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Central Bank Digital Currencies and Banking: Literature Review and New Questions

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Abstract

We review the nascent but fast-growing literature on central bank digital currencies (CBDCs), focusing on their potential impacts on private banks. We evaluate these impacts in three areas of traditional banking: payments, lending, and liquidity and maturity transformation. For each area, we discuss the lessons learned and identify gaps in the research yet to be fully explored. We also take a broader look at CBDCs and highlight two promising directions for future research. One is to study CBDCs through the lens of industrial organization, exploring issues such as platform competition and business models. The second is the crypto space and its new developments such as stablecoins and decentralized finance.

Topics: Central bank research; Digital currencies and fintech; Financial institutions; Financial stability
JEL codes: E50, E58, G00, L00

Résumé

Nous passons en revue le corps d'études naissant mais en développement consacré aux monnaies numériques de banque centrale (MNBC). Nous nous intéressons aux effets potentiels de ces monnaies sur les banques privées en examinant trois domaines du secteur bancaire traditionnel : les paiements, le crédit et la transformation de la liquidité et des échéances. Pour chacun, nous analysons les enseignements tirés et mettons en évidence les aspects qui devront faire l'objet d'autres travaux. Nous agrandissons également notre focale et soulignons l'apport prometteur de deux approches pour les futures recherches sur les MNBC. Un filon consiste à étudier les MNBC sous l'angle de l'organisation sectorielle en portant attention à des thématiques comme la concurrence des plateformes et les modèles d'affaires. L'autre filon est celui des cryptomonnaies, notamment des nouveautés comme les cryptomonnaies stables et la finance décentralisée.

Sujets : Recherches menées par les banques centrales; Monnaies numériques et technologies financières; Institutions financières; Stabilité financière
Codes JEL : E50, E58, G00, L00

1. Introduction

What does the relationship between central banks and the retail public look like in the future, and how should central banks plan for it? The past decade has seen large and accelerating changes in the financial and banking sectors as consumers move toward digital payments. These changes have the potential to fundamentally change how the banking system works and, by implication, to affect its stability and efficiency.

This shift toward digital payments has prompted most central banks around the world to begin to study the design and potential issuance of a central bank digital currency (CBDC) (Auer et al. 2022). The changes a CBDC could bring about for the banking system has spurred researchers both within and outside central banks to start building models to help them understand what the impacts could be.

This has spawned a new and rapidly expanding academic literature on CBDCs. The goal of this paper is to review and synthesize this literature, with a focus on the impacts a CBDC could have on banking and financial institutions.[2] We also hope to help chart a course forward by highlighting some important questions that remain unanswered.

A CBDC is a general concept; CBDCs can be designed and implemented in many different ways.[3] In this literature review, we focus on retail CBDCs that would be accessible to the majority of consumers for general payment use (versus wholesale CBDCs not for consumer use). We discuss important design considerations and their economic implications for the banking system. The most important design choices are:

- how the public accesses the CBDC—if holders of the CBDC are identified or not
- the architecture of the system—whether the CBDC is provided directly by the central bank or indirectly through intermediaries
- the CBDC's rate of remuneration (which could be zero)

The design of a new retail CBDC would likely have a material impact on a country's banking system. This is because it would be a new type of outside money (i.e., an asset that is not a liability of another private actor), in contrast to other traditional digital payment instruments that are inside money (assets that are liabilities of participants within the system).

For the purposes of this paper, we define banks as having three pertinent roles. Banks lend money for long-term illiquid investments. They do this by issuing short-term liquid deposits (i.e., inside money) to consumers, who then use them as a payment instrument for goods and services. In this way, banks fill the role of liquidity transformers for the economy. The design of a CBDC can impact all three aspects—lending, deposit creation and liquidity transformation—of this process.

[2] We note that this review has a more Canadian view, especially for the empirical work. This is a bit unavoidable given our roles at the Bank of Canada as well as the fact that the Bank has been at the frontier of CBDC research and payments research overall.
[3] See the "money flower" of Bech and Garratt (2017) for a succinct diagram of potential types of money, including CBDCs (or CBCCs in their diagram).

The first impact of CBDCs on traditional banking we discuss (see section 2.1) is the effect a CBDC could have by competing with bank deposits, both as a means of payment and as a store of value. This is a natural effect to study, since CBDCs are the digital equivalent of physical cash, which already competes with bank deposits for both of these uses.

Current research on competition with bank deposits tries to empirically estimate consumer demand for a CBDC as a new payment instrument. We discuss two methodologies researchers have used to study this demand:

- directly surveying the demand for a hypothetical CBDC
- building structural models to estimate consumer preferences for different features provided by existing payment products, then employing the resulting preference parameters to predict the demand for a CBDC modelled as a new bundle of these features

The current estimates from these approaches suggest that the demand for a CBDC could be significant. However, these estimates vary widely depending on the CBDC's design characteristics. For example, Li (2022) estimates demand for a CBDC could be between 4% and 52%, which is quite a large range. This is perhaps unsurprising, given the many dimensions of CBDC design that must be examined and the difficulty of estimating demand for a new product.

The second impact we discuss is the effect a CBDC could have on bank lending (see section 2.2). We explore how the design of a CBDC could change banks' funding costs. Obviously, an interest-bearing CBDC could act as a substitute for bank deposits. But this strand of research shows that even a non–interest bearing CBDC could reduce the deposits available and raise a bank's funding costs. However, this leaves out the effects of the banking system's market structure as well as general equilibrium effects.

In terms of market structure, the key idea is how competitive the banking sector is. Keister and Sanches (2022), for example, show that in a competitive banking sector, a CBDC that pays an interest rate higher than the equilibrium rate would decrease the funds available to banks and hence reduce the creation of credit. In contrast, research by Chiu et al. (2022), along with other studies, shows that the introduction of a CBDC could increase lending in an oligopolistic banking sector. Their main point is that a CBDC provides an outside option for depositors, causing oligopolistic banks to increase their interest rates on those deposits. This attracts more funds that banks can then use to lend, thereby increasing credit creation.

General equilibrium effects should also be considered, particularly how the credit creation process is affected by the introduction of a CBDC. Chiu and Davoodalhosseini (2021) show that an interest-bearing CBDC can increase bank intermediation even when the banking sector is competitive. An interest-bearing CBDC increases demand for goods from consumers receiving interest payments on their CBDC and deposit balances. This, in turn, increases the demand for loans to finance the production of goods.

The third impact we discuss is how a CBDC could affect the role banks have in liquidity and maturity transformation (see section 2.3). Banks create short-term, liquid liabilities to finance investment in long-term, illiquid assets. This mismatch creates the possibility of bank runs, a mechanism well known in the literature.

A concern often raised by policy-makers is that a CBDC could make banks more fragile by increasing both the likelihood and speed of bank runs. With a CBDC, depositors gain access to a digital form of outside money in addition to physical cash. Since a CBDC might be more convenient than physical cash for depositors, this additional option could make runs more appealing. The digital nature of the CBDC also means that it could be faster to withdraw than physical cash in the event of a bank run. These bank run concerns, and how design options could alleviate some of this risk, are articulated formally in Kumhof and Noone (2021).

Despite these concerns, the literature has identified some considerations that can offset these risks. One, first described by Tobin (1985) and formalized by Williamson (2022a), among others, is that a CBDC could cushion the disruption to the payment system in case of a bank failure by providing an alternative means for digital deposits. Also, withdrawals of a CBDC are easier to observe (relative to cash) and can transmit timely information to help policy-makers and banks manage runs (Keister and Monnet 2022; Priazhkina 2022). Recent work by Ahnert et al. (2022) shows how a CBDC could also induce banks to redesign their deposit contracts to be more run-proof. Finally, Bitter (2020) and Fernández-Villaverde et al. (2021) show how a CBDC coordinated with proper central bank asset-side policies could mitigate runs.

So far, most research on how a CBDC could affect banking has focused on traditional tools of money and banking. Much work still needs to be done to fully understand what the effects of a CBDC could be. We identify two new promising areas for future research (see section 3). The first is the effects of a CBDC on market structure, studied through the lens of industrial organization (IO). This is a largely unexplored area of research. The second is the new developments in the crypto space and how they relate to CBDC design and issuance.

The IO research approach to CBDC design and issuance aims to understand the impacts of a CBDC on the payments ecosystem and the financial system from the perspective of the firms involved—and to evaluate their strategic reactions. Understanding these impacts is crucial when deciding to issue a CBDC. As a new payment product, a CBDC would be introduced into a market that has many well-established electronic payment options. As a new entrant in this market, the CBDC product would face the challenge of having to compete in a complex market ecosystem, where multiple types of firms compete and cooperate in a myriad of ways to provide the current suite of options that consumers enjoy.

IO research will help us understand the impacts on the business models of payment service providers and on the payments business of banks. For example, the introduction of a CBDC might affect the product bundle that traditional banks offer to customers. This could potentially weaken the economies of scope that banks currently enjoy—especially those from deposits and payments services. IO research should further explore the extent of such effects as well as other channels through which banks might respond to the issuance of CBDC. This research could also potentially improve the overall understanding of the trade-offs inherent in the design of a CBDC business model. These questions, among others, are at the forefront of CBDC as well as IO research.

The second promising area of future research is related to new developments in the crypto space. Stablecoins and decentralized finance have had explosive growth in the past four years. They could

potentially have negative spillovers to traditional finance and the real economy. More research is needed to understand how CBDCs would interact with these new developments. Also worth exploring is how CBDC design and issuance should coordinate with future regulatory actions for the crypto space. Relatedly, researchers should investigate whether and how CBDCs can support programmability.

2. Impacts of CBDCs on traditional banking

In this section, we discuss the effects of CBDCs on traditional banking (we do not include here some of the new key developments in the payments landscape; these are explored later in section 3). We separate the discussion into three areas: payments, lending and maturity transformation.

The impact of a CBDC depends on the CBDC's design. The most discussed design features include:

- whether the users are identified (privacy)
- if the CBDC is interest-bearing
- whether the CBDC is provided directly by the central bank or indirectly through intermediaries

Other design features include:

- whether the CBDC is useful for budgeting
- if it can be used for offline payment
- whether it supports loss recovery
- if it has holding, withdrawal or transfer limits

In this section, we discuss the impacts of a CBDC together with some of its design features.

2.1 Payment demand for CBDCs

As an electronic payment method, a CBDC competes directly with payment instruments (e.g., debit cards and credit cards) and payment balances (deposits) provided by the banks. Because of this, its impact on the traditional banking sector depends on its attractiveness to consumers. If consumers find a CBDC attractive, the banking sector will have to work to retain them as depositors. This could lead to a significant outflow of deposits or to increased costs (e.g., higher interest rates on deposits). Either way, a CBDC could reduce the quantity of loans intermediated by banks, i.e., bank disintermediation. Because of this, it is important to understand consumer demand for a CBDC.

Predicting the demand for a CBDC is difficult because CBDCs are an entirely new product. To date, only a handful of research papers have attempted to tackle this issue. They use two different methodologies:

- surveying consumers about their demand for a hypothetical CBDC
- employing a structural model to estimate consumer preferences for features of existing payment products and then applying these preference parameters to predict the demand for a CBDC modelled as a new bundle of these features

Bijlsma et al. (2021) adopt the first approach. They surveyed a representative panel of consumers in the Netherlands about demand for a hypothetical CBDC. They find that 49% of respondents would like to open

a CBDC chequing account, with most wanting to hold a balance between 100 and 400 euros. About 54% of respondents are willing to put money in a CBDC savings account if it has the same interest rate as a savings account with a commercial bank. Younger and more educated respondents are more open to adopting a CBDC than others in the survey. In terms of design features, the most desired improvements over commercial bank accounts include:

- protection against theft and fraud
- privacy protection
- a higher interest rate

Respondents also value the fact that the central bank is not profit-driven, which shows a certain level of trust in the central bank.

Bijlsma et al. (2021) provide some valuable insights into consumer demand for a CBDC. However, their paper has two potential issues. First, it is based on a hypothetical product that most respondents are unfamiliar with. The paper notes that 53% of respondents had not heard about CBDCs, and among those who had, 33% did not know what a CBDC was. Therefore, how to interpret the survey results is unclear. Second, how to use this survey approach to study the demand for and impact of a CBDC with specific alternative design features is also not clear.

The second methodology noted above can, to some extent, address both issues. It models existing payment products as different bundles of payment features that consumers value. These features include privacy protection, cost of use, and budgeting usefulness, among others. Using data on consumers' actual demand for existing payment products, one can estimate their preferences for the different payment features. One then can introduce a CBDC as a new bundle of features into the model and predict the demand for that CBDC as well as its impacts on the demand for existing payment methods and balances provided by traditional banks.

Huynh et al. (2020) use this approach to study the demand for a CBDC in terms of its usage at the point of sale in Canada. The payment features they consider include ease of use, affordability, security and rewards (e.g., credit card points). The authors estimate that, if the CBDC were universally accepted and did not give rewards, a CBDC with the same features as cash (cash-like) can take 19% of the market share of point-of-sale transactions. A CBDC with the same features as debit cards (debit-like) takes 22% of the market share, and a CBDC with the top features of both cash and debit cards takes 25% of the market share. A cash-like CBDC reduces the market share of cash by 44% and that of debit cards by 12%. A debit-like CBDC reduces the market share of cash by 35% and that of debit cards by 32%. Under all the considered designs, the CBDC does not have a significant impact on the use of credit cards because unlike credit cards, the CBDC does not give rewards.

Li (2022) uses a similar approach but focuses on the demand for CBDC balances and finds that predicting CBDC demand is difficult due to data limitations. With a baseline CBDC design, the author estimates that households would want to hold between 4% and 52% of their total liquid assets in a CBDC. Therefore, a CBDC can have a potentially large impact on bank deposit balances. While it is hard to predict the level of

demand for a CBDC, one can estimate relatively precisely the preferences for various features. The most important features include rate of return, budgeting usefulness, privacy, and bundling of financial services.

Despite the progress in research, many gaps remain. First, existing work largely ignores the two-sidedness of payments—that is, consumers' demand for a payment method depends on the method's acceptance by merchants, and merchants' acceptance depends on consumers' demand.[4] This two-sidedness feature could lead to multiple equilibria and substantially impact the prediction of the demand for a CBDC. Progress in this area of research is much needed.

Second, the papers mentioned above focus on estimating consumer preferences and ignore banks' endogenous response. One interpretation is that the estimated impact of a CBDC is an upper bound, because banks are likely to respond to maintain consumers' use of the banks' payment services and balances, which reduces the market share of the CBDC. It would be helpful to quantitatively assess how much banks can offset the impact of a CBDC.[5]

Third, the current studies do not incorporate all relevant payment features. This is because of two issues:

- The observed variation in payment products is limited, making it difficult to identify consumer preferences across all relevant features. For example, the central-bank-issued retail payment instrument is physical (paper money) and private instruments are mostly electronic. Therefore, it is difficult to distinguish between preferences for the payment instrument that is issued by the central bank and preferences for the instrument that is physical.[6]
- Available data may not contain all information on the features of existing products. For example, one can observe from payment data whether a consumer uses a credit card in a transaction. However, we usually do not know the issuer or the brand of the credit card. Credit card features such as rewards and add-ons can vary significantly across issuers and brands. Another example is that most banks offer multiple chequing accounts with highly different features. But commonly used datasets do not report the exact type of chequing accounts held by users. Additional information could help refine the estimates.

Fourth, banks typically bundle services such as lending and investment with payment services and balances. This type of bundling can help banks retain customers and reduce the impact of a CBDC. This is an important factor largely ignored by existing studies. Li (2022) partly addresses this by including the bundling of services that offer financial planning advice as a product feature.[7] But obviously, other bundled services exist. A thorough analysis of bundling activities is crucial to understand the impacts of a CBDC.

Finally, current studies focus on the long-run, steady-state demand for a CBDC. But the transitional path is also of interest to policy-makers. For example, if a central bank finds that adoption of a CBDC is suboptimally

[4] Huynh, Nicholls and Shcherbakov (2022) consider the effects of the two-sidedness of the payments market but do not investigate the effects of introducing a CBDC. It would be interesting to consider the effects of a CBDC in this framework. A large literature on platforms studies two-sidedness. See section 3 for a discussion.

[5] Li (2022) briefly discusses banks' endogenous response in that paper's Appendix.

[6] The existence of privately issued paper money can help with this preference-identification issue by providing additional variation in payment products.

[7] This is measured by the level of agreement with the survey statement, "I would always go to my financial institution for financial planning advice service."

slow without intervention, it may want to provide monetary incentives to consumers and merchants to induce faster adoption. To determine whether interventions are needed and how to intervene, one must study the transitional path both with and without interventions. This involves understanding the frictions associated with adoption, including switching, information and search costs.

2.2 Bank lending

In this section, we evaluate the effects of a CBDC on bank lending. We elaborate on the positive implications while briefly discussing the welfare implications.

One important concern in the literature is the potential for disintermediation of the traditional banking sector. The basic idea is that an interest-bearing CBDC that is a substitute for bank deposits can raise banks' funding costs by competing with bank deposits, thus reducing deposits and credit creation (Keister and Sanches 2022).

The disintermediation result, however, depends on the market structure and the presence of general equilibrium effects. When banks have market power in the deposit market, they offer deposit interest rates below the competitive level. As a result, the quantity of deposits and loans can be inefficiently low and the loan interest rate inefficiently high. That is, the level of intermediation can be inefficiently low. A CBDC that is a substitute for bank deposits and that has a moderate interest rate can induce banks to offer better terms and services (e.g., higher interest rate on deposits). This, in turn, leads to increased deposit-taking and hence more intermediation. As an alternative to bank deposits, a CBDC limits banks' market power and induces banks to lend more (Chiu et al. 2022). The intuition is that the interest rate on the CBDC becomes an interest floor for the deposit rate, so banks attract more deposits (Andolfatto 2021).[8] Without the ability to set the deposit rate, banks are willing to absorb the higher deposit supply as long as their profit margin, which comes from the spread between deposit and lending rates, remains positive.

A CBDC can also affect intermediation through general equilibrium effects. Chiu and Davoodalhosseini (2021) show that an interest-bearing CBDC can increase bank intermediation even when banks are competitive. While a higher CBDC interest rate can increase banks' funding costs (the disintermediation channel), it can also increase aggregate demand for consumption goods. It does this both directly—because of interest payments on the CBDC—and indirectly—because of banks' endogenous response to raise interest rates on deposits. When the production of consumption goods is financed by banks (the general equilibrium channel), a higher CBDC interest rate can induce banks to create more loans and deposits. The

[8] Whether introducing an interest-bearing CBDC and regulating an interest rate floor are equivalent depends on the interest rate. With a moderate interest rate, the CBDC does not capture any market share and the two policies have the same effects. However, they differ when the CBDC interest rate is high. In this case, the quantity of payment balances demanded by households is greater than the quantity of deposits supplied by banks, and the CBDC helps clear the market by capturing some market share. In contrast, when the central bank regulates an interest rate floor, the quantity of payment balances demanded by households is greater than the quantity of deposits demanded by banks, but because no other source (such as a CBDC) exists to satisfy the demand, rationing occurs in equilibrium.

overall effect depends on the type of CBDC. A cash-like CBDC (one that is as useful as cash in transactions) is more effective in promoting intermediation compared with a deposit-like CBDC.

Heterogeneity among banks also plays a role in how a CBDC affects intermediation. Garratt, Yu and Zhu (2021) introduce two different-sized banks—a large one and a small one. They assume that the large bank gives depositors a higher convenience value and therefore offers a lower deposit rate than the small bank. The authors consider two scenarios. First, they suppose a CBDC inherits the same convenience value as deposits—that is, the convenience value of the CBDC offered through the large bank is higher than that offered through the small bank. In this case, the interest rate on the CBDC imposes a lower bound on deposit interest rates. As a result, the large bank raises its deposit rate and gains a higher market share in the deposit and loan market at the expense of the small bank. Second, they suppose the CBDC delivers its own convenience value to users, effectively improving the convenience value of the small bank (e.g., through interoperability). In this second scenario, a CBDC can level the playing field by shifting deposits and lending from the large bank to the small one.

Although the papers mentioned earlier have provided important contributions to the literature, they have not considered certain dimensions that could be relevant for analyzing the effects of a CBDC. These include:

- alternative funding sources in the presence of general equilibrium effects
- the quality of intermediation
- discipline imposed on banks
- the central bank's asset-side policy

In the remainder of this section, we describe these dimensions and note some early studies. We then discuss potential future research.

The first dimension worth considering is alternative funding sources. In most existing models, the banks' funding choice is limited to short-term retail deposits. However, banks may have access to other funding sources, such as wholesale funding. A BIS Innovation Hub report (Bank for International Settlements 2021) studies the effects of a CBDC on banks' balance sheets and profitability. Seeking to maintain their lending volumes and regulatory liquidity ratios, banks replace deposits lost to CBDCs with long-term wholesale funding, which is typically more costly. In the report's worst-case scenario, if the size of deposit outflows from the banking system is 20% of bank assets, the banks' return on equity (RoE) decreases by around 30 basis points (bps). This result is obtained when the average RoE of banks is around 7%–8% and the average wholesale funding–deposit spread is 63 bps in the sample (composed of some advanced economies). In a similar exercise with slightly different assumptions, Garcia et al. (2020) show that the RoE of the Big Six Canadian banks would decline by less than 1% following the introduction of a CBDC in their study's worst-case scenario (with the size of deposit outflows being 10% of assets and the wholesale funding–deposit spread being 184 bps). In both papers, the prices of assets and liabilities are assumed fixed and the potential effects of a CBDC on these prices are not considered. For example, greater reliance of banks on wholesale funding in the general equilibrium may increase wholesale funding costs, which puts additional pressure on banks' profitability.

Whited, Wu and Xiao (2022) study a model in which banks can choose the quantities of both deposits and wholesale funding. In their quantitative exercise, the authors estimate the price elasticities of demand for deposits and loans and use those to estimate the response of banks to the introduction of a CBDC. For a $1 market share captured by a non–interest bearing CBDC, they find that deposits are reduced by $0.7–$0.8 but lending is reduced by only $0.2–$0.3 because banks can replace most of their lost deposits with more expensive wholesale funding. A rise in the CBDC interest rate pushes banks to rely more on wholesale funding (which is not insured, in contrast to deposits), increasing banks' probability of default. Quantitatively, a 1% increase in the CBDC rate raises banks' default probability by around 1.1%, thus further increasing bank funding costs and reducing profitability. With more reliance on wholesale funding after the introduction of a CBDC, banks face higher interest rate risk, so bank capital is more affected by an unexpected increase in short-term rates. Finally, since small banks rely more heavily on deposits, a CBDC affects small banks more than big banks. Future research could consider the effects of a CBDC on banks' balance sheets in models where banks' different funding sources are considered and their prices are endogenized in the presence of general equilibrium effects of CBDC issuance.

Second, most existing papers focus on the effects of a CBDC on the quantity of intermediation, but CBDCs are likely to also affect the quality of intermediation, i.e., the riskiness of the loans and projects into which banks invest. For example, an interest-bearing CBDC can decrease bank profits and affect risk taking. In an extension of their benchmark model, Chiu et al. (2022) consider an environment with risky and non-contractible project returns together with deposit insurance. They show that if the riskiness of the projects is decided by firms independently from banks, issuing a CBDC can decrease risk taking. This is because a CBDC increases the quantity of deposits and loans, as mentioned above, thus lowering loan rates. Therefore, firms have access to cheaper funding, so they have less incentive to invest in risky assets. However, if firms and banks decide the riskiness of the projects jointly, an interest-bearing CBDC increases risk taking. This is because a CBDC squeezes bank profits, so banks have more incentive to take risk, knowing that they are protected by limited liability if the projects fail. The authors' analysis lays out some basic trade-offs. However, further research is needed to evaluate the robustness of these results. For example, one can consider the relationship between banks and firms when projects are risky and when agency problems exist between the two (e.g., firms with heterogenous productivities choose the riskiness of their projects but the bank has imperfect information about both the productivity of the firm and the riskiness of the project).

Other research can explore the implications of a CBDC when the CBDC provides banks with better information about the riskiness of the projects or productivities of the firms, given the observed data of payments processed through a CBDC. Finally, a richer bank balance sheet that includes assets with different risk profiles and liabilities with different liquidities and maturities can help us understand the effects of a CBDC on risk taking in more realistic settings.

A third dimension to consider is the idea that a CBDC may affect the discipline imposed on banks by market participants. Monnet, Petursdottir and Rojas-Breu (2021) build a model in which an interest-bearing CBDC competes (as a safe means of payment) with bank deposits backed by risky lending. When the CBDC interest rate is low, raising it induces banks to increase their deposit interest rate, which expands deposits and lending and enhances monitoring to provide safer deposits to compete with the CBDC. The CBDC basically

acts as a disciplining device for banks to provide safer deposits. Again, the authors lay out some basic trade-offs, but further research is needed to explore the disciplining role of a CBDC in models with agency problems between retail and wholesale depositors and banks, and between banks and their borrowers. Banks play an important role in addressing such agency problems by producing and evaluating the information. Whether and how a CBDC affects banks in such settings requires further exploration. Knowing which insights are robust and which are dependent on specific details of each model would also be helpful.

Finally, the effects of a CBDC on bank intermediation (and more generally on macro variables) depend on the central bank's policy on its asset side. Brunnermeier and Niepelt (2019) show that if the central bank lends to commercial banks, it can avoid crowding out bank lending under certain conditions. Essentially, the central bank swaps private liquid assets with public liquid assets, which keeps banks' and households' liquidity constraints unchanged. This is called the "equivalence result" in the literature, as it establishes that equilibrium allocations with and without a CBDC could be equivalent. This result should be viewed as describing some general conditions under which a CBDC would not change the allocation (thus not disintermediating banks). However, an important task for future research is to find conditions under which this equivalence does not hold. See, for example, Fraschini, Somoza and Terracciano (2021), who consider violations of the equivalence result to be due to liquidity requirements or quantitative easing, or when a CBDC is held against risky securities.

2.2.1 Bank intermediation and welfare

The question of whether issuing a CBDC is welfare enhancing is complicated and needs further exploration. The literature published to date has identified some factors that determine the welfare effects of introducing a CBDC in models with banks lending, including:

- the extent of investment (over- or under-investment compared with the first-best allocation) and market structure
- complementarity between lending and other bank functions
- banks' financial constraints

First, consider the extent of investment and market structure. If an economy demonstrates over-investment (under-investment) before a CBDC is introduced, disintermediation is welfare enhancing (reducing). Moreover, market structure matters too. In a competitive deposit market, a CBDC tends to disintermediate, while it improves intermediation in a monopolistic market, as discussed above. Therefore, one should consider four cases to evaluate the effects of a CBDC on welfare, which are summarized in **Table 1**. Generally speaking, disintermediation is not necessarily negative.

Table 1: Effects of a CBDC on welfare, by type of deposit market and investment

	Competitive deposit market	**Monopolistic deposit market**
Over-investment (e.g., shortage of safe, liquid balances)	↑ investment efficiency (crowds-out banking)	↓ investment efficiency (crowds-in banking)
Under-investment (e.g., significant frictions in loan market)	↓ investment efficiency (crowds-out banking)	↑ investment efficiency (crowds-in banking)

Another factor that affects the welfare implications of a CBDC is complementarity between lending and other bank functions. Piazzesi and Schneider (2022) show that a CBDC that does not come with credit lines can reduce welfare, because the CBDC decouples credit provision from deposit provision, thus making liquidity management more costly for banks.

Finally, the tightness of the financial constraints faced by banks affects the welfare implications of a CBDC. Williamson (2022b) studies a model in which private banks, being subject to a commitment problem, issue deposits backed by private capital and government bonds. A central bank that is not subject to incentive problems can potentially improve welfare by using a narrow banking arrangement, i.e., issuing a CBDC backed by government bonds. When there is over-accumulation of capital by private banks, inducing some households to switch to a CBDC can free up the scarce collateral for banks, lower capital accumulation and improve welfare.[9]

2.3 Liquidity and maturity transformation

Banks are special in that they create short-term, liquid liabilities to finance investment in long-term, illiquid assets. This liquidity and maturity transformation creates the possibility of bank runs. As defined by Diamond and Dybvig (1983), a bank run is a situation in which "depositors rush to withdraw their deposits because they expect the bank to fail," not because they need liquidity. A bank run could be self-fulfilling: a healthy bank could fail if many depositors rush to withdraw their funds in a short period of time.

A common concern is that a CBDC may increase the likelihood of bank runs (Kumhof and Noone 2021).[10] When depositors contemplate whether to withdraw their funds from the bank, they weigh the relative

[9] Some papers have studied the welfare implications of a CBDC when other issues in addition to lending are considered, such as default and privacy. For example, see Böser and Gersbach (2020) and Ahnert, Hoffmann and Monnet (2022).

[10] Kim and Kwon (2022) talk about bank panics, which is different from bank runs discussed here. In their model, depositors choose between either a CBDC account or a deposit account at a private bank, from which they can withdraw cash if needed. Banks are subject to idiosyncratic demand for withdrawals, and a panic is defined as the situation where the bank runs out of cash reserves. The authors show that the introduction of the CBDC account decreases the supply of private credit, inducing the banks to raise the

benefits of withdrawing against those of staying put. A CBDC is likely to increase the appeal of withdrawing by adding another run option. Depositors currently have three options to withdraw their money from a troubled bank. They can:

- transfer their bank deposits to another bank
- withdraw cash from their deposit accounts in the troubled bank
- use their deposits in the troubled bank to purchase (safe) assets such as gold or government bonds

As shown in **Table 2**, all of these options involve different costs, such as set-up and security fees, and provide different transactional and storage benefits.[11] As a new run option, the CBDC is similar to cash in that both are outside money and involve little credit risk, and a run to both leads to an outflow of funds from the banking system. Compared with cash, a CBDC could be an even more appealing and speedy option. A CBDC will likely involve lower withdrawal frictions. The digital nature of CBDCs means that one can simply transfer funds from a deposit account to a CBDC online instead of visiting a bank or an automated teller machine (ATM) for a withdrawal, which must be done to obtain physical cash. In addition, in an increasingly cashless economy, the CBDC may have higher transactional value and wider acceptance than cash. Finally, the CBDC may have potentially higher storage value—for example, because it bears interest or is less costly to store.

Table 2: Options to withdraw funds from an individual bank

	Option	**Frictions inhibiting this option**	**Does it provide a transaction medium?**	**Does it provide a store of value?**
Run to deposits	Transfer to another bank	Potential set-up and transfer fees	Yes	Yes
Run to non-deposits	Withdraw cash	Security and storage costs; access points	Yes	Yes, but with security and storage costs; zero return
	Withdraw CBDC	Lower frictions relative to cash	Wider acceptance relative to cash	Better storage value relative to cash
	Purchase (safe) assets	Potential set-up fees, financial illiteracy, market risk	No	Yes

A related but offsetting view is that even if a CBDC increases the risk of a bank run, it can help cushion a run's disruption to the retail payment system. Without a CBDC option, depositors rely on bank deposits for digital payments. A bank failure disrupts payments. With a CBDC, depositors can continue making digital

loan rate and reduce cash reserves, thereby leading to a higher probability of bank panic. However, if central banks lend CBDC balances to banks, then the CBDC increases credit supply and reduces the probability of a bank panic.

[11] For example, storing gold can involve the costs of purchasing or renting a safe or paying the bank or other third party to store the gold. To trade government bonds, one needs to open an investment account.

payments even if their banks experience runs.[12] Tobin (1985) discusses this intuitively, and recently Williamson (2022a) formalizes it with a model.

Countering the common concern of bank runs, the literature has also identified some channels through which a CBDC may reduce the probability of bank runs occurring. Keister and Monnet (2022) describe two channels. First, when depositors have access to a CBDC, banks perform less maturity transformation, which leaves them less exposed to depositor runs. Second, policy-makers can observe the flows of a CBDC more easily and more quickly than they can observe the flow of cash. As a result, policy-makers can identify weak banks more quickly and take appropriate action, which will help reduce the incentive for a run on the bank. Priazhkina (2022) proposes a related mechanism: with a CBDC, runs could happen earlier because depositors could initiate withdrawals online instead of physically visiting ATMs or bank branches. This allows the individual bank itself to identify run withdrawals and react more quickly to optimally discourage further run withdrawals. Ahnert et al. (2022) use a global-games model to study how the interest on a CBDC affects the probability of bank runs and suggest another countervailing effect. As the interest on a CBDC increases, the bank raises its deposit interest rates to retain funding, which reduces the incentive to run. As a result, the overall relationship between the run risk and CBDC remuneration could be U-shaped.

Other papers suggest that a CBDC coordinated with proper central bank asset-side policies could also mitigate runs. As the central bank issues the CBDC and expands its liabilities, it could consider increasing its scope of investments on the asset side and become more involved in the provision of intermediation. Fernández-Villaverde et al. (2021) point out that the central bank may have some inherent advantage over the private sector in managing the assets to avoid runs. For example, although central banks must rely on investment banks to invest in long-term projects, the rigidity of the central bank's contract with the investment banks helps avoid liquidation of the long-term projects and deter runs (to the central bank) during a panic.[13] Bitter (2020) discusses the comparative advantage of the central bank as a large depositor of commercial banks by committing not to run, and as an investor in the capital market in stabilizing the banking system by better managing capital relative to households, utilizing knowledge that arises from its supervisory role.[14]

The studies above lay out various counteracting channels through which CBDCs may affect run risk. In addition to exploring other channels in the future, more work is needed to assess the relative strength of the opposing channels, conduct more quantitative analysis and evaluate policies to mitigate the run risk related to a CBDC.

[12] During bank runs, a CBDC can function as an alternative means of payment even if it shares the same payment infrastructure as other digital payment instruments. A separate CBDC payment system will have the additional advantage of acting as a backup in case the other payment systems are down, for example, due to temporary network disruptions.

[13] Schilling, Fernández-Villaverde and Uhlig (2020) point out a channel other than active asset-side policies through which the central bank can deter bank runs at the cost of sacrificing price stability.

[14] In the short run, large-scale, direct lending to households and firms seems difficult due to legal and political considerations and to operational challenges such as managing credit relationships and screening and monitoring borrowers. Central bank lending through private banks seems to be a more viable option.

For example, given the opposing forces involved in a CBDC's effect on the probability of bank runs, it will be useful to further explore the different channels within the same framework and identify which channels dominate in which situation. Another consideration is that even if a central bank's more active involvement in intermediation is beneficial in reducing bank runs, it is plausible that the central bank may not be as efficient as private banks in managing assets and choosing good investment opportunities. Exploring the trade-offs between efficiency and stability is also useful.

Regarding quantitative studies, some preliminary policy analysis has been performed on how a CBDC affects the liquidity risk of banks in terms of satisfying the liquidity coverage ratio (LCR).[15] For example, Gorelova, Lands and teNyenhuis (2022) calculate the new LCR for Canadian banks in various scenarios where a CBDC increases the run-off rates (i.e., the percentage of outflows) of the funding volume equal to transactional retail deposits (for which a CBDC is a close substitute). They find that the Big Six can still meet the regulatory requirements of the LCR even if the run-off rate increases to 40% (for reference, the current run-off rate is 3%–5% for transactional retail deposits and 40% for uninsured wholesale deposits). Mid-sized banks, on average, can also meet the LCR requirement, but the effects are more heterogeneous because mid-sized banks have a different starting LCR and overall funding profile. This analysis is mechanical in nature, and it will be useful to expand the quantitative analysis—possibly by using and modifying the theoretical framework discussed above—to endogenize bank responses in terms of funding and investment decisions, such as the holding of liquid assets. The study focuses on whether banks can still satisfy the LCR requirement if a CBDC increases the run-off rates of retail deposits. Another angle the authors could take is to calculate the probability of bank runs and quantify a CBDC's marginal contribution to bank run risks in addition to the current run options.

Regarding policies to mitigate the run risk associated with a CBDC, research has proposed several design choices. For example, a cap can be imposed on CBDC withdrawals, transfers and holdings. Bindseil (2020) discusses a two-tier remuneration scheme that imposes penalty fees or rates for CBDC transfers or holdings beyond a threshold. Formal evaluation will be useful for enhancing the policy discussion. For example, Ahnert et al. (2022) explore the effects of CBDC holding limits on fragility and find that this policy could have ambiguous effects on fragility depending on the interest rate of the CBDC.[16] Priazhkina (2022) shows that imposing liquidity gates, such as suspending withdrawals, may not be effective in preventing runs if depositors do not believe that the bank will commit to those measures throughout the run. Another consideration is that the run-mitigating policies could have some adverse effects. Restricting CBDC transfers during a crisis could hinder digital payments. A cap on CBDC holdings can reduce depositors' ability to protect their wealth in a time of crisis; in normal times, it can discourage adoption and usage, and even affect the fungibility between the CBDC and cash. Finally, it would be useful for future studies to consider CBDC-related policies together with other policies already in place, such as prudential regulation and

[15] The LCR was introduced as part of Basel III post-crisis reforms. It is designed to enhance a bank's short-term resilience and ensure that banks hold a sufficient reserve of high-quality liquid assets to cover net cash outflows during a 30-day liquidity stress scenario.

[16] When interest on a CBDC is low (high), the introduction of holding limits results in higher (lower) bank fragility than in an economy without holding limits.

deposit insurance, and to consider other new options for withdrawal, such as private digital currencies. Rigorous theoretical and quantitative analysis of the different implications of these policies will be useful in directing the design of a CBDC to manage the run risk.

3. New research questions

After reviewing the existing literature on CBDCs and banking, we explore two new directions for further economic research on this topic. First, we focus on the industrial organization (IO) perspective of CBDC issuance—an area largely overlooked by the existing literature—and discuss the implications for payment ecosystems and platforms as well as for the business models of private banks and CBDCs. Second, we review some new developments in the private cryptocurrency space and discuss how they relate to CBDC issuance and design.

3.1 CBDCs and the industrial organization of payments

As a new payment product, a CBDC would be introduced into a market that already has many well-established electronic payment options. The CBDC would face the challenge of entering a market with a complex structure where multiple firms compete and cooperate in various ways to provide the current suite of options. Studying a CBDC through the lens of IO involves conducting research to understand the impacts of a CBDC on the payments ecosystem and the financial system from the perspective of the firms involved in providing a means of payment. In this section, we outline the IO issues that CBDC research should tackle in coming years, specifically in three main areas:

- implications for the payments ecosystem and existing payment platforms
- implications for bank business models (from an IO perspective)
- design of a CBDC business model

Advancing these three areas will be important for policy and CBDC product design choices. We discuss each of these areas below.

3.1.1. Implications of a CBDC for the payments ecosystem and existing platforms

Introducing a CBDC will have implications for the payments ecosystem. To a large extent, these implications will likely depend on the model chosen to distribute the economic activities of the CBDC system among different intermediaries (see section 3.1.3 for more details). Regardless of the specifics of the distribution model, a CBDC will introduce new competition among established electronic payment instruments. The channels through which a CBDC could affect the ecosystem are expected to be intricate (mirroring the complex arrangements between multiple types of firms that currently provide private electronic payment services). Two key channels will be the effects on the established payment intermediaries and changes in prices, especially on interchange fees. We discuss each channel in turn below.

To illustrate the potential effects of a CBDC on the relationships of payment intermediaries, consider point-of-sale (PoS) payments as an example. In this case, the ecosystem of firms includes the card networks (that establish the connections between consumers' and merchants' banks), the commercial banks (that issue the deposits used to transfer value between the parties and coordinate with the networks to issue the payment cards to depositors), and the merchant acquirers (that provide payment services to merchants, like through terminals). A top priority of policy-makers will be to ensure that the CBDC is easy to use, which implies a need for it to interoperate with the existing systems that merchants use to accept electronic payments. In this PoS scenario, the relationships between the merchant acquirers and card networks could be affected if, for example, the former were to offer to merchants the option of enabling their terminals to accept the CBDC.

CBDCs could also affect the relationships in the ecosystem through the entry of new types of intermediaries—in particular, firms that are not deposit-taking institutions. These new financial technology—or *fintech*—firms might have incentives to provide services in the CBDC system (e.g., electronic wallets) to complement their other business lines. Although they would not compete directly with banks in issuing deposits, they could offer financial services using a CBDC as a vehicle and compete with banks for customer relationships. Exploring these channels will require detailed theoretical and empirical work.

In addition, a CBDC could affect a multitude of prices in the payment system. Perhaps the most important will be the interchange fee charged by debit and credit card networks. A key feature of electronic payment arrangements is that they are organized as platforms—environments with two sides in a market that has distinct types of users (e.g., consumers and merchants). Platform operators can (and often do) resort to cross-subsidization pricing to expand adoption and usage (Rochet and Tirole 2003; Armstrong 2006; Weyl 2010). The interchange fee is part of such a mechanism used by credit and debit networks. It has received significant attention from research and regulators worldwide (Jullien, Pavan and Rysman 2021; Rysman and Wright 2014). The importance of this price channel is underlined by a contentious history of regulation. In many jurisdictions, competition authorities have had mixed success in bringing legal cases against card networks to lower fees and modify certain rules imposed by the card networks on members of the ecosystem (e.g., the "honour all cards" and "no surcharge" rules). As a competing platform that sets its own interchange fee and rules, a CBDC could affect the interchange fee and rules of existing payment platforms. The equilibrium outcomes are likely to be complex, particularly because network effects will play a prominent role—in other words, the effects will depend on the scale of adoption of the CBDC. The importance of the network effects for outcomes has been documented by Rysman and Wright (2014). For example, in some cases, networks with low interchange fees have difficulty attracting consumer usage, leading providers to set high interchange fees. Research needs to determine if introducing a CBDC as a new rival would lead incumbents to increase interchange fees even if the CBDC itself has a low interchange fee.

One strand of IO literature is making progress in some specific aspects of payment networks. Huynh, Nicholls and Shcherbakov (2022) estimate a structural model of the equilibrium in the payments market to quantify the network externalities and determinants of consumer and merchant decisions. Their estimates for the Canadian PoS market imply an inefficiently high level of credit card use, while their counterfactuals suggest that the welfare maximizing interchange fee would be lower than the one observed in their sample.

Halaburda, Kim and Shcherbakov (2022) drill further into the specifics of different structures of card payment schemes, such as the four-party scheme (described above) and the three-party scheme (like American Express, which acts as both the card issuer and merchant acquirer). An important aspect of the four-party scheme is that the card network and the merchant acquirers behave, respectively, as upstream and downstream firms, giving rise to a double marginalization problem. The authors show that increased competition between card networks results in overuse of cards, while increased competition among merchant acquirers lowers fees for merchants and increases welfare. Structural models like these could allow policy-makers to quantify the relationship between network externalities and the specific design choices of the CBDC product and distribution model.

Another strand of IO literature explores competition between platforms when one is welfare maximizing, like a CBDC. Most of the literature so far has explored the effects of competition between profit-maximizing platforms and finds that, in general, competition results in excessive card usage due to over-subsidization of the consumer side (Bedre-Defolie and Calvano 2013). In contrast, Liu, Reshidi and Rivadeneyra (2022) theoretically analyze the effects on the interchange fee and market share when one of the platforms is welfare maximizing, when consumers are heterogeneous in their preferences for different means of payments, and when merchants can multi-home (i.e., accept more than one payment method). The key result is that the socially optimal interchange fee of the *public* platform is determined by a trade-off between two considerations. The first is the need to attract customers to the public platform so that it can generate its own network effects—setting a low interchange fee attracts consumers away from the private platform. The second is the preference that some agents have for the private platform (due to preference heterogeneity), which limits how low the public platform's interchange fee can go without harming the network effects of the private platform. This result suggests that setting the interchange fee in a CBDC platform will not be as straightforward as setting the fee consistent with a cost recovery objective, as is done in other payments systems provided by central banks.

3.1.2. CBDCs and bank business models

If CBDC balances are used to pay at the point of sale and online, they would substitute commercial bank deposits, which are the balances currently used by established card networks to transfer value. How would the disintermediation of deposits in payments affect the business model of banks? This question goes beyond how a substitution away from deposits and toward a CBDC can affect lending (addressed in section 2.2). The monetary models in the literature reviewed earlier in this paper do not consider that bank deposits offer services beyond store of value and payment. In those models, the demand for deposits is determined by their rate of return (Chiu et al. 2022, among others) and, sometimes, by aspects such as convenience (Garratt, Yu and Zhu 2021). However, the IO perspective recognizes that deposits are only part of a suite of services that banks provide to their customers.

One way to understand how banks provide services to customers is through the *relationship account,* which becomes the foundation to offer multiple products. The relationship account is established after the bank verifies the identity of the individual, effectively making the bank an identity custodian (Kahn 2016). The main product that banks offer is a chequing account (allowing customers to hold deposits but also to make

and receive payments through debit cards, cheques, wire transfers and other methods), but they also provide other products, such as a mortgage, a line of credit, or a credit card. Lastly, banks, through subsidiaries or associated firms, provide investment products (like mutual funds) as well as investment access and advisory services (trading platforms). Thanks to the identity custodianship, banks can hold troves of personal and payment data that allows them to engage in the provision of credit, which is informationally intensive.

Therefore, the adoption of a CBDC (as a store of value or a means of payment) will have implications for banks beyond the change in the size of the banks' balance sheets, i.e., the potential reduction in the quantity of deposits. A CBDC might also affect banks through its effects on the complementarity between deposits, payments, lending, investments and data. For example, the adoption of a CBDC as a means of payment could affect the economies of scope between payments data and consumer and business credit, which has been documented empirically quite extensively (see, for example, Mester, Nakamura and Renault 2007).

The specific effects of a CBDC will be further complicated by the ongoing generalized digital disruption in banking. Banking is facing profound transformation and restructuring, including the entry of new fintech firms, a move toward platform-based business models and the entry of bigtech (Vives 2019). Some recent work is exploring these channels. For example, Parlour, Rajan and Zhu (2022) study the impact of fintech competition in payment services when a bank uses payment data to learn about consumers' credit quality. They find that competition from fintech payment providers disrupts the information spillover. If a CBDC competes with banks for payments, its informational disruption effects on banks could be similar.

At the outset, the direction of these effects is unclear because banks could be involved in the CBDC ecosystem in ways that could allow them to maintain customer relationships or even offer new services related to the CBDC product (see section 3.1.3 for more detail). For example, banks could be providers of electronic wallet services that allow customers to hold CBDC balances. In this case, the customer relationship could be largely unaffected even if the balance a customer uses for payments is no longer issued by the bank. If the complementarity between different bank products and services is determined mostly by the presence of a customer relationship instead of the amount of balances the customer holds, then one could expect the effects of a CBDC on banks through this channel to be limited. One can conjecture that the effects could go in the opposite direction: banks could differentiate themselves from other CBDC distributors as being the most trustworthy providers of electronic wallets, resulting in a strengthening of the relationship relative to other providers.

The effects of a CBDC on bank business models will be multi-faceted and complex. But if the effects that fintech has had on banks during the last decade are any guide (Vives 2017), we should expect bank business models to adapt to the new environment and accommodate CBDCs.

3.1.3. The business model of a CBDC

Most central banks have signalled that if they were to issue a CBDC, they would use a tiered arrangement, where intermediaries distribute CBDC balances and provide CBDC services (e.g., onboarding customers, providing account statements and verifying identity if required). This arrangement makes designing a

business model for the CBDC ecosystem challenging. The business model of the CBDC ecosystem can be understood as the set of incentives derived from market forces and the contractual arrangements that central banks establish with participants of the ecosystem. The task of central banks will be to ensure that ecosystem participants derive enough value from the CBDC so that the system is sustainable. Achieving this will require breaking new ground in IO research.

To establish a sustainable CBDC ecosystem, central banks will have to build vertical relationships with intermediaries to incentivize them to distribute balances and provide services. The core questions of the business model are these: What are those incentives for intermediaries to offer services? How would those incentives vary based on the type of intermediary or service? Intermediaries could be traditional financial institutions like banks but also fintech firms. They would have different incentives, given their own business models, since banks perform maturity transformation while fintech firms don't. Further, because a CBDC, like any other means of payment, requires a two-sided platform, central banks will need to set up vertical relationships on both the consumer and merchant sides. The intermediaries on each side of the market will likely be different.

When establishing vertical relationships with intermediaries, central banks will likely encounter multiple trade-offs, particularly one between standardization and horizontal differentiation of the services related to the CBDC. Central banks may be inclined to try to incentivize CBDC intermediaries (banks or fintech firms) to offer highly similar products for the sake of interoperability, ease of choice and low fees to consumers and merchants. However, intermediaries might not want to offer a CBDC if they are not allowed to differentiate themselves from their competitors. The importance of this trade-off has been documented in cases in which payment innovations were unsuccessful (Crowe, Rysman and Stavins 2010).

Another consideration of the business model is the CBDC's pricing structure. Central banks have a keen interest in ensuring consumers' costs for CBDC services remain low to achieve the objective of the CBDC being universally accessible. What is less clear at the moment is whether a specific target should exist for merchant costs. As discussed above, the interchange fee is a key question for a CBDC. An important area of research for the CBDC business model will be to determine how the costs of the system should be distributed across the public and private sectors, and, for private sector costs, how those should be distributed among the different players (including intermediaries, merchants and consumers).

Finally, another key area of research—and policy debate as well—will be to determine the appropriate policy tools that a central bank might consider in setting up the CBDC ecosystem. For example, should the central bank rely mostly on market mechanisms, or should it use some regulatory tools? A crucial question here will be whether the central bank should directly offer a CBDC wallet, which could serve as horizontal competition with other providers, to ensure universal access and minimum standards of service.

All things considered, IO research will be needed to design a business model that generates incentives for intermediaries and users to ensure efficient distribution, interoperability and a level of adoption to garner sufficient network effects.

3.2 CBDCs and new developments in the crypto space

New developments in the crypto space, such as stablecoins and decentralized finance (DeFi), are relevant because some perform functions closely related to those offered by traditional finance. Whether and how a CBDC is introduced will significantly influence the future of this fast-growing space. For example, CBDC issuance could potentially facilitate or inhibit the future development of privately issued stablecoins, depending on the design of the CBDC. In this section, we first provide an overview of these latest developments and then discuss how they are related to the issuance of a CBDC.

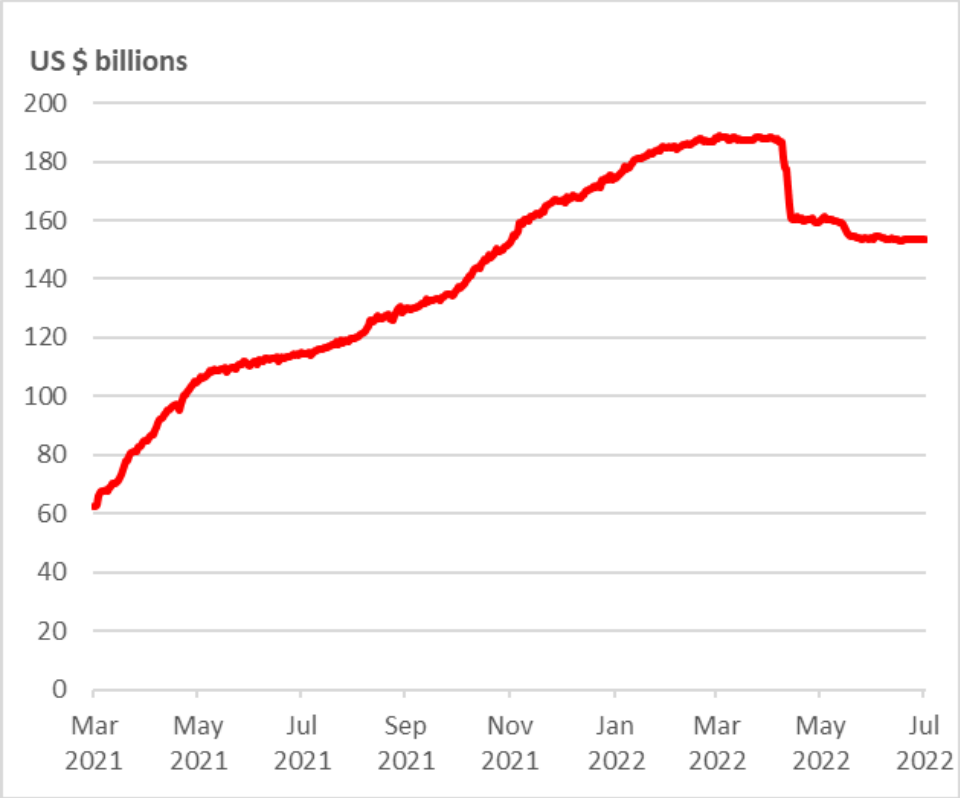
3.2.1 Stablecoins

Since the introduction of Bitcoin in 2008, both the scale and scope of the crypto space have grown tremendously. This development was driven by multiple forces. Some users utilize cryptoassets to avoid regulation and censorship, while others treat them as a new asset class for investment or speculation. In addition, the development of Ethereum in 2015 allowed smart contracts to be run on a distributed ledger. Since then, blockchain-based cryptoassets have been issued to finance start-up projects (e.g., initial coin offerings [ICOs]), provide financial products and services (e.g., DeFi), facilitate governance (e.g., decentralized autonomous organization [DAO]) and manage asset ownership (e.g., non-fungible tokens [NFTs]).

The growth of the crypto space was accompanied by demand for a stable means of payment, giving rise to the emergence of stablecoins. This is because standard payment methods offered in traditional sectors are not readily accessible in the crypto space due to regulatory and technical constraints. At the same time, bitcoin, ETH and other popular cryptocurrencies have a high price volatility, reducing their attractiveness as a store of value and unit of account.

Stablecoins are basically cryptocurrencies that peg their value to a stable asset, such as the US dollar. Stablecoins can have different designs. First, the issuance can be centralized or decentralized. Centralized stablecoins such as Tether (USDT) and USD Coin (USDC) are issued by third parties that offer off-chain custody of the reserve assets. Decentralized stablecoins such as Dai are minted through smart contracts that also hold the reserve assets on-chain, limiting the need for a trusted third party. Second, the choice and management of reserve assets differ. Stablecoins can be backed by fiat currencies, financial assets (e.g., corporate bonds), commodities (e.g., gold) or cryptocurrencies. Stablecoins backed by cryptocurrencies (e.g., Dai) are often over-collateralized due to the price volatility of the reserve asset. Algorithmic stablecoins also exist, which are not backed explicitly by reserve assets but follow an algorithm to adjust the coin supply to maintain the peg (e.g., TerraUSD). As **Chart 1** shows, the market capitalization of top stablecoins has grown over time and reached US$160 billion in June 2022. **Chart 2** shows the shares of different stablecoins on June 30, 2022.

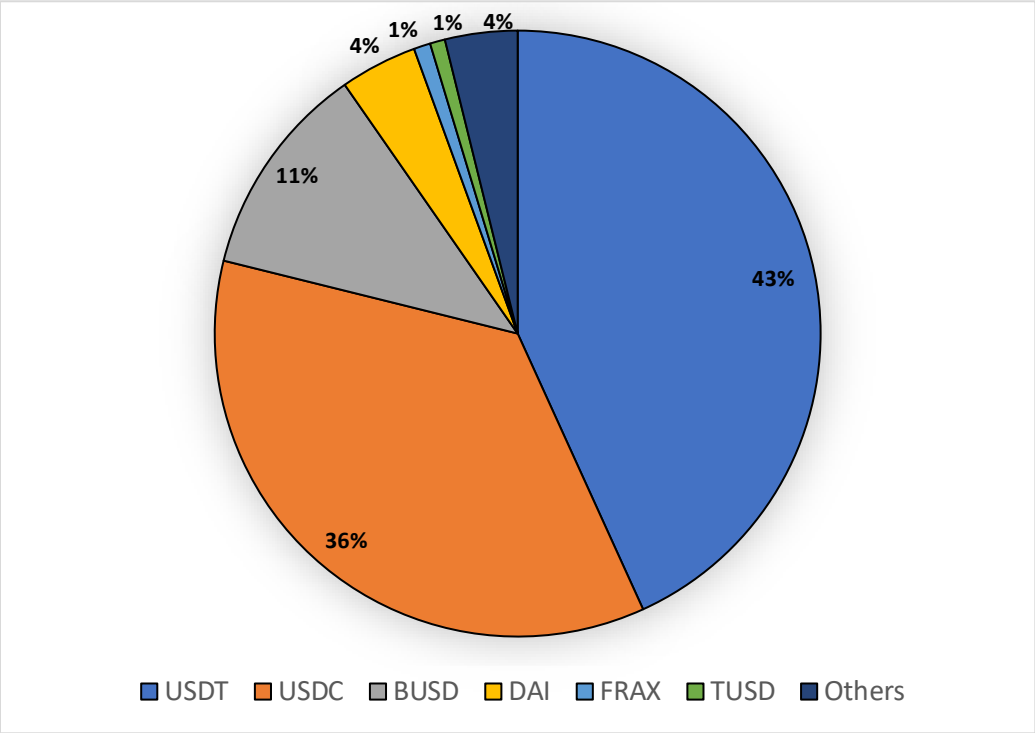
Chart 1: Total market capitalization of all stablecoins



Source: DeFiLlama

Last observation: July 2022

Chart 2: Market share of major stablecoins



Note: USDT is Tether; USDC is USD Coin; BUSD is Binance USD; DAI is Dai stablecoin; FRAX is Frax stablecoin; TUSD is TrueUSD.
Source: DeFiLlama Last observation: June 30, 2022

3.2.2 Decentralized finance

Closely related to stablecoins are DeFi protocols that allow users to engage in borrowing (e.g., Aave) and in the issuance of synthetic assets based on over-collateralization (e.g., Synthetix). These are anonymous, permissionless financial arrangements that aim to replace traditional intermediaries by running smart contracts on a blockchain. By automating the execution of contracts, DeFi protocols can avoid incentive problems associated with human discretion (e.g., fraud, censorship, racial and cultural bias), expand access to financial services and complement the traditional financial sector.[17] The growth of decentralized finance has been substantial since summer 2020. According to data aggregator DeFiLlama, the total value locked (TVL) of DeFi reached US$250 billion in late 2021, up from less than US$1 billion two years ago (see **Chart 3**). However, the TVL declined significantly in the second quarter of 2022 as a result of the general cryptoasset price crash during this period. **Chart 4** shows the decomposition of the DeFi TVL. Lending and decentralized exchanges account for about half of the TVL. As DeFi becomes increasingly complex and increases its linkages to the non-crypto sectors, its vulnerabilities might have negative spillovers to traditional finance and the real economy.

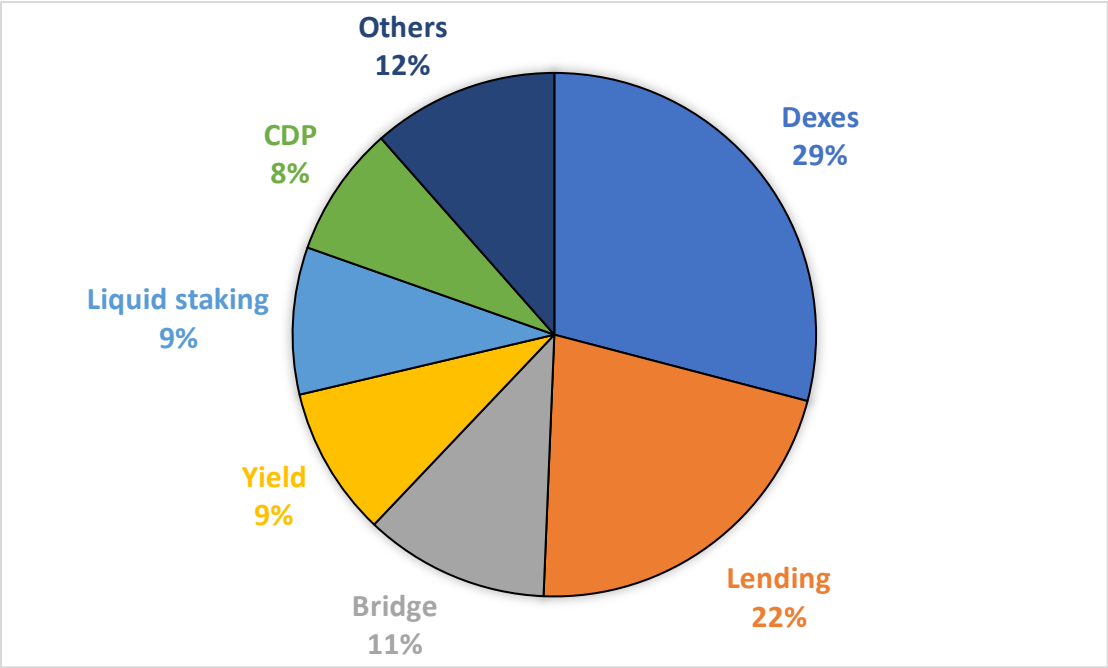
[17] See Chiu, Kahn and Koeppl (2022) for a discussion of the value proposition and limitations of DeFi lending.

Chart 3: Total value locked in decentralized finance

Source: DeFiLlama

Last observation: July 31, 2022

Chart 4: Decentralized finance total value locked, first quarter of 2022



Note: CDP is collateralized debt position; Dexes are decentralized exchanges; *Others* group consists of the remaining 20 DeFi activities.
Source: DeFiLlama Last observation: 2022Q1

3.2.2 Regulatory concerns and CBDCs

Regulators and policy-makers have raised concerns about the potential impacts of global stablecoins (GSCs) and other DeFi arrangements on financial stability. For example, a report by the Financial Stability Board suggests that "if a stablecoin entered the mainstream of the financial system as a means of payment and/or a store of value in multiple jurisdictions, with the potential to achieve substantial volume, it could become a GSC, posing greater risks to financial stability than existing stablecoins" (Financial Stability Board 2021, 6).

These new forms of money creation work very much like a shadow bank. They are short-term, demandable assets and hence are susceptible to runs. This is particularly risky for stablecoins that are subject to liquidity mismatches. They can also be a source of systemic risk to the financial system through different spillover channels (e.g., fire-sale externalities, holdings of cryptoassets by banks and non-banks) (Aramonte, Huang and Schrimpf 2021). A pressing question is whether and how stablecoins should be regulated. Their borderless and decentralized nature makes them harder to regulate. Different potential policy responses are possible, such as imposing regulations, as in the case of shadow banks. Another approach is to require stablecoin issuers to back coins with central bank reserves, as is done with narrow banks. Some economists such as Gorton and Zhang (2021) argue for the issuance of a CBDC to compete with stablecoins and to

replace low-quality inside monies. This proposal, however, may require a particular design of the CBDC to make it a close substitute for stablecoins.[18]

It is worthwhile to point out that the introduction of a CBDC could crowd in, rather than crowd out, private stablecoins. For instance, stablecoin issuers could choose to hold part of their reserves in a CBDC if the CBDC is more liquid, anonymous, programmable or safe relative to some other reserve assets. While this may help stabilize the value of stablecoins, it could also facilitate their issuance. Hence, a CBDC could potentially promote or restrain the issuance of stablecoins. Chiu and Monnet (2022) study how the issuance of a CBDC could be a blessing or a curse for stablecoins and illicit trades. More research is needed to understand how a CBDC would interact with stablecoins and DeFi, and how a CBDC should coordinate with future regulatory actions for the crypto space.

Relatedly, one important design question is whether and how CBDCs can support programmability, which is essential for running DeFi contracts. In particular, should a CBDC support partial or general programmability? For example, a CBDC can support partial programmability by incorporating some limited "conditional payment" features, such as multi-signature, pre-authorized payments and expiration dates. Many of these features can be implemented already by existing payment service providers and banks, and hence the underlying technology is more well understood. Future research could examine the costs and benefits of the public provision of these features, technical feasibility and general trade-offs (e.g., Kahn and van Oordt 2022; Kahn, van Oordt and Zhu 2021).

Alternatively, a CBDC could support general programmability similar to those features offered by existing DLT-based systems (e.g., Ethereum) where a blockchain serves as a Turing-complete virtual machine running any program (smart contracts) (e.g., supporting atomic swaps, creation of private tokens, NFTs, operation of protocols, and DAO). However, the design of these systems is still not fully matured, and the implications for risk and efficiency are not entirely understood. Future research should explore whether a CBDC should or could be designed as a new, public platform (like Ethereum) that supports the execution of privately created smart contracts and decentralized protocols.

4. Conclusion

This paper reviews the nascent but fast-growing economic literature on CBDCs and banking and discusses some new directions for economic research. To fully understand what issuing a CBDC implies for banking, one needs to evaluate its impacts on banks through three channels: payments, lending, and liquidity and maturity transformation. The existing literature has already made important progress; however, certain questions have not yet been fully explored. Hence, more research is needed to fill some gaps. For example:

[18] For example, to be a close substitute for stablecoins, a CBDC issued by a central bank can be tokenized and transacted on public blockchains. Alternatively, private stablecoin issuers could be granted access to the central bank's balance sheet and operate as a narrow bank to issue stablecoins that are fully backed by central bank reserves. The second model is similar to a synthetic CBDC.

- Richer models for quantitative and empirical analysis should be developed to estimate the impacts of CBDCs on payment choices.
- Banks' funding sources and business models should be further examined to evaluate the quantitative impacts on bank deposits and loans.
- In relation to bank run risk, the implications of CBDC design and specific mitigation policies, like holding and transaction limits, should be assessed.
- The market structure of the fast-evolving payment systems and new developments in the crypto space should be better understood.
- A holistic welfare assessment is needed to evaluate different trade-offs and inform policy decisions.

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