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Brazil's Central Bank Digital Currency: Improving Financial Infrastructure with Programmability

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Abstract

This paper explores the benefits of incorporating technological innovations in ledgers, digital transfers, programmability, and encryption in resolving key financial markets' inefficiencies, such as asymmetric information, limited commitment, and transaction costs. Central banks can deploy these tools in adopting a fully programmable Central Bank Digital Currency (CBDC), as Brazil's Digital Real exemplifies. This CBDC serves as a public infrastructure for exchange and contract execution, enabling the creation of new applications, such as those developed in the LIFT Challenge. Example use cases highlight the potential of CBDC technology: VERT shows how CBDC can improve existing subsidized credit policies, VISA shows how decentralized finance tools can match small and medium enterprise borrowers with foreign investors, and Santander demonstrates how to improve real assets ownership transfers. Finally, we consider the design challenges of CBDCs and their potential use to enhance fiscal and monetary policy.

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Introduction - from Fast Payments to Programmability

The main goal of the Digital Real for the Central Bank of Brazil, BCB, is to create a reliable and secure infrastructure for innovations that include but go beyond programmable money and enable smart contract technology, not just for payments but also for improved wholesale and retail financial infrastructure.

This perspective differs from those who see central bank digital currencies (CBDCs) as facilitating and integrating payment systems, specifically instant payments or messaging systems, as either a replacement for traditional currency or a tool to reduce fees charged by payment intermediaries. Indeed, in advanced economies, research and development of CBDCs often focus on improving the safety and efficiency of digital payments and fulfilling their mandate for smooth payment system functioning.[3] In contrast, emerging market economies tend to prioritize financial inclusion. (Boar and Wehrli ,2021).

Brazil already has a successful instant payment infrastructure, PIX, launched in November 2020. By the end of 2022, PIX had 128 million individual users (around 75% of the adult population) and, in the year 2022, processed 20 billion (155% increase compared to 2021) transactions valued at approximately BRL 9.4 trillion (110% increase compared to 2021), surpassing every other electronic payment system in the number of transactions.

Since PIX intends to provide better payments and financial access, the Central Bank of Brazil emphasizes that the Digital Real as CBDC should enable new functionalities, mainly the use of technologies such as programmable money and smart contracts. (Araújo (2022)). So, let us elaborate first on PIX; then the attributes that Digital Real would share, namely a successful public good; and then, crucially, how these would differ.

The BCB has two roles in PIX as a public good. It operates the system, and it sets the general rules. These are general principles that Digital Real would share. As the operator of PIX, the BCB has fully developed the infrastructure. The BCB also determines PIX's rules and technical specifications in accordance with its mandate for retail payments. Two important aspects of PIX are worth noting (Duarte et al., 2022):

1. Participation of large financial institutions: As the regulator, the Central Bank has required banks and other payment institutions with more than 500,000 transaction accounts to participate in PIX. This includes almost all checking accounts in Brazil due to the high concentration of banks in the country. Even smaller institutions not initially required to participate joined PIX, seeing the value in being on the same platform as their larger competitors.

2. The Central Bank decides the rules for who can use PIX and how it can be used. Open APIs are crucial to these rules, as they securely transmit only the necessary data for a given transaction. This includes account information service APIs, which share information between users and payment institutions, and payment initiation service (PIS) APIs, which ensure the execution of payment requests. These open APIs allow

3 According to the Federal Reserve Board: "A CBDC could potentially serve as a new foundation for the payment system and a bridge between different payment services, both legacy and new. It could also maintain the centrality of safe and trusted central bank money in a rapidly digitizing economy." (FED (2022)). Moreover, according to the European Central Bank: "A digital euro would be an electronic means of payment issued by the central bank and accessible to everyone in the euro area. A digital euro would complement cash – not replace it – by allowing central bank money to also be used in digital form. This would expand the availability of digital central bank money beyond its current use – for transactions between banks – to also include everyone's daily payments." (Lagarde and Panetta (2022)).

third-party applications, such as ride-sharing apps, to integrate PIX into their products easily.

To understand the key difference between PIX and the Digital Real, let us note the difference between programmed money and full programmability. Indeed, there are various levels of programmability (Narula and George, 2023). Level 0 is API only. A software layer is created around an existing legacy system to allow other systems (both within the organization and outside) to access the system's functionality and data. It allows better standardization between financial companies. This is where PIX can be classified. Level 1 is a system that ties ownership of tokens to signatures (public/private keys), enabling minimal programmability. With this, cryptographically ensured Payment vs. Payment (PvP) protocols can be constructed, and multi-signature wallets can allow use cases such as joint accounts or inheritance accounts. Level 2 is a system where not just some but all funds are associated with some conditionality, and time locks can be supported. This allows more detailed PvP and Delivery vs. Payment (DvP) swap constructions across different ledgers and even some derivative contracts. Level 2 is not intended for non-money information (e.g., users, real estate covenants), and transactions are deterministic and valid regardless of other events. Level 3 is the highest and, in contrast, allows any contracts that can condition (and possibly update) the current state, with if/then lines in the code and with persistent memory of history, including nonmonetary information for distributed applications and general programming. In short, any program can be stored and run with any outcome. Use cases include sub-tokens, market exchanges, and flash loans, among many others.

The Digital Real is being developed to be a level 3 programmability solution designed to reduce key frictions in trade and financial markets. By introducing programmability, the financial infrastructure can be optimized, transactions can be carried out more efficiently and effectively, and competition can be enhanced, all with the end goal of reducing credit costs, increasing credit supply, and fostering innovation in financial markets. Before diving into the BCB infrastructure for their CBDC, let's first explore the benefits of programmability in reducing market inefficiencies. Through a series of examples, we will illustrate why programmability is crucial, which motivates why a central bank would befit to implement a CBDC with full programmability capabilities rather than just a fast payment system that lacks these features.

The paper proceeds as follows. Section 2 describes, through a series of concrete examples, how programmability can mitigate market frictions. Section 3 describes how CBDC technology can implement these tools and explains the Digital Real infrastructure. Section 4 highlights three LIFT challenge use cases: VERT, VISA, and Santander, which are great examples of the application of the CBDC infrastructure to problems on the ground. Section 5 elaborates on the main challenges for designing the Digital Real, primarily how to ensure consistency of contracts across multiple platforms. In section 6, we show that CBDC can enhance the toolbox for monetary and fiscal policy. Section 7 concludes.

2 Barriers to Trade/ Financial Frictions and New Tools to Mitigate

Barriers to trade and financial frictions are pervasive in current markets: transaction costs, adverse selection, moral hazard, unobserved interim states, and costly asymmetric information, including on collateral. In addition, there are industrial organization concerns: the rents earned by legacy system providers with manufactured (artificial) barriers to entry. But a range of new tools can mitigate these problems: ledgers, e-value transfers, programmability, and encryption. This section will explore the barriers and new tools through several economic examples.

2.1 Transfer of Ownership of Real Assets

In Brazil, an expensive legacy system burdens the transfer of real assets, including real estate and vehicles. The issue of trust, or the lack thereof, is often resolved through oligopolistic intermediaries and convoluted regulations, making the process even more burdensome. The conventional process is often complicated, expensive, and time-consuming due to manual operations and a mismatch between payment and transfer of ownership. For instance, in São Paulo, notary fees for real estate transfer of ownership can reach a staggering 1% of the asset's value. This also harms the proper functioning of credit markets, as many credit agreements, such as mortgages, leasing, and corporate debt, rely on these assets as collateral.

To reduce the costs associated with the asset ownership transfer process, the improvement of ledgers that track ownership data at a low cost and with full commitment is necessary. Such a system would ensure asset ownership and transaction history accuracy and integrity. Recent steps, such as establishing the Electronic System of Public Records (Serp) under Law No. 14.382/22 in Brazil, enable remote and electronic access to public record service while also addressing the need for interoperability of databases. However, there is still room for improvement by incorporating programmable money and decentralized smart contracts, such as atomic swaps. This would enable a secure and efficient transfer of ownership between parties while also automating the collateral process.

Integrating Brazilian public records with the Digital Real platform, which the recent legislation should streamline, would enable the issuance and transaction of tokenized assets legally required to be notarized by law. This would make the transfer process more efficient, secure, and cost-effective.

2.2 Limited Risk Sharing

Research on data in Thailand (Townsend, 1995, Samphantharak and Townsend, 2018) confirms that shocks are not uniform across households, villages, regions, and sectors. This risk could be shared for better consumption smoothing and enhanced small and medium enterprise investment. In practice, risk sharing is limited, apparent from risk premia in return on assets and from regressions of consumption onto income shocks, showing unmet needs for targeting (Samphantharak and Townsend, 2018). Attempts at insurance for meteorological shocks have suffered from basis risk due to a high degree of heterogeneity, i.e., the impact of the weather is not tailored to individual needs. Within village networks, family-related households do better, but there is virtually no system for dealing with strangers (Ru and Townsend, 2022). Improvements are needed to make the array of institutions in Thailand more adequate to deal with these problems.

One potential solution to this problem is using blockchain-based common ledgers with pre-committed funds in escrow for premia and programmed indemnities. This would provide a secure and transparent way to track and manage risk-sharing funds. Additionally, the programmability of these ledgers would allow for the creation of tailored risk-sharing instruments, see Townsend et al. (2023). In addition, the transactional layer provided by these programmable ledgers can be leveraged by a data layer, as with the "Open Insurance" framework in Brazil, which is part of a broader "Open Finance" initiative.[4]

2.3 Asymmetric Information and Limited Commitment of SMEs

Small and medium-sized enterprises (SMEs) often struggle to secure credit due to a lack of information about their credit history. One potential solution is using payment data to provide a more detailed picture of a borrower's creditworthiness. By collecting and sharing payment information, lenders can make more informed decisions, and borrowers can use their future payments as collateral. FinTech companies, such as Mercado Pago in Latin America and Alipay in China, are already employing this approach.

A public CBDC could also address this issue through carefully designed data sharing that ensures the accuracy and security of the information and commitment so providers can not alter the functionality of the code, a worry of regulators. Furthermore, creating a common ledger for registering invoices can also expand credit to SMEs, as seen with India's TReDS and related sales platforms via auctions to third-party investors of accounts receivable, avoiding a double invoice problem. A notable example in Brazil was the centralized registry of credit card receivables that started in 2019. One of the potential advantages was enhancing credit to SME firms, which could pledge future credit card payments as collateral. Law 13.775/18 established the legal framework for implementing an electronic bill receivables system. Despite this and increased competition, a unified system's launch has been delayed due to interoperability difficulties among various registries. A Digital Real platform as a centralized synchronized registry can eliminate this problem.

2.4 Problems in rural credit markets

A common problem that firms worldwide face is that they must pay for their inputs before they get paid for their output. This issue is significant for farmers for three reasons. First, there are several months-long delays between outbound payments for input expenditures at planting time and inbound payments from revenue at harvest time. Second, agricultural commodity markets are volatile, so farmers face significant price volatility. Third, agricultural production is risky, so farmers face significant output quantity volatility. To address this challenge, countries often implement a mix of credit and insurance subsidies.[5]

In Brazil, the subsidized rural credit system for producers is complex and fragmented, with 16 funding sources and 12 programs (in 2020), each with separate terms and

4 Open Finance is an initiative in Brazil that promotes the sharing of financial data among authorized institutions in a secure way. The idea is to enable consumers and businesses to access a broader range of financial services and products from different providers, leveraging their data to obtain better rates, terms, and user experiences. Open Finance in Brazil builds on Open Banking, which was launched in 2020 and requires banks and financial institutions to provide secure and standardized access to customer data and payment services to authorized third-party providers (TPPs). This enables TPPs to offer financial services, such as personal finance management tools, credit scoring, and digital wallets, among others. Open Finance in Brazil aims to extend the scope of Open Banking beyond the banking sector to other areas, such as insurance, investment, and credit. This will allow consumers and businesses to access a wider range of financial services and products, such as insurance policies, investment products, and loans, from different providers, using their financial data to make better-informed decisions. For more information about Open Finance, see https://liftchallenge.bcb.gov.br/en/financialstability/open_finance

5 For instance, in the US, the federal government provides low-cost loans, loan guarantees, or capital to rural borrowers or intermediaries through these programs. In some circumstances, the federal government has set up government-sponsored enterprises to facilitate credit to agricultural business (Congressional Research Service (2021)). For a detailed description of subsidized rural credit policy in Brazil see Souza et. al. (2020).

conditions for providing credit to producers and complying with the credit line rules. The uneven distribution of financial institutions and variation in rural credit rules based on geographical location, farm size, and farm revenues creates inefficiencies and distortions in the availability of funds and loan conditions (Souza et al. 2020), making credit costlier for both farmers and financial institutions. In addition, subsidized credit systems face significant barriers. The agriculture sector is expanding more rapidly than the rest of the economy. The country is facing severe fiscal constraints, which limit the ability to direct resources dedicated to the system. Recent advancements have been made to promote private credit in the sector.[6] For instance, the registry and regulation of private debt instruments have been improved, and collateral requirements updated, resulting in increased lending by capital markets.[7] Despite these efforts, there is still room for improvement, as this market relies heavily on pre-existing relationships. By incorporating registry tools into a complementary programmable infrastructure, borrower-lender matching can be improved, lowering costs and enhancing the efficiency of current legacy systems.

Moreover, there needs to be a better measurement of carbon reductions in agriculture. There is a general view that there is much potential for generating carbon credits in Brazil, and conditioning credit contracts on carbon reduction could incentivize the development of this market.

3 A public infrastructure for programmable contracts and mechanisms, from international cross-border payments to domestic CBDC

3.1 Cross Border and the X-C exchange and contracting platform

Adrian et al. (2022) describe how to use these new tools in the context of the well-known problem of cross-border payments in an exchange and contracting platform, X-C. Each central bank of a participating country allows a 1-1 exchange of reserves held by domestic institutions for a tokenized version of those reserves. In turn, on X-C, such institutions convert tokenized reserves into escrow certificates, CEs, locked up by code for particular uses, to bid in spot exchange auctions, sell forward with a specified time designation, fund contracts in a mutualized insurance arrangement, and so on. Though reserves are in escrow, the platform minimizes the need for liquidity for operations on the X-C platform; a participant does not have to hold a buffer stock in advance but can contract to acquire assets when needed, subject to contingencies. A seller need not hold the asset currently as that seller can be under a previous contract to acquire it. For instance, an Ethereum Virtual Machine (EVM) platform has a unique state, and one can require contracts to be consistent with each other, even though transactions can be encrypted.[8] Central banks also participate in X-C and can put their respective central bank money in escrow.

6 According to the Confederation of Agriculture and Livestock of Brazil, the average GDP growth of the agriculture and livestock supply chain increased on average 5.8% from 2014-2021, reaching a 25% share on total GDP. In contrast, data from IBGE shows that the average growth rate of the country's GDP in the period was -0.2%.

7 See Law 13.986 from April 2020 (text in Portuguese).

8 Pending full development and implementation of X-C technology, an alternative is Ethereum which is a public blockchain. Encryption capabilities are more limited, so there can emerge a tradeoff between privacy and the range of permitted implementable applications. But as in Lee, Martin and Townsend (2021) note, that includes forward and derivative contracts.

Next, we discuss a domestic version of the X-C platform, a CBDC, via a series of examples.

3.2 Domestic CBDC

As infrastructure, CBDC is a public good offered by a central bank, an exchange, and a contracting platform. The shared ledger includes at least the accounts of CBDC. The exchange rate of central bank reserves and CBDC is one-to-one, which can be achieved, for example, if the central bank offers full convertibility. Other assets can be tokenized and traded directly on the ledger, e.g., tokenized bank deposits, government treasuries, and stocks, as a country wishes and a design choice.

As part of the governance, permissioned entities could be registered on the CBDC infrastructure in different ways: i) as wallets – accessing services for themselves and their clients; ii) as nodes – executing and offering services; iii) as sub-networks – executing and offering services; and finally, iv) mixing these strategies, picking the best suited one for each service. What is public and private is also part of the design choice. With the development of X-C technology or with validation done on EVM technology by a central authority, cryptographic tools allow full privacy on the centralized ledger for wallets and nodes. With public validation on a blockchain, transactions on the centralized ledger are public. The degree of privacy in sub-ledgers also depends on internal validation methods, the degree of interoperability, and how the latter is achieved. The set of permissioned entities could be narrow and restricted to banks and payment service providers or broader and include some of the retail public, as a country wishes.

The BCB is currently envisioning the central ledger as a blockchain in the sense of having multiple validators and is focused initially on smart payments for wallets. However, nodes offering services are envisioned while retaining programmability and privacy within sub-ledgers, each as EVM blockchains with validation is a choice for sub-ledgers. The BCB also set as a guideline that the tokenized version of any asset or liability must inherit existing regulations, nevertheless allowing programmability and efficiency gains. The objective is to prevent any regulatory loopholes that could negatively impact the stability and efficiency of the financial system. The Digital Real, which represents the tokenized version of central bank reserves, can be used for interbank settlements, though other use cases are envisioned. Only banks and Payment Service Providers (PSP) can access wallets. End users will interact with the CBDC infrastructure through wallets provided by these banks or payment institutions or indirectly through ledgers. Thus, tokenized bank deposits or stablecoins issued by Payment Service Providers (PSP) will play the role of the retail programmable currency.

The design aims to guarantee that the central bank's monitoring and liquidity safety net covers these currencies while avoiding any unwanted outcomes from having the central bank provide direct financial services that would result if consumers could hold deposit accounts directly. Tokenized bank deposits bear the same consequences for banks' capital and reserve requirements as regular deposits, and deposit insurance will also extend to them. Stablecoins issued by PSP are 100% backed by CBDC (or treasuries), which means that once it's issued, the underlying CBDC is locked in a smart contract and cannot be spent unless the stablecoin is burnt to reclaim it.

In analogy to the X-C platform, Brazil's Digital Real design may set contracts or applications to be executed in two ways, separating intra-wallet and inter-wallet operations. First, a given wallet can offer applications for its user clients subject to regulation, with settlement in CBDC accounts or tokenized deposits.[9] A premier example is using wallets for retail customers. Second, wallets and nodes can trade and contract with one another directly for public marketplace interactions. A premier example is wholesale trade. This allows a tiered ecosystem, with decisions about what is programmed within a given wallet or sub-network rather than what is programmed on the CBDC ledgers. The former retail part allows privacy within sub-networks, though the central bank still needs some information from these systems periodically for regulatory purposes. In this format, the Digital Real becomes a bit like X-C, which takes as given domestic systems, while the CBDC ledgers take what the sub-networks are doing as granted. However, this analogy has its limits, as the BCB has regulatory and reporting requirements for sub-ledgers. The wholesale part of the ledgers allows other programs to be built on top of the accounts of nodes and wallets, e.g., risk sharing, forward contracts, and derivatives are composable. Again, ledger accounts can be programmed and sequestered in escrow and are subject to stipulations. Escrow accounts ensure the absence of trade failures, and risk sharing and forward contracts mitigate the need for liquidity.

The code of a given contract or mechanism and its execution can be done in several ways. Within a sub-network, the decision is mainly up to the providers, subject to regulation. Clients of a financial institution need to consent to operate systems, including data and privacy. Again, a sub-network could offer the complete blockchain package with validation, but it is not required; where consent to access individual data was already given, the validation part can be dropped, for example. In the public marketplaces of the infrastructure, with transactions across nodes and wallets, the central bank can act as a trusted node for value transfers on the ledger, along with SEC-type regulators, possibly others with validation by proof by authority.

An issue with non-interoperable blockchains is that the problems of DeFi can emerge, and cross-chain transactions can be difficult. In principle, bridges can move toward completely interoperable blockchains, equivalent to centralized infrastructure, using zero-knowledge proofs or data sharing and some programmability via multi-party computation. DvP applications do allow interoperability for asset registration and transfer. But more generally, these bridge technologies are still maturing, so equivalence may hold only for particular applications.

To a large degree, the infrastructure just described allows judicious implementation of the new tools with a delegation of programmable contracts to the private sector. Townsend, 2023 speaks to what is required for auctions on platforms, competition in contracts, and implementing rules and regulations for financial and market design. Other topics, such as coordinated innovation and ways to deal with imperfect competition, require a more active public sector role. However, the technology could still be leveraged to achieve these goals.

4 Connecting “Main street to Wall street”- examples from Brazil: all this can happen, is happening

CBDC infrastructure can drive technological innovation and bring real-world applications to life, as evidenced by the LIFT Challenge use cases. We picked VERT, VISA, and Santander as examples to clarify such advancements. The VERT use case showcases how

9 By tokenized deposits we mean both commercial bank tokenized deposits and PSP issued stablecoins (as PSP are required by law to maintain deposits in the BCB).

CBDC technology can enhance existing policy tools, such as subsidized credit lines. In contrast, VISA's use case bridges the divide between Decentralized Finance and supply chain finance. Finally, Santander's use case illustrates how the transfer of ownership of real assets can be improved. These three use cases offer insight into the potential benefits and applications of CBDC technology in retail applications.

4.1 VERT

VERT aims to mitigate the issues discussed previously in the earmarked lending system. The use case focuses on a credit line for small farmers destined to finance operational costs (Pronaf Custeio), which falls under commercial banks that require rural credit lending. Along with the subsidized price of credit, farmers must also pay for mandatory insurance and incur extra expenses to submit their loan proposal, which requires verification by an agronomist. This credit line is associated with high compliance costs, which can be one of the causes of high lending concentration in Pronaf: only two financial institutions account for about 80% of the loans.[10] Banks are responsible for ensuring that the farmers follow the credit line rules, including using the loan funds to pay their suppliers properly.

To reduce compliance costs, VERT will provide the farmer with loan funds in the form of a rural token with a value equal to the value of the credit line. This token purchases farming supplies after onboarding value onto his/ her wallet. Smart contracts automatically verify compliance with the credit line's rules and ensure appropriate spending of funds. For example, they handle the KYC process for farmers and suppliers and check if invoices for input sold are uploaded and verified by the system before the equivalent value on the token is transferred to the supplier. Permitted suppliers are on a pre-approved white list.

VERT's platform matches the farmer to a commercial bank via an auction process. Farmers submit the required documents to the interested banks, specifying their willingness to borrow and the banks' bid. Of course, part of the bid covers the verification and processing cost of making the loan. The main potential benefit of lowering verification costs and automated processing is having more banks willing to participate in lending activity, competing in the auction, leading to higher credit supply at lower rates.[11] The winner's bid triggers the signing of parties to the loan contract.

The VERT platform interacts with the Central Bank Digital Currency (CBDC) infrastructure in payments. However, it is somewhat agnostic regarding the settlement payment tokens, CBDC, PSP stablecoins, or tokenized bank deposits, as long as it is 1-1 with the unit of account and programmability is possible. The use case is an excellent example of how technology can improve legacy systems. VERT's objective is to foster competition by reducing compliance costs and enhancing the matching of borrowers and lenders while relying on existing institutions to handle events such as borrower default on loan obligations.

10 Regulation mandates that commercial banks allocate a portion of their checking and savings accounting towards rural credit lending (25 % in 2023). Of this allocated amount, a portion must be directed toward Pronaf (25 % in 2023). Compliance can be achieved by directly lending to farmers, or depositing funds into other banks or credit cooperatives that will provide these credit lines. However, market concentration leads to low returns for the larger commercial banks that do not actively participate in rural lending. See MAPA (2022) for more information.

11 Banks do not have an incentive to increase credit supply in Pronaf (as the lending rate is below market rate). In some years, such as 2019 (BCB 2020), there have been failures to comply with the total required lending volume. Despite the fact that interest rates are fixed, credit costs can be reduced because participants can offer a cheaper bundle of insurance and verification services.

4.2 VISA

The role of programmability is critical in the Visa DeFi platform. This platform allows SMEs to access funding from global financial markets, with a current focus on the present use case of rural credit. This is a salient example of the vision that connects "wall street" to "main street." It operates through tokens and NFTs, representing sales contracts between SMEs and traders. There is a high barrier to foreign finance in this market, as most alternatives are either based on pre-existing relationships (such as trade credit) or are delegated to internal financial institutions such as banks and investment funds.

The platform's use case involves a farmer selling crops to a cooperative at a pre-specified price to be delivered on a future date. This agreement is documented in two contracts: one for the farmer's obligation to deliver the crops, the physical farmer banknote (CPR)[12], and one for the trader to pay for the crops, a sales invoice. The latter promise to pay is like a future receivable. Both contracts are represented on the Visa platform as paired NFTs, with the sales contract as receivable being auctioned off and sold to the highest bidder among investors. The CPR contract contains farmer information: what is being sold, farmer identifier, location, crops he grows, and so on.

The use case envisions investors' fiat currency or stablecoins being converted to USDC and on to CBDC through a foreign exchange license, then, as a retail token, swapped to the sales invoice NFT (every step via DvP smart contracts). Or if domestic, then the process initiates with a tokenized deposit, commercial bank, or PSP. The retail token is then made available in a wallet owned by the farmer, which could then be used to make other payments.

Upon delivery of the crops to the cooperative, the payment from the cooperative to the farmer is settled. As outlined in the use case, the farmer is responsible for coming up with accepted stablecoins for paying back the loan uploaded to the platform. This is then converted to Real stablecoin and transferred to the domestic NFT owner, or if an international NFT owner, converted under a license to foreign exchange. As with initiation, the BCB maintains an appropriate format. As it has been redeemed, the NFT CPR is burned. Through the use of NFTs and automated processes, the programmability of the platform streamlines transactions and eliminates barriers to matching international investors with local farmers.

More explicit consideration of farmer default leads us back to the discussion of CBDC designs. If, for example, the farmer is required to purchase insurance for the crop, then indemnities can be tied to the smart contract and flow back to investors, funded with value put in escrow by guarantors. Or investors could be required to purchase default insurance as part of the contract, which likewise ensures with escrow from issuers of that insurance the flow back to investors. Another decision: are foreign investors required to cash out the CBDC into their domestic currency (and at what exchange rate)? If so, CBDC flows back to the Central bank. In that sense, the system is self-contained and closed.

12 CPR (Cédula do Produtor Rural) a title in which the issuer sells a certain amount of their crop in advance at a prespecified price committing to deliver in the quality and location agreed upon at a future date. It usually includes collateral such as land and machines. There is also the type of financial CPR where the farmer promises to pay a certain amount in the future (instead of delivering the good physically). CPR is the main instrument for financing the agribusiness production chain. In 2021, the total volume of CPRs issued and registered was around R$250 billion, but less than 40% of registrars operate in the market. The Digital Real platform can make the registration process more accessible and less costly, potentially broadening participation in this financing method for agribusiness.

4.3 Santander

Santander bank has proposed a marketplace to simplify the transfer of assets in Brazil, such as vehicles and real estate. They build a Delivery versus Payment (DvP) solution leveraging NFTs that represent assets, then smart contracts transfer assets and value instantly. Santander's marketplace serves as a bridge between the CBDC ledger and the registry of asset ownership. Two implementations were presented in the project, one based on Corda and another based on the Parchain EVM-compatible blockchain; here, we will focus on the latter. Parfin's permission Layer 0 blockchain is an ecosystem that allows the BCB blockchain to mint Digital Real which is then transmitted to the decentralized permission blockchains that run the tokenized asset transfers. The digital real is burned when the buyer's bank converts CBDC back into reserves. This would be another illustration of a closed system. With complete interoperability, one could go further, envisioning tokenized real assets as exchanged and held on the central bank ledger. The application showcases how a CBDC infrastructure can effectively interact with different registry systems to reduce transaction costs, potentially driving significant economic spillover impacts in both spot and credit markets.

5 Challenges of CBDC Going Forward

From the discussion toward the end of each use case above, one can see specific parallels and complementarity between IMF's proposed X-C platform and Digital Real Infrastructure. For the IMF proposed X-C platform, the various fiat money tokens guaranteed by their respective Central Banks are minted and burned 1-1 against central bank reserves in the opposite direction. When such tokens are placed on X-C ledgers, they can be locked in escrow via programmability, for spot and forward auctions and risk sharing. Likewise, a Digital Real could be placed in escrow and locked in private sector wallets and nodes for DvP exchange and on-lending with a further 1-1 exchange into stablecoins. If there are programmed guarantees, these tokens are directly or indirectly fully backed claims on central bank reserves. They fulfill their purpose in deepening financial infrastructure in a closed-loop system, with the Real as a unit of account and a medium of exchange in contracts. Also, contracts and the various applications on X-C are guaranteed to be consistent with each other. Note also that some of the stablecoins in the use cases are not traded on markets, ensuring value 1-1 to the fiat as a unit of account and maintaining the closed-loop nature of the applications.

Some questions emerge. If the CBDC returns to the central bank ledgers with a lag later in time, it might bear interest, as a forward CBDC contract, at rates determined by the auctions in forward contracts mentioned earlier.

There are two notions for CBDC as liquidity. A closed-loop system through contracting mitigates liquidity needs, as one can contract to have CBDC when needed, further subject to programmed contingencies, without the need for buffer stocks. However, this raises a concern that a locked CBDC might lower the economy's overall liquidity and that a digital version of central bank money should circulate freely at par. Likewise, digitized commercial bank deposits as stablecoins could circulate at par, allowing bank intermediation. The two notions are not necessarily in conflict. The Central bank on the infrastructure can track commitments, and contracts are consistent, so adjustments to domestic liquidity can be made for the portion that is in escrow. However, a tradeoff between contractibility and liquidity may need to be determined. In open-loop systems, tracking is more complicated, and it is hard to maintain consistency across contracts, as with trades that fail in legacy systems when the buyer does not come up with liquidity at the time of settlement. In the end, one needs to understand the role money plays in an economy, jointly with contract structure, the degree of incompleteness, and so on.

Relatedly, the use cases facilitate intermediation, both for commercial banks in the case of Vert and other financial service providers as in the case of Visa. There remains a concern in the literature that CBDC could disintermediate commercial banks. But note that the entire point of the use cases is to allow improved intermediation by banks and also new intermediation by non-banks, intermediation which had not been taking place before, so the disintermediation terminology is misplaced.

It should be noted that this distinction between closed and open loop systems is not as sharp in practice as it is in principle, as in Brazil, the RTGS does not operate 24/7. However, CBDC has tools to mitigate that risk, which is likely a transition risk, as eventually, the RTGS could be moved on-chain, and wholesale settlement money could be CBDC.

The IMF X-C platform envisions validation of transactions as part of governance, with validation ensured and agreed to by participants. This allows programmable contracts with encryption tools, so privacy is not an issue. With multiple blockchains and diverse applications running off the main platform, a tradeoff between contractibility and privacy emerges, which needs to be explored.

Tracking and consistency are also problematic for legacy operating systems, as noted. The risk in a Central Bank Digital Currency ecosystem with multiple independent blockchains is also significant. It stems from the complexity of coexisting platforms and registry systems for tokenized assets. While Adrian et al. (2022) have discussed the design of a common ledger in which consistency is achieved through a unique state, the challenge for the Digital Real with its tiered structure is ensuring consistency across multiple applications, which in turn will determine the role of the Digital Real itself.

6. Implementing Public Policy with CBDC

Central Bank Digital Currency (CBDC) can significantly impact monetary and fiscal policies. First, it enhances the data available for authorities to observe, allowing for more informed and effective policy execution. Second, part of the execution of fiscal and monetary policy can be automated and even made state-contingent by conditioning on information on the ledger. We see that as the main benefit for the policy, in contrast with the view that the primary tool would be the interest rate paid on CBDC.

The PPP[13] and Mainstreet programs implemented in the US under covid targeting SMEs were implemented through commercial banks that arguably have information on clients. Yet studies have shown that targeting was relatively inefficient, and there has been fraud (Arseneau et al., 2022, Autor et al., 2022, Joaquim and Wang, 2022). New tools can help by offering better data systems with encryption to preserve privacy with more efficient marketplace designs to match customers with investors.

Moreover, the information in the payment network can be used to inform public authorities about the propagation of economic shocks. By combining interfirm payments data from different electronic payments systems in Brazil (Bank Transfers, Invoices, and

13 Paycheck Protection Program.

PIX), Orestes, Silva, and Zhang (2023) document how an extreme weather event, the 2021 frost, affected the payment flows of affected farmers. The frost affected mainly regions in the south/southeast. The primary crops affected were perennial crops such as coffee and sugar, so damage caused by the frost resulted in both a destruction of capital stock and a corresponding decrease in output. Payments data reveal that one channel of propagation was underinsurance, as farmers affected by the shock did not increase payments in capital stock replenishment relative to non-affected farmers. This information could be used both to target better emergency credit lines in response to weather shocks and to inform policies that deal with underinsurance.

7. Conclusion.

Throughout the paper, we emphasized the role of the Digital Real as a public infrastructure that would allow government and private sector agents to innovate using programmability and smart contract technology beyond what is possible to achieve with only a fast payment system such as PIX. The LIFT Challenge is a primer on how these applications can have a direct impact on the ground and how central banks can innovate in partnership with the private sector. Given that so much focus has been given to the role of CBDC exclusively as a payments system (under the primary motivation of moving towards a "cashless economy"), central banks around the world can draw important lessons about the potential of a programmable CBDC from the Digital Real infrastructure and LIFT Challenge use cases.

References

Adrian, Tobias, Federico Grinberg, Tommaso Mancini Griffoli, Robert M. Townsend, and Nicolas Zhang. . International Monetary Fund (2022).

Araújo, Fabio. **Initial steps towards a central bank digital currency by the Central Bank of Brazil**. (2022).

Arseneau, David M., Jose L. Fillat, Molly Mahar, Donald P. Morgan, and Skander Van den Heuvel. **The Main Street Lending Program**. 28, no. 1 (2022): 58-92.

Autor, David, David Cho, Leland D. Crane, Mita Goldar, Byron Lutz, Joshua Montes, William B. Peterman, David Ratner, Daniel Villar, and Ahu Yildirmaz. **The $800 billion paycheck protection program: where did the money go and why did it go there?.** 36, no. 2 (2022): 55-80.

Banco Central do Brasil (BCB). **Boletim Derop, Junho 2020**. (2020)

Boar, Codruta, and Andreas Wehrli. **Ready, steady, go? -Results of the third BIS survey on central bank digital currency**. (2021).

Congressional Research Service. **An Overview of Rural Credit Markets**. (2021).

Duarte, Angelo, Jon Frost, Leonardo Gambacorta, Priscilla Koo Wilkens, and Hyun Song Shin. **Central banks, the monetary system, and public payment infrastructures: lessons from Brazil's Pix**. (2022).

Federal Reserve (FED). **Money and payments: The US Dollar in the age of digital transformation**. (2022).

Hong Ru, and Robert M. Townsend. **Kinship Networks Enhanced by a Formal Financial Intervention: Costly State Verification and the Thai Village Fund**. , (2022).

Joaquim, Gustavo, and J. Christina Wang. **What Do 25 Million Records of Small Businesses Say about the Effects of the PPP?**. (2022).

Lagarde, Christine, and Fabio Panetta. **Key objectives of the digital euro**. (2022).

Lee, Michael, Antoine Martin, and Robert M. Townsend. **Zero Settlement Risk Token Systems**. (2021).

Ministério da Agricultura, Pecuária e Abastecimento (MAPA). **Plano Safa 2022-2023**. (2022).

Narula, Neha, and Nikhil George. **Programmability in CBDCs: A Primer**. (2023).

Orestes, Victor, Thiago Silva and Henry Zhang. **Payments and liquidity: evidence from extreme weather events in Brazil**. (2023).

Samphantharak, K., and Robert M. Townsend. **Risk and return in village economies**. , (1), 1-40, (2018).

Souza, Priscila; Stela Herschmann; and Juliano Assunção. **Rural Credit Policy in Brazil: Agriculture, Environmental Protection, and Economic Development**. (2020).

Townsend, Robert M. **Consumption insurance: An evaluation of risk-bearing systems in low-income economies**., (3), 83-102 (1995).

Townsend, Robert M. **Delegation of Programmable Contracts to the Private Sector and the Role of CBDC as a Public Good**., (2023).

Townsend, Robert M., Benoit Mojon and Luiz A. Pereira da Silva. **The importance of better risk-sharing for social policies: the potential of big data, mechanism design, platforms, and smart contracts**., (2023).