Rise of the Central Bank Digital Currencies*

Raphael Auer,[a] Giulio Cornelli,[a,c] and Jon Frost[a,b]
[a]Bank for International Settlements
[b]Cambridge Centre for Alternative Finance
[c]University of Zurich

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 factors that correlate with CBDC project efforts. Most projects are found in economies with high mobile phone use and 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.

JEL Codes: 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, the American Economic Association annual meetings, 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. Author contact: Raphael Auer, Mainzer Landstraße 16, 60325 Frankfurt am Main, Germany/115 rue Réaumur 75002 Paris, France; e-mail: Raphael.Auer@bisih.org. Giulio Cornelli, Centralbahnplatz 2, 4002 Basel, Switzerland; e-mail: Giulio.Cornelli@bis.org. Jon Frost, Rubén Dario 281, Polanco, Lomas de Chapultepec, Miguel Hidalgo 11580 Ciudad de México, CDMX, Mexico; e-mail: Jon.Frost@bis.org.

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—i.e., only for transactions between financial institutions—or retail use, meaning they are open to the general public. Wholesale CBDCs 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, like cash, are a direct claim on the central bank.

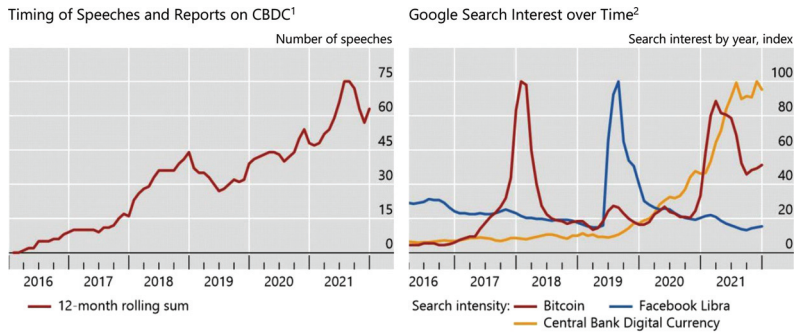
While the notion of providing electronic central bank money directly to the public is not new,[2] it has been gaining traction recently. Attitudes about whether central banks should issue CBDCs—in particular, retail CBDCs—have changed noticeably since 2019. Only a few years ago, most central banks had 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

[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 (Bank for International Settlements 2020, 2021; 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), Menon (2016), Mersch (2016), Nakaso (2016), Skingsley

Figure 1. CBDCs: The Next Hype or the Future of Payments?



[1]Twelve-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]Three-month moving average of worldwide search interest. The data have been normalized to the three-month 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 January 16, 2022.
Sources: BIS Central Bankers' Speeches; central banks' websites; Google Trends; authors' calculations.

Facebook's Libra (later renamed to Diem) and the ensuing public sector response. In late 2020, central banks representing a fifth of the world's population reported that 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 further sped up the shift toward digital payments (see Auer, Cornelli, and Frost 2020a). This gave 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]

CBDCs have seized global attention and feature broadly in central bank communications and public search interest (Figure 1).

(2016), and Wilkins (2016) were among high-level policymakers who argued early on that the idea should be taken seriously.

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

As of early 2022, three retail CBDCs have been launched (in the Bahamas, the Eastern Caribbean, and Nigeria), a large-scale pilot is ongoing in China, and major reserve central banks like those of the euro area, Japan, and the United States are stepping up their research and experimentation.[5] Yet many open questions are the focus of a rapidly growing literature (Auer et al. 2022). One aspect is how central banks should create money and whether CBDCs are desirable in that context.[6] Another aspect is the systemic implications of CBDCs, e.g., whether they would disintermediate private banks, deposit taking, and lending to the real economy, and how to cope with these effects.[7] There is a budding literature on the international dimensions of CBDC issuance, including the potential for changes to monetary policy effectiveness, "digital dollarization," and international reserve currency competition.[8] Another strand of literature looks at the case for CBDCs to maintain privacy in payments.[9] Finally, the technology of retail CBDCs and how they relate to private sector proposals is hotly contested (see Brunnermeier, James, and Landau 2019; Clark and Mihailov 2019; Vives 2019; Auer and Böhme 2020, 2021; and Klein, Gross, and Sandner 2020).

To shed light on these issues, this study analyzes the cross-country economic and institutional factors that correlate with 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 questions this paper aims to answer are as follows: Which economic and institutional factors are associated with central bank work on CBDCs? What are the technical solutions sought?

[5]See Bank of Japan (BOJ) (2020), Fan (2020), ECB (2020), People's Bank of China (PBC) (2021), and Federal Reserve Board (FRB) (2022).

[6]See Kim and Kang (2019), Armelius, Clausen, and Hendry (2020), Armelius et al. (2020), Jackson and Pennacchi (2021), and Keister and Sanches (2023).

[7]See Brunnermeier and Niepelt (2019), Bindseil (2020), Carletti et al. (2020), Keister and Monnet (2020), Kwon, Lee, and Park (2020), Andolfatto (2021), and Fernández-Villaverde et al. (2021).

[8]See Auer et al. (2021), Chorzempa (2021), and Ferrari, Mehl, and Stracca (2022).

[9]See, e.g., Garratt and Lee (2021), Garratt and van Oordt (2021), and Agur, Ari, and Dell'Ariccia (2022).

To assess the former question, 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, of either the wholesale or retail variant. We find that higher mobile phone use 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. Only a few central banks have considered 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 favor a design with indirect claims on the central bank (referred to as an "indirect" architecture). Central banks are considering both distributed ledger technology (DLT) and conventional technological infrastructures, with many considering multiple technological options simultaneously. Nevertheless, access frameworks tend to be based more often on account identification rather than allowing for token-based fully anonymous access. More and more CBDC projects explicitly envisage international use, e.g., by non-resident visitors and for cross-border payments.

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

2. Cross-Country Factors Behind CBDC Development

Several global developments—including the digitalization of commerce, the proliferation of private digital currencies, and specific policy concerns around financial inclusion, informality, or data privacy—have recently driven increased interest in CBDCs (Auer et

al. 2020). 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 factors that correlate with 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.

2.1 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. This extends the initial stocktaking exercise of Auer, Cornelli, and Frost (2020b), which focused only on retail CBDC as of early 2020.[10] The information on CBDC projects was collected through desk research and with the help of contacts at several individual central banks.[11]

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

- Score of 0 for jurisdictions without any CBDC work publicly announced by the central bank.
- 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.

[10]Compared with that earlier stocktake, we include wholesale CBDCs and newer projects (now through January 2022). Moreover, we complement this with data on speeches and search interest (discussed below), and we conduct empirical analysis.

[11]The list of projects is broadly consistent with other stocktakes, such as Kiff et al. (2020), Atlantic Council (2020), and Mikhalev et al. (2021). Unlike these sources, we only take account of official central bank communications, not press articles.

- Score of 2 for pilot projects. These projects flesh out the details of a pilot or proof-of-concept (PoC). This stage requires applied technological development, experimentation, and the involvement of external actors. We can confidently say that these reports indicate a more advanced stage of CBDC work.[12]
- Score of 3 for live CBDCs. This score is given when a CBDC is rolled out for large-scale use. As of our cut-off date, three central banks had live retail CBDCs, while no central bank had yet rolled out a wholesale CBDC.

Each score is sequential—i.e., 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 January 2022.[13]

Construction of the index requires some judgment. For instance, we consider only jurisdictions that have a central bank or monetary authority that could in theory develop a CBDC.[14] Currency unions require special consideration. Currency unions without national central banks are considered one observation, with all independent variables calculated as weighted averages according to 2018 GDP. For instance, the Eastern Caribbean Currency Union (ECCU), served by the Eastern Caribbean Central Bank (ECCB), is included as a single observation comprising the eight member states.[15] For the euro area, which features national central banks in addition to the ECB, 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

[12]We include completed pilots, e.g., those by the Central Bank of Uruguay in 2017/8 and the National Bank of Ukraine in 2018. We also include Ecuador's Dinero Electrónico, which was launched in 2014 and discontinued in 2018. See Arauz, Garratt, and Ramos (2021).

[13]Regular updates to the database are made available on the authors' websites (https://www.bis.org/publ/work880.htm).

[14]Countries without a central bank are dropped. 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 International Monetary Fund (IMF) (2018).

[15]Similarly, the countries of the West African Economic and Monetary Union (WAEMU) are consolidated as one observation (project index of 0), as are the members of the Economic Community of Central African States (ECCAS).

or 1, depending on whether the national central bank has published any CBDC research).[16] Full links to public sources are available as part of the background documentation.

In the total sample of 176 countries or currency areas, 68 had a non-zero value for the CBDC project index as of January 2022. This included 66 retail CBDC projects. In the other 108 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 governors and board members of central banks. 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 Bank for International Settlements (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 organizations.[17] Speeches are added to the database regularly, and many are translated from other languages into English by the domestic central bank. As of our cut-off date, the database counted 17,448 speeches, covered a period of more than 25 years (1997–2022), and had a wide geographical coverage (104 countries and 116 institutions). A query yielded a set of 242 speeches that contained at least one of the keywords of interest. The resulting sample covers the period December 2013–January 2022 and speeches from 45 central banks, including those of the euro area and several of its member countries.[18]

After compiling relevant speeches, we go through each and classify them by interpreting the stance of the speech towards adoption

[16]Empirical results are robust to treating the euro area as one observation.

[17]In addition to speeches by central bankers, many governments and parliaments have published reports or made statements on CBDCs. See, for instance, the U.K. House of Lords (2022) or the White House (2022). These reports and statements are not included in our database.

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

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. A value of −1 is given if the speech stance was clearly negative or if it was explicitly said that there was no specific plan at present to issue a digital currency. The score takes a value of 0 in the case of a neutral stance. Finally, it takes a value of +1 if the speech stance was clearly positive or a project was launched or was in the pipeline. The country-level speech score is calculated as a simple average of the individual scores to date.

Finally, in order to gauge public interest in CBDCs, our database also includes an *Internet search interest* score. The score reflects both interest by residents in the idea of a CBDC, and how widely the public knows about any central bank plans to introduce a CBDC. 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–January 2022. 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 China, we used the Baidu index for keywords "Central Bank Digital Currency" and "DC/EP" (the Digital Currency/Electronic Payment program) or "e-CNY" (electronic Chinese yuan). We have rescaled the values to make them comparable to Google Trends figures (i.e., 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 the 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 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 is higher where central banks have communicated that they are working on a project (see pairwise correlations in Table 1).

Table 1. Pairwise Correlations between CBDC Indicators

	CBDC Project Index[1] (Overall)	Central Bank Speech Score[2]	Search Interest Index (Google/Baidu)[3]
CBDC Project Index[1] (Overall)	1		
Central Bank Speech Score[2]	0.47***	1	
Search Interest Index (Google/Baidu)[3]	0.39***	0.26***	1

[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 have been classified as neutral. Normalized and winsorized at the 5 percent level. [3]Data have been normalized.

Note: *** denotes significance at the 1 percent level.

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

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 (e.g., 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 anonymized responses of central banks through official surveys. In the next section, we try to explain the cross-country heterogeneity in the CBDC project index.

2.2 Examining the Cross-Country Factors Behind CBDC Projects

In this section we investigate the factors that correlate with the CBDC project index. To complement central bank surveys and official motivations, we look at "revealed policy preferences," i.e., 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

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

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 factors; α and β are estimated coefficients; and ε_i is an error term.

Some potential factors behind CBDC development can be related to 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.[19]

[19]We have also looked at various measures of cash use, such as small-denomination bank notes to GDP. These are available from the CPMI Red Book statistics, but unfortunately for only 18 jurisdictions. A broader measure of cash in circulation, available for 149 jurisdictions, is positively associated with the CBDC project index in the univariate setting, implying that CBDC projects are more advanced where cash in circulation is increasing. Yet this measure may include large bills held as a store of value. Moreover, it is insignificant when

Meanwhile, jurisdictions with higher *financial development* may have greater demands on innovative solutions for wholesale settlement; data for this are available from Svirydzenka (2016). Finally, countries with greater market power in the banking sector, as measured by the *Lerner index* of banking sector markups, may see greater need for policy interventions to increase competition in payments. Data on the Lerner index come from Igan et al. (2021).

- *Cross-Border Transactions:* while most CBDCs serve a domestic purpose, one could expect that some types of CBDCs (e.g., 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.

The CBDC project index has 176 observations and it takes values ranging from 0 to 3. 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 (e.g., 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 phone and Internet use, a higher innovation capacity, an existing or planned FPS, and greater government effectiveness. 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

controlling for other factors. Overall, declining cash use is not a consistent indicator of CBDC work across our global sample—even if it may be important in individual jurisdictions (e.g., Sweden).

Table 2. Descriptive Statistics[1]

	Observations	Mean	Standard Deviation	Min.	Max.
Dependent Variables:					
Overall CBDC Project Index	176	0.58	0.82	0	3
Retail CBDC Project Index	176	0.51	0.74	0	3
Wholesale CBDC Project Index	176	0.23	0.59	0	2
Independent Variables:					
Mobile Cellular Subscriptions (per 100 People)	170	109.66	39.17	12.60	320.55
Broadband Subscriptions (Fixed Line, per 100 People)	168	14.30	13.67	0	47.16
Innovation Output Score (WIPO)[2]	118	29.67	12.69	7.90	67.13
Fast Payment System Dummy	176	0.36	0.48	0	1.00
Government Effectiveness	175	0.08	0.99	–2.25	2.22
Informal Economy (% of GDP)	122	26.08	11.62	5.43	55.78
GDP per Capita (USD)	169	16,857.15	22,027.54	391.56	114,009.80
Account Ownership (1% Age 15+)	135	60.39	27.96	6.45	99.96
Financial Development Index[3]	158	0.36	0.22	0.06	0.93
Lerner Index[4]	76	0.31	0.15	0.06	1
Remittances[5] to GDP	110	5.75	7.50	0.18	42.03
Trade Openness[6]	134	80.06	48.87	0.00	345.69
Search Interest Index (Google/Baidu)[7]	176	0.13	1.12	–0.40	9.78
Central Bankers' Speech Stance Index[8]	176	0.09	0.90	–0.23	3.08

[1]For all the independent variables, average over the period 2013–20, subject to data availability. [2]Data for 2018. [3]Svirydzenka (2016). [4]The Lernex index of banking sector markups in economy i reflects market power by incumbent banks. For more details, see Cornelli et al. (2020). [5]Sum of inflows and outflows. [6]Sum of imports and exports divided by the country GDP. Data for 2018. [7]Data have been normalized. [8]Normalized and winsorized at the 5 percent level.

Sources: Bech et al. (2020); G. Cornelli, J. Frost, L. Gambacorta, R. Rau, R. Wardrop, and T. Ziegler, "Fintech and Big Tech Credit: A New Database," BIS Working Paper No. 887, September 2020. Media 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.

Table 3. Univariate Ordered Probit Regressions on Overall CBDC Project Index[1]

Digital Infrastructure:												
Mobile Cellular Subscriptions (per 100 People)	0.008*** (0.003)											
Broadband Subscriptions (Fixed Line, per 100 People)		0.027*** (0.006)										
Innovation Capacity:												
Innovation Output Score (WIPO)[2]			0.031*** (0.009)									
Fast Payment System (FPS) Dummy				1.009*** (0.196)								
Institutional Characteristics:												
Government Effectiveness					0.465*** (0.096)							
Informal Economy (% of GDP)						–0.016 (0.011)						
Development and Financial Inclusion:												
Ln(GDP per Capita)							0.293*** (0.067)					
Account Ownership (% Age 15+)								0.017*** (0.004)				
Financial Development Index[3]									2.606*** (0.408)			
Lerner Index[4]										0.072 (0.930)		
Cross-Border Transactions:												
Remittances[5] to GDP											–0.06*** (0.022)	
Trade Openness[6]												–0.001 (0.003)
Number of Observations	170	168	118	176	175	122	169	135	158	76	110	134
Pseudo R^2	0.035	0.047	0.054	0.084	0.07	0.013	0.054	0.071	0.111	0.000	0.042	0.001

[1]For all the independent variables, average over the period 2013–20, subject to data availability. [2]Data for 2018. [3]Svirydzenka (2016). [4]The Lerner index of banking sector markups in economy *i* reflects market power by incumbent banks. For more details, see Cornelli et al. (2020). [5]Sum of inflows and outflows. [6]Sum of imports and exports divided by the country GDP. Data for 2018.

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

Sources: Bech et al. (2020a); G. Cornelli, J. Frost, L. Gambacorta, R. Rau, R. Wardrop, and T. Ziegler, "Fintech and Big Tech Credit: A New Database," BIS Working Paper No. 887, September 2020; 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.

correlation of this variable with mobile phone 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, higher account ownership, and greater financial development. Banking sector markups show no significant association with CBDC project work, and remittances are negatively correlated. Univariate results are also very similar for the retail and wholesale indices separately (unreported for brevity but available upon request).

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 have stronger digital infrastructures, to be more innovative, and to feature more effective goverments and smaller informal economies. Moreover, isolating individual factors 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 overall 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 1). We further find that, controlling for mobile phone use, there is a significant positive association with the size of the informal economy and financial development for the overall project index (column 2). We do not find a significant link with trade openess.

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 3 and 4). There is actually a negative association with trade openness, ceteris paribus; this could reflect that retail CBDC projects are easier to implement in jurisdictions with fewer international trade ties and a more domestically focused economy.

Wholesale CBDCs are positively correlated with financial development, which could reflect the focus of such projects on increasing the efficiency of wholesale settlement (column 5).[20] This is also

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

Table 4. Multivariate Ordered Probit Regressions on CBDC Project Indices[1]

	Overall CBDC Project Index		Retail CBDC Project Index		Wholesale CBDC Project Index	
Mobile Cellular Subscriptions (per 100 People)	0.008**	0.009**		0.012**		0.006
	(0.004)	(0.005)		(0.005)		(0.007)
Innovation Output Score (WIPO)[2]	0.027***		0.050***	0.060***		
	(0.009)		(0.013)	(0.013)		
Informal Economy (% of GDP)		0.038***	0.033**	0.042***		0.019
		(0.014)	(0.015)	(0.015)		(0.018)
Financial Development Index[3]		3.604***			2.959***	3.788***
		(0.706)			(0.620)	(0.966)
Trade Openness[4]		–0.004		–0.009***	0.002	0.001
		(0.003)		(0.003)	(0.002)	(0.003)
Number of Observations	118	105	110	100	132	105
Pseudo R^2	0.07	0.163	0.068	0.131	0.184	0.223

[1]For all the independent variables, average over the period 2013–20, subject to data availability. [2]Data for 2018. [3]Svirydzenka (2016). [4]Sum of imports and exports divided by the country GDP. Data for 2018.

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

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

apparent in the more parsimonious specification (column 6).[21] The link with trade openness is not significant. While many wholesale projects focus on the cross-border dimension, it thus seems that domestic financial development is more consistently correlated with the stage of wholesale CBDC project work.

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 1, at mean values of all variables, a country has a 49 percent probability of not doing any work on CBDCs, a 31 percent probability of conducting research, a 20 percent probability of a testing pilot, and a 0.6 percent probability of rolling out a live CBDC. A country with a one-standard-deviation increase in mobile phone subscriptions (ceteris paribus) has a 33 percent probability of research, a 26 percent probability of a pilot, and a 1.1 percent probability of a live CBDC.[22] A one-standard-deviation increase in the innovation output score is associated with probabilities of 33 percent, 30 percent, and 1.5 percent, respectively.

With respect to retail CBDCs, a one-standard-deviation increase in the size of the informal economy is associated with a 46 percent probability for research (6 percentage points higher than mean values), 19 percent for a pilot (8 percentage points higher than mean values), and 1.4 percent for a live CBDC (1 percentage point higher than mean values) (column 3). 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 13–16 percent probability of wholesale research and 21–28 percent probability of a wholesale pilot, depending on the specification (columns 5 and 6).

[21]The Lerner index of banking sector markups is also positively associated with greater wholesale CBDC work, at the 95 percent confidence level—but its inclusion implies a much lower number of observations (unreported but available upon request). This implies that wholesale CBDC work is more advanced where the potential efficiency gains from greater competition in the banking sector are larger, other factors equal.

[22]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, Karlson, and Holm (2018).

Table 5. Effect of a One-Standard-Deviation Increase on Predicted Probabilities (oprobit)[1]

		Overall CBDC Project Index		Retail CBDC Project Index		Wholesale CBDC Project Index	
	Probability of	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Predicted Probabilities at Mean Values	No Activity Research Pilot Live CBDC	49.1% 30.7% 19.6% 0.6%	45.2% 36.8% 17.8% 0.2%	48.8% 39.8% 10.9% 0.5%	45.8% 44.6% 9.3% 0.3%	86.3% 6.9% 6.9% —	85.1% 7.8% 7.1% —
Mobile Cellular Subscriptions (per 100 People)	No Activity Research Pilot Live CBDC	40.1% 32.7% 26.1% 1.1%	33.5% 39.4% 26.5% 0.5%		31.9% 50.7% 16.5% 0.9%		80.4% 9.7% 10% —
Innovation Output Score (WIPO)[2]	No Activity Research Pilot Live CBDC	35.6% 33.1% 29.8% 1.5%		25.2% 46.3% 25.9% 2.6%	19.1% 51.3% 27.2% 2.4%		
Informal Economy (% of GDP)	No Activity Research Pilot Live CBDC		28.4% 39.5% 31.3% 0.8%	33.8% 45.5% 19.2% 1.4%	27.5% 51.7% 19.6% 1.2%		79.3% 10.1% 10.6% —
Financial Development Index[3]	No Activity Research Pilot Live CBDC		16.5% 36% 45.2% 2.2%			65.8% 13.1% 21.1% —	55.9% 15.9% 28.2% —
Trade Openness[4]	No Activity Research Pilot Live CBDC		52.6% 33.9% 13.4% 0.1%		63.7% 32.4% 3.8% 0.1%	83.7% 7.9% 8.4% —	83.5% 8.5% 8% —

[1]For all the independent variables, average over the period 2013–20, subject to data availability. [2]Data for 2018. [3]Svirydzenka (2016). [4]Sum of imports and exports divided by the country GDP. Data for 2018.
Note: 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.
Sources: Medina and Schneider (2019); WIPO (2018); IMF, *World Economic Outlook*; World Bank; central banks' websites; Datastream; authors' calculations.

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 phone use, innovation capacity, and financial development, with some differences across retail and wholesale CBDCs, notably with respect to the informal economy. We have also noted that CBDC projects differ across countries, with regard to their economic and institutional motivations, policy approach, and their technical design.

In what follows, we focus on the 66 retail CBDC projects in our sample. We explore four key technological attributes of retail CBDC projects.

3.1 Attributes of Retail CBDC Projects

Approaches to CBDC design are heterogeneous across countries, requiring us to distill 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). 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*, i.e., 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 as follows:

- *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 offers retail payment services.
- *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 recognized retail CBDC architectures, another approach is the indirect provision of CBDC to financial intermediaries. Thus:

- *Indirect Architecture:* a payment system operated by intermediaries that resemble narrow payment banks. 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.[23]

We note that, as this does not allow the consumer to directly access central bank money, many central banks do not recognize this architecture as a retail CBDC.[24]

[23]See Adrian and Mancini-Griffoli (2019), who refer to this as "synthetic CBDC," and Kumhof and Noone (2019).

[24]For example, Bank of England (2020), Sveriges Riksbank (2020), and for the case of Canada, Shah 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 G-7 countries and others, states explicitly that "synthetic CBDC is not a CBDC."

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 centralized 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.[25]

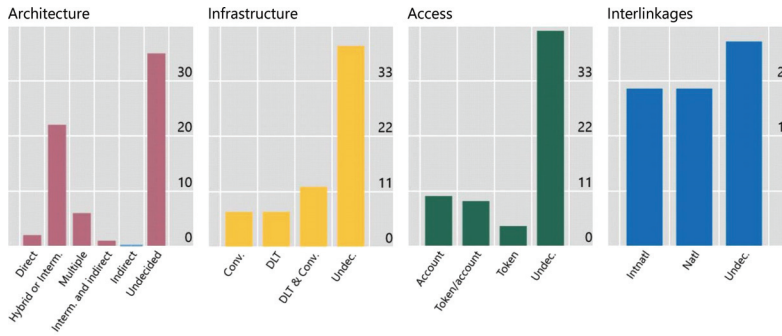
The third choice concerns how consumers can *access* the CBDC. Account-based CBDCs are tied to identification, which can serve as the basis for well-functioning payments with sound law enforcement. Yet access is likely to be difficult for one core target group: the unbanked and individuals who rely on cash. There may be challenges to match the qualities of cash as an inclusive, crisis-proof, and anonymous means of payment (Pichler, Summer, and Weber 2019). An alternative is to base access on so-called digital tokens.[26] This allows for value-based payment options—for example, pre-paid CBDC bank notes that can be exchanged both physically and digitally. Yet this also brings new risks of illicit activity and counterfeiting.

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 versus non-residents. Token-based domestic access would naturally be open to anyone, including non-residents. But

[25]See Auer (2019) for a discussion of the inefficient economics of permissionless models, Ali and Narula (2020) for a specific analysis of permissioned and permissionless DLT in the context of CBDCs, and Auer, Monnet, and Shin (2021) for a general discussion of the economics of distributed ledgers.

[26]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?' "

Figure 2. Number of Retail CBDC Projects Investigating Each Design Option



Note: 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.
Source: authors' calculations, as of January 2022.

central banks may allow for use by non-residents (while visiting the jurisdiction, or from abroad) in systems based on identification, as well. Some central banks may even see a role for CBDCs to support lower-cost and faster cross-border payments.

3.2 Diversity of Retail CBDC Designs

Figure 2 classifies the attributes of ongoing retail CBDC projects. 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 that only two central banks have considered a direct model, both as part of early-stage research projects. A much larger group—22 central banks—are considering the hybrid or intermediated options, with a strong role for the private sector in retail services. Six central banks are considering multiple options (i.e., hybrid or intermediated, direct); in some of these cases, the direct model is being considered as a potential "public option" that could be offered alongside services by private sector intermediaries, rather than a purely public CBDC system.

Meanwhile, one central bank (HKMA) is considering both the intermediated and the indirect model. A group of 35 central banks has not yet specified the architecture. Overall, most central banks that have made 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.

Regarding infrastructure, we find 7 central banks running their prototypes on DLT, 7 with conventional technology, and 12 considering both (Shah et al. 2020). Yet 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. In practice, designs may feature elements inspired by DLT but rely on trusted intermediaries. Among access methods, account-based access appears to be the most common to date, with 10 central banks clearly leaning toward account based, 4 looking at token based, and a further 9 looking at both account- and token-based access.

Finally, while many of the retail CBDC projects in our sample were initially focused on domestic use, a growing number explicitly target use by non-residents or the potential of CBDCs to support cross-border payments. Additionally, several projects—by the ECB; the central banks of France, Spain, and the Netherlands; and the ECCB—are by construction focused on cross-border use among the members of a multi-country currency area.

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 in their economic and technical design. Many central banks are pursuing models where a CBDC is a direct claim on the central bank, but with retail payment services performed by 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, central banks may respond in particular to ensure greater competition and privacy and 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. And a growing number of central banks are considering use of CBDCs for cross-border payments. 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 digital 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. 2022. "Designing Central Bank Digital Currencies." *Journal of Monetary Economics* 125 (January): 62–79.

Ali, R., and N. Narula. 2020. "Redesigning Digital Money: What Can We Learn from a Decade of Cryptocurrencies?" MIT DCI Working Paper (January).

Andolfatto, D. 2021. "Assessing the Impact of Central Bank Digital Currency on Private Banks." *Economic Journal* 131 (634): 525–40.

Arauz, A., R. Garratt, and D. F. Ramos. 2021. "Dinero Electrónico: The Rise and Fall of Ecuador's Central Bank Digital Currency." *Latin American Journal of Central Banking* 2 (2): 1–10.

Armelius, H., A. Clausen, and S. Hendry. 2020. "Is Central Bank Currency Fundamental to the Monetary System?" *Economic Review* (Sveriges Riksbank) 2 (June): 19–32.

Armelius, H., G. Guibourg, S. Johansson, and J. Schmalholz. 2020. "E-krona Design Models: Pros, Cons and Trade-offs." *Economic Review* (Sveriges Riksbank) 2 (June): 80–96.

Atlantic Council. 2020. "Central Bank Digital Currency Tracker." https://www.atlanticcouncil.org/cbdctracker/. Accessed December 1.

Auer, R. 2019. "Beyond the Doomsday Economics of 'Proof-of-Work' in Cryptocurrencies." BIS Working Paper No. 765 (January).

Auer, R., and R. Böhme. 2020. "The Technology of Retail Central Bank Digital Currency." *BIS Quarterly Review* (March): 85–100.

———. 2021. "Central Bank Digital Currency: The Quest for Minimally Invasive Technology." BIS Working Paper No. 948 (June).

Auer, R., C. Boar, G. Cornelli, J. Frost, H. Holden, and A. Wehrli. 2021. "CBDCs Beyond Borders: Results from a Survey of Central Banks." *BIS Papers* 116 (June).

Auer, R., G. Cornelli, and J. Frost. 2020a. "Covid-19, Cash, and the Future of Payments." BIS Bulletin No. 3 (April).

———. 2020b. "Taking Stock: Ongoing Retail CBDC Projects." *BIS Quarterly Review* (March): 97–98.

Auer, R., J. Frost, L. Gambacorta, C. Monnet, T. Rice, and H. S. Shin. 2022. "Central Bank Digital Currencies: Motives, Economic Implications and the Research Frontier." *Annual Review of Economics* 14: 697–721.

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. Monnet, and H. S. Shin. 2021. "Permissioned Distributed Ledgers and the Governance of Money." BIS Working Paper No. 924.

Bank of England. 2020. "Central Bank Digital Currency: Opportunities, Challenges and Design." (March).

Bank of Japan. 2020. "The Bank of Japan's Approach to Central Bank Digital Currency." (October 9).

Bank for International Settlements (BIS). 2020. "Central Banks and Payments in the Digital Era." In *Annual Economic Report*, Chapter III (June).

———. 2021. "CBDCs: An Opportunity for the Monetary System." In *Annual Economic Report*, Chapter III (June).

Barontini, C., and H. Holden. 2019. "Proceeding with Caution — A Survey on Central Bank Digital Currency." *BIS Papers* 101 (January).

Bech, M., and C. Boar. 2019. "Shaping the Future of Payments." In *Analysis of the 2018 Red Book Statistics* (November).

Bech, M., J. Hancock, T. Rice, A. Wadsworth. 2020. "On the Future of Securities Settlement." *BIS Quarterly Review* (March): 67–83.

Bech, M., J. Hancock, and W. Zhang. 2020. "Fast Retail Payment Systems." *BIS Quarterly Review* (March): 28–29.

Bindseil, U. 2020. "Tiered CBDC and the Financial System." ECB Working Paper 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* 114 (January).

Breen, R., K. B. Karlson, and A. Holm. 2018. "Interpreting and Understanding Logits, Probits, and other Nonlinear Probability Models." *Annual Review of Sociology* 44: 39–54.

Broadbent, B. 2016. "Central Banks and Digital Currencies." Speech at the London School of Economics, London, March 2.

Brunnermeier, M., H. James, and J. P. Landau. 2019. "The Digitalization of Money." NBER Working Paper No. 26300.

Brunnermeier, M., and D. Niepelt. 2019. "On the Equivalence of Private and Public Money." *Journal of Monetary Economics* 106 (October): 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." VoxEU e-Book (June 19).

Chorzempa, M. 2021. "China, the United States, and Central Bank Digital Currencies: How Important is It to be First?" *China Economic Journal* 14 (1): 102–15.

Clark, A., and A. Mihailov. 2019. "Why Private Cryptocurrencies Cannot Serve as International Reserves but Central Bank Digital Currencies Can." Discussion Paper No. 2019-09, University of Reading–Department of Economics.

European Central Bank (ECB). 2020. "Report on a Digital Euro." (October).

Fan, Y. 2020. "Some Thoughts on CBDC Operations in China." Speech, April 1.

Federal Reserve Board (FRB). 2022. *Money and Payments: The U.S. Dollar in the Age of Digital Transformation.* (January).

Fernández-Villaverde, J., D. Sanches, L. Schilling, and H. Uhlig. 2021. "Central Bank Digital Currency: Central Banking for All?" *Review of Economic Dynamics* 41 (July): 225–42.

Ferrari, M., M. Mehl, and L. Stracca. 2022. "Central Bank Digital Currency in an Open Economy." *Journal of Monetary Economics* 127 (April): 54–68.

Garratt, R., and M. Lee. 2021. "Monetizing Privacy." Staff Report No. 958, Federal Reserve Bank of New York.

Garratt, R., and M. van Oordt. 2021. "Privacy as a Public Good: A Case for Electronic Cash." *Journal of Political Economy* 129 (7): 2157–80.

Group of Central Banks. 2020. "Central Bank Digital Currencies: Foundational Principles and Core Features." Joint Report No. 1 (October).

Igan, D., M. S. Martinez Peria, N. Pierri, and A. Presbitero. 2021. "When They Go Low, We Go High? Bank Market Power and Interest Rates." IMF Working Paper No. 21/149.

International Monetary Fund (IMF). 2018. "Republic of the Marshall Islands: Selected Issues." IMF Country Report No. 18/271 (September).

Jackson, T., and G. Pennacchi. 2021. "How Should Governments Create Liquidity?" *Journal of Monetary Economics* 118 (March): 281–95.

Kahn, C. 2016. "How Are Payment Accounts Special?" Paper prepared for the Payments Innovation Symposium, Federal Reserve Bank of Chicago, October 12–13.

Kahn, C., and W. Roberds. 2009. "Why Pay? An Introduction to Payments Economics." *Journal of Financial Intermediation* 18 (1): 1–23.

Keister, T., and C. Monnet. 2020. "Central Bank Digital Currency: Stability and Information." Mimeo.

Keister, T., and D. Sanches. 2023. "Should Central Banks Issue Digital Currency?" *Review of Economic Studies* 90 (1): 404–31.

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 Paper No. 20/104, June.

Kim, J., and J. Kang. 2019. "Money, to be Publicly Issued, or not to be, That is the Question." (인터넷전자상거래연구) *Journal of Internet Electronic Commerce Research* 19 (5): 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 Paper.

Kumhof, M., and C. Noone. 2018. "Central Bank Digital Currencies — Design Principles and Balance Sheet Implications." Working Paper No. 725, Bank of England.

Kwon, O., S. Lee, and J. Park. 2020. "Central Bank Digital Currency, Inflation Tax, and Central Bank Independence." Mimeo.

Liikanen, E. 2016. "Cash and the Central Bank." Opening Remarks at the Bank of Finland Conference on Going Cashless, Helsinki, June 14.

McKelvey, R., and W. Zavoina. 1975. "A Statistical Model for the Analysis of Ordinal Level Dependent Variables." *Journal of Mathematical Sociology* 4 (1): 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 Paper No. 7981.

Menon, R. 2016. "Singapore's FinTech Journey — Where We Are, What Is Next?" Speech at the Singapore FinTech Festival, Singapore, November 16.

Mersch, Y. 2016. "Distributed Ledger Technology — Panacea or Flash in the Pan?" Speech, Frankfurt am Main, April 25.

Mikhalev, I., K. Burchardi, I. Struchkov, B. H. Song, and J. Gross. 2021. "CBDC Tracker." Mimeo.

Nakaso, H. 2016. "FinTech — Its Impacts on Finance, Economies and Central Banking." Speech at the conference on "FinTech and the Future of Money," Tokyo, November 18.

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

People's Bank of China (PBC). 2021. "Progress of Research & Development of E-CNY in China." (July).

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 the General Public?" *Monetary Policy and the Economy* (Oesterreichische Nationalbank) Q4/19: 40–56.

Shah, D., R. Arora, H. Du, S. Darbha, J. Miedema, and C. Minwalla. 2020. "Technology Approach for a CBDC." Staff Analytical Note No. 2020-6, Bank of Canada.

Skingsley, C. 2016. "Should the Riksbank Issue e-krona?" Speech at FinTech Stockholm, Stockholm, November 16.

Sveriges Riksbank. 2020. *The Riksbank's e-krona Pilot.* (February).

Svirydzenka, K. 2016. "Introducing a New Broad-Based Index of Financial Development." IMF Working Paper No. 16/15.

Tobin, J. 1987. "The Case for Preserving Regulatory Distinctions." In *Restructuring the Financial System.* Proceedings of the Economic Policy Symposium, sponsored by the Federal Reserve Bank of Kansas City, held in Jackson Hole, Wyoming, August 20–22.

United Kingdom (UK) House of Lords. 2022. *Central Bank Digital Currencies: A Solution in Search of a Problem?* (January).

Vives, X. 2019. "Digital Disruption in Banking." *Annual Review of Financial Economics* 11: 243–72.

White House. 2022. *Executive Order on Ensuring Responsible Development of Digital Assets.* (March).

Wilkins, C. 2016. "Fintech and the Financial Ecosystem — Evolution or Revolution?" Remarks at Payments Canada, Calgary, Alberta, June 17.

World Intellectual Property Organization (WIPO). 2018. *Global Innovation Index 2018: Energizing the World with Innovation.* (July).