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Cross-Border Central Bank Digital Currencies, Bank Runs and Capital Flows Volatility

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ABSTRACT: Central banks around the world are increasingly exploring central bank digital currencies (CBDCs). This paper investigates the possible impacts of cross-border CBDCs on capital flows and financial stability in a simple open economy extension of a classical model of bank runs, augmented with the presence of a credible foreign central bank, which issues an account-based interest bearing CBDC available to non-residents. The paper finds that the presence of a foreign CBDC which acts as an international safe asset may increase the risk of financial disintermediation in the domestic banking sector, which can be accompanied by higher and more volatile capital flows.

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1 Introduction

Central bank digital currencies, generally defined as a digital liability of the central bank - mostly for retail use, and thus intended to be a legal tender[1] - are considered by some as the next step in the evolution of money (Brunnermeier et al. (2019), Adrian and Griffoli (2019), Bordo (2021), Prasad (2021), Auer et al. (2021)). Central banks around the world have been considering CBDC for reasons ranging from modernizing payments, increasing financial inclusion, responding to the declining demand for cash or to the perceived risks posed by private digital currencies (see e.g. Agur et al. (2018), Kiff et al. (2020), Auer et al. (2021), IMF (2022)). Other potential benefits discussed in the literature may include: better consumer protection, fully-insured deposit accounts, greater financial and macroeconomic stability, improved monetary policy transmission, streamlined regulation and regulatory structures, increased fiscal revenue arising from the recapture of economic rents from the financial sector and other.

However, the enthusiasm caused by these new possibilities needs to be tempered with caution, as the introduction of CBDCs may give rise to a host of potential risks and vulnerabilities for macroeconomic and financial stability. Depending on design options, CBDCs could have substantial impact on the financial system and the transmission of monetary policy. They could lead the central bank to engage in large-scale intermediation, thus competing with private financial institutions for deposits, with potentially negative consequences for the availability of bank credit, economic activity, and overall financial stability. Other concerns include operational risks (stemming from technological issues, including cyber-security), risks to financial integrity, privacy and governance, to name but a few.

While most of the literature has analyzed the multifaceted implications of CBDC in a closed economy context, the literature on the international implications of CBDCs is still young (see, e.g. Brunnermeier et al. (2020), IMF (2020), Auer et al. (2021), CPMI (2021)). While cross-border CBDC usage may hold promise in terms

[1] For completeness, it is worth noting that central banks are also experimenting with wholesale CBDC, whose access is limited to financial institutions.

of easing frictions in international transactions (including for remittances and trade), it also raises important concerns regarding the impact of CBDCs on the stability and overall architecture of the global monetary and financial system. Important questions arise in an open-economy context as to the effects of cross-border CBDC usage on currency substitution, international capital flows, likelihood of financial crises, internationalization of currencies, degree of international risk-sharing and the global spillovers of shocks and policies.

This paper contributes to the literature on international implications of CBDCs on financial stability and capital flows. To the best of our knowledge, this is the first paper to consider these issues in a model with bank runs in the context of a cross-border CBDC. The paper also connects more broadly to the literature on currency substitution, capital flows and bank runs in an open-economy (e.g. Chang and Velasco (2000), Kawamura (2007)).

For this purpose, we employ a simple open economy version of the well-known model of bank runs of Diamond and Dybvig (1983), augmented with the presence of a foreign central bank, which issues a CBDC with international circulation. The CBDC issuer is assumed to be a highly reputable and credible central bank with a sound policy record, possibly a reserve currency issuer, which is thus considered to provide an internationally "safe" asset. While different design choices are possible, we will model the widely-considered option for the CBDC to amount to giving agents the possibility of holding an interest-bearing account with the central bank. The model thus allows for capital flows in the form of investments of non-residents into the foreign CBDC. As in the classical Diamond-Dybvig framework, there are domestic banks who engage in maturity transformation: they finance long-term projects with demand deposits, which may be withdrawn at a shorter horizons at a cost. Thus the domestic banking sector can be subject to bank runs, if investors withdraw early under the belief others would do the same. Given the likelihood of domestic runs, this gives rise to capital outflows into the foreign CBDC, which can be limited by the introduction of a capital account constraint.

The key implications of the model are as follows. If a country with a credible, reputable central bank issues a CBDC which is available to international investors, this can give rise to a new type of global safe assets which, under various circumstances, can become very attractive. The presence of a foreign CBDC as an international safe asset easily available to the non-residents allows it to attract domestic deposits, which increases the risk of financial instability for the domestic banking sector. The model thus implies financial disintermediation in the domestic financial system, as well as the possibility of banking crises that are accompanied by higher capital flows, save capital account restrictions.

Such risks to financial stability imply that policy-makers in recipient countries need to consider their appropriate strategic reaction function to foreign cross-border CBDC. While the model does not consider explicitly such policies, potential responses range from: the strategy choice regarding issuing their own CBDCs, strenghtening the domestic financial system, credible deposit insurance, instituting capital controls or an appropriate policy mix, to reduce the likelihood of destabilizing capital flights. Other responses include various forms of cooperation with the foreign CBDC-issuing central bank, which could include liquidity provision to domestic institutions (e.g. swap lines), or higher forms of monetary and/or financial integration.

At the same time, important policy considerations exists also for cross-border CBDC issuers. Depending on the international reach of the CBDCs, issuer countries may open themselves up to large capital flows fluctuations, which may be destabilizing and would require adequate policy responses and careful consideration of spillovers and spillback effects. Such risks point to the importance of careful consideration of the implications of various design options prior to the internationalization of a CBDC, so that adequate frameworks for monetary, exchange rate and financial policy are in place.

At the level of the international monetary system, the emergence of "global" CBDCs with broad international circulation is likely to call for significant international cooperation in order to preserve the stability of the international monetary and financial system. Given the potentially wide appeal and ease of access of such "global" CBDCs, their design, features, institutional set-up, availability of LOLR facilities, infrastructures and numerous other technical and policy aspects would benefit from broad international agreement, to mitigate the risks while maximizing the benefits.

The rest of the paper is organized as follows. First, we present a review of the theoretical literature. On this basis, several key CBDC features are identified and modelled. Section 2 presents the main theoretical model and its implications. Section 3 discusses policy recommendations and concludes.

1.1 Theoretical Literature Review

The literature on CBDCs has been growing rapidly, both in the academia and in policy-making institutions. While most of the theoretical literature has focused on macro-financial implication in a domestic economy setting, more recently a number of papers have started exploring also the open-economy context. In general, the literature finds that while there are various risks associated with CBDC issuance, most prominently regarding financial stability, they can in principle be well mitigated through adequate design features, as described in more detail below.

A large part of the literature is concerned with the implications of CBDC introduction for the banking sector. The issuance of a deposit-like CBDC may crowd out private banking and shift deposits away from the banking system, reducing bank lending and generating a risk of structural disintermediation of banks. For example in Fernández-Villaverde et al. (2021) - to which this paper is most closely related - the introduction of a CBDC allows the central bank to compete with commercial banks for deposits, which may lead to the centralization of the credit allocation process within the central bank (e.g. the central bank attracting all deposits in the system), when depositors internalize that the central banks is not subject to run risk). A CBDC may also have negative effects on financial stability by increasing the likelihood of commercial bank panics (Kim and Kwon (2019)). Because a CBDC provides a safe and easily accessible alternative to traditional demand deposits held in private banks, it can facilitate systemic runs on banks in crisis situations (Schilling et al. (2020)).

Other papers suggest that CBDCs can also trigger important efficiency gains for the financial sector which may improve financial stability. This may happen if the reduction in bank profits is outweighed by expansion in bank lending, itself made possible by the expansion in deposit funding through greater financial inclusion and desired saving (Andolfatto (2018)). In Chiu et al. (2019), a deposit-like CBDC with a proper interest rate would encourage banks to pay higher interest or offer better services to keep their customers, thus limiting banks' market power, and improve the efficiency of bank intermediation. Bitter (2020) also finds that while a CBDC reduces the net worth in the banking sector in normal times, it mitigates the risk of a bank run in times of crisis, by impeding the emergence of bank runs. Garratt and Zhu (2021) finds that the interest rate on CBDC puts a lower bound on banks' deposit interest rates and may level the playing field between large banks and smaller banks.

Most papers in the literature tend to concur that various design features (such as accessibility, remuneration and integration with the monetary policy framework) are essential is making sure the benefits outweighed the risks. One key design feature concerns accessibility, namely the possibility to allow or restrict CBDC access to either certain (financial) institutions, or the broader public, or both, possibly through some tiering system. This may lead to widely different implications for financial stability. For example, Cukierman (2019) finds that a CDBC design in which the entire private sector is allowed to hold digital currency deposits at the central bank may lead to a narrow banking system. However, Bindseil (2020) finds that the design of a two-tier remunerated CBDC helps address both the risk of financial disintermediation of the banking sector and the risks of systemic runs on banks. Kumhof and Noone (2018) discuss several design options which can mitigate large-scale run out of bank deposits into CBDC (which include remuneration and no guaranteed, on-demand convertibility of bank deposits into CBDC at commercial banks nor at the central bank).

A number of other papers also highlight the importance of CBDC design to integrate in an efficient manner with the existing monetary policy framework. This would require in general CBDCs to be interest-bearing, and that interest rates be adjustable according to the objectives of the central bank. Bordo (2021) argue for a CBDC which should be universally accessible and interest-bearing, with the central bank adjusting its interest rate to foster true price stability. Agur et al. (2022) discuss how a CBDC can be designed with attributes similar to either cash or deposits, including being interest-bearing, with the implications being that a CBDC that closely competes with deposits depresses bank credit and output, while a cash-like CBDC may even lead to the disappearance of cash.

If CBDCs allow for another instrument of monetary policy and can be used to implement the LOLR function, this may reduce the risk of systemic banking sector runs (Williamson (2019)). For example, the central bank can lend all the CBDC deposits back to commercial banks, thus a CBDC may actually enhance financial stability and even increase supply of private credit (Brunnermeier and Niepelt (2019), Kim and Kwon (2019)). A CBDC may be a useful additional policy tool also in the context of lowering the effective lower bound and implementing negative interest rates (Beniak (2019), Jia (2020)). Barrdear and Kumhof (2016) discuss how countercyclical CBDC price or quantity rules, as a second monetary policy instrument, could substantially improve the central bank's ability to stabilize the business cycle.

A few papers assess broader implication of CBDC issuance on output and welfare. Keister and Sanches (2019) find that while a digital currency tends to promote efficiency in exchange, it can also crowd out bank deposits, raise banks' funding costs, and decrease investment, yet despite these effects it can often raise welfare. In a DSGE model calibrated to match the pre-crisis United States, Barrdear and Kumhof (2016) find that CBDC issuance could permanently raise GDP due to reductions in real interest rates, distortionary taxes, and monetary transaction costs

Relatively few papers consider the international implications of CBDCs, where substantially more issues may arise due to the presence of additional frictions in cross-border payments and overall financial systems. A key concern is that CBDCs of reserve-currency countries available across borders could increase currency substitution ("dollarization") in other countries, in particular those suffering from high inflation, exchange-rate volatility and weak fundamentals more broadly. However, if a foreign CBDC were to be widely adopted internationally, it could affect also economies with stable currencies if it leads to the domestic currency losing some of its functions and traction, which could ultimately impair domestic monetary policy. Such an argument is made in Ferrari et al. (2022), who show how the presence of a

CBDC with features of scalability, liquidity, safety, remuneration and international circulation amplifies the international spillovers of shocks and may reduce monetary policy autonomy in foreign economies, with the magnitude of these effects depending crucially on the CBDC design. From the perspective of an issuer of such a CBDC, in a open-economy model with trade and capital flows, George et al. (2020) show that a CBDC with an adjustable interest rate may be welfare-improving, as it offers a secondary monetary policy instrument, which is akin to arguments made in the closed-economy setting.

1.2 How to Model a CBDC ? Motivations and Design Features

Discussing an environment with a CBDC raises the question of modelling choices, given the potentially critical importance of various design features. The limited practical experience with CBDCs[2] leaves many open questions as to which particular elements might end up being most prevalent. We rely on the literature discussed above to identify several possible realistic features, focusing on the following key dimensions: form, access, remuneration and cross-border availability[3]. This paper will define a (retail) CBDC as a digital central bank liability which is account-based, accessible to the general public, interest-bearing and internationally available to non-residents. These features are consistent with the common foundational principles and core features of a CBDC as outlined in the joint report by major central banks (see Group of Central Banks (2020)) and can be implemented technically within various architectures. We discuss the motivation behind these features in more detail below.

The first set of considerations is whether the CBDC should be account-based or token-based. Whereas token-based CBDCs are similar to cash, with the difference

[2]While over 80 percent of the world's central banks are conducting research on CBDCs and some have already progressed to experimental or pilot development phase (Boar and Wehrli (2020), Boar et al. (2020)), in terms of actual CBDC issuance, there are only very few instances. For up to date information on the CBDCs which have been launched, see https://cbdctracker.org/.

[3]For other relevant design features, encompassing: legal, governance, regulatory, cybersecurity and other angles, the reader is referred to Kiff et al. (2020), Carapella and Flemming (2020), Auer et al. (2020), Bofinger and Haas (2020), Agur et al. (2018).

that they take the form of cash cards or electronic media (wallets) which enable anonymous peer-to-peer payments, account-based CBDCs on the other hand constitute deposits generally envisioned to be held in a central bank account, to be used either for payment and/or store of value purposes. In addition, they could allow the verification of users' identity in different layers and thus offer advantages in terms of monitoring illicit activity in the payment system - a key concern of all central banks - making them a more realistic design choice. A related consideration is whether the CBDC would allow access only to selected users such as financial institutions or operators of payment systems (wholesale CBDC), or to the broader public (retail CBDC). Various policy objectives that central banks may have, such as improving financial inclusion, may suggest that retail CBDCs are the most impactful design option.

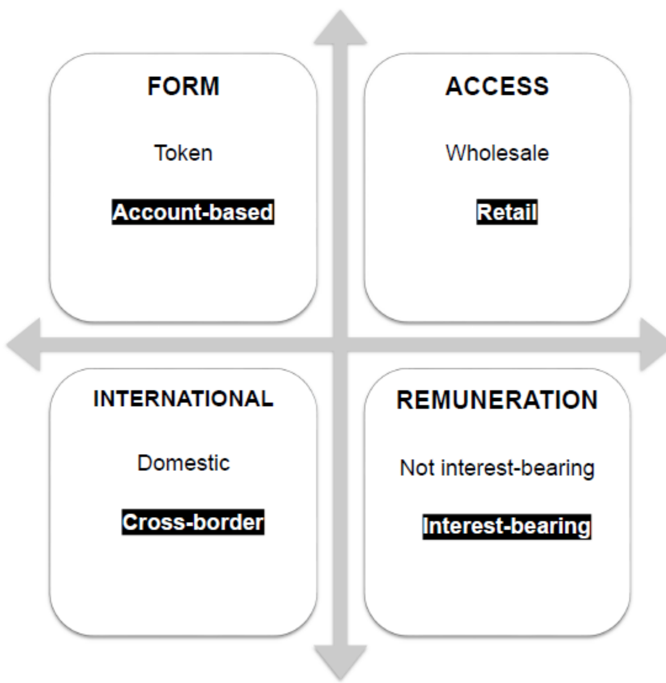

Figure 1. Key Dimensions of CBDC Design Options

Another very important feature for a CBDC is whether it would offer any remuneration. Account-based CBDCs can easily be designed to pay an interest rate consistent with the monetary policy objectives of the central bank, including price stability and business cycle stabilization. The literature generally argues that an interest-bearing CBDC is the most desirable and thus realistic set-up, bringing important advantages such as allowing a potentially new powerful tool for the conduct of monetary policy, which could include a relatively easy way to implement negative rates or "helicopter money" if needed.

Let us note that while we model an account-based retail CBDC, which constitutes a liability of the central bank, this does not necessarily mean that all agents would hold directly accounts with the central bank. While this design is certainly possible, in general it can be expected that the central bank would not want to substitute itself completely or overwhelmingly to the private financial markets (see e.g. BIS (2021)). Such a "direct" CBDC could impose a significant operational burden on the central bank, and substitute the central bank to some front-end operations which the private sector (banks, fintechs) may do better, which generally is associated with more innovation and better outcomes for consumers. Instead, an "indirect/hybrid" (also called two-tiered) system could be envisioned, in which the private sector provides the majority of operational tasks and consumer-facing activities and the central bank retains its role operating the core of the CBDC system and focuses on its traditional mandates[4]. Such CBDC designs are the ones which appear most favored by the few central banks who have moved towards an actual CBDC launch.

However, regardless of the precise configurations and technologies, CBDCs could offer agents a closer access to the relative safety of the central bank's balance sheet, in a manner which had previously generally not been possible. Thus they could offer advantages compared to other forms of domestic money, such as cash or commercial bank deposits, both in terms of digital features and ease of access, but also in terms

[4] In such a model, the central bank would have access to the ledger with full record of CBDC transactions and all retain balances, allowing it to easily step in as a backstop to the payment system, should private sector providers fail. Alternatively, in an "intermediated" CBDC model, the central bank would not record retail transactions, but only the wholesale balances of individual private service providers, which would allow for more decentralized architectures and potentially more privacy for end-users.

of superior safety features.

Finally, we shall consider a CBDC that is available cross-border, e.g. allows the access of non-residents (not only it its own jurisdictions, but is also circulating abroad). There are numerous complex questions on system design and interoperability which need to be addressed before CBDCs can be widely used cross-border, which is why this step has currently not been taken in the CBDCs currently in circulation. Such an evolution is likely to require significant international cooperation. Interoperability would require consistent technical standards, oversight frameworks, private and public laws and requirements for anti-money laundering and counter terrorism financing, among others (Auer et al. (2021)). At the international level, an active collaboration has emerged to improve existing payment systems and interoperating across borders (CPMI (2021)) and more broadly lay the foundations for the CBDC systems of the future (Financial Stability Board (2020), IMF (2021))[5].

2 The Model

With the design features outlined above in mind, we now proceed to describe in detail the modelling framework. The environment consists of a domestic economy populated by consumers and commercial banks, who engage in banking activity along the lines of the canonical model of Diamond and Dybvig (1983). While the domestic economy does not have a central bank for simplicity, there is a highly credible foreign central bank which issues a CBDC accessible to domestic residents in the form of interest-bearing deposits[6]. This environment can be thought of as a short-hand for

[5]In terms of practical applications, a number of central banks have run various international pilots in particular in the area of cross-border payments and settlement using distributed ledger technologies, which could support wholesale CBDCs.

[6]One key design feature of such a CBDC, which can fundamentally differentiate it from other classes of "safe" assets, is indeed that non-residents could have unrestricted access to the balance sheet of a foreign central bank. This could occur practically in various ways. One scenario under which this could happen is if the foreign economy is a reserve-currency issuer who is also home to large international digital networks that would facilitate access to the CBDC through their platforms to agents in different countries.

the situation in which a foreign country, possibly a reserve-currency issuer, would issue a CBDC with international circulation, while other economies may still have conventional fiat currencies. This model is a simple setup in which one can consider the impact of CBDC issuance on international capital flows, while leaving open for future research extensions to more realistic environments, such as including a richer set of financial contracts and institutions, or allowing for a domestic central bank - including modelling of the strategic choice of issuing its own CBDC.

As a key consequence of the way the CBDC is designed (account-based and accessible to foreigners), the model will generate competition for deposits between the domestic commercial banks and the foreign central bank. Consumers have the option to invest in the foreign CBDC, thus giving rise to capital outflows, subject to a capital account constraint (which is aimed to mimic any frictions which may restrict capital flows, like capital flows management measures, or other restrictive features of the regulatory framework).

2.1 Consumers

The domestic economy is populated by a $[0,1]$-continuum of *ex-ante* identical consumers. There are three periods indexed by $t = 0, 1, 2$. This is a real model, in which consumers are endowed in period 0 with one unit of a consumption-investment good, which can be saved domestically or abroad.

In period $t = 1$, consumers face idiosyncratic consumption shocks, in that they find out that they are either impatient with probability $\lambda \in (0, 1)$, namely that they value consumption in period 1, or they are patient with probability $1 - \lambda$, implying that they value consumption in period $t = 2$. Preferences are thus described by:

$$U(c_1, c_2) = \begin{cases} u(c_1) \text{ with probability } \lambda \\ u(c_2) \text{ with probability } 1 - \lambda \end{cases} \tag{1}$$

The utility function $u : \mathbb{R}_+ \to \mathbb{R}_+$ is strictly increasing, strictly concave and continuously differentiable. The realization of each agent's type is private information to that agent. Type realizations are i.i.d. across agents and there is no aggregate uncertainty.

The domestic economy allows for a short-term and a long-term investment opportunity (asset). The short-term technology is similar to storage and simply takes one unit of good at date $t = 0, 1$ and returns one unit of the domestic good in period $t+1$, e.g. a rate of return $r = 1$. The long-term investment, however, is more productive, and returns $R > 1$ in period $t = 2$. The long-term technology can be liquidated in period 1 at a loss, namely it pays off a liquidation value $l \in (0, 1)$ for each unit invested. If consumers would be able to anticipate their type in period 0, then all the impatient consumers would invest in the short-term technology and consume in period 1 and all the patient consumers would prefer the long-term technology, which yields them a higher return and consumption in their preferred period $t = 2$.

However, as consumers cannot anticipate their shock, if they acted in financial autarky they would bear the idiosyncratic risk, as costly liquidation of the long-term asset would occur with positive probability. This justifies the introduction of banks to achieve a superior allocation by pooling resources and risks. In our model, consumers will have access to either a domestic or a foreign investment option. Domestically, they can save via commercial banks offering savings deposits. Internationally, there is a foreign central bank offering CBDC deposits, in which agents can also invest up to a maximum limit (for simplicity, there is no international borrowing). We start first by describing the characteristics of the deposit contracts offered by domestic commercial banks.

2.2 Domestic Commercial Banks

The domestic economy is populated by banks who offer demand deposits. There are a large number of perfectly competitive domestic banks, who make investments on behalf of consumers. Banks offer consumers *demand deposit* contracts $(c_1, c_2) \in \mathbb{R}^2_+$. In return for deposit one unit of good with the bank in period 0, the bank promises to pay either c_1 units of the good in period $t = 1$ or the lower amount between c_2 units of the good and the resources available to the banker in period $t = 2$.

Banks have access to the same short-term and long-term productive investment technologies that would be available to consumers. They decide to invest a portion

$y \in (0, 1)$ of the goods in the short-term technology, yielding a return of $r = 1$, and the remaining portion $1-y$ in the long-term asset, which return $R > 1$ if held for 2 periods and $l < 1$ if liquidated prematurely. The banker achieves paying c_1 to the domestic consumers by using the returns from the short-term investment and if necessary, by liquidating the long-term investment until all resources are exhausted (resources will be pro-rated if necessary). Any left-over resources in period 1 are invested in the short-term technology. The banker pays the lower of c_2 and any leftover resources in period 2 to the patient consumers (again pro-rated as needed), and consumes any leftovers in period 2. We assume bankers are in Bertrand competition when offering demand deposit contracts to consumers, which forces them to maximize the expected utility of consumers:

$$\max_{(c_1,c_2,y,l)\in\mathbb{R}^3_+} \lambda u(c_1) + (1-\lambda)u(c_2) \tag{2}$$

subject to:

$$\begin{aligned}
0 &\leq y \leq 1 && \text{(3a)}\\
\lambda c_1 &\leq ry + (1-y)l && \text{(3b)}\\
(1-\lambda)c_2 &\leq R(1-l)(1-y) + ry + (1-y)l - \lambda c_1 && \text{(3c)}\\
c_2 &\geq c_1 && \text{(3d)}
\end{aligned}$$

Constraint (3b) is the feasibility constraint in period 1. The consumption of impatient consumers c_1 is financed by the return on the short-term investment and possibly by liquidating some portion of the long-term asset.

Constraint (3c) is the feasibility constraint for period 2, which implies that each patient consumer receives c_2, which is derived after the non-liquidated long-term asset yields its return and also from any left-over period 1 investments carried over into period 2.

Constraint (3d) is the incentive-compatibility (truth-telling) constraint for patient agents. As banks cannot discriminate between consumers based on their types, this ensures that agents reveal their true type (namely no patient agent will pretend to be impatient). For this to happen, c_2 has to be greater than c_1. Thus if a patient agent lies about her her type, she will be given c_1 units of consumption. As she actually wants to consume in period 2, the best she can do is to invest this amount in the short-term technology (storage), which implies that she would only be able to consume c_1 in period 2. As this is inferior to consuming c_2, constraint (8d) ensures that patient depositors will not lie.

Before the introduction of the foreign central bank, the solution to this problem in the closed economy context admits an equilibrium in which agents reveal their true type and there is no early liquidation of the long-term asset, e.g. $\widetilde{l} = 0$. In this equilibrium, the expected utility of consumers is maximized, subject to the feasibility constraints and the incentive compatibility constrains (truth-telling constraint) and banks make zero profits. This is intuitive, since banks pool resources to prevent the inefficient liquidation and face no aggregate uncertainty. Banks are a welfare-improving solution to the financial autarky world, since they essentially perform the function of pooling the risks from patient and impatient consumers and thus allow for a superior optimum allocation. As consumers behave according to their type, the optimal deposit contract achieves an allocation which coincides with the efficient allocation derived from the planner's problem (see Appendix for derivations).

2.3 A Foreign CBDC-Issuing Central Bank

The CBDC is modelled as an account-based and interest-bearing claim on the central bank. Thus, we assume that domestic residents can invest in direct CBDC deposits at the foreign central bank. The introduction of the foreign CBDC-issuing central bank is the key modification in this model, so we describe in detail the assumptions and features which characterize it.

First, the foreign central bank is assumed as perfectly credible, in the sense that consumers face no uncertainty or risk of loss to withdrawing their deposits (e.g. the central bank is not subject to runs). This "contract rigidity" can be justified in various ways. Diamond and Dybvig (1983) show that a combination of punishment and regulatory intervention can achieve the result of deterring runs from happening. Alternatively, the assumptions of no runs on the central bank can be theoretically modelled as in Fernández-Villaverde et al. (2021), as either deriving from a punishment that the central bank can impose on depositors who attempt to run or from a situation of equal treatment, in which the central bank treats depositors who contribute to a potential run as if they had rolled over their deposits (see Appendix).

The second key feature of this highly stylized foreign central bank is that CBDC deposits at the central bank are open to foreigners. The potential demand for perceived safe store-of-value foreign currencies has been exemplified by the spread of dollarization in numerous economies. Indeed it has been conjectured that compared to hoarding cash, the potentially high accessibility and ease of availability of CBDCs could incentivize further currency substitution in countries with weak credibility of the policy frameworks.

Third, we shall assume that the foreign central bank conducts its own monetary policy, which determines the interest rate offered on CBDC deposits (and is exogenous in the model). While we will not model explicitly the foreign central bank's monetary policy decision, further work along making this more realistic appears a promising question for future research.

Overall, such assumptions capture the situation that a central bank with sound monetary policy and a robust track-record (possibly an issuer of a reserve currency) could offer a "safe-haven" international financial asset. More specifically, we will model the foreign central bank as offering a special type of deposit contract, where in exchange for one unit of good at time 0, it allows depositors to withdraw *with certainty* either $c_1^* \in \mathbb{R}_+$ units of the common good in period 1 or $c_2^* \in \mathbb{R}_+$ units in period 2. The fact that the central bank deposit are perfectly "safe" is a crucial difference compared to the demand deposits offered by commercial banks (which can be subject to runs, as we discuss next). The safe rates of return for period 1 and 2 ($c_1^* < c_2^*$) can be thought of as being determined by the term-structure of foreign interest rates.

2.4 The Consumer's Problem

The consumer must decide whether to deposit with the commercial bank, consuming either c_1 upon withdrawal in period 1 or c_2 in period 2, or with the foreign CBDC, consuming either c_1^* upon withdrawal in period 1 or c_2^* in period 2. For simplicity, we assume that domestic residents can invest, but not borrow internationally. A more complex international financial market is an extension which deserves further analysis, yet we conjecture that international borrowing would not change the main implications of this model in terms of the volatility of capital flows.

Consumers choose the contract which delivers the highest *ex-ante* utility. If both contracts offer the same utility, then some fraction $f \in [0,1]$ will pick the foreign central bank, and the remaining fraction will pick the domestic commercial banks. We denote by $d_i \in \{0,1\}$ the deposit decision of consumer $i \in [0,1]$, where $d_i = 0$ represents depositing with the commercial banks and $d_i = 1$ represents depositing with the foreign CBDC.

Consumers also face a strategic decision about when to withdraw their funds. We define a withdrawal strategy for the consumer i as the variable $w_i \in \{1,2\}$ that denotes the time period when the consumer withdraws her deposit. An impatient consumer always has $w_i = 1$, that is it chooses to withdraw in period 1. A patient consumer has the option to withdraw early or late, a choice which will depend on her beliefs regarding the actions of others (denoted w_{-i}).

A further restriction on the consumers' portfolio choice is given by the fact that domestic agents' investment in the foreign asset is constrained by an investment cap $k > 0$, which we shall call a *capital account constraint.* While we treat this type of investment ceiling as exogenous, it can be justified as the result of domestic restrictions (e.g. regulated capital account or capital flow measures) or other frictions and biases (e.g. home bias) that limit the amount that domestic residents would invest in foreign assets.

2.5 Equilibrium with No Runs

We define now an equilibrium for this economy provided that depositors behave according to their type. An equilibrium is a description of the strategies of each depositor and aggregate outcomes as implied by the depositors' strategies, given that each depositor's strategy is optimal for her given the aggregate outcomes.

Definition 1 *An equilibrium consists of: a demand deposit contract (c_1, c_2) for the representative domestic commercial bank, a deposit contract (c_1^*, c_2^*) for the foreign central bank, deposit decisions $d \in \{0, 1\}$ in the initial period, a strategy profile $w \in \{0, 1\}$ for the withdrawal game in the intermediate period, a fraction $f \in [0, 1]$ of consumers depositing in the foreign CBDC and a fraction $\alpha \in [0, 1]$ of depositors who withdraw in period 1 such that:*

1. *In period 0, given contracts (c_1, c_2) and (c_1^*, c_2^*), each consumer $i \in [0, 1]$ optimally chooses where to deposit her unit of endowment so that it offers the highest expected utility. Total deposits in the CBDC cannot exceed the capital account constraint, i.e. $f \leq k$.*

2. *The strategy profile $w_i \in \{1, 2\}$ represents a Nash equilibrium of the withdrawal game in period 1.*

3. *Each commercial banks chooses the deposit contract to offer (c_1, c_2) to maximize profits in period 2, given (c_1^*, c_2^*).*

4. *Withdrawals in period 1 satisfy satisfy: $\alpha = 1 - \int\limits_{\{i \in [0,1]: w_i = 2\}} di.$*

5. *Deposits in the CBDC in period 1 satisfy: $f = \int d_i di.$*

We start by first noting that we can restrict attention to symmetric equilibria, in which all commercial banks use the same deposit contract.

Lemma 2 *In equilibrium, all commercial banks that have depositors make zero profits and offer the socially optimal contract.*

Let's denote by π the commercial bank's profit, by $(y(\pi), c_1(\pi), c_2(\pi))$ the solution to the depositor's utility maximization problem, e.g. the value function describing the maximum expected utility for the consumer, contingent on the bank making profit π :

$$V(\pi) = \max_{(c_1,c_2,y,l)\in\mathbb{R}^3_+} \lambda u(c_1) + (1-\lambda)u(c_2) \tag{4}$$

subject to: $0 \leq y \leq 1, \lambda c_1 \leq ry + (1-y)l, c_2 \geq c_1$ and

$$(1-\lambda)c_2 \leq R(1-l)(1-y) + ry + (1-y)l - \lambda c_1 - \pi \tag{5a}$$

By the envelope theorem, it must be that $V'(\pi) < 0$ for any $\pi > 0$. Thus, all consumers will deposit with the banks which offer the highest expected utility contract, which may thus absorb the entire mass of deposits. As banks internalize the effects of the price competition, their incentive is to offer a contract with lower profits, say $0 < \pi' < \pi$, whose payouts $(y(\pi'), c_1(\pi'), c_2(\pi'))$ would offer the consumer a higher value. It follows that $\pi \to 0$ and $(y(\pi), c_1(\pi), c_2(\pi)) \to (\overline{y}, \overline{c}_1, \overline{c}_2)$, which implies that all banks offer the socially optimal contract and make zero profits.

Next, we discuss the competition for deposits between domestic commercial banks and the CBDC-issuing central bank. First, it is trivial to see that there is an equilibrium in which, through its remuneration of CBDC deposits, the foreign central bank could replicate the socially optimum contract.

Lemma 3 *The foreign central bank can replicate the socially optimum bank deposit contract, if the interest rates on the CBDC are such that* $c_1^* = \overline{c}_1$ *and* $c_2^* = \overline{c}_2 = \frac{R(1-\overline{y})}{1-\lambda}$.

While the foreign central bank is capable of replicating this outcome, its objective function may be quite different. This gives rise to different outcomes, since effectively there will be a competition between the central bank and the commercial banking sector.

Proposition 4 *If only domestic commercial banks offer the optimal contract, they absorb de entire deposit market and* $f = 0$. *If only the foreign central bank CBDC* *deposit offers the optimal contract, or if the foreign central bank offers a better contract than the optimal contract, then the CBDC absorbs all deposits up to the capital account constraint, e.g. $f = k$. If both the domestic commercial banks and the foreign central bank offer the optimal contract, then any $f \in [0, k]$ is an equilibrium.*

Proof. Assume that the foreign central bank offers a deposit contract (c_1^*, c_2^*) which is offering a value $V = \lambda u(c_1^*) + (1 - \lambda)u(c_2^*)$ to the consumer. Because $V(.)$ is continuous and decreasing, there exists a profit level π^C so that the commercial bank can replicate the central bank contract. If $\pi^C = 0$, then the central bank has been offering the optimal contract, in which case consumers are indifferent where they deposit their savings, and any $f \in [0, k]$ is an equilibrium. If $\pi^C > 0$, then the central bank is not offering the socially optimal contract, and the commercial bank can offer a better contract with $\pi < \pi^C$ thus undercutting the central bank. Through Bertrand competition between the commercial banks, profits will be driven to 0 and the socially optimal contract will prevail, attracting all deposits, namely $f = 0$. If however $\pi^C < 0$, this implies that the contract offered by the CBDC is better than the domestic socially optimal contract. As banks are not able to replicate this contract, they will lose depositors, up to the capital constraint of $f = k$. ∎

2.6 Domestic Commercial Bank Runs

So far we have considered a situation in which depositors behaved according to their types, and found that in this situation, the socially optimal contract is offered by commercial banks. When the foreign CBDCs mimics the payoffs of the optimal contract, there is competition for deposits with domestic banks, which may give rise to capital outflows (trivially, this also occurs if the foreign CBDC deposit payoffs dominate). However, when consumers do not behave according to their types, a different equilibrium is also possible, in which their payoffs may deviate from those promised in the deposit contract.

In this section, we consider the possibility of panics in the domestic commercial bank system. These occur when patient consumers, instead of consuming in period 2, instead rush to the banks and demand their deposits early, under the apprehension that other agents may do the same. Since an agent's type is unobservable, it is possible for the agent to pretend to be impatient, with the consequence that a self-fulfilling run occurs.

When patient depositors withdraw early, e.g. if $\alpha \in (\lambda, 1]$, the commercial bank needs to liquidate some portion of the long-term investment in order to service the early redemptions. The timing of events is as follows. In period 1, depositors arrive at the bank in random order. The bank satisfies a sequential-servicing constraint which requires that it attends to all withdrawal requests on a first-come first-served basis. If the bank is forced to liquidate the long-term asset, it uses the proceeds from the early liquidation $(1-\overline{y})l$ and the return on the short-term investment $\overline{y}$ to satisfy as many as possible of the withdrawals. This may not be able to fully satisfy every consumer if $\alpha\overline{c}_1 > r\overline{y}+(1-\overline{y})l$. The expected payoff of an agent who liquidates early in case of a run is thus rationed by the number of agents in the queue who demand to be served, namely $\frac{r\overline{y}+(1-\overline{y})l}{\alpha\overline{c}_1}$.

Furthermore, early liquidation of the long-term asset reduces the payoffs to those depositors who roll-over at period 1. However, agents internalize the reduced payoffs to depositors who remain patient, which determines them, if they believe that others would run on the bank, to also run. If all agents attempt to withdraw their deposits in period 1, the bank will run out of resources and fail before it can meet all the claims made on it, which implies that the payoff to consumer from rolling over during a bank-run is 0.

The payoffs matrix can thus be described as follows:

Event/Action	Withdraw	Roll-over
No run	$u(\overline{c}_1)$	$u\left(\frac{R[(1-\overline{y})-(\alpha-\lambda)\overline{c}_1/l]}{1-\alpha}\right)$
Run	$\frac{r\overline{y}+(1-\overline{y})l}{\alpha\overline{c}_1}u(\overline{c}_1)$	0

(6)

The payout structure makes clear that this game exhibits strategic complementarity in actions: conditional on a bank run, the payoff from withdrawing exceeds the payoff form rolling over and withdrawing is optimal. However, in the event of no run (patient consumers acting according to their type), then the payoff from rolling over exceeds the payoff from withdrawing and roll-over is optimal (as $\bar{c}_1 < \bar{c}_2$).

Proposition 5 *The withdrawal game of commercial bank deposits has two pure equilibria. There is one "good" equilibrium, in which all patient agents roll-over their deposits in period* 1 ($\alpha = \lambda$)*, and the socially-optimum contract is attained. However, there is also a second "bank-run" equilibrium, where all patient depositors panic and demand to withdraw in period* 1*, assuming that others would do the same* ($\alpha = 1$)*. In this "bad" equilibrium, a lower allocation than in the socially optimum contract is attained.*

2.7 Equilibrium with Runs in the Foreign CBDC

Relative to the framework presented before, we further assume the presence of the foreign CBDC riskless deposit which competes with domestic commercial bank deposits. The safety features of CBDC deposits are empirically credible, as central banks can operate even with negative equity without being forced into bankruptcy (even abstracting from their ultimate fiscal backing). However, there are various ways to rationalize the risk-free central bank deposits, without imposing it exogenously (two such mechanisms are presented in Annex B).

The presence of 'safe' CBDC deposits leads to the following result.

Lemma 6 *If the foreign central bank offers a riskless deposit contract which mimics the payoff of the socially-optimal contract, then it will attract all deposits up to the capital account constraint.*

The intuition for this result is simple. Even if the domestic commercial banks offer the socially-optimal contract, they can still face the risk of runs, leading to a worse outcome. If the foreign central bank were to offer the socially-optimal allocation, it would be able to guarantee the returns, thus it would attract all deposits. The domestic economy will experience capital outflows into the foreign CBDC up to the limit imposed by capital account restriction.

Given that the CBDC deposit is less risky than domestic commercial bank deposits, the foreign central bank enjoys a type of market power which allows it to offer a "safe" deposit contract even with *inferior* payoffs to the socially-optimum contract, and still attract all deposits up to the capital account constraint. Essentially, the risk-free asset that the central bank provides can be offered as a discount because of its superior safety features.

Proposition 7 *As consumers internalize that the central foreign bank deposit contract is perfectly safe, the foreign central bank can offer a deposit contract with lower payoffs than the socially optimal one, and still attract the highest possible amount of deposits (up to the capital account constraint).*

Proof. Let's denote by U_1 the utility the agent derives from the socially-optimal commercial bank deposit contract, which can be subject to runs, and by U_2 the utility derived from a 'safe' CBDC deposit contract with the same payouts. As runs can occur with commercial banks, but not with the central bank, it has to be that $U_1 < U_2$. In this case, the central bank can offer lower payoffs $c_1^* < c_1$ and $c_2^* < c_2$ such that $U_1 < U(c_1^*, c_2^*) < U_2$ and still attract all deposits up to the capital account constraint. ■

We have previously seen that the presence of a foreign CBDC as an alternative international "safe" asset may increase the risk of financial instability for the domestic banking sector even in the absence of panics, if it is at least as attractive as domestic deposits. When runs are possible, the result is strengthened. The foreign CBDC could pay *lower* interest rates and still, due to its superior safety features, lead agents to flee domestic assets - absent CBDC features or other frictions that would prevent such an outcome. This case is indeed the most relevant one in practice, given that in general interest rates in countries with credible central banks and/or reserve currency issuers would tend to be lower than those in most emerging and developing economies.

2.7.1 Possible Extensions

A key question is whether, given the limitations of a simple model, its implications would survive the relaxation of some key assumptions and in a more realistic environment. While these are promising questions for future research, in this section we will only speculate on the potential implications of several extensions.

First, allowing for a domestic central bank which acts as a lender of last-resort and offers emergency liquidity assistance to banks in times of stress, coupled with domestic deposit insurance, would reduce the likelihood of domestic bank runs and broadly improve financial stability in the home economy. Allowing the domestic central bank to issue a CBDC would also potentially reduce the extent of currency substitution, if this CBDC is sufficiently attractive, which would require at a minimum that is be backed by a credible domestic monetary framework. At the same time, allowing for a more comprehensive menu of financial assets (including cross-border) may weaken the channel emphasized in this paper in terms of implications for capital flows.

Another possible interesting extension of this framework would be casting the model in nominal terms, and allowing for various exchange rate regimes (from fixed to flexible). This would introduce exchange rate uncertainty in the model and allow for more complex dynamics. While such a modification should not change the fundamental intuition that runs into foreign CBDCs increase financial fragility in the domestic banking system, it would allow moving away from the assumption that commercial banks bank runs occur due to "sunspots" and a richer policy discussion.

With flexible exchange rates, if expectations regarding exchange rates would change (e.g. in the direction of a depreciation), then a run from the domestic banking system may occur also driven by this information, generating a self-fulfilling crisis. This would create an additional amplification mechanism which would render the foreign CBDC even more attractive in "bad" times. Even with a fixed exchange rate regime, while the commitment of the central bank to maintain the parity can protect commercial banks for a period of time, it may still result in a balance of payments crises and devaluation, if sufficient impatient agents demand early withdrawals or the regime in not credible. The difference with the introduction of a CBDC is that such a crisis can happen faster and through channels which would make prevention more difficult.

2.7.2 Discussion of Results

The findings in this paper enrich our understanding of the international impact of CBDCs along a few key dimensions, compared to the earlier literature.

Relative to the literature on the closed-economy implications of a CBDC, this paper extends the discussion regarding the risk of financial disintermediation to the international context. In a closed-economy setting, the literature generally concurs that CBDCs may increase the risk of a significant downfall of deposits in the banking system, as well as potentially amplify bank runs. Compared with access by foreigners to traditional bank deposits, a CBDC can offer additional ease for people to transfer deposits out of the banking system. In an open-economy, this paper shows that the risk of financial disintermediation is also accompanied by higher and potentially more volatile capital outflows from the domestic economy, which may be associated with exchange rate volatility and balance of payments crises. Another important difference to a closed-economy context is that a foreign central bank cannot be generally expected to provide liquidity support to financial institutions from other jurisdictions in times of stress.

Compared to the previous literature on the international implications of CBDCs, such as Ferrari et al. (2022), there both similarities and differences. The finding in Ferrari et al. (2022) that CBDCs would cause stronger international spillovers parallels this paper's finding about the conduit nature of a safe-haven CBDCs for international capital flows. However, while Ferrari et al. (2022) emphasize that foreign CBDCs could impact the effectiveness of monetary policy, the key contribution of our paper is to stress the raising financial stability risks. More specifically, in our paper, the financial disintermediation risks which a CBDC issued by a credible central bank generates in recipient economies can be the source of capital flows and the key mechanism through which the CBDC's global implications unfold.

While this paper models a real economy with no explicit actual currencies, the key insight of the foreign CBDC attracting non-resident deposits highlights the risk of currency substitution. This can occur not only in emerging and less developed economies with weaker fundamentals, but also in small advanced economies that are integrated in global value chains, due to the important network externalities which accompany a currency's internationalization (see e.g. He and Yu (2014), IMF (2020)). More specifically, since international trade and financial links tend to complement each other, if the CBDC is issued by a country playing a key role in the global trade and or financial networks, then important synergies may emerge, which could set in motion strong incentives for adoption across its economic partners. These effects can be much stronger if compounded by the presence of Bigtech companies and other large international digital networks in the issuing country, if these would use the CBDC on their platforms, or a CBDC-linked stablecoin.

While this paper has focused primarily on risks, it would be important to mention possible positive implications. If international CBDCs are issued by a highly credible central bank (such as reserve currency provider) with well-designed features to achieve public policy goals while reducing systemic implications, this may give rise to new classes of international safe assets. They could be expected to offer superior preservation of value during adverse systemic events at a global level and thus help alleviate a global shortage of safe assets (Caballero et al. (2017)). Such a development could have positive impacts on portfolios diversification and potentially improve international risk-sharing in the context of adverse shocks. However, the macroeconomic consequences of changes in the supply and composition of safe assets are complex and the implications on international reserves and global safety net are still an open question for research.

3 Policy Implications and Conclusion

What policies does the home country have to respond to the potentially negative spillovers effects of a foreign CBDC? Our results suggest that the emergence of foreign CBDC as an alternative 'safe' asset available internationally may impact the volume and volatility of capital flows, creating additional policy dilemmas for recipient countries. In this section we discuss potential policy response, starting from recipient countries, to issuer and in the end, policies at the international level, drawing on our reading of the relevant literature, in addition to the specific findings of this paper. At the level of recipient economies, we focus on three main types of policies: monetary, financial sector, and finally, capital account management measures (CFMs).

First, concerning the impact on monetary policy of the recipient country, there are various scenarios which would require exploration. First, for non-issuer countries, how should monetary policy react to the introduction of a foreign CBDC, which is an attractive internationally traded safe instrument ? In this context, policies similar to those defending against involuntary dollarisation are relevant, aiming to reduce the incentives for residents to switch to the foreign CBDC. This would include the need to maintain low and stable inflation, as well as financial and economic stability, including by building up buffers in the financial and monetary sector (FX reserves) as well as in terms of maintaining adequate fiscal space.

However, keeping the domestic economy in order may still not be sufficient to prevent widespread adoption of the foreign CBDC, due to powerful network externalities, as mentioned before. In this case, central banks need to consider their own strategic response, in terms of potentially issuing their own CBDCs with sufficiently attractive features, in order to maintain monetary autonomy and mitigate dollarisation pressures. Such a decision would need to be based on a non-trivial cost-benefit analysis, and take into consideration that the attractiveness of a CBDC to non-residents may derive more from the credibility of the issuer than from specific design features, which raises interesting questions for future research.

Besides monetary policy, another potential response to foreign CBDCs consists in policies to strengthen the resilience of the domestic financial system. While this involves a multifaceted approach, one key element of such a framework is deposit insurance. As has been emphasized in the literature on bank runs, in a world without CBDCs, a framework of deposit insurance renders the bank run equilibrium inferior, if the government is credible in its promise to provide insurance, so there is no run on the banking system. With the presence of a foreign CBDC competing for deposits, deposit insurance is also expected to mitigate the impact of the introduction of the digital currency. However, compared to a pre-CBDC world, the government might need to raise the level of deposit insurance. Given that increasing deposit insurance is costly, it is conceivable that, for a certain rate of return on the CBDC or value that agents place on the safety-premium offered by the foreign CBDC, it could still end up attracting a considerable share of domestic deposits, as described in this paper.

A third set of policies that we consider are those related to capital account management measures. Our paper considers a simple proxy for the level of tightness of capital controls, which captures both the quantitative effect of different measures, but also the impact of biases (such as home-bias) and other factors limiting the free flow of capital. Under this simple set-up, adjusting the capital account constraint parameter during periods of extreme volatility would be stabilizing for the financial sector and thus welfare-enhancing.

In practice, however, the impact that CBDCs might have on the effectiveness of capital account management measures is bound to depend crucially on specific design features. On the one hand, enforcing CFM measures in a rapidly evolving payment landscape could prove challenging, as measures would need to be continually fine-tuned to keep pace with evolving technologies, lest they can be circumvented. On the other hand, there is the potential that some of the technologies underlying the current digital revolution could be applied also to enforcing exchange and capital control regulations (Reg Tech and Suptech). This can be particularly the case for issuers of CBDCs, who can choose design features to facilitate compliance with their regulatory requirements, for example if restrictive measures are built in through smart contracts. Other technological innovations such as the use of artificial intelligence for machine learning in Reg Tech and SupTech might help to efficiently execute repetitive operations such as enforcing CFMs. In this respect, CBDC-issuers may be in a much stronger position to impose CFMs both on outflows and inflows, while recipient countries may find it more challenging to enforce their own restrictive measures. Such asymmetry in enforcement capacity and thus potentially effectiveness of CFMs is one key issue calling for international cooperation in the design of CBDCs.

While so far we have focused primarily on the risk that a foreign CBDC can cause capital outflows and financial disintermediation in the recipient economy, the economy of the issuer country also needs to consider risks from CBDC internationalization. As described in this paper, issuers may need to contend with possibly large capital inflows. The extent to which these could be destabilizing may depend on the level of depths and sophistication of the issuer's financial markets, relative to the volume of flows. This may be less of a problem if the issuer is a large advanced economy and already a reserve currency provider, while the recipient economies would be smaller emerging economies. However, depending on the relative importance of such flows, the issuer central bank does need to consider that impact on its own monetary policy and financial stability objectives. The domestic policy mix, in particular monetary policy, may need to be calibrated placing more importance on the risk of spillovers and potential spillbacks. Policy makers in issuer countries also need to design CBDCs with features which would allow their desired level of control over flows, as described above. In addition, in particular in crisis circumstances, issuer central banks need to consider innovative ways of providing liquidity assistance to foreign central banks or even more directly to foreign financial institutions, where CBDC penetration is significant.

At the international level, cross-border CBDCs would compete among themselves and with existing fiat reserve currencies, which could lead to a reconfiguration of the architecture of the monetary and financial system (see e.g. IMF (2020)). While transitions in the global system have historically been gradual, specific features of CBDCs and the underlying technologies may usher in much faster evolutions. Whether CBDCs would dominate would depend both on the traditional drivers for the international adoption (e.g. size of the economy and stability, trade and financial linkages, institutional proximity, historical connections), but also on new drivers, such as the spread of digital infrastructures, activities of Fintech companies, related technological innovations, and others.

Most of the challenges discussed thus far point to the importance of international cooperation in CBDC design. A key policy question which emerges is what types of international cooperation could best mitigate the potential negative externalities, while maximizing the benefits. This is an area in which increased efforts are being made in international fora in terms of setting common high-level principles for CBDC issuance [7]. International cooperation is also key to ensure interoperability and the common setting of standards, which are essential to CBDCs facilitating cross-border trade and financial flows. Other options could include multi-CBDC arrangements in which participating central banks would make their CBDC systems compatible and interlinked.

However, CBDC design may be a complex choice, with features driven by each country's social preferences, economic environment, legal framework, financial markets structures, etc., which may complicate the convergence between key elements of CBDC projects. Additionally, strategic objectives of potential CBDC issuers may be also very different and not necessarily easily aligned. It is also conceivable that competition between issuers may emerge, given the "exorbitant privileges" that currencies at the core of the global financial system tend to enjoy.

Overall, it is far from clear whether a cooperation equilibrium at the global level could eventually emerge. One can also envision an outcome of global fragmentation into "CBDC-areas" (akin to currency unions or the "digital currency areas" in Brunnermeier and Niepelt (2019)), where multiple country clusters would emerge globally which are centered around a CBDC-issuer. The powerful network effects associated with CBDCs can act as an additional force for economic, financial and possible even political integration, be it at a regional level, or, with considerable international cooperation, on a global scale.

3.1 Conclusions

In a streamlined model of banks runs with a foreign CBDC, we find that the introduction of the CBDC leads to competition for deposits between the foreign central bank and private sector banks. The foreign CBDC can become an attractive asset to hold especially if it is issued by a credible foreign central bank and pays interest. The model allows for an equilibrium in which self-fulfilling runs on domestic banks can occur, if investors believe others would withdraw early. Given the likelihood of domestic runs, the foreign CBDC which offers superior safety ends up attracting all

[7] See, e.g. the G7 Public Policy Principles for Retail Central Bank Digital Currencies.

deposits from the commercial banking sector, up to a capital account constraint on outflows. Thus, domestic commercial banks may be drained of a significant fraction of their deposits. Absent some form of capital controls or CBDC design features which would limit non-resident inflows, large scale disintermediation of the banking system is possible, with negative implications for bank lending and financial stability more broadly.

The efficient allocation in this case will represent an equilibrium in which the domestic economy experiences higher capital outflows, as domestic agents shift part of their deposits into the foreign CBDC. The salient feature driving the results is that the foreign CBDC opens up the central bank balance sheet to foreigners, and given its high credibility (effectively offering a global safe asset), domestic agents find such deposits attractive, even when they offer lower returns than the more productive domestic investment technology. Thus, the forces driving currency substitution in countries with weak policies and fundamentals may be further reinforced.

This paper highlights one key avenue through which allowing non-residents to use a CBDC issued in another jurisdiction may give rise to financial instability due to capital outflows. The presence of elevated risks to financial stability in both issuer and recipient countries calls for international cooperation and coordination in the design of CBDCs. Regardless of the particular architectural solutions, key design principles for international CBDCs would benefit from being coordinated at the global level, so that they best benefit all countries and minimize the risk of currency substitution and financial instability.

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4 Appendix

4.1 A. Characterization of the Commercial Bank Deposit Contract

This Appendix characterizes the socially optimal contract that commercial banks would offer in a closed-economy setting. This solution coincides with the efficient allocation derived from the social planning problem where the planner knows the type of each agent (we will denote this solution by "$^-$")

Bertrand competition among the banks forces them to maximize the expected utility of consumers:

$$\max_{(c_1,c_2,y,l)\in\mathbb{R}^3_+} \lambda u(c_1) + (1-\lambda)u(c_2) \tag{7}$$

subject to:

$$\begin{aligned}
0 &\leq y \leq 1 && \text{(8a)}\\
\lambda c_1 &\leq ry + (1-y)l && \text{(8b)}\\
(1-\lambda)c_2 &\leq R(1-l)(1-y) + ry + (1-y)l - \lambda c_1 && \text{(8c)}\\
c_2 &\geq c_1 && \text{(8d)}
\end{aligned}$$

The solution to this problem can be found as follows:

$$\begin{aligned}
\mathcal{L} &= \lambda u(c_1) + (1-\lambda)u(c_2) + \alpha_1\{R(1-l)(1-y) + ry + (1-y)l - \lambda c_1 - (1-\lambda)c_2\} + \\
&\quad + \alpha_2[ry + (1-y)l - \lambda c_1] + \alpha_3(c_2 - c_1)
\end{aligned}$$

$$
\begin{aligned}
\lambda u'(c_1) - \lambda\alpha_1 - \lambda\alpha_2 - \alpha_3 &= 0 \\
(1-\lambda)u'(c_2) - (1-\lambda)\alpha_1 + \alpha_3 &= 0 \\
-\alpha_1 R + \alpha_1(r-l) + \alpha_2(r-l) &= 0 \\
R(1-l)(1-y) + ry + (1-y)l - \lambda c_1 - (1-\lambda)c_2 &= 0 \\
ry + (1-y)l - \lambda c_1 &= 0
\end{aligned}
$$

It can be further shown that in equilibrium, as long as the incentive compatibility constraint $c_1 < c_2$ is satisfied strictly (which implies that $\alpha_3 = 0$) then no early liquidation of the long-term investment will take place, e.g. $\bar{l} = 0$. This is intuitive, since liquidation is costly, and the banks face no aggregate uncertainty. With this contract, it is optimal for all patient consumers to withdraw only in period 2, provided all other patient consumers do so.

$$
\begin{aligned}
\lambda u'(c_1) &= \lambda(\alpha_1 + \alpha_2) + \alpha_3 \\
(1-\lambda)u'(c_2) &= (1-\lambda)\alpha_1 - \alpha_3 \\
\alpha_1 R &= (\alpha_1 + \alpha_2)r \\
\lambda c_1 &= ry \\
(1-\lambda)c_2 &= R(1-y) + ry - \lambda c_1
\end{aligned}
$$

It follows that:

$$
\begin{aligned}
\bar{c}_1 &= \frac{r\overline{y}}{\lambda} \\
\bar{c}_2 &= \frac{R(1-\overline{y})}{1-\lambda}
\end{aligned}
$$

One can further show that:

$$\begin{aligned}
\frac{u'(\overline{c}_1)}{u'(\overline{c}_2)} &= \frac{\alpha_1+\alpha_2}{\alpha_1} = \frac{R}{r} \\
u'\left(\frac{\overline{y}}{\lambda}\right) &= \frac{R}{r}u'\left(\frac{R(1-\overline{y})}{1-\lambda}\right)
\end{aligned}$$

For $r = 1$, this is equivalent to:

$$\begin{aligned}
\overline{c}_1 &= \frac{\overline{y}}{\lambda} \\
\overline{c}_2 &= \frac{R(1-\overline{y})}{1-\lambda} \\
u'\left(\frac{\overline{y}}{\lambda}\right) &= Ru'\left(\frac{R(1-\overline{y})}{1-\lambda}\right)
\end{aligned}$$

4.2 B. Characterization of the Foreign Central Bank Safe Deposit Contract

While this paper presents the foreign CBDC as a safe/riskless asset by construction, this assumption can be justified in a set-up in which runs on the central bank could in principle occur, however, certain mechanisms would prevent this outcome from happening. Following Fernández-Villaverde et al. (2021), we describe two such pay-out structures, one that would involve punishment for early withdrawal and a second one which would imply equal treatment of early withdrawals.

4.2.1 Punishment for Early Withdrawals

Let's assume that the central bank is able to "punish" impatient consumers who attempt to withdraw early by committing to pay 0 to depositors beyond measure λ who show up in the queue. Therefore, the payoff to impatient consumers who run is going to be

$$\frac{\lambda}{\alpha}u(\overline{c}_1) + (1-\frac{\lambda}{\alpha}) * 0 = \frac{\lambda}{\alpha}u(\overline{c}_1) \tag{9}$$

Such a payment is less than $u(\bar{c}_1)$, if $\alpha > \lambda$, which is the case when impatient consumers would demand early redemption.

At the same time, the central bank could guarantee that all remaining patient depositors would share in the undiminished period 2 returns, e.g. receive $u\left(\frac{R[(1-\overline{y})}{1-\lambda}\right)$.

Thus, the payoff matrix is as follows:

$$
\begin{array}{|l|l|l|}
\hline
\text{Event/Action} & \text{Withdraw} & \text{Roll-over} \\
\hline
\text{No run, } \alpha = \lambda & u(\bar{c}_1) & u\left(\frac{R(1-\overline{y})}{1-\lambda}\right) \\
\hline
\text{Run, } \alpha > \lambda & \frac{\lambda}{\alpha}u(\bar{c}_1) + (1-\frac{\lambda}{\alpha}) * 0 & u\left(\frac{R[(1-\overline{y})}{1-\alpha}\right) \\
\hline
\end{array}
\tag{10}
$$

It can be shown that rolling over is the dominant strategy, as in the event of no run:

$$u(\bar{c}_1) < u(\bar{c}_2) = u\left(\frac{R(1-\overline{y})}{1-\lambda}\right) \tag{11}$$

while in the event of a run, it can be shown that:

$$\frac{\lambda}{\alpha}u(\bar{c}_1) < u(\bar{c}_1) < u\left(\frac{R(1-\overline{y})}{1-\lambda}\right) < u\left(\frac{R(1-\overline{y})}{1-\alpha}\right) \tag{12}$$

Thus, if the central bank punishes early withdrawals by not serving them, then the withdrawal game has one equilibrium in which all patient depositors roll-over and there are no runs on the central bank.

An alternative strategy for the central bank is described below.

4.2.2 Equal Treatment with Patient Depositors

An alternative to "punishment" of early withdrawals by not servicing their requests is to offer any impatient depositors beyond measure λ the same payout as if they had rolled-over their deposits. This, the expected payout for these consumers is

$$\frac{\lambda}{\alpha}u(\bar{c}_1) + (1-\frac{\lambda}{\alpha}) * u\left(\frac{R[(1-\overline{y})}{1-\lambda}\right) \tag{13}$$

The overall payoff matrix is described below:

Event/Action	Withdraw	Roll-over
No run, $\alpha = \lambda$	$u(\overline{c}_1)$	$u\left(\frac{R[(1-\overline{y})}{1-\lambda}\right)$
Run, $\alpha > \lambda$	$\frac{\lambda}{\alpha}u(\overline{c}_1) + (1 - \frac{\lambda}{\alpha}) * u\left(\frac{R(1-\overline{y})}{1-\lambda}\right)$	$u\left(\frac{R[(1-\overline{y})}{1-\lambda}\right)$

(14)

As it can be again shown that

$$\frac{\lambda}{\alpha}u(\overline{c}_1) + (1 - \frac{\lambda}{\alpha}) * u\left(\frac{R(1-\overline{y})}{1-\lambda}\right) < u(\overline{c}_1) < u\left(\frac{R[(1-\overline{y})}{1-\lambda}\right) \tag{15}$$

it follows that there is no complementarity in actions and rolling over is a dominant strategy again. Again, in equilibrium all agents behave according to their type, runs on the central banks are avoided and the socially optimal contract is always attained when offered.