Evaluating Effects of the Payment Ecosystem on Central Bank Digital Currency Adoption and Design

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Abstract

Central bank digital currency (*CBDC*) *has become a discussion topic with worldwide economic and societal relevance. Payment system efficiency is a top driver for digital currency adoption. We examine literature gaps for payment ecosystem impact for adoption and design and conduct a test for 65 World Bank countries. We assess payment alternatives and preference impacts and estimate least squares and limited dependent variables regressions based on cross-national data. CBDC adoption is driven by payment ecosystems, alternative payment characteristics, e-money usage, perceived security, and infrastructure. This signals that user familiarity with digital payments, trust in authorities, and structural capabilities support adoption. It also is inversely related to alternatives that dampen the need for CBDC. Transaction volume and trust in authorities are linked to choosing a central database instead of a digital ledger technology infrastructure. Deviations occur due to ambiguous effects of cash and ledger technology usage for CBDC adoption and industry concentration, architecture, and systems linkages.*

1. Introduction

Over the past decade, central banks, policymakers, and academics have discussed and evaluated the potential of CBDC. Interest peaked when the threat from private cryptocurrencies increased, suggesting digital currency system feasibility. Cryptos, stablecoins, and other currency initiatives threaten central banks' pivotal role in the financial ecosystem (Bijlisma et al. 2021). El Salvador declaring Bitcoin (BTC) as its legal tender in 2021 is an exemplar of how institutions are increasingly open to non-conventional instruments in the financial landscape (Asamblea Legislativa 2021). Implementing a digital currency issued by central banks may answer these threats.[1] Also, it can be a great opportunity for the monetary system and a valuable instrument for achieving economic and social goals (BIS 2021a).

This year, 87 countries with over 90% of global GDP were evaluating whether to adopt a digital currency. Around the world, CBDC projects are in different development stages. Most are researching CBDC benefits (Atlantic Council 2022). We aim to understand the opportunities and how payment ecosystems influence adoption intention and design.

The reasons for central banks to consider the issuance of a digital currency depend on institutional and macroeconomic factors at the country and currency level, with payment efficiency a key driver (Boar & Wehrli 2021). The era of digital innovation is transforming the global payment system. And CBDCs, like credit cards and e-payments, may be the next leap forward in the payment landscape. CBDCs' disruptive power is conditioned on its acceptance in society though. This force may determine if CBDC is the future of payments, reshaping worldwide economic exchange in the 21st century – or just a nice-to-have alternative.

Our perspective is on CBDC as a payment system innovation. To evaluate its adoption, the supply-side rationale by central banks must be matched with the demand-side view of their counterparties. The supply side and macroeconomic goals are more well known, but *willingness-to-adopt* needs assessment (Alonso et al. 2021). What matters is the degree of acceptance in society and a CBDC's advantages compared to other digital payment means. Users also may not see sufficient reason for another payment instrument with other efficient alternatives already in place. Building on network theory, users and merchants must benefit from adopting a CBDC (Jiang 2020).

We will evaluate the potential of retail CBDC as a novel payment instrument in the existing ecosystem. For central banks and policymakers, it is vital to assess the impact of the current system on CBDC development.

[1] A reviewer characterized a CBDC as a *decentralized autonomous organization* (DAO): "[*M*]*any governments are developing CBDC systems … mostly to take full control over the finances and economy. The organizations and people who are developing CBDC fear* [*on one side an*] *incoming … financial and* [*economic crash and*] *from the other side are afraid* [*of*] *fast developing startup companies creating* [*their*] *own token*[*s*] *on a blockchain* [*base. This has become a*] *popular (decentralized, and … more democratic) alternative for government (centralized) financial solutions.*"

URI: https://hdl.handle.net/10125/103283
978-0-9981331-6-4

Evaluating whether it has business value is a first step toward measuring whether the benefits will outweigh the costs from implementation. We offer an evaluative framework to assess CBDC adoption given a country's characteristics. We address two key RQs:

(RQ1) What effects do the available payment alternatives have on national CBDC adoption and payment alternative preferences? We posit that the extent to which alternatives are available to users should influence a CBDC project's status. We will assess the impact of the instruments and payment services quality available. The more alternatives and the higher their quality, the lower will be the need for adopting a new CBDC.

(RQ2) How do payment ecosystems impact CBDC design choices? The more users are ready for CBDC in terms of their familiarity with digital means of payment, the lower the barrier to adoption should be. Thus, the closer user payment behavior will be to CBDC usage mechanisms, and the more advanced a CBDC project should be.

We will evaluate whether payment variables we identify are associated with different design choices, to connect them with the payment ecosystem's characteristics for payment alternatives and user preferences. We also will test theory based on hypotheses that address country-level RQs. Our dataset was built using data from the World Bank and the Bank for International Settlements (BIS) for 2017 to 2022.

2. LITERATURE & BACKGROUND THEORY

2.1. Background

Several studies examined CBDC research due to attention from the public, research, and professional communities after 2018. The primary streams of research in this area can be seen in a *keyword co-occurrence network map*. (Figure 1.)

CBDC is due to Tobin (1987), who proposed *deposited currency*. These are funds offered by the U.S. Federal Reserve to provide an instrument with built-in safety, public currency, and convenient deposits. This evolved over the years into CBDC as we know it today (Meaning et al. 2018). A useful definition offered by the International Monetary Fund (IMF) is:

> "A d*igital representation of a sovereign currency issued by and as a liability of a jurisdiction's central bank or monetary authority*" [Kiff et al. 2020, p. 9].

A CBDC is intended to be a *sovereign currency* convertible at par with other forms of money as national currencies. It is recognized as legal currency so debtors can meet monetary obligations by tendering it to creditors (Bossu et al. 2022). The BIS (Bech & Garratt 2017) and the European Central Bank (ECB) (Bindseil 2020) view it as a *third form of money*.

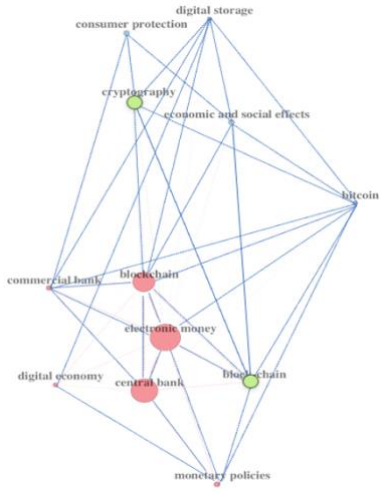

Figure 1. CBDC Keyword Co-occurrences
Adapted from Aria and Cuccurullo (2017) and Scopus

2.2. Common Characteristics of CBDCs

CBDCs can be issued by central and commercial banks, non-bank institutions, or individuals as private currencies in e- or non-e-form – with universal or limited access, and a P2P transfer or exchange mechanism. CBDCs are like reserves and cash, but differ from deposits, mobile money, and private currency. These are liabilities of banks, *payment service providers* (PSPs), and firms (Bech & Garratt 2017).

As a direct liability of the central bank supported by sovereign credit, CBDCs implement the functions of money differently than other digital assets such as private cryptos, whose characteristics depend on legislation (Yao 2018). Unlike cash, CBDC is electronic, can bear interest, and can support P2P transfer based on decentralized exchange, enabling transactions without financial intermediaries (Kumhof & Noone 2018). CBDC access depends on whether retail or currency for public or wholesale use with limited access for a specified user group in settlement for financial institutions (Auer et al. 2020). (Table 1.)

What differentiates CBDCs from other payment methods depends on the selected design. CBDCs may be faster, cheaper, and guaranteed, enabling cross-border payments and anonymity, but depend on their design and implementation (Bijlsma et al 2021). A survey of central banks (Boar & Wehrli 2021) noted motives for issuance: (1) payment efficiency; (2) financial stability; (3) monetary policy; and (4) financial inclusion. Emerging economies often have more reason for CBDC implementation compared to advanced economies. The key for them is financial inclusion, while advanced economies promote safety, robustness, domestic payments efficiency, and financial stability.

Table 1. CBDC & Other Money Forms Compared

Aspect	Retail CBDC	Cash
Issuer	Central bank	Central bank
Form	Electronic	Physical
Accessibility	Universal	Universal
Transfer	P2P	P2P
Remuneration	Interest or none	No interest
Payment finality	Design choice	Immediate
Merchant, user cost	Design choice	Low
Identification	Design choice	None
Anonymity	Design choice	High
Offline payment	Possible	Yes
Cross-border	Design choice	Yes

Aspect	Mobile Money	Cryptos
Issuer	Banks, fintechs	Firm, individual
Form	Electronic	Electronic
Accessibility	Universal	Universal, limited
Transfer	Centralized	Both
Remuneration	No interest	No interest
Payment finality	PSP confirms	If transaction valid
Merchant, user cost	Transaction fee	Mining fees
Identification	Account-based	Token-based
Anonymity	None	High
Offline payment	No	No
Cross-border	Often avail	Yes, by default

Efficiency. Support for CBDCs lies with the benefits of payments, clearing, settlement efficiency, and safety. They encourage transparent spending and settlement and lower transaction costs as an alternative to digital payments (Ozili 2022). This is due to central banks' non-profit nature, so CBDCs are public goods in a society (Bordo & Levin 2017). Also, they may support payment system resilience, overcoming risks arising from natural disasters and digital failures.

Issuing a new digital currency can foster competition in the payment sector if it is offered via a platform open to PSPs. A beneficial effect is lower barriers to market entry when there is a concentrated group of operators (Soderberg et al. 2022). This can spur new technology and platform adoption on top of existing payment infrastructures though. CBDCs may result in direct competition with existing payment instruments as a result, representing new rivalry.

2.3. CBDCs and Payment System Challenges

The advantages of domestic payment efficiency gains are not straightforward and differ by jurisdiction (BIS 2018). CBDCs may not lead to higher transaction speed though, with cross-border retail payments still slow, expensive, and less transparent. So, for large-value payments, existing *real-time gross settlement* (RTGS) mechanisms may be better. They ensure liquidity savings, access to overdrafts, and security, so CBDCs' value is unclear (Gnan & Masciandro 2018).

Stability. Issuing a CBDC contributes financial stability due to central banks' role in intermediation by limiting the scope for commercial bank operations. As demand grows, a widely adopted CBDC may increase disintermediation risk though, with funds moving from private financial institutions toward central banks. In periods of distress, an appealing CBDC may facilitate bank runs, disrupting the banking system. Thus, advantages arising from CBDC issuance and design must be weighed against risks and drawbacks, and solutions to lessen reintermediation risk (e.g., a ceiling on maximum CBDC amount).

Policy. CBDCs issued by central banks may become valuable tools for monetary policy too, enabling price and currency stability, and systematic, transparent policy (Bordo & Levin 2017). They can augment policy via transmission pass-throughs of policy rates to money and lending markets. CBDCs don't alter monetary policy though they may bring new system risks. Demand volatility could make liquidity forecasting less predictable, but interest rates will still be dependent on other factors – adding complexity (BIS 2018).

Inclusion. Adopting CBDC is beneficial for financial inclusion. It supports access to more affordable financial services in less profitable areas for commercial operators (Raskin & Yermack 2016). This is due to offering offline transactions enabling payments in remote areas without the Internet. CBDCs may not reduce the constraints that create financial exclusion, however. Digital exclusion, digital illiteracy, and low incomes will remain barriers, even with CBDC adoption. Another difficulty is strong pushback against cash usage in the population, too (Ozili 2022).

Miscellaneous. There are other reasons that central banks report as relevant when considering CBDCs. Such instruments strengthen monetary sovereignty by providing households with central bank-issued money for situations in which cash usage is declining. Further, a digital currency may help to tackle money laundering and terrorism financing, thus reducing illicit money usage. Payment traceability can support a*nti-money laundering and combating financing of terrorism* (AML / CFT) goals and incentivize reduced illicit economic activities. Greater transparency can be levered to build economic activity and reporting yet allow for extensive real-time data collection (BIS 2018). So, CBDCs are a response to the threat of wider adoption of private currencies. Issuing CBDCs may also discourage adoption of private digital currencies, redirecting demand (Yanagawa & Yamaoka 2019).

2.4. Technical Choices for CBDC Designs

Framework. Adopting CBDC involves implementation decisions that will shape its nature, scope, and effectiveness. A useful design framework can activate demand for digital currency (BIS 2021b). In the *CBDC pyramid framework* (Auer & Böhme 2020), decisions are: (1) *architecture* for the claims structure and operational roles of central and

commercial banks; (2) *infrastructure* adopted for a DLT or database; (3) *account access* or *token credentials*; and (4*)* domestic or cross-border payment links.

Architecture. The technical design choice for different operational models is key. This determines the legal structure of claims and the division of scope for central banks and private intermediaries. Central banks' balance consumer needs to have an instrument with the same advantages as cash for P2P and real-time exchange – though it may be offered in a less convenient way. If a *direct model* is chosen, a CBDC will involve a direct claim on the central bank. It also must manage retail payments, transaction recording, and updating balances.

Another possibility is to adopt a *hybrid CBDC architecture* (Auer et al. 2020). Consumers still will have direct claims on central banks, but their payments will be managed by other intermediaries. Central banks will record retail balances periodically only, while delegating transaction management to commercial banks or other authorized intermediaries. Under *intermediated architecture*, central banks won't record retail transactions or balances, just wholesale balances, so CBDCs retain their claim on central banks.

Finally, with the *indirect model* – with a *synthetic* or *two-tier CBDC* (Auer et al. 2020), the claim is no longer on the central bank but on other intermediaries, though fully backed by the central bank. This is the closest option to the current two-tier financial system we have today, where customers' claims are only indirectly linked to a central bank, which is dedicated to wholesale account management. This approach allows shifting responsibility for resolving disputes and *know-your-customer* (KYC) due diligence to intermediaries. An intermediated model may minimize the disintermediation risk too but need more supervision.

Infrastructure. CBDCs operate with two infrastructure models: (1) *conventional databases controlled by central banks*; or (2) *distributed ledgers based on blockchain technology*, with each transaction having a ledger update with CBDC transfers between accounts. If a centralized database is selected, the transaction registry is owned and managed by a single entity. A DLT system involves multiple parties with decentralized digital cryptography. Central banks can jointly own and update a ledger-as-an-entity or retain ownership. With DLT, authorized private intermediaries are responsible for ledger management and update recording (Soderberg et al. 2022).

In traditional databases, *resilience* is achieved by storing data in multiple physical nodes. In DLT systems, resilience relies on message broadcasting and replies from multiple nodes which need to achieve consensus to successfully append transactions to the ledger. *Decentralization* is due to distributing the validation of the transactions to a network of "miners" within a permissioned network of recognized institutions from the central bank. Using a blockchain ledger to record transactions may save processing and bookkeeping costs. It may also facilitate tax evasion detection and money laundering due to easier transactions monitoring.

With lower transaction levels compared to conventional architecture, DLT may not be suitable for direct architectural models, except for settings with low data volume. DLT is an emerging technology so its capabilities are under evaluation. DLT settlement finality of irrevocable and unconditional transfers of value may be unclear if finality for distributed blockchain systems is unregulated (BIS 2017).

Access and linkages. Accessing a CBDC can occur via an account or a *token-based access model*. In the first instance, access involves linking currency ownership to identities. With a token-based authentication form, access is based on cryptographic schemes. The key distinction regards the identification requirements since access is based on accounts and an identity system must be in place. A token system is cash with no ID required, but knowledge of an encrypted value instead. So, losing tokens may be easier (e.g., no log-in information would cause asset usage to decline) (Bossu et al. 2022).

CBDCs can be also classified according to selected domestical or international linkages. If central banks pursue a national-only CBDC, they still must face the issue of linkages in the domestic payment system. *Interoperability* is viewed as a barrier to CBDC adoption and functionality. To ensure its competitiveness and the transition among alternative methods, interoperability between a CBDC and substitute forms of payment must be guaranteed (Lee et al. 2021). Linkage choices are influenced by the access features chosen. With token-based identification, CBDC should be accessible for anyone – foreign residents too – with account-based access, so international features become design choices.

3. Research Setting: The CBDC Context

We next turn to the context of this research in the countries and conditions under which CBDC adoption decisions occur. We considered the environments in which the involved parties interact: the public, industry-specific entities, and bank regulators.

3.1. Adoption Status and Design

As of 2022, 87 countries were evaluating adoption of CBDCs – 148% growth since 2020. Adoption status differed by degree of development of the projects reported (Appendix A). The extent of adoption was based on when a CBDC was launched and became live.

Nine countries in three currency areas with CBDCs were live in 3Q 2022. Those launched in: The Bahamas,

Eastern Caribbean, and Nigeria. Also, fifteen countries including China, Russia, and South Korea were in the pilot stage; the CBDCs were not launched but in prototyping to evaluate public response before going live. Canada, Brazil, and Australia were without plans for launch, but actively building the required capability for issuance. Ecuador's project was canceled after launch in 2014 due to lacking central bank trust; in Senegal, the central bank withdrew.[2]

Most countries are undecided on how to implement CBDCs. Among those having decided, the hybrid model is most popular for architectural design. Hong Kong is the only country evaluating an indirect architecture. In terms of infrastructure, half of the countries have been evaluating centralized databases and the rest DLT.[3] Further, account-based access has been a primary choice to manage CBDC access, followed by adopting both infrastructures to accommodate different types of access.[4] The choice for international versus national linkages for cross-border CBDC interoperability is 50% (Auer et al. 2020). But the preference for a national-only CBDC indicates standards and interoperability issues due to missing cooperation (Atlantic Council 2022). A final aspect of CBDC project status involves currency areas. They began to emerge recently.[5]

3.2 Stakeholder and Ecosystem Issues

To evaluate, issue, and maintain a CBDC, multiple parties (besides central banks) are involved or affected in the process. Three launched CBDCs – Bahamas' Sand Dollar (www.sanddollar.bs), Eastern Caribbean's DXCD Caribe (www.eccb-centralbank.org), and Nigeria's eNaira (enaira.gov.ng) – exemplify stakeholders' ecosystem roles (Atlantic Council 2022).[6]

The Bahamian Sand Dollar was launched in December 2019 as a retail and wholesale project. The goal was universal user access to digital payments and banking services for the population and for micro, small, and medium-sized enterprises. The country was 35th for bank branch presence but this average hides disparities among the 700+ islands belonging to the archipelago. With high population dispersion in rural areas, family-focused island communities have had limited services access and thus have been cash-reliant. To address this, the central bank envisioned a digital instrument like cash, only with similar value as the existing currency. The Caribbean CBDC didn't aim to substitute for cash but to overcome financial frictions due to an excessively slow and expensive national payment heritage.[7]

The Bahamian CBDC's requirements involve a basic due-diligence process without the need for a traditional banking account if the volume and profile of transactions are not classifiable as business operations.[8] The Sand Dollar was designed to be non-interest bearing to reduce its similarity to bank deposits, thus limiting disintermediation risk. The same mechanism applies to the e-Naira with its prespecified daily transaction and balance limits, with the applicable thresholds differing according to the tiers. For bank account holders, the limits were higher compared to non-account owners. In contrast to the Sand Dollar, the e-Naira has placed no limits on merchants' wallets also.

The main CBDC stakeholders have been institutions operating in the financial sector – either licensed intermediaries or non-bank firms providing financial services. In the Sand Dollar project, commercial banks maintain the currency ledger and oversee due diligence activities with credit unions. They don't provide customer services and digital wallet platforms. The Bahamian Central Bank, in its mission to foster innovation, encouraged participation of non-banks in the e-payment market. Mobile wallet solutions for the public are complements to PSPs' offerings. Banks are required to share customer KYC documentation with PSPs and to honor withdrawals in real-time from the wallet accounts.[9]

As anticipated, central banks partnered with technology solution companies to ensure the capability to run a CBDC. The Central Bank of the Bahamas, following a selection process to guarantee the robustness of the services regarding infrastructural and regulatory standards, selected NZIA Ltd. (nvia.io) as its

[2] 43% of countries were in the research stage with CBDC included in their strategic plans without any immediate commitment to development. The U.S. is the largest economy and farthest behind in the research phase. Seven projects were inactive and two got cancelled. An inactive project was in Denmark, where progress stopped because the CBDC was deemed unnecessary. The central bank declared unclear benefits from implementation. Denmark has an innovative, already secure, and efficient payment infrastructure.

[3] Large countries (Brazil and Sweden) were interested in DLT infrastructure. A majority is considering both solutions.

[4] Only four countries (S Africa, Uruguay, Kazakhstan, Curaçao) prefer token-based access.

[5] Project Dunbar has aimed to establish payment interoperability across Singapore, Australia, Malaysia, and South Africa. This project is led by the BIS Innovation Hub (2022) and based on a platform for international settlement among the involved national CBDCs.

[6] Sources are the Central Bank of The Bahamas (2019), Eastern Caribbean Central Bank (2019), and eNaira.com (2021).

[7] The central bank reported, for example, that fees for merchants approached 3.5% on every merchant sale via a credit card – too high.

[8] For high-value transactions and commercial operators, tighter requirements were put in place, and a link with a domestic account at a financial institution became compulsory. Both individual and business accounts are subject to ceiling amounts of issuable currency and monthly transaction limits also.

[9] For the Bahamian CBDC, fintech firms partnered with banks in CBDC activities. In this case, the parties are reversed though. Bitt Inc., a crypto solutions fintech approached Eastern Caribbean Central Bank to propose a CBDC. Factors that mattered were firm fit, shared values, vision, Caribe identity, technical, and financial skills. Its CBDC was issued by a central bank and by shared by banks and non-banks.

IT services provider. It was selected due to its interoperability, offline, real-time, and point-of-sale support. Audible transaction trails, transaction monitoring, and security features such as KYC and multi-factor authentication were salient and valued. Instead, the Eastern Caribbean CBDC selected IBM Hyperledger Fabric (www.hyperledger.org/use/ fabric) as the technology provider due to its secure, flexible, and scalable blockchain platform.[10] Though launched, the project is considered a pilot with many details not yet fully defined. This platform is experiencing technical issues, so it seems stalled.[11]

The public sector and regulators play key roles in CBDC contexts. Authorities need to intervene in supervision and reviewing system members. They must ensure the process is undertaken with regulatory compliance to avoid AML and CFT crime. Compliance surveillance may not differ from the current system. In the e-Naira project, for example, customers are linked to a bank during onboarding. The same bank is then responsible for orchestrating all due diligence activities. This bank retains a supervisory role for related checks, as in traditional two-tier banking compliance.

4. Theory and Hypotheses

We conducted theory-building work. *We* observed no systematic understanding of how payment ecosystems contribute to CBDC adoption. Factors such as illegal activities, technological capabilities, and financial system characteristics have been proposed (Auer et al. 2020). CBDC demand depends on payment alternatives and social preferences for value-adding use, and accounting for different socio-technical factors. So, we viewed the value of adopting a CBDC as greater than the benefit of available alternatives (e.g., lower service costs, higher efficiency) and for institutional environment factors (e.g., opportunity costs, and institutional and valence theory effects). Three effects hypotheses on CBDC adoption and design are:

- **Hypothesis 1 (Payment alternatives).** *CBDC implementation is tied to ways to pay for banking, fintech, industry, and infrastructure.*
- **Hypothesis 2 (User preferences).** *CBDC implementation links to user preferences for ways to pay, e-money, cryptos, and perceived safety.*
- **Hypothesis 3 (Social reactions).** *CBDC design is associated with social reactions to new currency architecture, infrastructure, access, and links.*

5. Data and Empirical Methods

5.1. Dataset

Our sample of 65 countries[12] has five dependent and 23 independent variables (Table 2).[13]

Table 2. Model Variables and Definitions

Dep Vars	Definitions
CBDC Adoption, Likert 0-5	0: *CBDC project cancelled* 1: *Inactive project* 2: *Research stage* 3: *Development phase* 4: *Pilot project activated* 5: *CBDC launched and active*
CBDC Design: 1 if specific design, else 0	*Architecture* (direct, hybrid, indirect, mix) *Infrastructure* (central database, DLT, mix) *Access* (account, mix, token) *Linkage* (national, intl)
Indep Vars	**Definitions**
Banking	1: *Presence:* # branches per 100,000 adults 2: *Remittance prices:* Avg prices 3: *Regul:* Offers basic financial products
Fintech	1: *Adoption:* Fintech users % 2: *Fees:* Interchange card fees at standard rate 3: Regs: Non-bank e-money issuer scheme
Industry structure	1: *Bank concentration:* Assets of 3 largest commercial banks
Infrastructures	1: *Payments:* Faster payments innovation index 2: *Digital:* Mobile phone subscriptions and Internet users
Payment Methods	1: Cash transactions by individuals 2: Cash transactions by businesses
E-money Use	1: Mobile phones & online payment use
Crypto Adoption	1: *Individual:* % owning or using cryptos 2: Business: # of businesses accepting cryptos
Perceived Safety	1: *Index* on population perception of corruption, govt. effectiveness if Cronbach $\alpha \geq 0.96$
Design Arch	1: *Account fininst*: Account at financial institution 2: *Account mobile:* Mobile account ownership * *Proxy*: % adults in population with account
Design Infrastructure	1: *Trust:* Higher or lower reliability of authority 2: *Transactions:* Volume of transactions
Design Access	1: *Fin inclusion:* Bank offers basic financial products to population
Design Linkage	1: *Remittances outflow:* Annual volume 2: *Remittances price:* Avg price for sending countries

Note. Variable measures: Likert scales, binary, and continuous. Model specification: 5 dependent and 23 independent variables.

Of the countries, 32% are European, 26% Asian, 25% Americas (evenly representing North and South)

[10] This platform guarantees a private blockchain, able to limit access to the network and handle transaction validation in DLT fashion.

[11] A similar issue has been reported for El Salvador's Chivo wallet (*Finextra News* 2022), with technical malfunctions calling for infrastructure adjustments by the relevant PSPs (Sparkes 2022).

[12] Our sample was selected from among 193 countries (UN 2022) with a 90% confidence interval through non-probabilistic sampling based on subjective judgment rather than random selection. We considered the issue of sample selection bias, distortion of the results of the study, and erroneous conclusions. We dealt with this bias with our data analytics. For small populations, a sample like this gives more information compared to a large population (Israel 1992).

[13] Design variables are from BIS (Auer et al. 2020); adoption status from CBDC Tracker (Atlantic Council 2022). It is an open-source resource for global research. It covers cancelled, investigated, proof-of-concept, pilot test, and in operation CBDCs. (Appendix A.)

America, 14% in Africa, and 3% in Oceania. (See Appendix A.) Summary stats offer these insights:

- **Architecture.** 35 of 65 countries did not decide on their CBDC architecture, while 19 chose hybrid architectures. Seven chose a mix and two went with direct or indirect architectures.
- **Infrastructure**. 40 countries did not decide, while eleven opted for a mix and seven chose either a central database or a DLT solution.
- **Access**. 43 countries had not yet chosen a specific access method. Ten chose account-based access, eight adopted a mix, and the remaining four decided to proceed with token-based access.
- **Linkages.** 26 countries had not decided on their linkages either. However, 20 chose national linkages and the other 19 adopted international linkages, indicating contrasting views.

5.2. Empirical Models and Methods

The research design is based on a multivariate cross-sectional model with secondary data. It involves data collection for country observations, so more than one independent variable can be analyzed at a single point in time (Bell 2009). To explain CBDC adoption and design by testing the model's explanatory power, we invoked a path analysis method. Paths between variables were tested to yield readings on RQ1 and RQ2.

The model has an endogenous outcome, CBDC adoption, and eight coefficients. Four are payment alternatives and four are preferences. The effect of *payment alternatives* on CBDC adoption is formalized by subscript *A*, and *payment preferences* by subscript *P*.

We ran *ordinary least squares* (OLS) *regressions*:

$$CBDC_A = \beta_{0A} + \beta_1 x_{1A} + \beta_2 x_{2A} + \beta_3 x_{3A} + \beta_4 x_{4A} + \varepsilon_{iA}$$
$$CBDC_P = \beta_{0P} + \beta_1 x_{1P} + \beta_2 x_{2P} + \beta_3 x_{3P} + \beta_4 x_{4P} + \varepsilon_{iP}$$

To quantify the effect of the variables, we used a limited dependent variable model. It predicts the probability of implementing a design choice based on the payment ecosystem's characteristics. The general equation for the predictive model on CBDC design is reported with a design subscript *i* indicating architectural, infra-structural, access, or linkage choices. This let us test the effects of different design choices with the variables identified in our theory work instantiated via:

$$p(CBDC_i = 1|x) = G(\beta_0 + \beta_1 x_{1A} + \beta_2 x_{2P} + \varepsilon_i)$$

6. Results for CBDC Adoption & Design

Our hypotheses were confirmed, though some only partially. Tables 3 and 4 show OLS results for RQ1-2, and outcomes of the average marginal effects at the margin for variables in the logit regression.

The results are in line with our model structure and theory-based explanations, with minor exceptions. CBDC adoption was driven by differences in payment ecosystem characteristics, though the available payment alternatives seemed to have stronger influence.

Table 3. Payment Alternative & Preference Effects

Variables		CBDC Adoption	Variables		CBDC Adoption
Banking	1	-0.009*** (0.000)	*Payment*	1	0.064** (0.028)
	2	0.064*** (0.001)		2	-0.232*** (0.022)
	3	-0.275*** (0.008)			
Fintech	1	2.026*** (0.015)	*E-money*		0.081*** (0.008)
	2	3.154*** (0.680)			
	3	-0.216*** (0.008)			
Industry		-0.008*** (0.000)	*Crypto*	1	0.032*** (0.001)
Infrastructure	1	0.129*** (0.002)		2	0.000 (0.000)
	2	0.004*** (0.000)	*Perceived*		1.738*** (0.021)

Note: Robust SEs in parens. Signif.: *** $p < 0.01$, ** $p < 0.5$, * $p < 0.1$; vars: see Table 2 for varnames associated with #s (1, 2, 3) above.

Table 4. Estimation of CBDC Design Variables

Vars		*Architecture*	*Infrastructure*	*Access*	*Inter-linkage*
Account	1	0.001*** (0.000)			
	2	-0.052*** (0.007)			
Infra-struc	1		0.144*** (0.009)		
	2		33.618*** (1.778)		
Fin				0.066*** (0.004)	
Remit	1				7.978*** (0.518)
	2				-0.017*** (0.001)

Note: Robust SEs in parentheses *** $p < 0.01$, ** $p < 0.5$, * $p < 0.1$, See Table 2 for variables associated with # (1 and 2) above.

For RQ1, CBDC adoption is associated with banking presence and payment alternatives' quality, measured by fees, remittance costs, and consumer protection. A positive relationship was found for the extent of fintech adoption in the countries. Payments and digital infrastructures, hardware, and software were positively associated with adoption also. In contrast, industry concentration did not have a strong impact, yet

it was bit negatively related to the outcome.

For RQ2 on payment preferences, CBDC adoption was positively related to cash usage by individuals and negatively related to business usage. The use of e-money and cryptos was directly linked to adoption, though their acceptance by businesses was not relevant as for individuals. Money safety proxied by government reliability was linked to CBDC adoption, too.

Our results for CBDC design choices signal a higher likelihood of choosing a direct architecture and less mobile account ownership. However, accounts at formal financial institutions reduced the probability of observing a direct model. The higher that trust was in authorities and transactions, the higher the probability of a central database being used. Stronger financial inclusion led to a higher probability of choosing account-based access. Last, the probability of international features being chosen was positively impacted by the remittance volume and negatively associated with price.

7. Discussion & Limitations

7.1. Discussion

Payment ecosystem variables play a key role in CBDC adoption progress toward launch. Payment alternatives and preferences also impact adoption and design choices. Fintech adoption also seems strongly affected by the payment alternatives present and their design quality. Payment infrastructure status and perceived safety seem to matter too.

Identification of the relative importance of factors influencing adoption are likely to support policymakers in evaluating the fit of a CBDC according to the characteristics of the country under analysis. Applying our model aids understanding which country and instrument characteristics count most for a country and should have more weight in CBDC decisions.

Further, extension of the analysis to CBDC design choices suggests which combination of features may be suitable for each of the countries. Central banks can exploit the proposed links between the design choices and the variables to search for the best fit based on business policy objectives and payment ecosystem characteristics in each country.

This work offers a theoretical contribution from its novel model based on authoritative literature and the links it levers between different explanatory foundations. In contrast, our methods contribution lies not in the data and analytics chosen. Instead, our empirical application of a relatively simple model is to a large selection of countries of interest. This allowed us to quantify the salient effects, while going beyond a purely descriptive approach. This work forms a basis for further research. We hope to validate the results, address the key issues in more refined ways, and tailor the explanatory model and its variables for studying payment region issues. The impact of the fintech construct also highlights the importance of bridging different disciplines and research perspectives in the study of CBDCs.

The research also contributes to practice and industry. CBDCs represent a business opportunity, especially for firms involved in the fintech sphere. This is demonstrated by the case of Bitt Inc.'s engagement with the Eastern Caribbean Central Bank. Other firms in the sector can leverage this example and propose capabilities for banking regulators to test and develop, to support central banks for the CBDC work. Many types of firms will benefit. Merchants can begin a digitization processes the closer their country is to being future-ready for CBDC adoption and to accept emerging digital payment methods in their business models.

7.2. Limitations

The study has several limitations. Our results depend on the model and variables we used. They may not necessarily fully reflect the complex nature of national-level CBDC adoption. Regarding the model, our approach has not effectively demonstrated causal relationships among the dependent and independent variables yet. The conclusions we arrived at are related to the existence of relationships among variables and their relative strengths (Jeon 2015). A limitation lies also in the variables chosen and measures applied to represent the various constructs. Different variables could have been employed to capture the proposed construct links – with the possibility that the effects might be a bit different.

There are other factors that may influence CBDC adoption and design besides the ones we considered, too. Our goal was to analyze the effects that arose within the payment ecosystem only. This may be narrower than what we hope to accomplish with this research though – by looking beyond national ecosystem issues. On a more positive note, our conscious decision was to "do what was doable" and "research what was reachable" in the challenging industry context we selected for this inquiry. With these caveats in mind, the likely generalizability of the results is surprisingly high, considering the large sample size we achieved compared to the overall number of UN countries.

We are realistic and self-critical though: our sample is not balanced in terms of the characteristics of the countries that were included – a scientific impediment for effective *causal inference*. We plan to tackle that problem in future *quasi-experimental research* on CBDC adoption and design. That is likely to involve *propensity score matching* (PSM)-based country subsample construction, *synthetic dataset replication*

(SDR) to expand our sample to support experimental simulation, and deep learning-based data analytics like *convolutional neural network* methods.

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Appendix A. CBDC Adoption: Global Status (Atlantic Council 2022) and Results Robustness

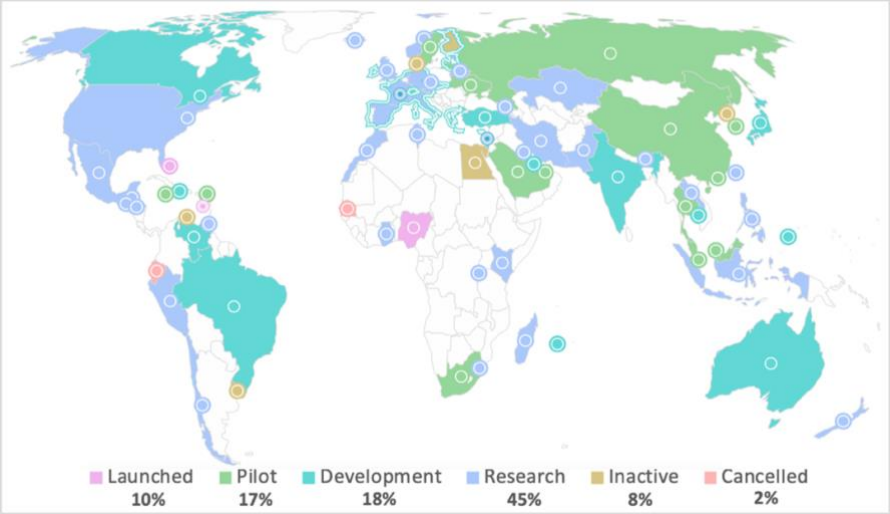

Figure A1. CBDC Projects: Launch, Pilot, Development, Research, Inactive, Postponed

Interpretation. Almost every country that has examined wholesale CBDC has also been assessing retail CBDC. Their adoption status around the world differs according to their degrees of development for the projects reported. (Figure A1.) Nine countries in three different currency areas have live and operational CBDCs. Also, fifteen are in the pilot stage, where the CBDC has not yet been launched but is still in prototyping to evaluate the public's response before going live. Canada, Brazil, and Australia are currently in development with no immediate plans for launch but building capability for potential issuance. Further, 43% of countries are still doing research, with CBDC included in their plans but without commitment to development. The U.S., behind in CBDC project R&D. Finally, seven projects have been inactive and two were cancelled. An inactive project is in Denmark, where it was stopped because the CBDC was deemed unnecessary due to the country's already-advanced digital payment infrastructure.

Robustness checks. To understand the reliability and quality of our results, we performed checks for internal consistency and model assumptions. *Internal consistency* is ensured by aggregating only measures with Cronbach α's higher than 70%. This was done to favor validity over interpretation, as shown by multiple variables reported, instead of one per construct. To ensure unbiased OLS results, we first plotted the standardized residuals against the regressors, and saw no deviation from linearity. Then, the absence of collinearity was tested by calculating centered *variance inflation factors* (VIFs) for the independent variables. The mean VIF ($1.36 < 1.80$) suggested no regressors among the 47 we specified were highly correlated with the constant. Thus, no multicollinearity was detected.

We also ran tests that suggested the presence of heteroscedastic data could not be rejected. Skewness and kurtosis tests for normality also revealed non-normal data. Yet our results are still reliable: the two necessary assumptions were met. To adjust for heteroscedasticity, we used *robust SE estimation* (Hayes & Cai 2007). Finally, with the large sample involved, the normality assumption could be relaxed based on the *central limit theorem*. The distribution of estimates thus converged to a normal distribution, so the absence of normality did not impair the results (Pek et al. 2019).