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Acceptance of IoT-based E-coin Track-and-trace: A Case of the Digital Euro Project in Italy

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ABSTRACT

As the world becomes increasingly digitalised, there are growing concerns about the use of big data and machine learning techniques to monitor and control citizens' spending habits. This is particularly the case regarding Central Bank Digital Currencies (CBDC), which are being trialled by an increasing number of countries. There is a perception that such currencies could violate privacy due to the centralisation of money liability. The aim of this research is to assess whether a universal e-coin level tracking service of money and public expenditures, available to everyone and inspired by Internet of Things (IoT) architectures and standards, could instil trust in institutions while increasing the acceptance of CDBCs. The research methodology comprises three key elements: (i) the conceptualisation and implementation of an IoT-based CBDC, (ii) a qualitative, technical and compliance assessment with regard to the specific reference to the Digital Euro (D€) project, and (iii) a survey we conducted among 351 respondents to ascertain the potential for CBDC acceptance within Italy. The results demonstrate that the prototype is a viable concept despite storage limitations. Furthermore, 73.83 percent of respondents who initially expressed scepticism indicated that they would be more inclined to adopt the CDBC instrument if a universal track-and-trace tool of money were made available.

Keywords: Cryptocurrency, CBDC, banking, customer acceptance, internet of things.

INTRODUCTION

Over the past decade, cryptocurrencies have emerged as a prominent financial asset, prompting the advent of numerous Central Bank Digital Currencies (CBDCs) (Reiss, 2018; Pocher & Veneris, 2022; Tronnier et al., 2023). In contrast to conventional digital currencies, a CBDC is accessible and available to retail consumers (Bilotta, 2021). Additionally, a key difference can be identified regarding liability. While commercial banks currently assume liability for the funds held in individual accounts, the central bank assumes this liability in the case of a CBDC. As Auer et al. (2023) documented, by January 2022, 68 countries had disseminated research findings on CBDCs. The authors indicated that as of July 2023, there are as many as 87 countries with CBDC projects, some of which are in an advanced stage of development, including Nigeria and Jamaica.

Although the privacy and anonymity of the user who spends a digital currency is a fundamental aspect of any CBDC, this may be compromised when investigations regarding illegal activities or crimes are launched. The use of big data and machine learning algorithms is emerging to detect fraudulent payment transactions and combat money laundering (Doerr et al., 2021). Furthermore, the employment of artificial intelligence (AI) technologies has the potential to enhance the ability to process and generate insights from vast troves of data in the banking sector (Biswas et al., 2020). The adoption of AI algorithms is quite accepted in the traditional banking industry (Choi & Huang, 2021), as they are somehow perceived as mere extensions of the customer experience (CX), such as chatbots and biometrics (Vergallo & Mainetti, 2022). However, concerns surrounding the disclosure of private spending data have led to a certain degree of reticence towards CBDCs. Indeed, recent studies have demonstrated that privacy and anonymity exert a considerable influence on the behavioural intention (BI) of CBDC users (Alaklabi & Kang, 2021; Garratt & Van Oordt, 2021; Tronnier et al., 2022; Bijlsma et al., 2021).

Both institutions and researchers strive to gain insight into the BI gap of CBDC, and new efforts are required to address such constraints. In this context, the history of the social network era provides a useful reference point. The evidence suggests that people are generally more willing to relinquish a degree of privacy in exchange for access to new and useful tools that engage them (Rubenfeld, 2008; Srivastava & Roychoudhury, 2021). It is, therefore, pertinent to enquire whether a similar phenomenon may occur regarding CBDCs. Recent studies have confirmed that perceived usefulness directly influences individuals' BIs (Liu et al., 2022). Consequently, marketing campaigns are currently being conducted globally to inform the general public about the characteristics of the new CBDC instrument and the profuse attention to privacy requirements. It is disappointing that, in many instances, central banks have been unable to effectively convey the key benefits of utilising centralised digital currencies compared to conventional payment methods.

It is recommended that they be positioned as a payment method that is more democratic, accessible, transparent and fair (readers may also recognise in these values the opposite of the foundations on which AI – particularly deep learning (DL) – is built) than the electronic money issued by private banks to facilitate the adoption of CBDCs. Institutions' efforts to propose a flexible and comprehensible currency are contingent upon their active pursuit of mutual trust and transparency, which can facilitate constructive interaction between institutions and citizens (Moyson, 2016). As the necessity for more transparent institutions becomes increasingly apparent, it is imperative to investigate the feasibility of developing an instrument of money tracking that is universally accessible to citizens and capable of reporting on the expenses of public bodies. The same principles can be observed in the field of supply chain management, where Radio-Frequency Identification (RFID) technology-based single-item traceability provides universal access to detailed track-and-trace information for goods (Ilic et al., 2009). To achieve the goals declared, this study assesses the technical feasibility of an alternative CDBC based on Internet of Things (IoT) standards and protocols. The technical process described in this study can potentially improve the acceptance of current CBDC initiatives by enhancing transparency between citizens and institutions.

This paper aims to understand to what extent the introduction of a fine-grained track-and-trace service of money – based on IoT standards and protocols and publicly accessible – could improve the customer acceptance of CBDCs. Consequently, the study aims to answer the following research questions (RQs):

RQ1: How could an IoT-based CBDC be implemented?
RQ2: Is a track-and-trace service for e-money a viable proposition in the European context?
RQ3: Has this service the potential to enhance the BI of customers?

The research covers only the Eurozone area to provide evidence of feasibility within a real case. This approach offers researchers and practitioners from other countries useful insights on how to steer the adoption of local CBDC initiatives. A prototypal architecture was developed to achieve the first two research questions (RQ1 and RQ2), which have been developed to provide evidence of the feasibility of an IoT-based CBDC. Differently, to answer the RQ3, a survey was conducted on a sample of 351 people. The survey aims to validate the proposed solution and evaluate additional new features. The results demonstrate a high conversion rate of 73.83 percent among those who have not yet adopted CBDC if they were offered an IoT-based CBDC capable of tracking and tracing all e-money received by financial institutions for taxation purposes.

To encourage open science and the reproducibility of this study, we provide all data and scripts in a replication package available online with an open-source license (Softengunisalento, 2024). The remainder of the paper is structured as follows. The "Related Works" section provides an overview of the relevant literature. The "Research

Methodology” describes the steps to address the research questions. Furthermore, a quali-quantitative evaluation is presented, which is applicable to the Eurozone. Subsequently, the results of the survey are presented. In the “Discussion” section, we analyse the main findings of this work, emphasising its contribution to the state of the art. Finally, we offer closing remarks in the “Conclusions” section.

RELATED WORKS

Digital Euro

In 2021, the European Central Bank (ECB) launched the Digital Euro (D€) project’s investigation phase (ECB, 2020), focusing on digitalising cash within the Eurozone. This includes developing supporting infrastructure, distribution strategies among individuals and financial intermediaries, and creating Value-Added Services (VAS) for D€. The D€ project aims to combine the benefits of central bank money with a modern currency approach. Its importance lies in supporting digitalisation and economic growth and addressing unregulated solutions like crypto-assets and non-major card payment methods, which could threaten financial stability. Eurozone countries are running experimental D€ trials to identify challenges and opportunities. A comprehensive examination of how the implementation of the D€ project could influence economics, society, and industry, as well as its interaction with cryptocurrencies and stablecoins, can be found in Passacantando’s (2021) previous work.

European tech and payment systems are assessed for their fit in creating a CBDC for the D€. The TARGET Instant Payment Settlements (TIPS) platform is favoured for hosting D€, with proposals like an account-based CBDC on TIPS (Bechtel & Otto-Schleicher, 2021). Trials with lightweight Bitcoin protocols are also underway (Urbinati et al., 2021). Blockchain features, like smart contracts and NFTs (Gellman, 2021), are relevant to D€, especially for token programmability. However, Blockchain’s original decentralisation and authority resistance principles (Nakamoto, 2008) raise questions about its suitability for D€ if central authority replaces Proof of Work (PoW) and miners (Wüst & Gervais, 2018). In the pursuit of a CBDC for the Eurozone, the ECB has formulated seven relevant requirements (i.e., R1-R7) for the D€ project:

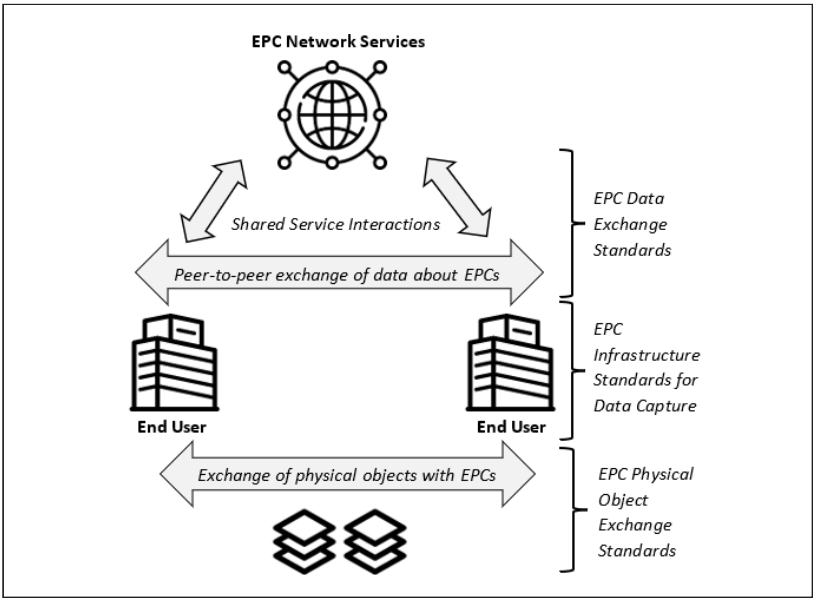
- R1: Enhanced digital efficiency. The D€ should constantly incorporate state-of-the-art technology to meet market demands in terms of usability, convenience, speed, cost efficiency, and programmability.
- R2: Cash-like features. To replicate the key attributes of cash and address declining acceptance, a D€ aiming to replace cash should facilitate offline payments. It should be user-friendly for vulnerable groups, free of charge for basic use, and protect privacy.
- R3: Competitive features. The D€ should incorporate cutting-edge functionalities comparable to payment solutions available in foreign currencies or provided by unregulated entities.
- R4: Monetary policy option. If considered a tool for enhancing monetary policy transmission, the D€ should be reimbursed and remunerated at interest rates that the central bank can modify over time.
- R5: Backup system. To enhance the overall resilience of the payment system, the D€ should be widely accessible and transacted through separate, robust channels that can withstand extreme events.
- R6: International use. The D€ should be potentially accessible outside the Eurozone in line with the objectives of the Eurosystem and convenient for non-Eurozone residents.
- R7: Cost savings and environmental friendliness. The design of the D€ should aim to reduce the costs of the current payment ecosystem and be environmentally friendly.

EPCglobal Framework

EPCglobal, led by GS1, develops standards for the Electronic Product Code (EPC) to enhance RFID use and global traceability in trading (GS1, 2009). Focusing on EPC/RFID tags and EPC Information Services (EPCIS), it sets syntax for unique identifiers for various entities in business operations, as outlined in the EPC Tag Data Standard (TDS) by GS1. EPCIS (GS1, 2016) facilitates the sharing information among trading partners regarding the movement and status of physical and digital products as they traverse the supply chain. It enables different applications to create and share visibility event data within and across enterprises (Figure 1).

Figure 1

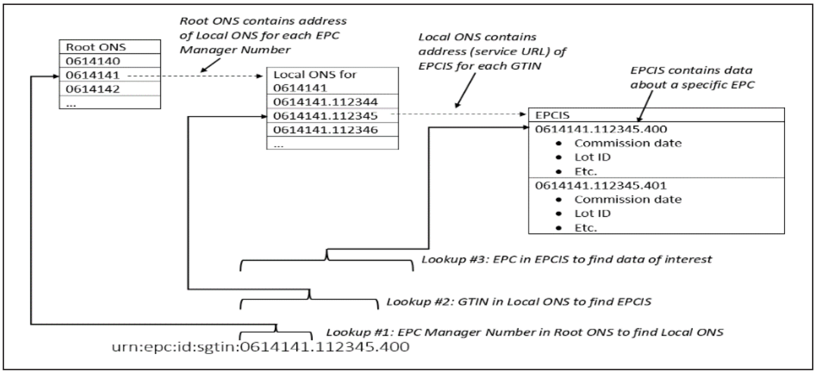
EPCglobal Architectural Framework



Within the EPCglobal Architecture Framework (GS1, 2015), end users engage in activities spanning different components. An end user refers to any organisation incorporating EPCglobal Standards and EPC Network Services into its business operations. The EPCglobal Architecture Framework allows for collecting information from one or more companies, making it available to other parties. Each end-user has complete control over its data and determines which parties can access it. An "EPCIS Accessing Application" allows the partner end users to retrieve information about a particular EPC. An EPCIS Accessing Application may locate the data of interest in several ways. The most interesting is the Object Name Service (ONS), which locates the EPCIS service of the end user who commissioned the EPC of the object in question (Figure 2).

Figure 2

ONS Muti-Steps Lookup Process



The ONS is a scalable lookup service using the Internet Domain Name System (DNS) for EPCs. It inputs an EPC and returns the EPCIS service's Uniform Resource Locator (URL) with related information. Queries are made to a local DNS resolver, which appears as a single operation to the user but involves a multi-step process. Initially, it consults the root ONS (controlled by EPCglobal) to identify the local ONS of the EPC Manager, and then the local ONS provides the EPCIS service URL. The ONS uses a convention where an EPC is converted into a DNS within the onsepc.com domain. Let's consider an example EPC: urn:epc:id:sgtin:0614141.112345.400. To perform an ONS lookup, the EPC is transformed into the corresponding Internet Domain Name: 112345.0614141.sgtin.onsepc.com. Detailed information can be referred to the DNS specifications (IETF, 1987a; 1987b) and the ONS Standard (GS1, 2013).

IoT-based CBDC Information Architecture

In the context of a CBDC, we can draw a parallel between the CBDC and a supply chain. This approach envisions tracking individual e-coins to their digital wallets, offering universal access to their transaction histories. Inspired by smart contracts' if-this-then-that logic, it aligns with IoT scenarios for detailed money tracking. Furthermore, the implementation of fine-grained tracking of items would enable both owner-tracking and coin-tracking capabilities. This approach likens the financial ecosystem to a supply chain, where money is the "goods" moving between "warehouses" (wallets) through transactions akin to shipping. Just as goods can shift within an entity, similar to bank transactions, each digital coin is assigned an Electronic Coin Code (ECC), functioning as its unique identifier, comparable to an EPC code in this metaphor. Following this, we refer to the IoT-based CBDC with the acronym ECC. Table 1 maps concepts between the two worlds, EPC and ECC, illustrating their alignment and correspondence.

Table 1

EPC and ECC Concepts Mapping

Concept	EPCglobal	ECC
Nature of items to be tracked	Physical (e.g. goods)	Virtual (e-coins)
Support to store the EPC	RFID tag memory	Database
End users	Supply chain actors	Banks
Business locations	Warehouses	Wallets
Aggregation of items	Pallet	Transaction amount
Transfer of ownership	Shipment	Transaction

Figure 3

Coin Flows Among Actors in the ECC Network

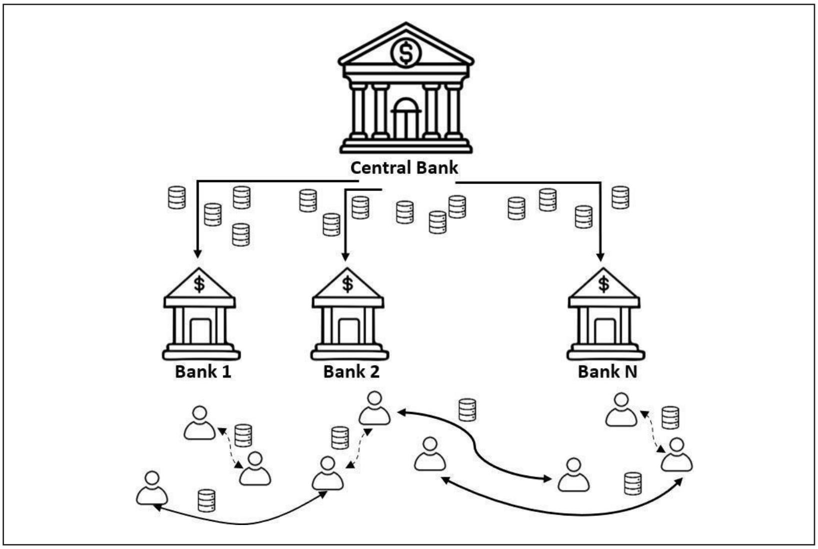


Figure 3 provides a schematic representation of the general architecture. The upper part of the diagram illustrates the Cloud Layer, which serves as an infrastructure supporting universal access to traceability information and ensuring transparency of institutions to citizens. The Cloud Layer includes the central and commercial banks. The lower part represents the Peer-to-peer (P2P) Layer, which consists of microblocks where transactions occur between users asynchronously and offline, aiming to facilitate cash-like payments while ensuring complete privacy and anonymity.

The central bank issues digital currencies to commercial banks, which manage user accounts and handle digital currency transactions. It also implements traceability features for individual units spent on taxes. The P2P Layer, comprising end users, allows offline, cash-like transactions between users, independent of the Cloud Layer, ensuring anonymity and privacy (Mainetti et al., 2023). The central bank possesses the exclusive authority to mint ECCs. It is responsible for creating new ECCs by the applicable monetary policy. ECCs are distributed to user wallets through financial intermediaries, such as banks. Each bank, including the central bank, maintains an EPCIS repository that stores ECCs, wallets, and transaction information. Every ECC e-coin will be encoded in the SGTIN format, as described in GS1 (2019). Specifically, we utilised the SGTIN-198 encoding for this experimentation. An example of an SGTIN code is:

urn:epc:id:sgtin:0614141.112345.400

The SGTIN code consists of three numeric and hierarchical parts:

- The company prefix represents the distinctive code assigned to the central bank responsible for minting the ECC (0614141 in the example above).
- The product code stores the token type (112345 in the example). While only one type of token exists in basic usage, this field can be utilised to create Non-Fungible Tokens (NFTs), which are programmable ECCs that cannot be interchanged.
- The serial number (400 in the example, but it can be any string up to 140 bits) represents the unique number assigned to the ECC for the specific product code minted by a particular central bank.

ECC is token-based: an ECC wallet contains a collection of SGTIN codes. In EPCglobal terms, an ECC wallet is like a private warehouse holding tagged items. Therefore, an ECC wallet is identified by a business location code known as the Serial Globe Location Number (SGLN), which follows the format:

urn:epc:id:sgln:030001.111111

The SGLN consists of two primary numeric parts:

- The company prefix (030001 in the example above) represents the distinctive code assigned to the commercial bank issuing the wallet.
- The location code (111111 in the example) is a unique identifier assigned by the bank to the specific location (wallet).

An ECC transaction involves transferring a certain amount of SGTIN tags "packed" from one wallet to another. There are two possible scenarios:

1. The ECCs move from one location to another within the same company. In this case, both the paying wallet and the recipient wallet are under the same commercial bank.
2. The ECCs move from a location in one company to a location in a different company. In this case, two banks are involved, and business communication is required between the parties.

Although the two scenarios have slight differences, they share the same coding format. In the supply chain context, when items are grouped for storage or shipping, they form a unit called a pallet. Pallets have their own identifier used to track the grouped items as a whole. In EPCglobal, this identifier is encoded in the Serial Shipping Container Code (SSCC) format. In the ECC context, this SSCC can be used as the transaction identifier, and it follows this format:

urn:epc:id:sscc:88511111.000001111

Similar to the SGLN, the SSCC is composed of two numeric parts, with the following meaning in ECC:

- The company prefix (88511111 in the example) represents the code assigned to the commercial bank initiating the transaction.
- The logistic unit serial number (000001111 in the example) identifies the transaction within the bank initiating it.

In the ECC system, transactions in the two scenarios leave distinct traces. In Scenario 1, where ECCs move within the same bank, they transfer between "wallets" but remain inside the bank. This movement triggers an EPCIS transaction event recorded in the bank's EPCIS, described by properties like event time and business location (beneficiary wallet). EPCglobal events natively support extensions, allowing for additional information like a custom payment description field (e.g., up to 1024 characters).

Scenario 2 is the most challenging, as it involves digital wallets stored in two different banks. In this case, storing a transaction event in the sending bank is not enough, as we need two further steps:

1. storing a transaction event also in the receiving bank;
2. leaving a trace in the ECC system about the change of ownership of the involved ECCs.

For the first point, the sender bank should be allowed to "ship" the e-coins to the receiver bank. In the supply chain, it is like a pallet that was shipped (e.g., via trucks) and then received by the recipient company. In this case, IoT readers placed in the warehouse entrance detect the pallet and contained items, storing the event in the EPCIS. ECC e-coins are shipped "virtually" instead of via APIs. To this aim, all the participating banks should know each other's API endpoints. As seen in the previous subsection, EPCglobal provides a service that retrieves the endpoints and retains information about a specific EPC code: the ONS.

Feasibility in the Eurozone

To assess the impact and the scalability of an IoT-based CBDC within the context of the D€ project, we implemented the EPCglobal stack and tried to configure it to support the D€ scenarios. We instantiated a prototype of the ECC architecture using the Fosstrak (Auto-ID Labs, 2015) project. It is an open-source RFID software platform that implements the EPC Network specifications. We also used Oliot ONS (Auto-ID Labs & KAIST, 2015), a Node.js-based RESTful Interface for easy service records management. Finally, a Discovery Service (DS) has been implemented to bridge the two domains, Fosstrak and Oliot ONS. The prototype allowed us to estimate the memory space needed to manage the transactions related to ECC in the European context. Based on the protocols and architecture described in the previous sections, we can consider three items in computing the weights of a transaction in terms of physical memory allocation, as shown in Table 2.

Table 2

Transaction Item	Protocol/Format	Memory Allocation
ECC Token (ECC)	sgtin-198	25 Bytes
Transaction Event (TE)	EPCglobal table format	1024 Bytes for both transferring and destination banks
ONS record (ONS)	NAPTR record markup	per ECC: 100 Bytes

Storage Allocations for Main EPC Global Items

In computing the estimation, we considered a set of parameters to describe the context in which such transactions can exist. These parameters were obtained anonymously from a mid-size Italian bank. The third parameter was retrieved from The World Bank. The values of these parameters, referring to the year 2020, are listed in Table 3.

Table 3

Eurozone Market Variables

Transaction Item	Protocol/Format
The average number of monthly transactions per cardholder (TN_{Avg})	54
Average transaction amount (TA_{Avg})	€ 43,00
European 15-64 years-old population (P_{15-64})	287.217.454

Note: The table provides the variables used to perform our analysis in the Eurozone area.

This estimation of memory allocation for electronic transactions over two years focuses on a population familiar with electronic transactions, including both private and business entities. To get a reliable estimate, first calculate the transaction weight (TW) for a typical transaction using Equation 1:

$$TW = TA_{Avg} \times (ECC + ONS) + 2 \times \mathrm{TE} = 7.405 \ Bytes \tag{1}$$

The equation considers the items listed in Table 3, including the average amount of an electronic transaction in the Euro area, which represents the number of ECCs to be transferred between the two involved wallets. Using the TW parameter as in Equation 2, we can then compute the estimation of the monthly memory allocation due to the transactions conducted by the entire considered population:

$$TW_{Month} = TW \times TN_{Avg} \times P_{15\text{-}64} = 114.851.859.008.482\ \textit{Bytes} \quad (1)$$

The estimated storage requirement for the ECC architecture in a typical European scenario is about 115 TiB per month for electronic transactions. At 24 months, the forecasted total storage size would be around 2,756 TiB.

E-Money Tracking

Various approaches and techniques have been proposed to address owner-tracking and coin-tracking, each with its own nuances and considerations. In the context of owner-tracking, the central bank or a Trusted Third Party (TTP) can access banking information and obtain a comprehensive list of a user's e-coins. On the other hand, coin-tracking involves tracing an e-coin back to its owner. The issue of reporting lost or stolen e-cash in the absence of a TTP has been addressed by Zhang and Zhong (2008), where the concept of "tracing" refers to the ability to control the deanonymisation of e-coin ownership. In an earlier paper by Davida et al. (1997), traceability is linked to the capability of selectively revealing coins and owners only when strictly necessary. Anonymity is a control parameter that facilitates note holders' privacy level flexibility. Another work by Zhang et al. (2007) explores a concept of tracing like the one discussed in our work. The authors present a method to trace e-coins in abnormal situations such as blackmail or kidnapping. In these cases, a marked bank issues a marked e-coin, which the bank and the bank in the group can recognise the marked e-coin during the deposit process.

Lian et al. (2014) make an important statement about incomplete tracing, emphasising that unconditional tracing and anonymous spending are conflicting properties of e-cash. Therefore, any CBDC should address the simultaneous implementation of such properties. Juels (1999) highlights the importance of traceability in e-cash systems, which has led to the proposal of numerous trustee-based coin tracing schemes. A "trustee" is a certified third party capable of performing coin-tracing and generating a list of all coins belonging to a given user. The paper itself discusses the implementation of a relatively simple trustee-based payment scheme. Furthermore, new directions are being explored to enhance tax control for imported goods in customs territories, leveraging blockchain technology and the concept of traceability from the supply chain domain (Lyutova & Fialkovskaya, 2021; Ciriello et al., 2023). This approach aims to connect the tracking of goods with automated tax payments, emphasising the importance of traceability for regulatory compliance. Kutubi et al. (2021) proposed a secure offline payment scheme based on Schonorr's untraceable blind signature. When an e-coin is spent more than once, the Bank and Central Authority can reveal the customer who owned that e-coin.

The mentioned studies demonstrated coin and owner tracking using cryptographic methods like knowledge and blind signatures. Traceability, common in supply chains, is new to money tracking, but tracking individual coins could increase household trust in the currency system (Söilen & Benhayoun, 2021). The notions of mutual trust, understanding, transparency, and cooperation, have been extensively researched in supply chain management (Youn et al., 2012; Jharkharia & Shankar, 2004; Love et al., 2002; Saberi et al., 2019; Sahoo et al., 2022; Wang et al., 2019), are vital for ensuring business continuity, regulatory compliance, and customer satisfaction. In particular, IoT technologies like RFID have been instrumental in enabling single-item traceability (Mainetti et al., 2013; Chen & Chou, 2015), enabling real-time retrieval of the complete history of a specific unit of a product.

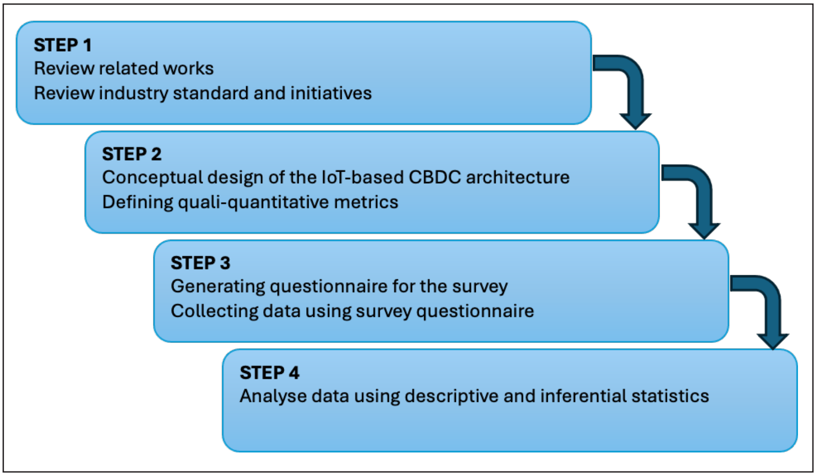
METHODOLOGY

This study aims to understand the conditions by which citizens can accept a CBCD. The study focuses on the European context, in which several concerns are emerging among people about the issue of a D€ by the European Central Bank. To this aim, the study involves a subset of 351 citizens to be provided with a stimulus, and we hypothesise that citizens would be more willing to give up a piece of their privacy if institutions were more transparent in managing public money. Besides the survey, a more technical validation is performed in order to check the feasibility of an IoT-based CBDC – whose aim is to give the citizens a new fine-grained track and trace service of public money expenses – and measure the correlation between such a service and the change in BI. BI is the main variable that the study monitors. In Figure 4, we report the research methodology adopted in our work, which comprises four steps. The initial stage (Step 1) of the research process entails a comprehensive examination of existing literature pertinent to the subject matter under investigation.

Furthermore, the review examines IoT track-and-trace standards and investigates the D€ project as a technical and regulatory benchmark. Step 2 provides the conceptual mapping between the IoT and CBDC world, focusing on the track-and-trace feature and the quantitative and qualitative metrics useful to assess the practical feasibility of an IoT-based CBDC. With Step 3, we begin the social assessment part of this work by defining a questionnaire and the mode of administration toward a set of respondents. Subsequently, Step 4 entails the analysis of the questionnaire results through the application of statistical techniques.

Figure 4

Methodology for the Study

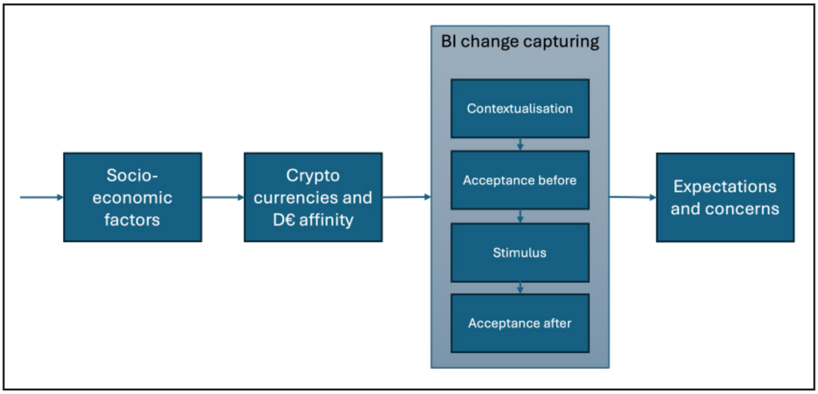


With regard to data elaboration (Step 4), the methodology consists of two subsequent activities. The first involves the use of descriptive statistics to identify the most basic relationships between clusters of people, their characteristics, and the trends in their questionnaire responses. Then, a more sophisticated level of analysis employed inferential tools to uncover hidden relationships among the variables.

The survey gives insights on the change in BI for the use of CBDC of 351 respondents, particularly focusing on the ECB project. Other surveys about the willingness to adopt the D€ were made early (Abramova et al., 2022). However, our survey aims to identify the conditions by which a specific software feature may make a CBDC more accepted. Due to any person's intended use of CBDC, the respondents were selected using convenience and snowball sampling techniques. The survey was administered to people from southeast Italy between 2 November and 7 November 2023. The questionnaire was written in Italian. The language adopted to formulate the questions was intended to be accessible to every level of education. Figure 5 depicts the basic structure of the questionnaire, from left to right.

Figure 5

The Components of the Questionnaire



The questionnaire contained a brief introduction about the aim of the research and comprised eleven single-choice and two multiple-choice questions, with the latter having the option for open-ended comments. Attitude is measured with the help of a semantic differential scale, as suggested by Ajzen (1980) and Davis (1989), which allows for operationalising the attitude toward a behaviour. The BI change capturing block contains paragraphs intended to provide a stimulus that affects people's motivation to adopt CBDC. The stimuli were designed to impact both hedonic and utilitarian motivations in respondents, according to the Stimulus-Organism-Response (SOR) (Mehrabian & Russell, 1974; Jacoby, 2002). The hedonic motivation was particularly triggered by instilling a spirit of social payback in citizens who felt oppressed by tax institutions. The acceptance before and after the stimulus allowed us to measure the BI change. Table 4 provides the details of the components of the survey.

Table 4

The Operational Definition of the Components in the Survey

Components	Definition	Questions/Items
Socio-economic factors	The demographic and economic charateristics of individuals, such as age, gender, occupation, education.	1, 2, 3, 4, 5
Cryptocurrencies D€ affinity	The degree of knowledge that individuals have towards cryptocurrencies and Digital Euro.	6, 7
Contextualisation	Information about ratio between taxes paid and services obtained, and the way by which Italian economic authorities act.	Informative items between questions 7 and 8
Acceptance before	The acceptance of the *modus operandi* of Italian economic authorities.	8, 9
Stimulus	Short description about the proposed CBDC solution.	Informative items between questions 9 and 10
Acceptance After	The degree of acceptance/ adoption of an IoT-based. CBDC.	10, 11
Expectation and concerns	Additional features proposed by individuals, and users' concerns of CBDCs.	12, 13

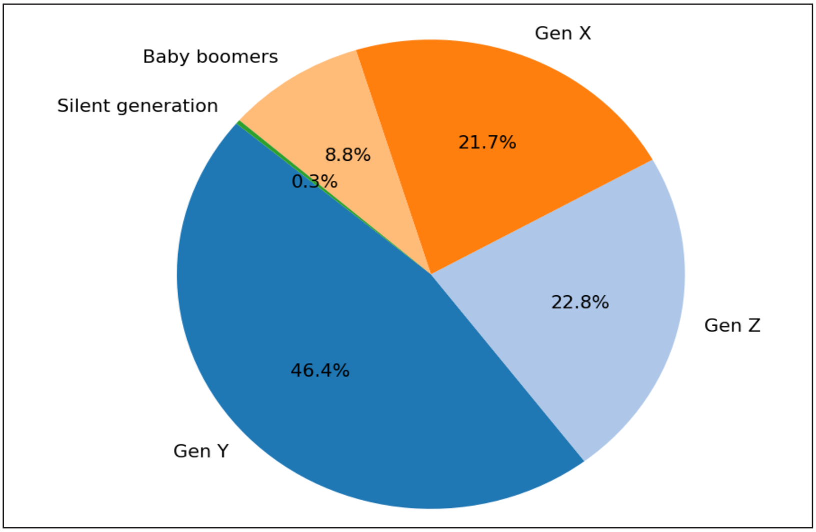
RESULTS

Demographics

A survey was initiated in which 351 people were asked to respond to general questions such as age, gender, occupation, and education, along with more specific questions geared toward validating the proposed solution and evaluating additional new features. In addition, the focus was on finding out the various concerns people might experience in using a CBDC based on the proposed architecture. A total of 351 people participated in the survey, including 169 men, 181 women, and one of the others. In terms of age, a breakdown by generation was made, as shown in Figure 6. The figure provides a distribution of survey respondents by generation. The analysis includes Gen Z, born 1997-2012; Gen Y, born 1981-1996; Gen X, born 1965-1980; Baby Boomers, born 1946-1964; and Silent Generation, 1928-1945.

Figure 6

Distribution of the Respondents by their Generation



The respondents were asked to specify their current employment, industry and educational qualifications. In a nutshell, the sample turns out to be very diverse: students, managers, teachers, and entrepreneurs employed in sectors such as information technology, consulting services, communication and public relations, construction and facilities, and having educational qualifications such as high school diplomas, bachelor's degrees, master's degrees, and doctoral degrees (Figures 7 and 8).

Figure 7

The Respondents' Employment

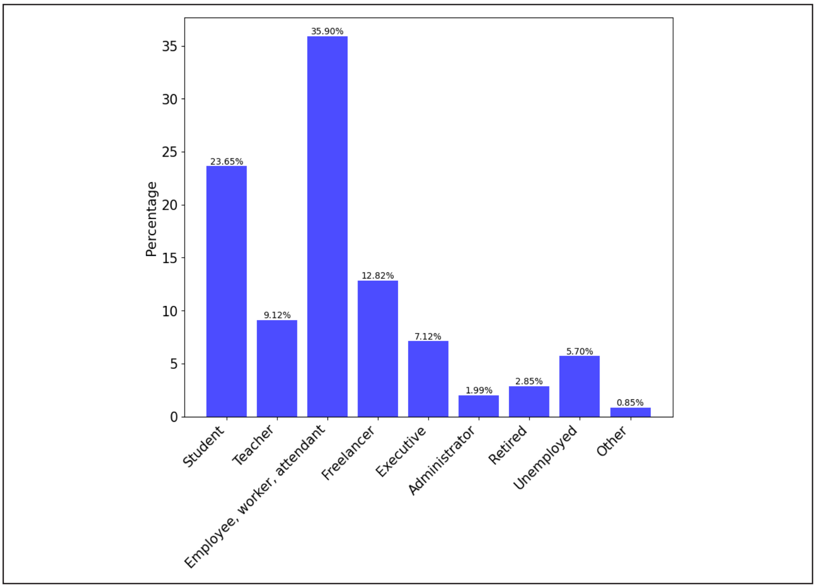
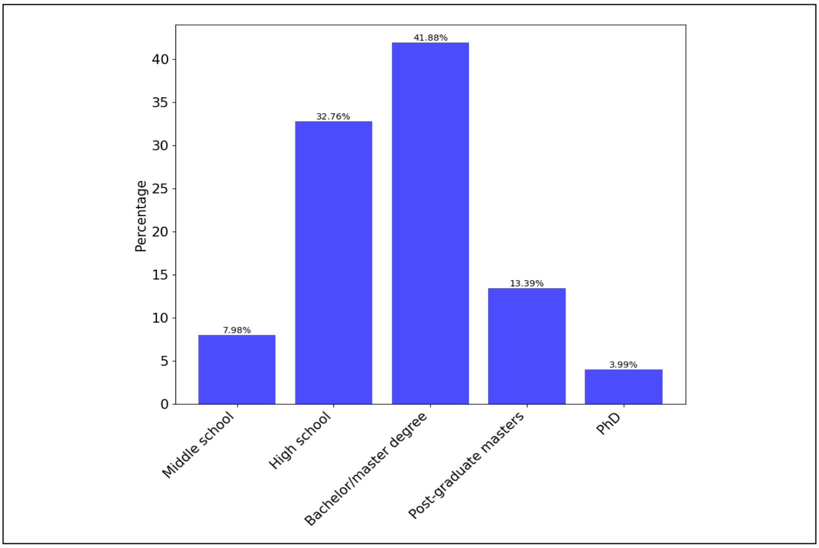


Figure 8

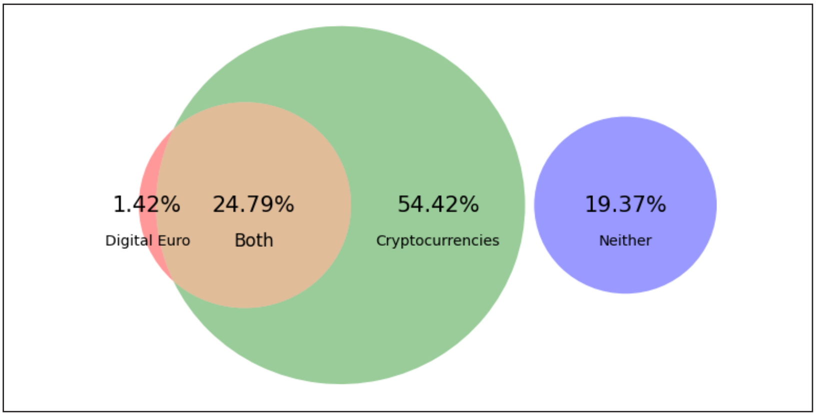
The Respondents' Level of Education



The respondents were also asked whether they knew about cryptocurrencies and the D€ initiative. Interestingly, 79.2 percent, corresponding to 278 people, are aware of cryptocurrencies, and only 26.2 percent, corresponding to 92 people, are aware of the D€ (Figure 9). The figure provides Venn's diagram for D€ and cryptocurrency knowledge.

Figure 9

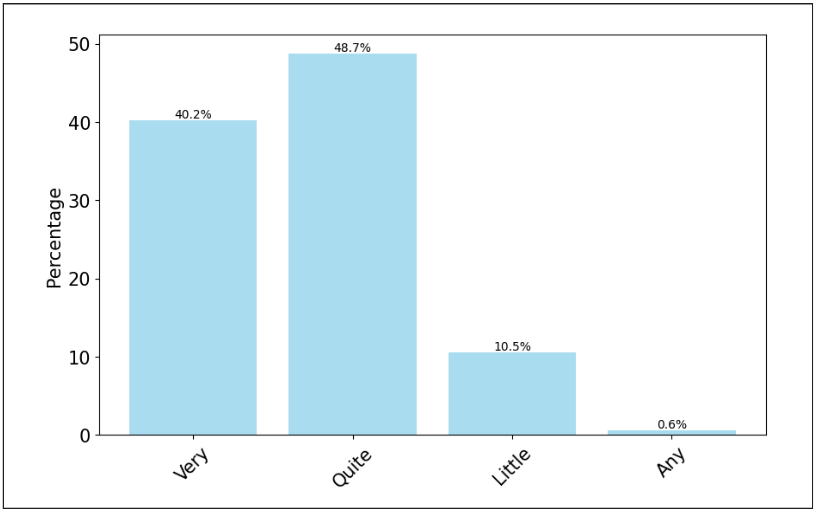
The Venn's Diagram for the Knowledge of D€ and Cryptocurrencies



At this point, the respondents were provided with a stimulus. From a regulatory point of view, in Italy, the "Guardia di Finanza" and the "Agenzia delle Entrate" can access citizens' banking information to check for suspicious movements without the final citizens' prior consensus. Often, taxpayers do not find a match between what they pay to the state and the services it provides to the citizens. As shown in Figure 10, only 11.1 percent of participants find a match between what they pay to the state and what the state makes available to the citizens. The figure provides the results of the question, "*Citizens are required to pay taxes but very often do not find a match between what they pay to the state and the services it provides to the citizen. How much do you identify with what you just read?*"

Figure 10

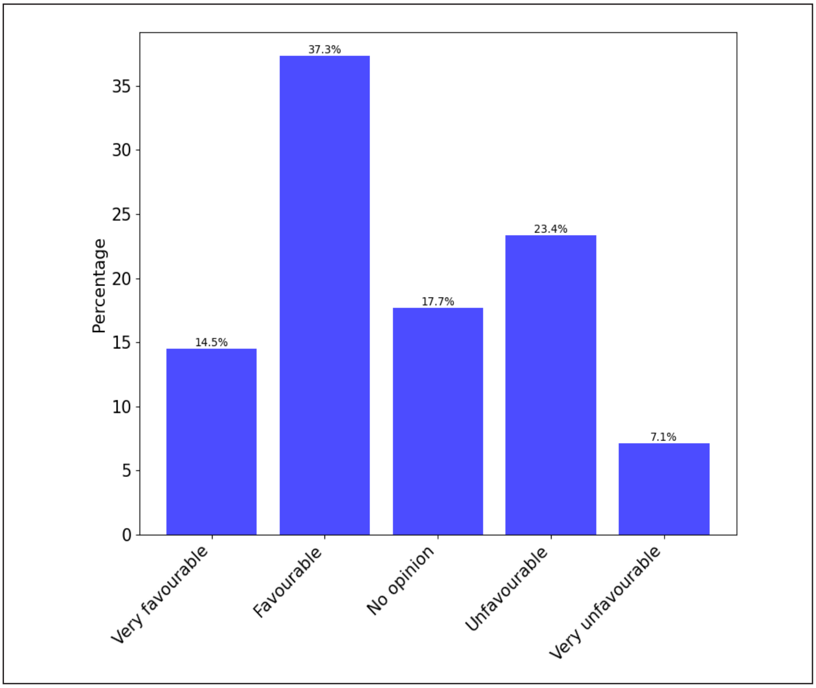
The Respondents' Opinion on Their Taxes and Services They Obtained



Then, the study measured the sample's sensitivity to privacy concerns in CBDC. As shown in Figure 11, only 14.5 percent are very much in favour of the Guardia di Finanza and Agenzia delle Entrate using CBDC to access bank accounts and check for tax evaders. The figure provides the results of the question, "*The Guardia di Finanza and the Agenzia delle Entrate could use the D€ CBDC to access your bank account information in order to monitor any suspicious movements without your knowledge. How supportive are you with what you just read?*".

Figure 11

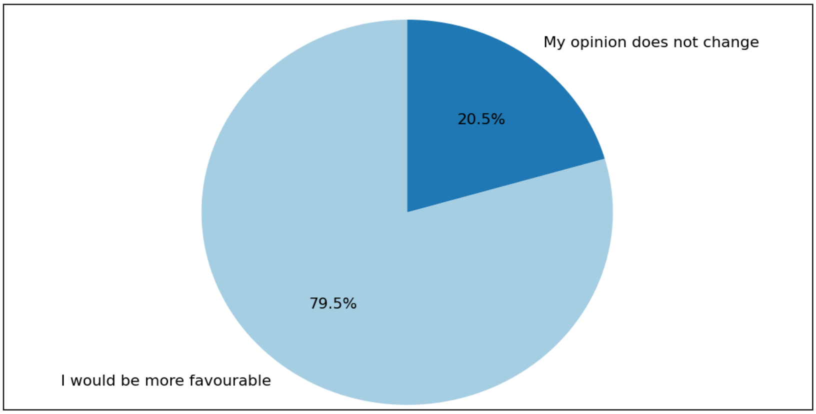
The Respondents' Opinion on Monitoring of Their Bank Account



Now, the respondents were provided with the stimulus: participants were explicitly asked whether they were more in favour of allowing tax authorities to access their bank account information and if there was a system to track every Euro the state receives for taxes (Figure 12). 79.5 percent of participants would favour "getting audited" if they could "monitor" how the state spends tax money. Figure 12 provides the results about the question, "*If you could use the CBDC to know clearly how the state uses every single Euro of your taxes, how would your opinion compare with the previous answer?*".

Figure 12

The Respondents' Opinion on the Use of Their Taxes by the State



Then, the study asked the respondents about their "expectations and concerns". It comprised two multiple-choice questions, with an option of open text for both (Tables 5 and 6). It is relevant that the open text option was almost unused. The most interesting open inputs were the fear that tax tracking may not contribute significantly to fighting tax evasion and the concern that information on tax usage may be manipulated and used for "illicit activities." Table 5 provides additional information about the question, *"What kind of functionality do you expect from a system like this?"*. On the other hand, Table 6 displays the respondents' responses to the question, *"What would scare you/what are your concerns about using this system?"*.

Table 5

The Respondents' Expectation on the System Uses

Feature	Number of respondents	Rate
Track local-level public expenses	306	87.2%
Track charity donations	123	35%
Track businesses' social commitment	152	43.3%

Table 6

The Respondents' Concerns on the System

Name	Number of respondents	Rate
I am afraid that my privacy will be violated	172	49%
I am afraid of having my money stolen	61	17.4%
I am afraid that my information may be stolen	147	41.9%
I am afraid that I might be scammed in some way	131	37.3%
None	18	5.7%

A more in-depth analysis of survey responses, grouped by age group and other socio-demographic dimensions, was conducted. In Figures 13 and 14, it can be seen that the younger generations have more knowledge of D€ and cryptocurrencies. Figure 13 provides the results about the question, "*Are generations aware of the D€ project?*". On the other hand, Figure 14 displays the respondents' responses to the question, "*Do generations know or use crypto*?".

Figure 13

The Respondents' Awareness of the D€ Project Based on Their Generation

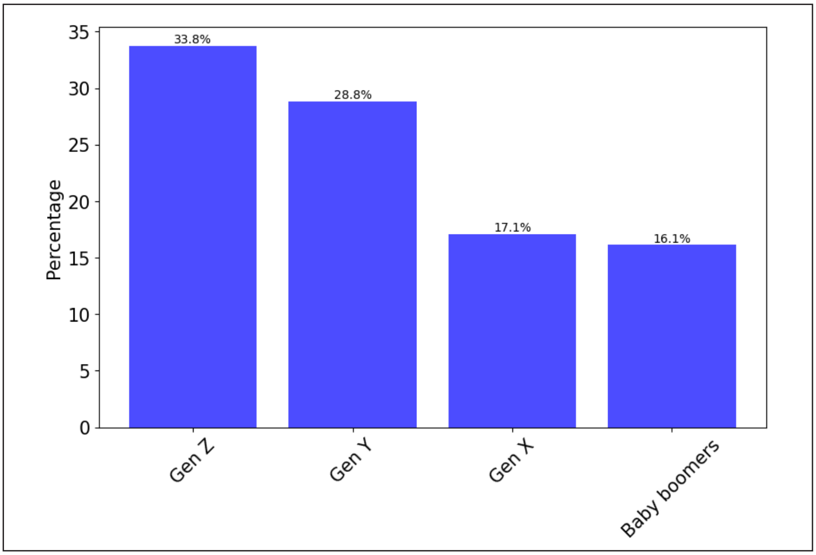
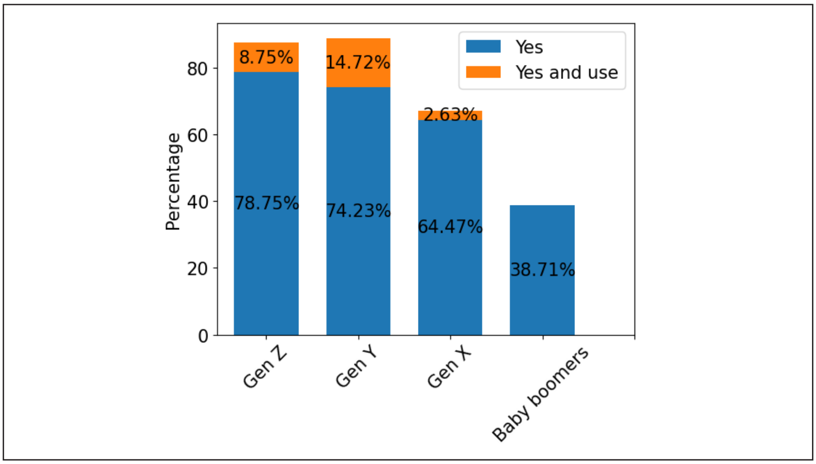


Figure 14

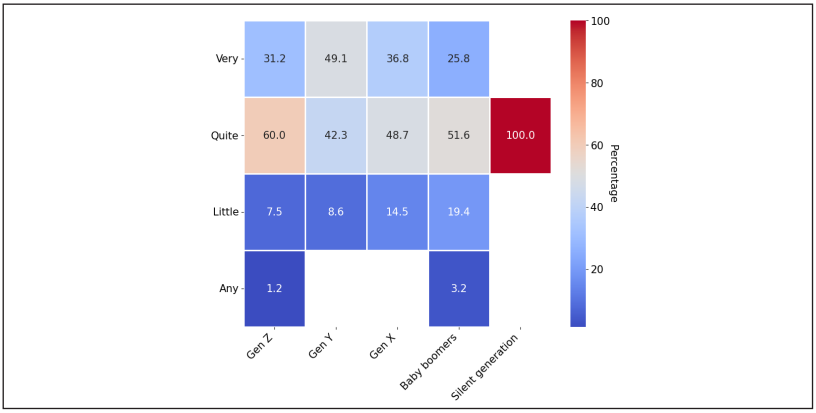
The Respondents' Awareness and Usage of Cryptocurrencies



On the other hand, regarding the correlation between taxes and perceived public services (Figure 15), general discontent can be seen across all generations. Figure 15 provides the results about the question, "*Citizens are required to pay taxes but very often do not find a match between what they pay to the state and the services that the state itself provides to the citizen. How much do you identify with what you just read?*".

Figure 15

Comparison of the Respondents' Opinion on Their Taxes and Services They Obtained Across Generations



In reference to a CBDC where the Guardia di Finanza and Agenzia delle Entrate can access citizens' banking information (Table 7), there are similarities between Gen Z and Gen X and Gen Y and Baby Boomers. As far as Gen Y and Baby Boomers are concerned, these generations are more reluctant to share information for profiling. The question, "*The Guardia di Finanza and the Agenzia delle Entrate could use the D€ CBDC to access your bank account information in order to monitor any suspicious movements without your knowledge. How supportive are you with what you just read*".

Table 7

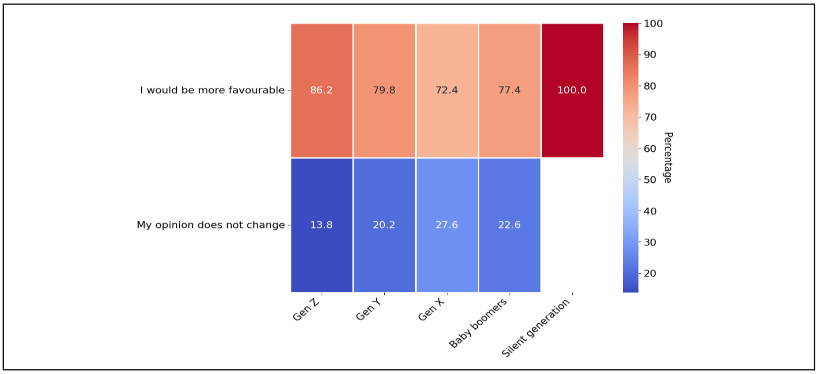
Comparison of the Respondents' Opinions on Monitoring Their Bank Account Across Generations

Generation	Very favourable	Favourable	Irrelevant	Unfavourable	Very unfavourable
Gen Z	15%	40%	18.75%	18.75%	7.5%
Gen Y	15.33%	30.67%	20.85%	25.76%	7.36%
Gen X	13.15%	47.36%	11.84%	22.36%	5.26%
Baby boomers	12.90%	41.93%	12.90%	22.58%	9.67%
Silent generation	0%	0%	0%	100%	0%

As reported in Figure 16, if citizens had a money tracking of public expenditures, most of each age group would be more supportive of having the authorities access their movements.

Figure 16

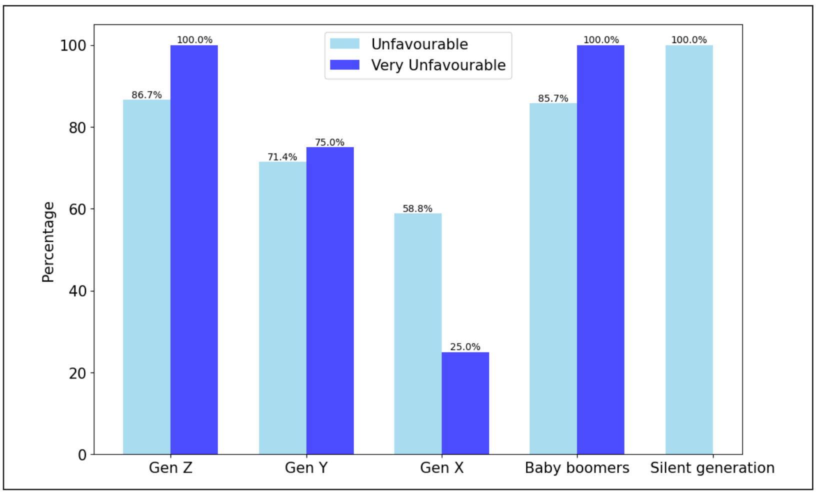
Comparison of the Respondents' Opinion on the Use of Their Taxes by the State Across Generations



The percentages in Figure 16 include the part of the sample that was already favourable. We must further detail this result, focusing on the unfavourable subsample in CBDC adoption because we want to understand the conditions in which a reluctant person becomes favourable. The respondents who are now more willing to adopt CBDC include 73.83 percent of those initially unfavourable or very unfavourable. In Figure 17, we report in detail by generation. The figure provides the results about the question, "*Attitude change: how many of those (very) unfavourable people are now willing to adopt CBDC?*".

Figure 17

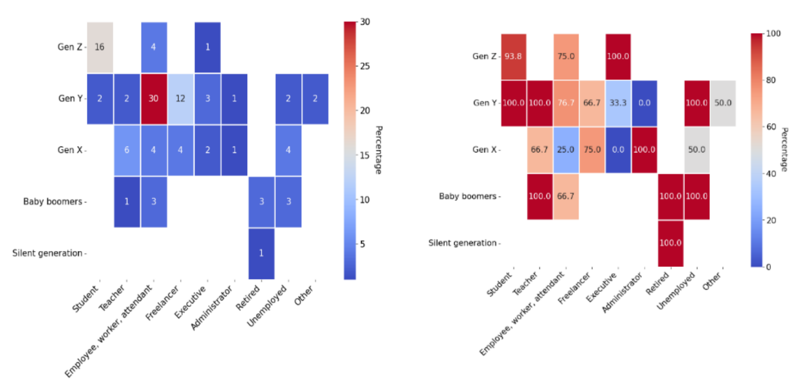
Adoption of CBDC Across Generations



Besides the size of the subsample impacted by the stimulus, it is necessary to understand the demographic behind the former reluctant. We summarise this information in the next heatmaps. The Generation-Occupation heatmap in Figure 18 (a) shows how discontent related to authorities' access to banking information is distributed among professions per generation. We can't detect a specific trend, except that it is likely that the older the respondents, the higher the malcontent. Moreover, the discontent is distributed more or less equally amongst all the professionals, with employees and the unemployed tending to be more reluctant. Figure 18 (b) shows the related BI change. Red cells (100%) mean that the submitted stimulus has led the entire subsample to change its opinion: those previously unfavourable are now more likely to adopt a CBDC. A blue cell means no one in that category has changed their opinion (0%). For example, all Gen X executives and all Gen Y administrators remain unfavourable even after the stimulus. White cells in (a) and (b) mean no participant falling in that specific category. Figure 18 presents the percentage of individuals who are "unfavourable" and "very unfavourable" (category (a)) in comparison to the BI change rate (category (b)), with distinctions made according to generational and occupational characteristics.

Figure 18

Comparison of CBDC Adoption Across Generations and Occupations



(a) Number of Individuals Across Generations and Occupations which initially were Unfavourable and Very unfavourable.

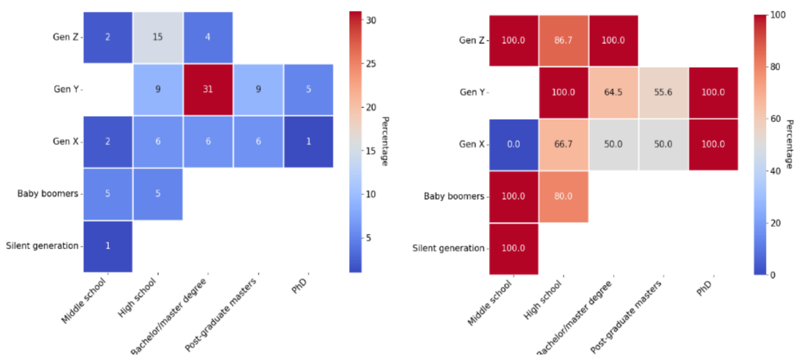
(b) Percentage of individuals across Generations and Occupation who initially were Unfavourable and Very unfavourable but changed their opinion after our stimulus.

A peak is relevant among employees of Gen Y. Gen Y freelancers and Gen Z students have a notable peak. Cross-checking with Figure 7, we can state that employee and student peaks result from a bigger share of participants for those categories, while it is interesting that 35.6 percent of freelancers are unfavourable (freelancers have a huge tax burden in Italy). Another interesting fact is that we expected lower adoption friction among people with higher education degrees. Instead, we discovered that reluctance is a cross-social characteristic. While it is relatively meaningful to look at the counts in specific cells of Figure 18 (b) (because of the high fragmentation for a relatively small sample), it is more interesting to look at horizontal and vertical slices and the overall map. In fact, we can see a global positive response to the stimulus.

In Figure 19, we performed the same analysis but grouped it by education level. Also, regarding the education level, there is no specific discrimination in the profile of the reluctant. Also, in this case, the impact of the stimulus is positive, with no less than 50 percent as a conversion rate. Unfavourable Gen Y's graduated respondents seem very high, but cross-checking with Figure 7 reveals a high student sample size. The stimulus is quite effective on them (64.5% change their mind). Figure 19 provides the results of the comparison of levels of education across generations. The figure presents the percentage of individuals who are "unfavourable" and "very unfavourable" (category (a)) in comparison to the BI change rate (category (b)), with distinctions made according to generational and educational characteristics.

Figure 19

Comparison of CBDC Adoption Across Generations and Levels of Education



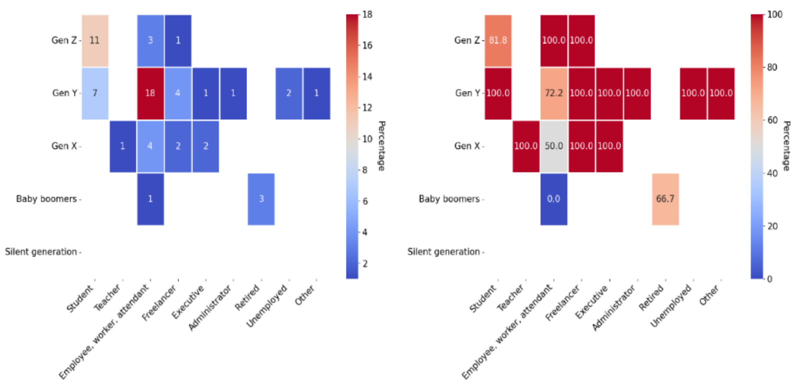
(a) Number of individuals across generations and levels of education who initially were unfavourable and very unfavourable.

(b) Percentage of individuals across generations and education who initially were unfavourable and very unfavourable but changed their opinion after our stimulus.

The "no opinion" group represents a neutral area where the stimulus could not attach. They could be disinterested as well as undecided, with the latter case (which we can't seize) potentially sensible to the stimulus. For the sake of completeness, we performed the same analysis we did for this subsample for the unfavourable samples (Figures 20 and 21). The figure presents the percentage of individuals who are "neutral" (category (a)) in comparison to the BI change rate (category (b)), with distinctions made according to generational and occupational characteristics.

Figure 20

Comparison of CBDC Adoption Across Generations and Occupations



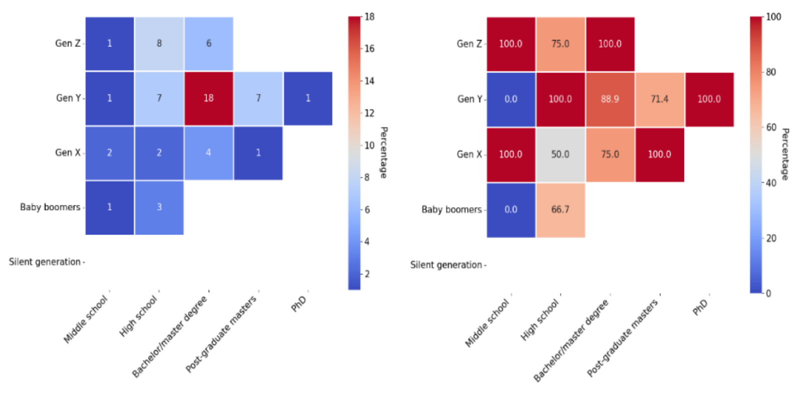
(a) Number of individuals across generations and occupations who initially were neutral.

(b) Percentage of individuals across generations and occupations who were initially neutral but changed their opinion after our stimulus.

Figures 20 and 21 show that most neutral respondents would be more likely to adopt the proposed CBDC. Those who remain without an opinion are a tiny part of retirees and the entire Baby Boomers. So, we can state that a track-and-trace CBDC could be very impactful in convincing disinterested and undecided citizens.

Figure 21

Comparison of CBDC Adoption Across Generations and Levels of Education



(a) The number of individuals across generations and levels of education initially were neutral.

(b) Percentage of individuals across Generations and Education who initially were neutral but changed their opinion after our stimulus.

DISCUSSIONS

The study applies the IoT track-and-trace standards called EPCglobal – born to boost RFID adoption in supply chains – to enable single-coin traceability in CBDCs, and then a survey is conveyed to see if it enhances trust and transparency. Although the use of the EPCglobal standard is not new in the literature, the motivations behind our study stem from analysing the change in behaviour intention towards the adoption of CBDCs.

The first part of our research aimed to find proof of the feasibility of an IoT-based CDBC in terms of technical viability and storage requirements, together with a specific analysis of compliance with EU regulations. The conceptual mapping we reported in the previous sections proved that the IoT-based CBDC – which we called ECC – can support the main typical cases of a CBDC (requirement R1 of D€). Based on the IoT standards, ECC supports if-this-then-that rules analogue to DLT smart contracts. In fact, the IoT-based infrastructure enables programmable event-driven payments as well as other compelling features like M2M and pay-per-use scenarios (R3).

Moreover, being a mix of account- and token-based CBDC, it supports fast exchange of tokens. In particular, mapping each ECC code with digital coins can also enable P2P offline payments (R2 – not treated in this work). ECC also enables support for multiple central banks via SGTIN codes (R6). Requirements R4 (monetary policy option) can be met at the application level (it is out of scope for this work). While R5 (backup systems) could be met at the architectural level, some concerns are related to the huge storage requirements of 115 TiB per month. R7 met the cost-saving requirement because it used consolidated standards and open-source technologies. At the same time, ECC's environmental friendliness must be assessed carefully, and it represents future work (for example, the great size of track-and-trace data impacts the energetic sustainability). In Table 8, we provide a comparison with the state of the art. The table shows how the IoT-based CBDC differs from existing money track-and-trace solutions already available in the literature.

Table 8

Comparison with the State-of-The-Art

Feature	Zhang and Zhong (2008)	Davida et al. (1997)	Zhang et al. (2007)	Lian. et al. (2014)	Jules (1999)	Kutubi et al. (2021)	ECC
Presence of TTP	No	Yes	No	Yes	Yes	Yes	Yes
Loss report issue	No	N/A	N/A	No	N/A	N/A	No
Type of security (Crypto-Graphic (C) vs. Applicative (A))	C	C	C	C	C	C	A
Coin-tracking	Yes	Yes	No	Yes	Yes	Yes	Yes
Owner-tracking	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Single coin level tracking	Yes	Yes	Yes	Yes	Yes	N/A	Yes
Based on well-known industrial standards	No	No	No	No	No	No	Yes
Architecture resiliency	No	No	No	Yes	No	N/A	Yes
Universal access to track-and-trace information	No	No	No	No	No	No	Yes
Native "if this then that" rules support	No	No	No	No	No	No	Yes
Native non-fungible coins support	No	No	No	No	No	No	Yes

Regarding coin and owner-tracking, ECC aligns with the state-of-the-art. What changes is the universal access to track-and-trace information, which opens the implementation of different kinds of politics for a transparent administration? While other works allow tracking coins and owners, this possibility is cryptographically limited to a few entities. Specifically, in some works, only the bank or TTP can track the coin and owner independently; in others, it is required that the user "send" useful tracking information. This implies that if a citizen wanted to know how his tax money was spent, he would have to request "special permission", non-standard based, from the bank or TTP. If he even wanted to check how the total amount of all taxes was spent, additional information would be required. On the other hand, ECC does not require any information from citizens, and everything can be accessible to everyone.

Regarding the resiliency feature, ECC can continue working even if a part of the system (e.g., a DNS server) becomes unavailable. In this case, only the information retained by the impacted server would not be available. This differs from blockchain architectures, where the resiliency is extreme (no one can block, mutate or destroy a blockchain) but with issues that make them unsuitable for central banks (e.g., high energy consumption and subsequent environmental impact, pseudo-anonymity). Finally, the last two rows of the comparison table show significant improvements to state-of-the-art, native, standard-based support for two important features of future cash: smart rules and non-fungible coins. They are the mere porting of two of two interesting features of the blockchains.

Blockchain is considered the de facto standard for transparency and traceability, inspiring the development of CBDCs. However, central banks do not favour complete decentralisation and pseudo-anonymity; they prioritise control and data management. While some CBDCs are based on Blockchain, they incorporate significant modifications that alter the original purpose for which Blockchain was invented. Additionally, blockchain technologies are often criticised for high energy consumption due to consensus algorithms like proof of work, which do not align with the sustainability requirements that all public entities, especially banks, must adhere to. For all these reasons, the state-of-the-art review did not include works related to blockchains, not because they are uninteresting but because they would have significantly complicated the discussion without providing substantial contributions, given their partial applicability to the world of CBDCs. Finally, the ECB itself has stated that the D€ project, which serves as a benchmark for our study, will not use blockchain technology.

The second part of our study was aimed at proving that the architectural complexity brought by the e-money track-and-trace service is worth the increase in customer acceptance. A survey was designed to assess the change in BI after a stimulus was provided to respondents. Privacy issues and unperceived benefits are the leading causes of poor CBDC adoption, so our suggestion to improve customer acceptance of CBDC (i.e. the stimulus) consists of giving citizens the new track-and-trace service to check public money expenditures. The foundations of our hypothesis are:

- Privacy will always be a concern for citizens. But the social network era is teaching us that people are willing to give up a piece of privacy if provided with new and engaging tools;
- If privacy concerns can't be dismissed, then institutions should give up the same piece of "privacy" (let's say "confidentiality") as well.

The stimulus is designed to impact the hedonic motivations of respondents. People are generally unhappy paying taxes, particularly in Italy, where it is particularly high to compensate for tax evasion. The survey confirmed this since 88.9 percent of respondents are very to quite concordant with the statement of a poor match between tax amount and perceived benefits. So, it proves we found the right stimulus: the track-and-trace service could instil a spirit of social payback in citizens who felt oppressed by tax institutions. When we asked if it would be favourable to be monitored by institutions by means of a CBDC, almost a third of respondents were unwilling to adopt the CBDC (30.5%). Also, 17.7 percent declared that they had no opinion. Surprisingly, we discovered that the unfavourable subset presents no significant traits in the sense of generation, occupancy and education.

After giving the stimulus, we measured the new willingness to adopt the CBDC. The acceptance before and after the stimulus allowed us to compute the increase in BI. 79.5 percent of respondents said they would be more willing to adopt the instrument, with the remaining 20.5 percent having the same opinion. These percentages are not fair since they include the opinion of people who were already favourable to be monitored on the D€ CBDC: we are not interested in this subset because they don't manifest privacy issues. So, we deepened our analysis by inspecting the size and the characteristics of unfavourable people to understand the specific target of people who can change their minds after the stimulus. The conversion rate over unfavourable respondents remains consistent (73.83%), even if it is notable a systemic reluctance in Gen X where participants remain more sceptical. Are these BI change rates worth the effort to implement the IoT-based CBDC? It is not our task, but the central bank's and the authorities' task is to understand it.

In this work, we made some assumptions that may impact the significance of the results. The main threat to internal validity is that the participants were selected using convenience and snowball sampling techniques. This mixed approach was the quickest to implement, but it made the results representative of an uncontrolled population and made them susceptible to biases. For example, we may not have reached a sample of the population with a different opinion. Particularly, since the snowball technique relies on the relevance of the participant referrals and being the first set of respondents being selected in the university population, the respondents with very low levels of education were relatively low in number and broadly corresponded with parents and relatives of the first set. Moreover, we administered the questionnaire with online forms, whose link was shared across conventional messaging apps and social networks, so we have limited information on the non-response bias. It suggests that our sample could be somewhat biased regarding Internet usage, which is likely correlated with the willingness to adopt CBDC. Finally, the rather high share of self-selected interviews causes uncertainty. To compensate for this, we checked for potential biases in relevant variables by cross-checking the responses to the questions.

The main threat to external validity is the design of the study around the specific needs of the Eurozone, which may lead to the non-applicability of the results to other contexts. To mitigate this risk, we carefully reported the main characteristics of the clusters of people involved so other institutions could cross-check the characteristics of different samples. Moreover, we provide the replication package, which can be useful to reproduce the same experiments in other economic areas. The main threat to construct validity stems from selecting only one stimulus as a proxy for BI change, which may be subjected to other variables. To mitigate this risk, we encourage other researchers to reproduce this study, extending it with another kind of stimulus, like using value-added services in CBDC.

CONCLUSIONS

This paper investigates the potential for increased acceptance of CBDC, such as the D€, through sophisticated tracking services that facilitate monitoring governmental expenditure. The adoption of CBDCs is facing challenges on a global scale, with privacy concerns and the lack of perceived benefits emerging as significant obstacles. We surveyed a sample of 351 Italian respondents to ascertain the impact of a stimulus on respondents' hedonic motivation in accordance with the SOR model. The hedonic motivation was triggered by instilling a spirit of social justice in citizens who perceived themselves to be oppressed by the tax system. The pre-and post-stimulus acceptance rates enabled us to calculate the change in BI. The proposed IoT-based track&trac CBDC can improve the customer acceptance of CBDCs, and this can be inferred from the survey that was conducted. The survey yielded the following result: 73.83 percent of participants who were initially sceptical about being controlled by authorities on the D€ CBDC would be more willing to adopt the same CBDC if they could monitor the state's expenditure of public money.

The main outcomes of this work are the following:

- The study discusses and emphasises the importance of transparency as a prerequisite for a productive relationship between banks, financial institutions and citizens. It identifies the challenges for comprehensive monitoring of individual coins to achieve genuine transparency in CBDCs.
- They study reports and discuss state-of-the-art e-money tracking from 1997 to date, proving that none of the existing solutions can satisfy the requirements of a typical CBDC.
- The study reports on the development of an IoT-based CBDC called ECC. Particularly, detailed track-and-trace mechanisms are.
- The study provides an overview of the public acceptance of CBDCs on a sample of 351 respondents from south Italy, highlighting an effective way to increase their BI.

This paper can be of significant interest to various stakeholders in the banking and financial industry:

- Central bank working groups could enhance customer acceptance of digital payments by offering powerful money-tracking services to citizens.
- Financial intermediaries, such as private banks, can provide their customers with new mobile banking apps to monitor how the bank uses their investments.
- Fintech start-ups could launch innovative stablecoins based on the proposed technological model.
- Computer science researchers can design and experiment with novel payment services on top of the proposed IoT-based CBDC, thereby enhancing the user experience in financial transactions within smart cities.
- Researchers in the financial and economic fields can investigate how specific individuals use public subsidies and government incentives and analyse the precise economic benefits for countries, regions, or even specific sectors.

Several limitations and constraints must be acknowledged, which may impact the interpretation and generalisation of the results. Firstly, the considerable storage necessities present a substantial challenge. The estimated 115 terabytes (TiB) of storage required on a monthly basis for the tracking of transactions within the European market, in addition to the requisite backup procedures, give rise to concerns regarding the feasibility and environmental impact of such a system. Future research would benefit from concentrating on optimising storage solutions and assessing the ecological footprint.

Secondly, privacy concerns could be a limitation. The centralisation and detailed tracking of transactions may raise concerns about the extent of surveillance. It is of the utmost importance to balance transparency and the protection of privacy, which can only be accomplished by developing privacy-preserving mechanisms. Thirdly, the study's findings on the potential for increased CBDC acceptance are based on hypothetical scenarios presented to respondents. While these scenarios are grounded in the proposed technical framework, user behaviour may differ when interacting with a fully implemented system. In order to observe and analyse user adoption patterns over time, it is necessary to conduct real-world pilot projects and longitudinal studies, taking into account evolving perceptions and potential technological advancements.

Considering all the study's limitations, further research is required to evaluate the potential benefits of an IoT-based approach for CBDC for various stakeholders, including regulators, citizens, companies, and researchers. Although this proposal represents a significant advancement in the field of digital currencies and the integration of the Internet of Things (IoT), it also reveals the necessity for further research to be conducted in order to realise its full potential. The future research challenges encompass a number of critical areas, including the development of privacy-oriented transparency models, the formulation of security considerations for IoT payments, the creation of AI algorithms for regulatory compliance, the advancement of energy sustainability, and the resolution of scalability concerns.

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