Vieider (2019), who showed that risk tolerance was higher in Eastern and less economically developed countries than in Western countries. However, the appetite for riskier investments is characterized by individuals with less sophisticated financial knowledge (Panos et al., 2020). Prete (2022) demonstrates that increasing financial literacy and enhancing digital skills must be implemented in tandem to improve individuals' access to and use of digital-payment tools.

Variables	PRT2	ENIDE	IEWE	NIPPS	FAPCO15	MEDIUM FINLIT	CPIX	MINMAX	HIGH FINLIT	LOW FINLIT	CARIX3T	LIX	FDM	PSEES
PRT2	**1**	-0,399	0,326	-0,072	-0,100	0,240	**0,648**	**-0,598**	-0,386	0,380	-0,332	-0,388	-0,021	-0,086
ENIDE	-0,399	**1**	**-0,606**	**0,558**	**0,637**	**-0,655**	**-0,630**	**0,501**	0,459	-0,136	0,458	0,329	-0,293	-0,155
IEWE	0,326	**-0,606**	**1**	**-0,753**	**-0,701**	**0,587**	**0,669**	**-0,608**	**-0,496**	0,237	**-0,595**	**-0,650**	0,378	0,389
NIPPS	-0,072	**0,558**	**-0,753**	**1**	**0,813**	**-0,668**	**-0,537**	**0,572**	**0,515**	-0,219	**0,493**	**0,602**	**-0,550**	**-0,583**
FAPCO15	-0,100	**0,637**	**-0,701**	**0,813**	**1**	**-0,807**	**-0,599**	**0,577**	**0,472**	-0,028	**0,510**	0,427	-0,379	-0,399
MEDIUM FINLIT	0,240	**-0,655**	**0,587**	**-0,668**	**-0,807**	**1**	**0,745**	**-0,678**	**-0,782**	0,344	**-0,475**	-0,391	0,363	0,458
CPIX	**0,648**	**-0,630**	**0,669**	**-0,537**	**-0,599**	**0,745**	**1**	**-0,901**	**-0,811**	**0,597**	**-0,707**	**-0,602**	0,398	0,381
MINMAX	**-0,598**	**0,501**	**-0,608**	**0,572**	**0,577**	**-0,678**	**-0,901**	**1**	**0,772**	**-0,616**	**0,790**	**0,781**	**-0,613**	-0,315
HIGH FINLIT	-0,386	0,459	**-0,496**	**0,515**	**0,472**	**-0,782**	**-0,811**	**0,772**	**1**	**-0,852**	**0,676**	**0,563**	-0,457	**-0,634**
LOW FINLIT	0,380	-0,136	0,237	-0,219	-0,028	0,344	**0,597**	**-0,616**	**-0,852**	**1**	**-0,623**	**-0,539**	0,424	**0,551**
CARIX3T	-0,332	0,458	**-0,595**	**0,493**	**0,510**	**-0,475**	**-0,707**	**0,790**	**0,676**	**-0,623**	**1**	**0,643**	**-0,642**	**-0,474**
LIX	-0,388	0,329	**-0,650**	**0,602**	0,427	-0,391	**-0,602**	**0,781**	**0,563**	**-0,539**	**0,643**	**1**	**-0,685**	-0,348
FDM	-0,021	-0,293	0,378	**-0,550**	-0,379	0,363	0,398	**-0,613**	-0,457	0,424	**-0,642**	**-0,685**	**1**	0,267
PSEES	-0,086	-0,155	0,389	**-0,583**	-0,399	0,458	0,381	-0,315	**-0,634**	**0,551**	**-0,474**	-0,348	0,267	**1**

Values in bold are different from 0 at a significance level of alpha = 0.05

Table 11. Correlation matrix (Pearson, 14 selected variables, without SK)

A strong negative correlation exists between the MinMax and average financial-literacy scores. Furthermore, the proportion of individuals with an average financial-literacy score is strongly associated with a high propensity for cash. Meanwhile, a strong positive correlation was found between MinMax and high financial literacy. Moreover, the higher the level of financial assets per capita, the more significant the proportion of individuals expressing a negative opinion of th**e** digital euro. High financial capacity to cope with adverse financial events and high levels of digital financial inclusion plus elevated levels of digital skills (CARIX3T) are associated with a high proportion of individuals with high financial literacy and high MinMax levels. The fintech sector is more developed in countries with higher CARIX3T indices. In addition, the degree of libertarianism is positively correlated with a high CARIX3T level. It should be noted that the higher the degree of libertarianism in a country, the lower the level of adoption of the digital euro if individuals are not convinced that the digital euro respects a set of high-privacy principles. A low risk-tolerance level is associated with a high propensity for cash, meaning that a share of the people who could and would adopt the digital euro could be represented by individuals who held more of their money in cash than in a commercial bank if they trusted the central bank.

8.3. A particular type of potential holder (F12)

A particular situation relates to low-income individuals with digital skills and a favourable attitude toward modern transfers and payments. According to the Venn diagram in Figure 1, these individuals do not fit a digital-euro

holder's profile. There is a moderate to high negative correlation between the propensity to hold and use cash, on the one hand, and the average per-capita income and level of per-capita financial assets, on the other hand. Suppose we recalculate MinMax (as MinMax2), excluding the indicator referring to the capacity to cope with adverse financial events (IND10ES) and keeping only those referring to digital financial inclusion and digital skills. In this case, we obtain a result that is higher by only 1.23 percentage points than that of MinMax. In conclusion, Max(F12) will equal MinMax2 minus MinMax. This minimal difference between MinMax and MinMax2 suggests that predominantly digital financially included and digitally skilled individuals are not in a state of financial deprivation (furthermore, structural indicators from World Bank (FINDEX) and Eurostat indicate that financially deprived individuals are less digitally skilled and do not use digital finance as much as those with above-average income). However, this statement is only valid in the case of the maximum intersection of indicators, where the set with the smallest size is exhaustively present in all other sets. I consider that the number of individuals from the categories that fit the profile of the holder but who, for various reasons (mentioned above), would not adopt the digital euro, multiplied by € 3000, could easily surpass the number of individuals of this particular type plus all the unbanked individuals multiplied by significantly lower amounts than € 3000. Below, I plotted (Figure 74) all the ins and outs of individuals' categories (numbered F1 to F13 across the study).

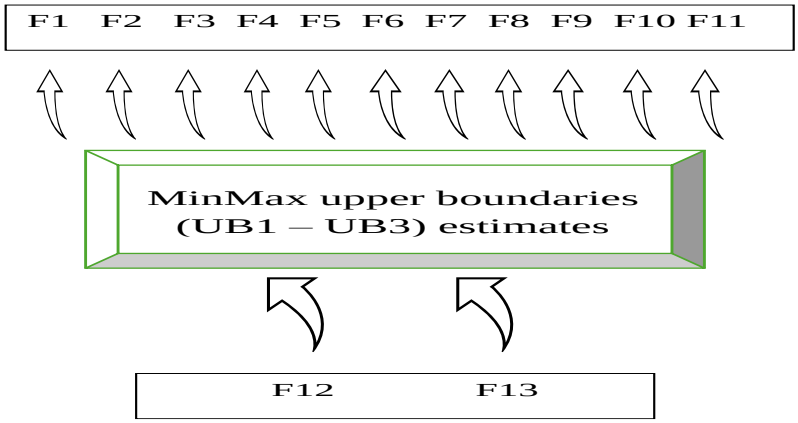


Figure 74. Ins and outs of individuals' categories and factors modifying the MinMax result (numbering across the study).

8.4. Financial decision-making

As Figure 75 shows, people who advise individuals on their financial decisions play an important role. If these advisors favour the digital euro, the likelihood of a higher adoption rate increases. Incentivizing banks to participate in the digital-euro ecosystem might be a good solution for attracting as many consumers as possible.

	A recommendation of bank staff or other financial advisors	Specialist product comparisons or best-buy guidance	A recommendation from friends, family, or acquaintances	Information from an advert or brochure about a specific financial product	Social media and influencers	Other	Don't know
AT	51	34	32	14	6	9	7
BE	51	27	29	10	3	9	12
CY	17	40	34	24	8	12	3
DE	42	37	34	19	6	14	10
EE	33	44	38	15	6	9	8
ES	51	36	40	11	4	10	6
FI	36	34	32	11	9	9	14
FR	49	29	37	10	4	9	8
GR	22	52	28	18	8	9	4
HR	38	42	41	28	5	8	4
IE	37	28	44	14	5	11	7
IT	57	33	30	12	3	6	7
LT	31	36	38	11	4	14	8
LV	32	30	40	13	5	10	8
MT	36	25	31	10	8	15	4
NL	37	42	36	14	2	13	10
PT	43	41	32	13	7	8	8
SI	41	39	34	16	6	10	6
SK	43	29	30	18	6	9	6

Figure 75. Sources of information for financial decision-making

9. Discussions and concluding remarks

The adoption of the digital euro by households in the euro area could be impeded by a range of challenges, including technological barriers, security and privacy concerns, trust issues, economic factors, behavioural and cultural resistance, regulatory and legal concerns, financial inclusion issues, transition and integration challenges, and educational and awareness gaps. However, overcoming these challenges will pave the way for the potential benefits of the digital euro, instilling optimism and hope for its successful implementation and acceptance.

The results of this research suggest that in the best-case scenario with a capped digital-euro holding, the take-up in mid-2022 would not have been more than approximately 60% of the maximum amount from Adalid et al.'s (2022) working paper. The demand for the digital euro would be relatively limited if presently issued if we considered the inertia of some individual characteristics. From this perspective, I argue that the euro area's financial stability would not be compromised. Additionally, given that the loan-to-deposit (LTD) ratio in the euro area was approximately 95% as of mid-2022, the materialization of my projections would not likely lead to financial disintermediation or risky behaviour among lenders in their quest for funds to ensure that credit activity was not diminished. This indicator peaked almost 20 years ago at more than 140% (Q3 2007 before the global financial crisis (GFC)). Following these numbers, we can obtain an idea of the intensity of the impact of the full materialization of the MinMax results on financial stability. Considering that the LTD ratio as of June 2022 was approximately 95%, a rough calculation indicates that even if the 4% (maximum upper boundaries as a percentage of total bank liabilities) will be sourced from deposits, banks will have the capacity to support financial intermediation at least at the same level as before the issuance of the digital euro.

By combining my results with those obtained by Gross and Letizia (2023), I conclude that if the digital euro were non-remunerative, the lower boundary of adoption would then be 1% of the broad money (M3). The upper limit would be no more than 4% of the total deposit liabilities in the euro area (which is lower than the broad-money share). The main difference between these two methodologies is that Gross and Letizia (2023) employ a scenario in which digital-euro holdings are not capped. In the capped scenario, the lower boundary calculated by Gross and Letizia (2023) would be less than 1% of the M3.

Zamora-Pérez et al. (2022) and Schilling et al. (2024) estimate that, in pursuing at least a decent level of digital-euro adoption, the ECB faces a trilemma: there is an attempt to identify a balance in meeting the ECB's objectives; avoiding adverse economic and financial outcomes; and increasing the likelihood of adoption by the population and merchants. A high level of digital-euro adoption may prove to be a more difficult objective to achieve in countries in which the size of the informal economy is considerable (Oh and Zhang, 2022). An interest-bearing digital euro could foster the efficiency of this asset and reallocate resources from the informal to the formal economy.

The preference for using cash has slightly declined in recent years, whereas that for holding cash reserves has increased over the years. Older individuals are much more favourable to holding and using cash than younger individuals, indicating that as the population structure changes, meaning that today's young people who favour modern means of payment or transfer will become tomorrow's elderly, their appetite for cash will dramatically decrease (Khiaonarong and Humphrey, 2022). There is no panacea for reducing the population's appetite for cash. This reversal occurs over time with a generational shift. An ECB working paper (Meyer and Teppa, 2024) highlights the factors determining individuals' shifting from cash usage to modern means of payments and money transfers. The ECB could use these insights to find solutions to increase non-cash payment means usage33.

The contribution of my study to the domain is substantial and threefold: 1) By using the MinMax estimates, macro- and monetary-impact studies could be performed with a higher degree of accuracy than by assuming that all individuals could hold digital euros. Additionally, my results show that in a capped scenario and with a non-interest-bearing digital euro, no threat arises to the euro area's financial stability; moreover, the holding limit and potential remuneration could be more accurately calibrated to solve the trilemma mentioned above. 2) Section 7 clearly shows that the ratio between cash and deposits, as fuelling sources for digital-euro holdings, tends toward 10:90. 3) Correlations show which aspects and socio-economic dimensions should be addressed to increase the appetite for the digital euro.

This study does not eliminate the uncertainty regarding the adoption level of the retail digital euro. It is more like a successful attempt to diminish this uncertainty. What needs to be added to this study, from a financial-stability viewpoint, is a section estimating the impact on the euro-area's banking sector using MinMax estimates. The lack of this extra analysis is due to the unavailability of granular banking balance-sheet data for the public. Further research avenues could include calibrating the holding limit and assessing potential remuneration and the impact of a digital-euro issuance on the euro area's financial stability using MinMax results and granular banking data. Another disadvantage could be that WB and Eurostat indicators are qualitative data obtained through surveys. A

certain margin of representativity error typically alters the data resulting from the sampling process. Additionally, the results of the surveys could be negatively affected by biased answers, which are sometimes challenging to detect and avoid. Furthermore, some voluntarily unbanked individuals might join the digital-euro ecosystem if they trusted the central bank more than a commercial financial institution. The most significant weights of the total population who do not own a financial-institution account are to be found in Croatia and Portugal (approximately 8% and 7%, respectively). This figure lies between 0,05% and 5,12% for the rest of the countries. The proportion of the population that is in poverty and faces social-exclusion risk lies between 13.2% in Slovenia and 28.3% in Greece. I assume that most unbanked individuals also find themselves in a situation of financial deprivation and are less likely to adopt the digital euro. In my opinion, the rest of the individuals constitute a minority (a weight less than 50% of 0,05 and 8,2% of the total population) and would probably be the ones who were voluntarily unbanked. Nonetheless, this is the reason for which, in Table 2, I included upper boundaries that considered scenarios in which all the unbanked individuals were voluntarily unbanked (for not underestimating) and who would trust a central bank more than commercial financial institutions (F13).

Policymakers and the ECB could also consider León et al.'s (2023) five scenarios of consumers' retail digital-euro adoption.

It must be emphasized that it is essential that the surveys measuring households' willingness to adopt the digital euro provide figures significantly below the MinMax results, which quantifies the capability to adopt the digital euro. Regarding the calibration of the holding limit, finding a balance is crucial. A limit that is too low could make the digital euro less appealing to the population, while a limit that is too high could impact the euro area's financial stability. However, a well-calibrated limit could bring about positive outcomes for both financial stability and the public's well-being (Bidder et al., 2024). Bidder et al. (2024) also suggest that, in the case of Germany, the population's interest in adopting the digital euro is linked to the stress levels in the banking sector. Therefore, a balanced calibration of the holding limit is crucial. This will make the digital euro more attractive without triggering bank runs or flight-to-safety episodes.

My expertise and curriculum are predominantly focused on economic and financial domains. However, I can propose a series of solutions for calibrating the digital euro's holding limit in the euro area, with the caveat that I need to be informed if some of these solutions comply with the EU acquis. The first proposal is to decentralize and transfer the prerogatives of the ECB to the Eurosystem's central banks in terms of setting the holding limits tailored to each member state. In this case, each central bank would have the freedom to set its holding limit to make the digital euro more attractive to the population and increase the total volume of holdings, which would be beneficial and would not lead to financial disintermediation. This proposal is based on the principle that one solution does not fit all.

The second proposal is to calibrate a dynamic holding limit whose size depends on the level of stress in the banking sector. This dynamic limit would adjust according to the current financial conditions, ensuring that the digital euro remained attractive while maintaining financial stability.

Calculating 90% of the € 578 billion yields approximately € 520 billion, funds that would come from deposits. This amount is significantly lower than the approximately € 620 billion estimated by Adalid et al. (2022) and Meller et al. (2023). Considering that if € 620 billion came from deposits and this level would not be harmful to the euro area's financial stability, then, if only € 520 billion came from deposits, a simple calculus reveals that a limit of approximately € 3500 would probably be more appropriate. These results suggest that, based primarily on data published in 2022, the euro area's financial stability would not be adversely affected in the short to medium term following the issuance of the digital euro. This finding represents a significant step forward in analysing the impact on financial stability resulting from issuing a retail digital euro. All the estimates in this study will be updated in the second half of 2025 when the WB publishes its 2024 datasets. After these calculations have been recompiled, near the date of issuance of the digital euro, the potential remunerations and limits imposed on digital euro holdings can be recalibrated.

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