Rise of the central bank digital currencies: drivers, approaches and technologies*

Raphael Auer,♦ Giulio Cornelli♦ and Jon Frost♦†

This version: 15 December 2021

Abstract

Central banks around the world are researching and developing central bank digital currencies (CBDCs). Yet the motivations for issuance, policy approaches and technical designs differ across countries. We set out a comprehensive database of CBDC projects and technical approaches, and investigate the economic and institutional drivers. Most projects are found in digitised economies with a high capacity for innovation. Work on retail CBDCs is more advanced where the informal economy is larger. Many central banks are considering architectures in which a CBDC is a direct cash-like claim on the central bank, but the private sector handles all retail services.

Keywords: central bank digital currency, CBDC, payments, central banking, digital currency, digital money, distributed ledger technology, blockchain.

JEL classifications: E42, E44, E51, E58, G21, G28, F31.

* The views expressed here are those of the authors and do not necessarily reflect those of the Bank for International Settlements. For comments and input, we thank David Archer, Douglas Arner, Codruta Boar, Harro Boven, Haiwei Cao, Stijn Claessens, Carl-Andreas Claussen, Sebastian Doerr, Huberto Ennis, Umar Faruqui, Leonardo Gambacorta, Philippe Haene, Henry Holden, Martin Hood, Linda Jeng, Taejin Park, Mateo Piccolo, Martin Summer, Tara Rice, Amber Wadsworth, Peter Wierts, Hye-Rim Yoo, Nouran Youssef, Dirk Zetzsche, an anonymous referee and participants at a BIS research meeting, an Arab Monetary Fund Fintech Working Group meeting, the CEMLA / Central Bank of Colombia conference on payments and a meeting of the OECD Experts Group on Finance and Digitalisation. We thank Mu Changchun, Lyu Yuan, Scott Hendry, Francisco Rivadeneyra, Dinesh Shah, Gabriela Guibourg, Martin Johansson, Hanna Armelius and Stig Johansson for conversations regarding the CBDC approaches of the People's Bank of China, Bank of Canada and Sveriges Riksbank.

♦ Bank for International Settlements (BIS), † Cambridge Centre for Alternative Finance (CCAF).

1. Introduction

Digital technologies are disrupting sector after sector of the economy, and money and payments are no exception. As economic activity increasingly moves online, technological innovations are also affecting the way consumers pay and the underlying infrastructure used to serve them. Even new attempts to create money have arisen, in the form of private cryptocurrencies and stablecoins. These have so far not taken off as a means of payment, yet their emergence has opened a debate on what money should look like in the digital age, and who should issue it. In this light, central banks around the world are researching and developing central bank digital currencies (CBDCs).[1]

CBDCs can be meant either for wholesale use – ie only for transactions between financial institutions – or retail use, meaning they would be open to the general public. Wholesale CBDC allow for new ways to make central bank money available to regulated financial institutions. Retail CBDCs differ fundamentally from today's electronic money in the hands of households and non-financial firms, which is a liability on a financial institution. Retail CBDCs more closely resemble a digital form of cash.

While the notion of providing central bank money directly to the public is not new,[2] it has been gaining traction recently. Attitudes about whether central banks should issue CBDCs – in particular retail CBDCs – have changed noticeably since 2019. Only a few years ago, most central banks had considered CBDCs but expressed concern about systemic implications that warranted caution (Barontini and Holden (2019)). But over time, the need to respond to the declining use of cash in some countries came to the fore, and a number of central banks have warmed to the idea of issuing a CBDC.[3] A tipping point was the announcement of Libra (now renamed to Diem) by Facebook (now Meta) and the ensuing public sector response. In late 2020, central banks representing a fifth of the world's population reported that

---

[1] CBDCs are defined as digital payment instruments that are denominated in the national unit of account and a direct liability of the central bank (Group of central banks (2021)).

[2] Indeed, Tobin (1987) argued that the central bank should make a safe "deposited currency" accessible to the public.

[3] Neither electronic money nor the discussion on the central bank's role in providing it directly to the people is new. In the context of CBDCs, Broadbent (2016), Liikanen (2016), Mersch (2016), Wilkins (2016), Menon (2016), Skingsley (2016) and Nakaso (2016) were among high-level policymakers who argued early on that the idea should be taken seriously.

they were likely to issue CBDCs very soon (Boar and Wehrli (2021)). During the Covid-19 pandemic, social distancing measures, public concerns that cash may transmit the Covid-19 virus and new government-to-person payment schemes have further sped up the shift toward digital payments (see Auer et al (2020b)). This has given a further impetus to CBDC projects in many countries. Meanwhile, the need to improve cross-border payments and securities settlement has remained a driver for wholesale CBDC work.[4]

While CBDCs have seized global attention and feature broadly in central bank communications and public search interest (Graph 1), no major jurisdiction has decided to issue a CBDC, and many open questions remain. One aspect is how central banks should create money and whether CBDCs are desirable in that context.[5] Another aspect is the systemic implications of CBDCs, eg whether they would disintermediate private banks, deposit taking and lending to the real economy, and how to cope with these effects.[6] There is a budding literature on the international dimensions of CBDC issuance, including the potential for changes to monetary policy effectiveness, "digital dollarisation" and international reserve currency competition.[7] Another strand of literature looks at the case for CBDCs to maintain privacy in payments.[8] Finally, the technology of retail CBDCs and how they relate to private sector proposals is hotly contested (see Auer and Böhme (2020 and 2021)), Klein et al (2020), Clark and Mihailov (2019), Brunnermeier et al (2019) and Vives (2019)).

[Graph 1 here]

To shed light on these issues, this study analyses the cross-country economic and institutional drivers of CBDC projects. A first step is to understand the status, policy approaches and technical design of the various projects, and next to look for commonalities and differences across countries. The

---

4 The issuance of wholesale CBDCs is much less contentious. See Bech et al (2020b) and Pfister (2020).

5 See Keister and Sanches (2019), Jackson and Pennacchi (2019), Kim and Kang (2019), and Armelius et al (2020a; b).

6 See Andolfatto (2021), Brunnermeier and Niepelt (2019), Fernández-Villaverde et al (2020), Keister and Monnet (2019), Kwon et al (2020), Carletti et al (2020) and Bindseil (2020).

7 See Ferrari et al (2020), Chorzempa (2021) and Auer et al (2021).

8 See eg Garratt and van Oordt (2021), Garratt and Lee (2021) and Agur et al (2021).

questions this paper aims to answer are: what are the economic and institutional drivers for issuing CBDCs? What are the technical solutions sought?

To assess drivers, we develop a novel CBDC project index based on central bank research and development (R&D) projects. We empirically investigate common factors in countries that are investigating and piloting CBDCs, either of the wholesale or retail variant. We find that higher mobile phone usage (a measure of an economy's overall digitisation) and higher innovation capacity are positively associated with the likelihood that a country is currently researching or developing a CBDC. Retail CBDCs are more likely where there is a larger informal economy, and wholesale CBDCs are more advanced in economies that have higher financial development.

To assess technical solutions, we look at four attributes of CBDC technical designs, following the taxonomy of Auer and Böhme (2020), the CBDC Pyramid. We show that many central banks are considering "Hybrid" or "Intermediated" architectures where the CBDC is a cash-like direct claim on the central bank, but the private sector manages customer-facing activity. Some jurisdictions are considering designs in which the central bank takes on an important operational role in the customer-facing side of payments, generally as a complement to services by the private sector. None of the central bank reports favour a design with indirect claims on the central bank (referred to as an "Indirect" or "Synthetic" CBDC architecture). Whereas many central banks are considering multiple technological options simultaneously, current proofs-of-concept tend to be based on distributed ledger technology (DLT) rather than a conventional technological infrastructure. Nevertheless, access frameworks tend to be based on account identification rather than allowing for token-based fully anonymous access. Most CBDC projects have a domestic focus. Finally, we show that the circumstances of each jurisdiction also matter for the policy approach taken to researching and developing a CBDC. An explicit decision on CBDC architecture is more common in more advanced economies, while economies with greater remittances see more use of DLT but also a role for identification with account-based access.

The rest of the paper is organised as follows. Section 2 describes our data and empirical analysis on the drivers of CBDC projects. Section 3 discusses policy approaches and technical design. Section 4 concludes with policy implications and avenues for future research.

2. The cross-country drivers of CBDC development

Several global developments – including the digitalisation of commerce, the rise of private digital currencies and specific policy concerns around financial inclusion, informality or data privacy – have recently driven increased interest in CBDCs. Yet the economic and institutional motivations for issuance vary across countries. In this section, we first develop a novel CBDC database on central bank CBDC projects, alongside speeches, internet search interest and a range of economic and institutional variables. Next, we investigate the drivers of CBDC projects. Specifically, we want to find commonalities in *why* central banks choose to embark on – or step up – CBDC efforts in some countries more than in others, using cross section regressions. This will also help us to understand *how* they design CBDC projects.

A novel CBDC database

We start by generating a novel global index measuring central banks' progress toward the development of a retail or wholesale CBDC: the **CBDC project index**. This index captures publicly announced work by the central bank on CBDC projects. We construct this index based on publicly available reports by central banks, extending the stocktake of Auer et al (2020a). The information was collected through desk research and with the help of contacts at several individual central banks.[9]

Starting from these reports we assign the CBDC project index score based on the following rule:

[9] The list of projects is broadly consistent with other stocktakes, such as Kiff et al (2020) and Atlantic Council (2020). We only take account of official central bank communications, not press articles.

- Score of 0 for jurisdictions without any official central bank publicly announced CBDC work.
- Score of 1 for research reports. These are CBDC projects that are still in early stages. The reports are just a theoretical discussion of CBDC in general or of the potential CBDC model envisaged, without any practical testing or implementation. Additionally, at this stage there is no third-party or external actor involvement.
- Score of 2 for pilot projects. These projects flesh out the details of a pilot or proof-of-concept (PoC). This stage requires physical testing, outputs and the involvement of external actors. We can confidently say that these reports indicate a much more advanced stage of CBDC work.
- Score of 3 for live CBDC stage reports. This score is given when a CBDC is rolled out for large-scale use. As of our cut-off date, no central bank had rolled out a retail or wholesale CBDC.

Each score is sequential – ie to reach a score of 3 a central bank had gone through the pilot or PoC stage and the research stage. For each jurisdiction, the overall index is the maximum of the retail and wholesale sub-indices. In the following, we use data as of mid-July 2020.[10]

Construction of the index requires some judgment. For instance, we consider only jurisdictions that have a central bank or monetary authority.[11] Currency unions require special consideration. For the euro area, given the work by both the ECB and several national central banks of euro area countries, we include an observation for the euro area as a whole (with a project score of 1), and each of the 19 euro area members (with 0 or 1 depending on whether the national central bank has published any CBDC research).[12] For the Eastern Caribbean Currency Union (ECCU), served by the Eastern Caribbean Central Bank (ECCB), the eight member states are included as a single observation with a CBDC project index of 2 given the ongoing pilot. The countries of the West African Economic and Monetary Union (WAEMU)

[10] Regular updates to the database are made available on the authors' websites. The latest update is as of October 2021.

[11] This means, for instance, that the Marshall Islands are not considered. The SOV project, which involves a private sector developer, is generally not understood as a CBDC. See IMF (2018).

[12] Empirical results are robust to dropping individual euro area members.

are consolidated into one observation (project index of 0), as are the members of the Economic Community of Central African States (ECCAS). Full links to public sources are available as part of the background documentation.

In the total sample of 175 countries or currency areas, 55 had a non-zero value for the CBDC project index. This included 30 retail CBDC projects. In the other 120 countries or currency areas without any communication on CBDC, the project index takes the value of 0.

The information on CBDC projects is complemented by a **central bank speech score**, which reflects the stance on CBDCs in speeches by central bank management. This score is obtained by classifying the stance of each central banker speech containing at least one keyword from the following list: "CBDC", "Central Bank Digital Currency", "digital currency" or "digital money" (with a manual check to ensure it refers to CBDC and not private digital currencies). Speeches come from the BIS central bankers' speeches database (www.bis.org/cbspeeches/), a comprehensive database collecting central bankers' speeches as published on the BIS website for a wide selection of central banks and international organisations. As of our cut-off date, the database counted 16,036 speeches, covered a period of more than 23 years (1997-2020) and has a wide geographical coverage (108 countries and 125 institutions). A query yielded a set of 138 speeches that contained at least one of the keywords of interest. The resulting sample covers the period December 2013–July 2020 and 38 countries including the euro area and several of its member countries.[13] For China, given the scarcity of material translated into English, we complemented the results with public sources, including Fan (2020).

After compiling relevant speeches, we went through each and classified them by interpreting the stance of the speech towards adoption of CBDC or CBDC more in general. Each speech score can take a value of either –1, 0 or +1 according to the specific speech stance. The score takes a value of –1 if the speech stance was clearly negative or in case it was explicitly said that there was no specific plan at

[13] When the speaker was an ECB official we labelled the speech as euro area. Conversely, if the speaker was an official of a national central bank member of the Eurosystem we labelled the speech as the corresponding country.

present to issue digital currencies. It takes a value of 0 in case of a neutral stance. Finally, it takes a value of +1 if the speech stance was clearly positive or a project/pilot was launched or was in the pipeline. The speech score was calculated as a simple average of the country level scores. If a country did not have any speech score, we replaced the missing values with a zero, is in line with the interpretation of a neutral stance.

Finally, in order to gauge public interest in CBDCs, our database also includes an **internet search interest** score. The score reflects both interest by citizens in the idea of a CBDC, and how widely known any central bank plans to introduce a CBDC are with the public. The score is estimated as a simple average of the interest score from Google Trends for the keywords "CBDC" (search word) and "Central Bank Digital Currency" (topic) over the period January 2013–mid-July 2020. The resulting two values for each country range between 0 (no searches) and 100 (maximum level) and are averaged to arrive at the score. For the China, we used the Baidu index for keywords "Central Bank Digital Currency" and "DC/EP" (the Digital Currency / Electronic Payment programme) or "e-CNY" (electronic Chinese yuan). We have rescaled the values to make them comparable to Google Trends figures (ie values range between 0 and 100) and applied the same procedure described above.

For each of the indicators described above, we replace country-level missing observations with zeros. This choice is consistent with the absence of a project (research or pilot), a neutral stance towards the development of a CBDC (speech score) or a lack of public interest (as captured by the search intensity score).

These indicators – made available with this paper – can help to gauge the project work on CBDCs in specific countries and to compare it with communications by central banks and public interest. The CBDC project index and both the speech and search interest scores display substantial variance in the cross section. Naturally, the three variables are correlated with one another, as central bank board members often use speeches to broadcast project work, and public search interest may be higher where

central banks have communicated that they are working on a project (see pairwise correlations in Table 1).

[Table 1 here]

There are necessarily caveats to these measures. For instance, many central banks have not publicly released reports on their ongoing CBDC projects. Some central banks (eg the People's Bank of China) have quite advanced projects, but have given relatively few speeches on their plans. In some jurisdictions, Google (or Baidu) is not widely used for internet searches. Still, the index can provide a comparable yardstick to assess changes across countries and over time. Moreover, this can provide a useful complement to the anonymised responses of central banks through official surveys. In the next section, we try to explain the cross-country heterogeneity in the CBDC project index.

Examining the cross-country drivers of CBDC projects

In this section we investigate the drivers of the CBDC project index. To complement central bank surveys and official motivations, we look at "revealed policy preferences", ie the economic and institutional factors that are associated with central banks' actual work on overall, retail or wholesale CBDCs. Our cross section estimations use an ordered probit approach (McKelvey and Zavoina (1975)), and take the form of:

$$Prob(CBDCPI_i = 0,1,2,3|x_i) = F(\alpha + \beta x_i + \varepsilon_i)$$

where $Prob(CBDCPI_i = 0,1,2,3|x_i)$ is the probability that the CBDC project index (overall, or for retail or wholesale projects) in jurisdiction i equals 0 (no project), 1 (research), 2 (pilot) or 3 (live CBDC), F() is the functional form of ordered probit, X_i is one or more variables from a vector of potential drivers, α and β are estimated coefficients and ε_i is an error term.

Some of the potential drivers of CBDC development can be related to factors affecting a country's technological capability to develop and deploy a CBDC. Focusing on indicators from reliable sources that are available for a wide cross section of countries, we include in our analysis the following indicators:

- **Digital infrastructure:** jurisdictions with greater **mobile phone use** (mobile cellular subscriptions per 100 people) or **internet use** (fixed line broadband subscriptions per 100 people) may have a more developed infrastructure for the central bank to develop CBDCs. Data on both come from the World Bank.
- **Innovation capacity:** jurisdictions with a higher **innovation score** overall, and hence the ingenuity and R&D potential to support central banks in designing a new CBDC ecosystem, may be more likely to see CBDCs. Data come from the World Intellectual Property Organization (WIPO) Global Innovation Index, which aggregates measures in the political environment, education, infrastructure and business sophistication (WIPO (2018)). To look at the innovation capacity of the central bank, itself, we have a dummy for countries that have in place or plan to institute a retail fast payment system (FPS). Data for this come from Bech and Boar (2019).
- **Institutional quality:** jurisdictions with higher **government effectiveness** may be more likely to launch CBDC projects. Data come from the World Bank. Conversely, central banks in jurisdictions with a large **informal ("shadow") economy** may have greater interest in creating a data trail for transactions, and thus promoting use of a digital currency. Estimates of the size of the informal economy come from Medina and Schneider (2019).

On the other side, countries may differ in their perceived demand for a CBDC. To proxy these factors, we include the following indicators:

- **Development and financial inclusion:** countries that are more developed, as measured by **GDP per capita**, may see a higher demand for new digital payment methods. Yet all else equal, jurisdictions with lower **access to transaction accounts** may see a greater need for retail

CBDCs as a financial inclusion policy. Data come from the World Bank Findex.[14] Meanwhile, jurisdictions with higher **financial development** may have greater demands on innovative solutions for wholesale settlement; data for this are available from Svirydzenka (2016).

- **Public interest in CBDCs:** where the public has more **internet searches** for CBDCs and related topics, this may signal either that they are more aware of the topic of CBDCs in general, or the plans of their own domestic central bank in this area. Either way, a positive association can be expected. Data are from Google and Baidu, as discussed above.
- **Cross-border transactions:** while most CBDCs serve a domestic purpose, one could expect that some types of CBDCs (eg wholesale projects for cross-border interbank settlement or migrant remittances) may be more likely in more internationally integrated economies. **Trade openness** (the sum of imports and exports over GDP) can proxy for cross-border demand for new payment options for goods and services. **Remittance flows** (inflows and outflows divided by GDP) gauge the economic importance of migrants' remittances. Again, both series come from the World Bank.

Table 2 gives descriptive statistics for our sample.

[Table 2 here]

For our CBDC project index, we have 175 observations. This includes a number of jurisdictions that are part of a currency union. In these cases, we count jurisdictions only if they have a central bank that could in theory develop a CBDC; currency unions without national central banks are considered one observation, with all independent variables calculated as weighted averages according to 2018 GDP.[15]

---

[14] We have also looked at various measures of cash use, such as small-denomination banknotes to GDP. These are available from the CPMI Red Book statistics, but unfortunately for only 18 jurisdictions.

[15] For this reason, the 19 euro area members are included individually, plus an additional observation for the ECB, given the ECB's research work (project score of 1). For individual euro area members, values of the CBDC project index are 1 or 0 depending on work by national central banks. On the other hand, the eight members of the Eastern Caribbean Currency Union (ECCU) are aggregated to one observation, with a project score of 2 given the ECCB pilot. Empirical results are robust to dropping the individual euro area member countries from the sample.

Mobile cellular subscriptions range from 13 per 100 people (North Korea) to 321 (Macao), and GDP per capita ranges from USD 281 (Burundi) to USD 110,343 (Luxembourg). For some key variables (eg the innovation output score, estimates of the informal economy, account ownership and remittances) coverage is lower, but generally still well above 100 jurisdictions.

Table 3 displays our univariate regression results. We can confirm that the CBDC project index is strongly associated with higher mobile and internet use, a higher innovation capacity, an existing or planned FPS and greater government effectiveness. It is also higher in jurisdictions with higher search interest for CBDCs. Somewhat against our expectations, there is a negative association with the informal economy in these univariate estimations; as we will see below using a multivariate approach, this relates to the correlation of this variable with mobile use and other positively associated covariates. Further, when it comes to those factors potentially affecting the demand for CBDC, we find CBDC projects to be more advanced where there is higher GDP per capita, financial development and search interest. Higher account ownership is associated with more advanced CBDC project work, while remittances are negatively correlated. Univariate results (unreported) are also very similar for the retail and wholesale indices separately.

[Table 3 here]

Of course, these simple regression coefficients need to be interpreted with great care as many of the regressors are collinear. More advanced economies tend to be more digitised, more innovative and to feature more effective goverments and smaller informal economies. Moreover, isolating individual drivers is complicated by the fact that sample size for some indicators is more limited, thus not allowing us to include all possible regressors at the same time.

To better control for multiple country characteristics, Table 4 displays multivariate ordered probit regression results for the overal CBDC project index, and for retail and wholesale CBDCs. The results confirm that overall projects are more likely where there is greater use of mobile phones and greater innovation capacity (column (I)). We further find that, controlling for mobile use and other positively

associated covariates, there is a significant association with the size of the informal economy and financial development for the overall project index (column (II)). We do not find a significant link with trade openess.

[Table 4 here]

Retail CBDCs also appear to be more advanced in jurisdictions with high innovation capacity and where the informal economy is larger, all else equal (columns (III) and (IV)).

Wholesale CBDCs are positively correlated with financial development, which could reflect the focus of such projects on increasing the efficiency of wholesale settlement (column (V)).[16] In the more parsimonious specification (column VI), there is a link with trade openness. As many wholesale projects focus on the cross-border dimension, this link is also intuitive.

To quantify the economic significance of these results, we report in Table 5 the predicted probabilities at mean values and after a one-standard deviation increase in each variable at a time. For example, as shown in column (I), at mean values of all variables, a country has a 78% probability of not doing any work on CBDCs, a 14% probabiliy of conducting research, and 9% probability of a testing pilot. A country with a one standard deviation increase in mobile phone subscriptions (ceteris paribus) has a 19% probability of research, and a 17% probability of a pilot.[17] A one standard deviation increase in the innovation output score is associated with probabilities of 21% and 22%, respectively.

With respect to retail CBDCs, a one standard deviation increase in the size of the informal economy is associated with a 26% probability for research (9 percentage points higher than mean values) and 8% for a pilot (4 percentage points higher than mean values) (column (III)). This result, obtained only when controlling for other factors, could relate to a desire by authorities to have a data trail for transactions, as discussed above. An increase by one standard deviation in financial development is linked to a 5-7%

[16] The innovation output score is not included, given high correlation with financial development (81%).

[17] There are necessarily caveats to this simple calculation given the non-linear nature of the ordered probit and correlation between the independent variables. For a discussion of interpretation issues in logits, probits and other non-linear probability models, see Breen et al (2018).

probability of wholesale research and 9-13% probability of a wholesale pilot, depending on the specification (columns (V) and (VI)).

[Table 5 here]

3. Policy approaches and technical design of retail CBDCs

We have thus far established that CBDCs are more likely to be under research and development in jurisdictions with high mobile use, innovation capacity and search interest for CBDCs, with some differences across retail and wholesale CBDCs. We have also noted that CBDC projects differ starkly across countries, both in their economic and institutional motivations, policy approach and their technical design.

In what follows, we focus only on the retail CBDC projects in our sample. We explore four key technological attributes of retail CBDC projects, and the economic and institutional factors correlated with their use.

Attributes of retail CBDC projects

Approaches to CBDC design are heterogeneous across countries, requiring us to distil the main design choices and the dimensions along which national approaches differ. One way to classify design approaches is the "CBDC Pyramid" (see Auer and Böhme (2020; 2021)). This approach starts from the consumer needs that a retail CBDC could address, identifies associated technical design trade-offs, and then derives the design choices. The scheme of design choices forms a hierarchy in which the lower, initial layers represent design decisions that feed into subsequent, higher-level decisions. To reflect this hierarchy, the choices can be thought of as a pyramid.

The first and foundational design choice is the **architecture**, ie which operational role the central bank and private intermediaries take on in a CBDC. Intermediaries can run into technical difficulties or solvency issues. A CBDC should be safe from such outages. Yet payment intermediaries offer valuable

services to consumers, which are needed to ensure the same level of convenience, innovation and efficiency as in today's payments. The architecture needs to balance these two considerations.

We draw on the classification in Auer and Böhme (2021) by classifying various proposals for CBDC design into **three CBDC architectures and a fully-backed alternative**. These differ in the structure of legal claims and the record kept by the central bank. They are:

- ***Direct CBDC*** – a payment system operated by the central bank, which offers retail services. A CBDC is a direct claim on the central bank. The central bank maintains the ledger of all transactions and executes retail payments.
- ***Hybrid CBDC*** – an intermediate solution that runs on two engines. Intermediaries handle retail payments, but the CBDC is a direct claim on the central bank, which also keeps a central ledger of all transactions and operates a backup technical infrastructure allowing it to restart the payment system if intermediaries fail.
- ***Intermediated CBDC*** – an architecture that is a variant of the Hybrid CBDC, but in which the central bank maintains only a wholesale ledger, rather than a central ledger of all retail transactions. Again, the CBDC is a claim on the central bank and private intermediaries execute payments. For the purposes of this paper, this will be considered alongside the Hybrid model in our stocktake.

In addition to these three generally recognised retail CBDC architectures, another approach is the indirect provision of retail CBDC via financial intermediaries. Thus:

- ***Indirect architecture*** – a payment system operated by intermediaries that resemble narrow payment banks (also called "synthetic CBDC"). Consumers have claims on these intermediaries, which operate all retail payments. These intermediaries need to fully back all liabilities to retail clients with claims on the central bank.[18]

[18] See Adrian and Griffoli-Mancini (2019) and Kumhof and Noone (2019).

We note that, as this does not allow the consumer to directly access central bank money, not all central banks recognise this architecture as a retail CBDC.[19]

The second technical design choice regards the **infrastructure**. A CBDC must be secure from outages at the central bank. The infrastructure can be based on a conventional centralised database or instead on DLT. These technologies differ in their efficiency and degree of protection from single points of failure. DLT often aims to replace trust in intermediaries with trust in an underlying technology. Calle and Eidan (2020) describe some of these proofs-of-concept in detail. Also noteworthy is that all central banks experimenting with DLT use permissioned variants, where operators can decide who is admitted to the network. No central bank report examined in this study has ventured to rely on permissionless DLT, as used for Bitcoin and many other private cryptocurrencies.[20]

The third choice concerns how consumers can **access** the CBDC. Account-based CBDCs are tied to an identity scheme, which can serve as the basis for well-functioning payments with good law enforcement. Yet access is likely to be difficult for one core target group: the unbanked and individuals who rely on cash. There may be challenges to match the qualities of cash as an inclusive, crisis-proof and anonymous means of payment (Pichler et al (2019)). An alternative is to base access on so-called digital tokens.[21] This allows for value-based payment options, for example pre-paid CBDC banknotes that can be exchanged both physically and digitally. Yet this also brings new risks of illicit activity and counterfeiting.

---

[19] For example, Sveriges Riksbank (2020), Bank of England (2020), and for the case of Canada, Dinesh et al (2020) only consider architectures featuring direct claims on the central bank. The Group of central banks (2020), which includes central banks from the G7 countries and others, states explicitly that "Synthetic CBDC is not a CBDC".

[20] See Auer (2019) for a discussion of the inefficient economics of permissionless models and Ali and Narula (2020) for a specific analysis of permissioned and permissionless DLT in the context of CBDCs.

[21] Importantly, this definition of token versus accounts must not be confused with the one used in the field of computer science. Rather, it follows Kahn and Roberds (2009). As put by Kahn (2016), the distinction between accounts and tokens are the identification requirements: "In a token-based system, the thing that must be identified for the payee to be satisfied with the validity of the payment is the "thing" being transferred – "is this thing counterfeit or legitimate?" In an account-based system, however, the identification is of the customer – "Is this person who she says she is? Does she really have an account with us?"

Closely tied to the domestic access framework is the fourth design choice, the use of CBDC for **cross-border payments**, which relates to international interlinkages in a CBDC's design and its accessibility for residents vs non-residents. Token-based domestic access would naturally be open to anyone, including non-residents. But central banks may allow for use by non-residents.

Graph 2 classifies the attributes of ongoing retail CBDC projects, as of October 2021. Among the retail CBDC projects in our sample, we find a wide variety of approaches to architecture, infrastructure, access and international interlinkages. On architecture, we find just two central banks having considered solely a Direct model, generally just as part of early-stage research projects. In some cases, the Direct model has been considered alongside other architectures as a potential "public option" that could complement services by private sector intermediaries, rather than a purely public CBDC system. A much larger group are considering the Hybrid or Intermediated options, and over 30 central banks have not yet specified the architecture. Only one central bank (HKMA) is considering the Indirect architecture, as an option alongside the Intermediated model. Overall, most central banks who have taken a decision are considering options in which the CBDC is a direct cash-like claim on the central bank, but where the private sector handles all customer-facing activity.

[Graph 2 here]

Regarding infrastructure, we find six central banks relying primarily on conventional technology, five relying primarily on DLT, and eleven considering both (see eg Shah et al (2020)). Yet many of these infrastructure choices are often for first proofs-of-concept or pilots. Only time will tell if the same choices are made for large-scale designs. Among access methods, seven central banks are clearly leaning toward account-based, five are looking primarily at token-based and a further nine are looking at both account and token-based access. Finally, while 19 projects in our sample are focused on domestic use, another 18 are open to cross-border use. This includes those by the ECB, the central banks of France, Spain and the Netherlands, and the ECCB – which are by construction focused on cross-border use among the members of a multi-country currency area. Moreover, a number of central banks have flagged openness

for use of their CBDC by foreign tourists and business travellers, or for trade invoicing and use in settlement abroad.

The drivers of technological designs

Central banks choose these different attributes of CBDCs in line with the unique needs of their jurisdictions, but there may nonetheless be common features across countries.[22] In this light, we have also performed simple probit regressions for three of the four attributes (Table 6). For consistency with the empirical results in section 2, we again use the cut-off date of mid-July 2020. Indicators were chosen based on the statistical significance of differences between the projects; the top three are presented in each case. Because of the lack of variation in our sample regarding cross-border interlinkages, these differences are not presented.

For the architecture, we look at the probability of having chosen a specific model (either Direct, Hybrid or Intermediated). Here, we find that it is especially more developed jurisdictions, with higher government effectiveness, GDP per capita or account ownership, who have explicitly chosen an architecture (columns (I), (II) and (III)). Less developed countries have generally not specified their chosen architecture. Those central banks that have explored the Direct model are generally also high-income, and have high existing account access. It is notable that these central banks consider the Direct model as a complement to private sector CBDC services.

Regarding infrastructure, we expect that DLT – originally designed to substitute for trusted intermediaries – is more attractive in jurisdictions in which authorities are perceived to be less effective. This difference is not statistically significant. Some central banks do note explicitly that DLT presents no fundamental advantages when using a centralised issuance system (NBU (2019)). On the other hand,

[22] We note that central banks often consider multiple design options, to retain full flexibility when it comes to achieving the wide range of objectives such as privacy, monetary policy, inclusion, or financial stability.

countries researching or piloting DLT are more dependent on inward remittance flows than countries researching or piloting conventional architectures.

Regarding account-based vs token-based access, we find that countries looking at tokens have lower remittance outflows. This could reflect that relatively open countries are aware of the risks of token-based CBDCs for the displacement of domestic currencies and for financial integrity risks, and thus prefer an account-based approach. We do not find a statistically significant association with search interest or innovation capacity – factors that could reflect public demands on CBDC design.

[Table 6 here]

Overall, these results suggest that the unique circumstances of each jurisdiction also matter for the technical design of R&D projects on retail CBDCs. While CBDC projects are each tailored to their national context, there are commonalities, with more developed countries more likely to have taken a decision on architecture, and economies with more remittances considering DLT but account-based access.

4. Conclusion

This paper has examined the rise of central bank digital currencies, a new payment technology studied by central banks around the world. We have presented a novel CBDC project index. We have shown that this index is higher in jurisdictions with higher mobile phone usage and higher innovation capacity. Especially retail CBDCs are more likely where there is a larger informal economy, and wholesale CBDCs are more advanced in economies that have higher financial development. We have also noted that CBDC projects differ across countries, both in their motivations and their economic and technical design. Many central banks are pursuing models where a CBDC is a direct claim on the central bank, but with private intermediaries.

Given the novelty of CBDC, and the scope for "clean-slate" thinking on the nature and provision of money, it is natural that the approaches will differ across countries, in line with economic circumstances

and users' priorities. In countries where digital payments are already very advanced, and cash use is declining, central banks may respond in particular to ensure the ongoing availability of a public sector-provided means of payment. In countries with a lower penetration of digital payments, financial inclusion may be an important driver. The choice of architectures, infrastructures, access and interlinkages will be tailored to fit local circumstances.

Yet our overview has also shown some key common features. In particular, none of the designs we survey is intended to replace cash; all are intended to complement it. Most still involve a strong role for intermediaries – although potentially in parallel to direct provision of some services by central banks. None of the designs is pursuing the Indirect model, where a CBDC is a claim on intermediaries rather than on central banks. We believe that by sharing information on the drivers, approaches and technologies, central banks can learn from one another, thus complementing international policy work in this area.

Going forward, events such as the Covid-19 pandemic highlight the value of access to diverse means of payments, and the need for any payment method to be both inclusive and resilient against a broad range of threats, just as cash is. While it is difficult to anticipate the range of challenges ahead, central banks will continue to take a long-term view and carefully consider the role of CBDCs in a range of potential future scenarios.

References

Adrian, T and T Mancini-Griffoli (2019): "The rise of digital money", *IMF Note*, no 19/001, July.

Agur, I, A Ari and G Dell'Ariccia (2019): "Designing central bank digital currencies", *IMF Working Papers*, no 19/252.

Ali, R and N Narula (2020): "Redesigning digital money: what can we learn from a decade of cryptocurrencies?", *MIT DCI Working Papers*, January.

Andolfatto, D (2021): "Assessing the impact of central bank digital currency on private banks", *The Economic Journal* 131.634, pp 525–40.

Armelius, H, A Clausen and S Hendry (2020a): "Is central bank currency fundamental to the monetary system?", *Sveriges Riksbank Economic Review*, June, pp 19–32.

Armelius, H, G Guibourg, S Johansson and J Schmalholz (2020b): "E-krona design models: pros, cons and trade-offs", *Sveriges Riksbank Economic Review*, June, pp 80–96.

Auer, R (2019): "Beyond the doomsday economics of 'proof-of-work' in cryptocurrencies", *BIS Working Papers*, no 765, January.

Auer, R and R Böhme (2020): "The technology of retail central bank digital currency", *BIS Quarterly Review*, March, pp 85–100.

Auer, R and R Böhme (2021): "Central bank digital currency: the quest for minimally invasive technology", *BIS Working Papers*, no 948, June.

Auer, R, G Cornelli and J Frost (2020a): "Taking stock: ongoing retail CBDC projects", *BIS Quarterly Review*, March, pp 97–98.

—— (2020b): "Covid-19, cash and the future of payments", *BIS Bulletin*, no 3, April.

Auer, R, J Frost, T Lammer, T Rice and A Wadsworth (2020): "Inclusive payments for the post-pandemic world", SUERF Policy Note, August.

Auer, R, C Boar, G Cornelli, J Frost, H Holden and A Wehrli, "CBDCs beyond borders: results from a survey of central banks", BIS Papers, no 116, June 2021.

Bank of England (2020): "Central Bank Digital Currency: opportunities, challenges and design", March.

Barontini, C and H Holden (2019): "Proceeding with caution – a survey on central bank digital currency", *BIS Papers*, no 101, January.

Bech, M and C Boar (2019): "Shaping the future of payments", *Analysis of the 2018 Red Book Statistics*, November.

Bech, M, J Hancock and W Zhang (2020a): "Fast retail payment systems", *BIS Quarterly Review*, March, pp 28–9.

Bech, M, J Hancock, T Rice, A Wadsworth (2020b): "On the future of securities settlement", *BIS Quarterly Review*, March, pp 67–83.

Bindseil, U (2020): "Tiered CBDC and the financial system", ECB Working Paper Series, No 2351, January.

Boar, C and A Wehrli (2021): "Ready, steady, go? – Results of the third BIS survey on central bank digital currency", BIS Papers, no 114.

Breen, R, K Bernt Karlson and A Holm (2018): "Interpreting and understanding logits, probits, and other nonlinear probability Models", *Annual Review of Sociology*, vol 44, pp 39–54.

Broadbent, B (2016): "Central banks and digital currencies", speech at the London School of Economics, London, 2 March.

Brunnermeier, M, H James and JP Landau (2019): "The digitalization of money", National Bureau of Economic Research Paper, no 26300.

Brunnermeier, M and D Niepelt (2019): "On the equivalence of private and public money", *Journal of Monetary Economics*, no 106, pp 27-41.

Calle, G and D Eidan (2020): "Central bank digital currency: an innovation in payment", R3 White Paper, April.

Carletti, E, S Claessens, A Fatás and X Vives (2020) "The bank business model in the post-Covid-19 world", 18 June, VoxEU E-Book.

Chorzempa, M (2021), "China, the United States, and central bank digital currencies: how important is it to be first?", China Economic Journal.

Clark, A and A Mihailov (2019): "Why private cryptocurrencies cannot serve as international reserves but central bank digital currencies can", *University of Reading–Department of Economics Discussion Paper Series*, no 2019-09.

Fan, Y (2020): "Some thoughts on CBDC operations in China", speech, 1 April.

Ferrari, M, M Mehl and L Stracca (2020) "Central bank digital currency in an open economy", mimeo, ECB, July

Fernández-Villaverde, J, D Sanches, L Schilling and H Uhlig (2020): "Central bank digital currency: central banking for all?" *National Bureau of Economic Research Papers*, no 26753.

Garratt, R and M van Oordt (2021): "Privacy as a Public Good: A Case for Electronic Cash", *Journal of Political Economy*, vol 129, no 7, pp 2157–80.

Garratt, R and M Lee (2021): "Monetizing Privacy", Federal Reserve Bank of New York Staff Report, no 958, January.

Group of Central Banks (2020): "Central bank digital currencies: foundational principles and core features", Joint Report, no 1, October.

International Monetary Fund (IMF) (2018): "Republic of the Marshall Islands: Selected Issues", September.

Jackson, T and G Pennacchi (2019): "How should governments create liquidity?", mimeo.

Kahn, C (2016): "How are payment accounts special? Payments Innovation Symposium, Federal Reserve Bank of Chicago.

Kahn, C and W Roberds (2009): "Why pay? An introduction to payments economics", *Journal of Financial Intermediation*, vol 18, no 1, pp 1–23.

Keister, T and C Monnet. 2019. "Central bank digital currency: stability and information" Mimeo.

Keister, T and D Sanches (2019): "Should central banks issue digital currency?", mimeo.

Kiff, J, J Alwazir, S Davidovic, A Farias, A Khan, T Khiaonarong, M Malaika, H Monroe, N Sugimoto, H Tourpe and P Zhou (2020): "A survey of research on retail central bank digital currency", *IMF Working Papers*, no 20/104, June.

Kim, J and J Kang (2019): "Money, to be publicly issued, or not to be, that is the question", (인터넷전자상거래연구), 19(5), pp 77–91.

Klein, M, J Gross and P Sandner (2020): "The digital euro and the role of DLT for central bank digital currencies", *FSBC Working Papers*.

Kwon, O, S Lee and J Park (2020): "Central bank digital currency, inflation tax, and central bank independence", 13 February.

Kumhof, M and C Noone (2018): "Central bank digital currencies – design principles and balance sheet implications", *Bank of England Working Papers*, no 725.

Liikanen, E (2016): "Cash and the central bank", speech, Helsinki, 14 June.

McKelvey, R and W Zavoina (1975): "A statistical model for the analysis of ordinal level dependent variables", *The Journal of Mathematical Sociology*, vol 4, no 1, pp 103–20.

Medina, L and F Schneider (2019): "Shedding light on the shadow economy: a global database and the interaction with the official one", *CESifo Working Papers*, no 7981.

Menon, R (2016): "Singapore's FinTech journey – where we are, what is next?", speech at the Singapore FinTech Festival, Singapore, 16 November.

Mersch, Y (2016): "Distributed ledger technology – panacea or flash in the pan?", speech, Frankfurt am Main, 25 April.

Nakaso, H (2016): "FinTech - its impacts on finance, economies and central banking.", conference on "FinTech and the Future of Money", speech, Tokyo, 18 November.

National Bank of Ukraine (NBU) (2019): *Analytical Report on the E-hryvnia Pilot Project*, February.

Pfister, C (2020): "Central bank digital currency: a primer", *SUERF Policy Note*, no 143, March.

Pichler, P, M Summer and B Weber (2019): "Does digitalization require central bank digital currencies for public use?", *Monetary Policy and the Economy*, Q4/19, pp 40–56.

Shah, D, R Arora, H Du, S Darbha, J Miedema and C Minwalla (2020): "Technology approach for a CBDC", *Bank of Canada Staff Analytical Note*, no 2020-6, February.

Skingsley, C (2016): "Should the Riksbank issue e-krona?", speech at FinTech Stockholm, Stockholm, 16 November.

Sveriges Riksbank (2020): "The Riksbank's e-krona pilot", February.

Svirydzenka, K (2016): "Introducing a new broad-based index of financial development", *IMF Working Papers*, no 15.

Tobin, J (1987): "The case for preserving regulatory distinctions", *Proceedings of the Economic Policy Symposium, Jackson Hole*, Federal Reserve Bank of Kansas City, pp 167–83.

Vives, X (2019): "Digital disruption in banking", *Annual Review of Financial Economics* vol 11, pp 243–72.

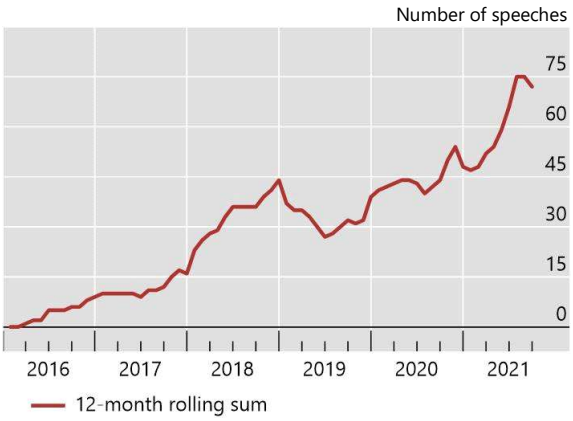
Wilkins, C (2016): "Fintech and the financial ecosystem – evolution or revolution?", remarks at Payments Canada, Calgary, Alberta, 17 June.

World Intellectual Property Organization (WIPO) (2018): "Global innovation index 2018: Energizing the world with innovation", July.

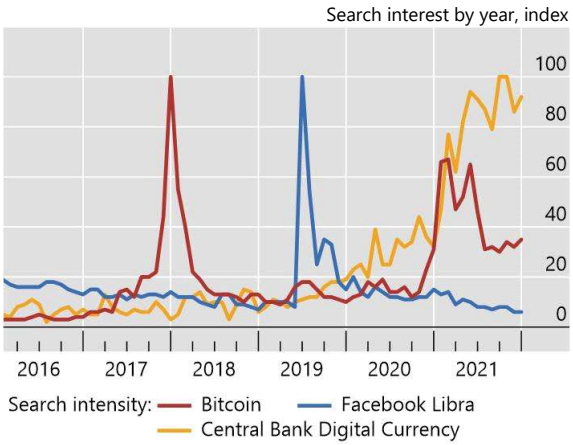
Graphs and tables

CBDCs: the next hype or the future of payments? Graph 1

Timing of speeches and reports on CBDC[1]



Google search interest over time[2]

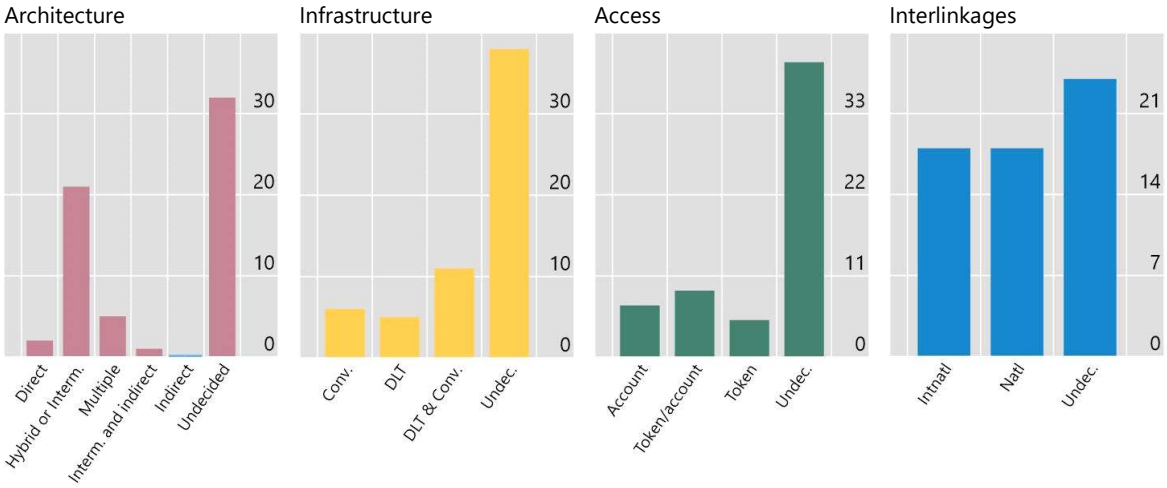


[1] 12-month moving sum of the count of central bankers' speeches resulting from a case-insensitive search for any of the following words/phrases: CBDC; central bank digital currency; digital currency and digital money. [2] The data has been normalised to the 12-week moving average peak of each series. The search was run on search terms "Bitcoin" and "Facebook Libra" and topic "Central Bank Digital Currency". Data accessed on 16 July 2020.

Sources: Central bankers' speeches; central banks' websites; Google Trends; authors' calculations.

Attributes of retail CBDC projects

Number of retail CBDC projects investigating each design option — Graph 2



Interm. = intermediated; Multiple = two or more options among direct, hybrid and intermediated under consideration; Undecided = undecided/unspecified or multiple options under consideration; DLT = distributed ledger technology; Conv. = Conventional; Token/account = tiering of token- and account-based access; Natl = national use; Intnatl = international use.

Sources: central banks' websites; authors' calculations.

Pairwise correlations

Table 1

	CBDC project index[1] (overall)	Central bank speech score[2]	Search interest index (Google/Baidu)[3]
CBDC project index[1] (overall)	1.00		
Central bank speech score[2]	0.52***	1.00	
Search interest index (Google/Baidu)[3]	0.40***	0.20***	1.00

*** denotes significance at the 1% level.

[1] The project stance is equal to 0 when there is no known work on retail or wholesale CBDC, 1 in the case of research output, and 2 in the case of an active or completed retail or wholesale CBDC pilot. [2] Search on keywords "CBDC", "digital currency" and "digital money". The classification is based on the authors' judgment. The score takes a value of –1 if the speech stance was clearly negative or in case it was explicitly said that there was no specific plan at present to issue digital currencies. It takes a value of +1 if the speech stance was clearly positive or a project/pilot was launched or was in the pipeline. Other speeches (not displayed) have been classified as neutral. Normalised and winsorised at the 5% level. [3] Data have been normalised.

Sources: Baidu; central banks' websites; BIS Central Bankers' Speeches; Google Trends; authors' calculations.

Descriptive statistics[1] Table 2

	Observations	Mean	Standard deviation	Min	Max
Dependent variables					
Overall CBDC project index	175	0.31	0.66	0	2
Retail CBDC project index	175	0.22	0.53	0	2
Wholesale CBDC project index	175	0.13	0.48	0	2
Independent variables					
Mobile cellular subscriptions (per 100 people)	169	109.24	39.54	12.60	320.55
Broadband subscriptions (fixed line, per 100 people)	167	13.60	13.38	0	47.16
Innovation output score (WIPO)	118	29.67	12.69	7.90	67.13
Fast payment system dummy	175	0.37	0.48	0	1
Government effectiveness	175	0.08	0.99	-2.24	2.19
Informal economy (% of GDP)	122	26.08	11.62	5.43	55.78
GDP per capita (USD)	168	16,652	21,423	301	110,344
Account ownership (% age 15+)	135	60.39	27.96	6.45	99.96
Financial development index[2]	158	0.36	0.22	0.06	0.93
Search interest index (Google/Baidu)[3]	175	0.11	1.13	–0.34	8.18
Remittances[4] to GDP	110	5.89	7.86	0.19	41.18
Trade openness[5]	134	80.05	48.87	0	345.69
Central bankers' speech stance index[7]	175	0.02	0.47	–0.13	1.68

[1] For all the independent variables, average over the period 2013–19, subject to data availability. [2] Svirydzenka (2016). [3] Data have been normalised. [4] Sum of inflows and outflows. [5] Sum of imports and exports divided by the country GDP. Data for 2018. [6] Data for 2014; for EA, latest observation available (2010). [7] Normalised and winsorised at the 5% level.

Sources: Bech at al (2020); Medina and Schneider (2019); Svirydzenka (2016); WIPO (2018); IMF, *World Economic Outlook*; World Bank, *Remittance Prices Worldwide*, remittanceprices.worldbank.org; World Bank; Baidu; central banks' websites; BIS Central Bankers' Speeches; Datastream; Google Trends; authors' calculations.

Univariate ordered probit regressions on overall CBDC project index[1]

Table 3

Digital infrastructure												
Mobile cellular subscriptions	0.010***											
(per 100 people)	(0.004)											
Broadband subscriptions		0.042***										
(fixed line, per 100 people)		(0.008)										
Innovation capacity												
Innovation output score			0.047***									
(WIPO)			(0.009)									
Fast payment system (FPS) dummy				0.882***								
				(0.221)								
Institutional characteristics												
Government effectiveness					0.674***							
					(0.118)							
Informal economy						–0.03***						
(% of GDP)						(0.013)						
Development and financial inclusion												
Ln(GDP per capita)							0.439***					
							(0.092)					
Account ownership								0.023***				
(% age 15+)								(0.005)				
Financial development									3.414***			
index[2]									(0.552)			
Public interest in CBDCs												
Search interest index										0.432***		
(Google/Baidu)[3]										(0.098)		
Cross-border transactions												
Remittances[4] to GDP											–0.157**	
											(0.068)	
Trade openness[5]												0.001
												(0.003)
Number of observations	169	167	118	175	175	122	168	135	158	175	110	134
Pseudo R^2	0.057	0.126	0.129	0.074	0.145	0.058	0.119	0.131	0.215	0.105	0.113	0.001

Robust standard errors in parentheses; ***/**/* denotes results that are significant at the 1/5/10% level.

[1] For all the independent variables, average over the period 2013–19, subject to data availability. [2] Svirydzenka (2016). [3] Data have been normalised. [4] Sum of inflows and outflows. [5] Sum of imports and exports divided by the country GDP. Data for 2018.

Sources: Bech et al (2020a); WIPO (2018); Medina and Schneider (2019); Svirydzenka (2016); IMF, *World Economic Outlook*; World Bank, *Remittance Prices Worldwide*, remittanceprices.worldbank.org; World Bank; Baidu; central banks' websites; Datastream; Google Trends; authors' calculations.

Multivariate ordered probit regressions on CBDC project indices[1] Table 4

	Overall CBDC project index		Retail CBDC project index		Wholesale CBDC project index	
Mobile cellular subscriptions	0.013**	0.015***		0.011**		0.022**
(per 100 people)	(0.005)	(0.006)		(0.005)		(0.010)
Innovation output score	0.045***		0.067***	0.082***		
(WIPO)	(0.010)		(0.017)	(0.019)		
Informal economy		0.027*	0.033*	0.042***		-0.009
(% of GDP)		(0.015)	(0.018)	(0.016)		(0.026)
Financial development		3.909***			3.303***	4.287***
Index[2]		(0.867)			(0.775)	(1.299)
Trade openness[3]		-0.003		-0.016**	0.004*	-0.001
		(0.004)		(0.007)	(0.003)	(0.004)
Number of observations	118	105	110	100	132	105
Pseudo R^2	0.167	0.241	0.144	0.244	0.263	0.352

Robust standard errors in parentheses; ***/**/* denotes results that are significant at the 1/5/10% level. Constants are not reported.

[1] For all the independent variables, average over the period 2013–2019, subject to data availability. [2] Svirydzenka (2016). [3] Sum of imports and exports divided by the country GDP. Data for 2018.

Sources: Medina and Schneider (2019); WIPO (2018); IMF, *World Economic Outlook*; World Bank; central banks' websites; Datastream; authors' calculations.

Effect of a one-standard deviation increase on predicted probabilities (oprobit)[1] Table 5

	Probability of	Overall CBDC project index		Retail CBDC project index		Wholesale CBDC project index	
		(I)	(II)	(III)	(IV)	(V)	(VI)
Predicted probabilities at mean values	No activity	77.7%	78.0%	79.4%	80.7%	94.9%	98.4%
	Research	13.6%	14.4%	17.1%	17.1%	2.3%	0.8%
	Pilot	8.7%	7.6%	3.5%	2.1%	2.8%	0.8%
	Live CBDC	-	-	-	-	-	-
Mobile cellular subscriptions (per 100 people)	No activity	64.2%	60.9%		69.4%		92.1%
	Research	18.9%	21.7%		25.8%		3.1%
	Pilot	16.9%	17.4%		4.8%		4.8%
	Live CBDC	-	-	-	-	-	-
Innovation output score (WIPO)	No activity	57.7%		48.7%	42.2%		
	Research	20.8%		34.5%	41.0%		
	Pilot	21.5%		16.8%	16.8%		
	Live CBDC	-		-	-	-	-
Informal economy (% of GDP)	No activity		67.6%	66.6%	64.4%		98.8%
	Research		19.2%	25.7%	29.3%		0.6%
	Pilot		13.2%	7.7%	6.3%		0.6%
	Live CBDC		-	-	-	-	-
Financial development Index[2]	No activity		44.0%			80.9%	86.9%
	Research		25.5%			6.5%	4.6%
	Pilot		30.5%			12.6%	8.5%
	Live CBDC		-	-	-	-	-
Trade openness[3]	No activity		81.5%		95.1%	92.3%	98.5%
	Research		12.5%		4.6%	3.2%	0.7%
	Pilot		5.9%		0.2%	4.5%	0.8%
	Live CBDC		-	-	-	-	-

The table reports the predicted probabilities for a one-standard deviation shock in each of the individual variables keeping all the other variables at their individual mean values.

[1] For all the independent variables, average over the period 2013–2019, subject to data availability. [2] Svirydzenka (2016). [3] Sum of imports and exports divided by the country GDP. Data for 2018.

Sources: Medina and Schneider (2019); WIPO (2018); IMF, *World Economic Outlook*; World Bank; central banks' websites; Datastream; authors' calculations.

Univariate probit on retail CBDC project features[1]

Table 6

	Architecture			**Infrastructure**			**Access**		
	1: Direct and Hybrid or Intermediated			1: DLT infrastructure			1: Token-based		
	0: Indirect / unspecified			0: Conventional / unspecified			0: Account-based / unspecified		
Government effectiveness	0.599**								
	(0.299)								
Ln(GDP per capita)		0.600**							
		(0.249)							
Account ownership (% age 15+)			0.033**						
			(0.015)						
Remittance inflows to GDP				0.205**					
				(0.096)					
Informal economy					0.02				
(% of GDP)					(0.023)				
Trade openness[2]						0.006			
						(0.007)			
Search interest index							0.157		
(Google/Baidu)[3]							(0.131)		
Remittance outflows to GDP								-1.873**	
								(0.828)	
Innovation output score									-0.008
(WIPO)									(0.022)
Number of observations	31	31	27	28	27	31	31	26	28
Pseudo R^2	0.103	0.150	0.148	0.118	0.027	0.0191	0.046	0.186	0.005

Robust standard errors in parentheses; ** denotes results that are significant at the 5% level. Constants are not reported.

[1] For all the independent variables, average over the period 2013–19, subject to data availability. [2] Sum of imports and exports divided by the country GDP. Data for 2018. [3] Data have been normalised.

Sources: WIPO (2018); Medina and Schneider (2019); IMF, *World Economic Outlook*; World Bank, *Remittance Prices Worldwide*, remittanceprices.worldbank.org; World Bank; Baidu; central banks' websites; Datastream; Google Trends; authors' calculations.