BIS Innovation Hub

Project Pine

Central bank open market operations with smart contracts

May 2025

FEDERAL RESERVE BANK of NEW YORK

Contents

Executive Summary

Tokenization has the potential to transform the financial market infrastructures underlying payments and securities. If the private financial sector adopts tokenization on a broad scale in wholesale markets, central banks may need to participate in novel financial market infrastructures and interact with digital tokens to continue effectively implementing monetary policy. Despite research on how wholesale external markets and conventions might change, there has been relatively little experimentation with implementing monetary policy using tokenization.

Project Pine, a joint research study by the New York Fed's New York Innovation Center and the BIS Innovation Hub Swiss Centre, explores if and how central banks can implement policy in a tokenized world. Project Pine successfully created a prototype of a generic, customizable monetary policy tokenized toolkit for further research and development by central banks across different jurisdictions. The toolkit prototype was created in consultation with advisers from multiple central banks, who helped outline the project scope and toolkit requirements.

A toolkit prototype was built using smart contracts, and it successfully met shared requirements. The prototype was designed with the capability to pay interest on reserves and create facilities that temporarily exchange reserves for collateral (and vice versa), swap assets, and execute asset purchases and sales. It was tested using hypothetical scenarios based on past market events (like interest rate tightening and easing cycles, quantitative easing and tightening cycles, and periods of strained market liquidity or broader disruptions in markets). The project demonstrated that central banks could use this new technology to carry out their existing roles if tokenization is adopted.

The project was a first step in highlighting the potential benefits of tokenization for central banks. If infrastructures underlying payments and securities are tokenized, the benefit to central banks would differ based on circumstances and existing operations. Yet Project Pine found that central banks could use smart contracts to easily and quickly create new facilities or adjust existing ones to optimize the implementation of monetary policy in a tokenized environment. This could allow future central banks to be nimbler in uncertain conditions and potentially reduce frictions between the time of announcements and offerings. There might also be operational efficiencies from automating collateral management.

Developing this prototype showed that central banks will likely play a very different role than other participants in tokenized systems. As well as deploying smart contracts, central banks may also require privileged access to data and higher standards of privacy and security. Outlining requirements for a jurisdiction is a task that each central bank will perform alone. However, Project Pine's results offer central banks a starting point for better understanding the opportunities, risks, and requirements of adopting tokenization in their respective jurisdictions.

While Project Pine moved the frontier for central bank tokenization research, technical experimentation is still at an early stage. There are more areas for research and collaboration that were beyond Project Pine's scope. For example, adding multiple currencies to the toolkit prototype and exploring the practical implications for market analysis and interoperability.

1. Introduction

The "tokenization" of money and securities is becoming increasingly mainstream. Over the last decade, experimentation with distributed ledger technology (DLT) has spread from early adopters and software start-ups to traditional commercial banks and wholesale financial market infrastructure. Some initiatives are now live. And central banks have also been involved in this experimentation through private-public projects (Box A).

Tokenization involves using technology such as DLT to create "digital tokens" representing legal claims like money and securities (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024). These tokens can be programmed with "smart contracts" – programs that execute when pre-specified conditions are met. Tokenization can create more distributed systems wherein the roles and responsibilities of infrastructure operators can be shared, potentially allowing novel arrangements. These designs can be combined with possible efficiency gains from smart contracts to improve post-trade processes for securities (for example, asset servicing, custody, or collateral management).

Project Pine is a research initiative undertaken by the BIS Innovation Hub Swiss Centre and the New York Fed's New York Innovation Center. It tackles a question highlighted by many central bank tokenization projects: How can monetary policy be implemented in a system with tokenized money and securities? Some tests with single central bank tools have been undertaken.[1] Project Pine focuses on a complete toolkit in a potential future where tokenization is adopted, and it aims to inform central banks about the practical possibilities and challenges that tokenization might bring for their market operations.

To understand how a central bank could implement monetary policy if wholesale money and securities were tokenized, Project Pine developed a prototype of a central bank toolkit with smart contracts and tested it. Because central banks' toolkits differ, the prototype is generic. Its scope, assumptions, and requirements were shaped by advisers from seven central banks.[2] Following development and testing, the same advisers then collaborated to evaluate the work and consider some of the broad implications for central banks. The toolkit prototype focuses only on domestic wholesale single-currency tools such as paying interest on reserves, temporarily creating or absorbing reserves in exchange for high-quality collateral, or permanently changing the amount of reserves through outright purchases or sales of securities. It does not include any tools for signalling or communications.

---

1 The Swiss National Bank (SNB) is currently running a pilot in a public-private partnership with SDX, a central securities depository. As part of this project, the SNB has already piloted the issuance of central bank bills in exchange for central bank money to implement monetary policy (Gerosa, Gloede, and Müller (2024))

2 The Reserve Bank of Australia, Bank of Canada, Bank of England, European Central Bank, Bank of Mexico, Swiss National Bank, Federal Reserve Board of Governors and Federal Reserve Bank of New York.

This report starts by outlining Project Pine's assumptions and requirements. The architecture, smart contracts, and testing arrangements are then detailed before findings and considerations are highlighted. The report concludes with some reflections on the project and possible next steps for research.

Box A: Central Bank Tokenization Research

The use of tokenization might enable changes to existing financial markets and underlying infrastructure. Significant central bank and private-sector exploration of the possibilities has been undertaken, especially the use of DLT in novel tokenized cross-border arrangements (Federal Reserve Bank of New York and Monetary Authority of Singapore 2023). Possible efficiency gains from smart contracts are also being explored for wholesale infrastructure. Smart contracts can perform different functions (potentially including some carried out by intermediaries) and, in so doing, potentially make 24/7 availability less costly (Bank for International Settlements 2023).

Tokenization is being considered to improve the infrastructure for securities settlement. In many parts of the world, post-trade processes (for example, asset servicing, custody, or collateral management) for securities rely on outdated technology and inefficient processes (Post-Trade Task Force (2022)). DLT experimentation for these arrangements has been predominantly driven by the private sector, and some arrangements are live. For example, JP Morgan's Kinexys service and Broadridge's Distributed Ledger Repo both offer DLT-based repo. In Switzerland, many tokenized bonds have been issued on the SIX Digital Exchange, a DLT-based central securities depository.

Smart contracts underlie many of the potential operational efficiencies for cross-border payments and securities settlement. Many of these smart contracts (for example, those used to automate asset servicing) require both the securities and the money to be tokenized (since the smart contract needs to interact with both). The desire for tokenized payment infrastructure introduces a broad range of research and policy questions for central banks (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024). Arguably some of the most important questions are related to monetary policy implementation.

2. Assumptions and Requirements

- Project Pine assumes a potential future where tokenization has been adopted for money and securities. The central bank's role and conceptual function are assumed to remain the same and the structure of the financial system and markets looks similar.
- To implement monetary policy, smart contracts are required. These contracts need to perform all the functions of a generic toolkit for implementing monetary policy (for example, paying interest on reserves, exchanging money for securities, and vice versa).
- The toolkit needs to be tested. In addition to performing the necessary functions, the technology should be assessed for its potential flexibility, reactivity, and robustness by using the smart contract toolkit in multiple hypothetical scenarios.

Project Pine's research question is about a hypothetical future. The project enlisted advisers from seven central banks to help shape assumptions about this future and set requirements for the generic central bank operational tools being developed (see Box B). No prescriptions or preferences underlie the assumptions. They simply aim to be conservative, coherent, and feasible.

Project Pine has a narrow scope. It focuses only on wholesale tools for implementing domestic monetary policy for a single, generic, and hypothetical jurisdiction in a single currency. Tools for supporting financial stability and cross-currency operations are not included. However, the project does not focus on a particular type of financial system, economy, or framework. Similarly, it does not focus on the exact technology used to tokenize money and securities. There are many types of DLT, and the project was agnostic as to the exact implementation.

2.1 Assumptions

The project assumes the existence of a central bank operating in an economy where the complexities and frictions of transitioning from account-based financial market infrastructures to tokens are history.[3] All financial assets and infrastructures are tokenized. The central bank's mandate is for monetary and financial stability. Monetary policy is determined by a committee based on the needs of the economy. The central bank controls the aggregate supply of central bank liabilities and the interest rates for these liabilities, which influences money market interest rates transmitted to the economy. The operational target is the interest rate that constitutes the initial stage of monetary policy transmission. In other words, there are no conceptual changes to a typical central bank or its role as it is currently understood.

---

[3] Although some research suggests that adoption might not be straightforward (Desch and Holden 2024).

In the assumed world, all money and securities are digital tokens. A "token arrangement" fulfills the function of payment and securities settlement systems for the economy.[4] Trading venues and exchanges are not tokenized and connect to the arrangement for post-trade activity and settlement. Participants in wholesale financial markets have tiered participation (that is, intermediation exists and not everyone is a direct participant in every system). Trading and settlement in government debt securities and money markets is possible 24/7. Yet settlement conventions still require some delay after trading (for example, t+1) and trading liquidity is higher during certain hours (for example, daylight).

The central bank uses tokenization and smart contracts to fulfill its role. Central bank reserves are digital tokens that exist in the token arrangement with other types of money and securities. The facilities offered as part of the central bank's open market operations are deployed using smart contracts in the same arrangement. The central bank permits access to reserves and facilities to its counterparties who are all participants in the token arrangement.

Finally, no specific economy or liquidity environment is assumed or assumed to be static. Credit in the economy could be capital-market–based (meaning there would be corporate bonds represented as tokens) or reliant on bank lending, or a mix of both. The number of commercial banks participating in the token arrangement is not fixed. Finally, the liquidity existing in the system (that is, the central bank reserves) could be scarce, ample, or abundant.

2.2 Requirements

Project Pine has two broad sets of requirements. The first set is requirements for the toolkit prototype (that is, what the contracts need to do to implement monetary policy). The second is for testing the effectiveness of the toolkit in the absence of a real economy, financial system, and tokenized infrastructure.

2.2.1 Prototype requirements

Central bank frameworks for implementing monetary policy are heterogeneous. They mirror the diverse economies and financial systems with which they interact. Yet despite this, there are common elements that most central banks share. The advisers who helped shape the requirements wanted to be able to use both the standard tools and the crisis tools available today (for example, interest payments, repos, loans, asset swaps) as well as tools to manage collateral. Central bank tools require flexibility (to calibrate and add new tools easily), reactivity (to be effective immediately), and robustness (to always be available when required).

[4] A sound legal basis and regulatory framework are assumed to be in place for all activity on the token arrangement. Legally, the asset is the token, not the representations of the legally recognized asset recorded elsewhere (for example, on a piece of paper or in a book-entry account). The exact details of the legal regime or of the claim on the token issuer and holder are outside the scope of this project. Some jurisdictions (for example, Switzerland) already have some laws in place.

For Project Pine, the environment in which a central bank implemented policy was not constrained (for example, there could be ample or scarce reserves, through a floor or corridor). Instead, the project favored various tools that could be deployed across changing circumstances. The toolkit includes tools for (i) interest-bearing reserves; (ii) open market operations; (iii) collateral management; and (iv) asset purchases.

Reserves and interest. The central bank must be able to restrict access to reserves. It should also be easy to change access and differentiate among access types with various conditions. Additionally, positive and negative interest rates should be applied to reserves. Rates must be able to change, and different reserve holders should be able to receive/pay different rates. Rates should also be payable across different reserve balance thresholds (for example, decreasing rates at increasing balance thresholds). Finally, reserves must be fungible. Payments must be possible without any of the features above being transferred (for example, if A pays B, the rate B receives on the reserves should be determined by B's own circumstances, not A's).

Additionally, for interest paid on reserves, the central bank must be able to accrue interest at a set frequency (for example, by the second or the minute). This is a departure from existing daily or overnight interest rate conventions. This requirement was driven by understanding the technological challenge of this different convention in the context of token arrangement initiatives that focus on cross-border uses and imagine running 24/7.

Open market operations. The central bank needs to be able to create multiple tools or "facilities." These facilities should be able to temporarily exchange money for assets or one type of asset for another with conditions and parameters: specifically, facilities that can create and absorb reserves or swap other assets while offering variable access, terms, schedules, and collateral eligibility (all of which should be easy to change). Facilities could be offered through a "window" (that is, available upon request) or an auction. Limits and thresholds on exchanges should be possible. Restrictions to counterparty access should be possible (so that a counterparty could have access to one facility but not another). The interest rate and term of any exchange should be variable and possible to change. The schedule of availability or operation for a facility should be possible and changeable (for example, a facility might be available 24/7, during business hours, or at other scheduled times).

Collateral. The ability for the central bank and counterparties to manage collateral is also required. This includes the ability to value collateral, set haircuts, and deliver a basket of different assets. For each facility, a central bank should be able to specify and change collateral eligibility. Multiple types of assets should be pledgeable in a "basket," valued frequently by the central bank. Counterparties should be able to substitute collateral in and out of a basket throughout the term. All collateral should be subject to a haircut determined by the central bank, and the haircut which can be changed as needed. Collateral requests should be triggered automatically if the post-haircut valuation falls below a threshold.

Asset purchases. The simplest requirement for the toolkit prototype was for a central bank to be able to purchase and sell assets.

2.2.2 Testing requirements

Validating that the toolkit prototype meets its requirements necessitates a system in which smart contracts can be deployed, their basic functionality tested, and their performance evaluated. Testing necessarily takes place in a simulated wholesale system, since Project Pine is concerned with a hypothetical future.

Token arrangement. The smart contracts that make up the toolkit prototype need to exist on a "programmable platform."[5] The project aims to be as agnostic as possible regarding the platform and assumes it meets scalability, security, and privacy requirements for adoption by future wholesale financial markets. Therefore, a platform that is popular, proven, and simple should be favored. Additionally, to test the smart contracts on the platform, the agents and their assets need to be simulated. Assets only need to function to the extent required by any simulation (for example, bonds do not need to calculate or pay a coupon). Therefore, as for the platform, the most popular, proven, and simple token standards should be used. The smart contracts and assets should all exist in a single "token arrangement."[6]

Testing. Each requirement for the prototype should be tested individually (in "unit testing"), and hypothetical scenarios should be used to combine requirements to ensure consistency, coherence, and flexibility (in "integration testing"). A range of hypothetical scenarios should include simple and complex combinations of events and functions together with a range of liquidity regimes, toolkit calibrations, and financial environments.

Testing arrangement. Additional systems are required to simulate the different scenarios in the token arrangement. Data input is required to (i) set up each scenario and create the starting token arrangement (for example, number of agents, types of assets, tools deployed by the central bank); and (ii) to run the scenario (for example, events that take place). Agents are also required to perform different roles with consistent rights and abilities (for example, to hold assets and interact with others on the token arrangement) and knowledge (for example, to know what assets they hold on the token arrangement). Data output from the token arrangement should be captured and visualized.

---

[5] A programmable platform is the technologies that enable eligible participants to develop and execute applications that update a common ledger (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024).

[6] A token arrangement comprises the programmable platforms and/or participating entities that enable financial market functions by utilizing digital tokens (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024).

Box B: Central Bank Market Operations and Technology

Market operations are a "portal to reality" for central banks (Bindseil 2016). Monetary policy decisions determine the rate of return for money supplied to an economy, for prices to be stable and inflation to be low. Market operations implement these decisions. Although all central banks need to implement their policies, they do so differently, depending on their domestic financial markets, their links with international financial markets, and the global and local economic environment.

Many central banks' market operations have significantly changed in recent years, especially following the global financial crisis (Hauser 2023). Technology has typically played a smaller role in catalyzing changes in more recent years. Yet nonetheless, many central banks are improving their systems to manage additional complexities and make their existing operations more efficient.

Market operations differ among central banks, reflecting differences in market structures, conventions, and institutions (Cap, Drehmann, and Schrimpf 2020). Yet there are often similarities, too. For example, for many central banks, the overnight interbank rate plays a key role in policy implementation. The overnight interbank rate depends on the supply and demand for central bank reserves. Central banks control the supply of reserves, and reserves can be increased or decreased temporarily (by lending and borrowing tools) or permanently (by buying and selling assets). Demand for reserves comes from payment and settlement activities (among other things), and central banks can also affect this demand further through reserve requirements.

Exactly how central banks manage reserve supply and demand differs. Before the global financial crisis, many central banks operated a "scarce" system: reserves are not supplied above the necessary quantities for settlement requirements. In this system, a "corridor" is formed between reserve borrowing and lending rates offered by the central bank. Today, many central banks operate an "ample" system. In this system, sufficient reserves are available for settlement, and therefore, the overnight interest a central bank pays on reserves acts as a "floor" to the interbank overnight rate.

Central banks face technology challenges in their operations. These include perennial challenges to respond to events and optimize existing processes; emerging challenges from evolving trading in markets; and potential challenges from adopting tokenization. Some challenges are exogenous to the central bank and arise from changes in the structure of markets and infrastructure, whereas others are endogenous and relate to improving existing understanding or evolving operations.

Perennial challenges are created by stress conditions and continuously optimizing processes. For example, many central banks needed to quickly launch novel facilities in response to the economic impact of COVID-19 and change existing facilities (Cantú et al. 2021). Accessing and analyzing data to inform decisions is a constant requirement and especially pertinent under stress conditions, as is risk management of the central bank's activities. For example, some central banks have expanded their counterparties and collateral eligibility in response to market changes and to include or favor "green" collateral (Cullen 2023).

Central banks may also face emerging challenges from increased demand for central bank money and how to meet that demand efficiently. For example, changes in markets, participants, or infrastructure have led some central banks to innovate in their account or facility offerings to make reserves available for different times, on different terms, or to a wider range of participants.* Relatedly, the additional complexity of central bank operations has increased incentives to use technology to automate tasks and processes. However, central banks still face a challenge in integrating automated processes with those that require human judgment.

Finally, market adoption of tokenization could bring additional challenges. Some of these challenges have been highlighted in previous research and naturally depend on many factors. For example, systems using tokens to represent assets "frozen" in accounts intraday perform a clearing function and pose few implications. Yet if tokenized assets are the sole representation and infrastructure becomes more interconnected, the potential challenges multiply. Tokenization could lead to changing and uncertain demand for reserves (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024). Many discussions of the potential benefits of tokenization cite its ability to remove intermediary functions, although it is likely that some intermediation will still be required in a tokenized system (Aldasoro et al. 2024). Nonetheless, there are risks of increasing concentration during the adoption of a new technology (Benos, Garratt, and Gurrola-Perez 2017).

* For example, new "omnibus accounts" from the Bank of England and intraday repos from the Reserve Bank of Australia.

3. Prototype and testing infrastructure

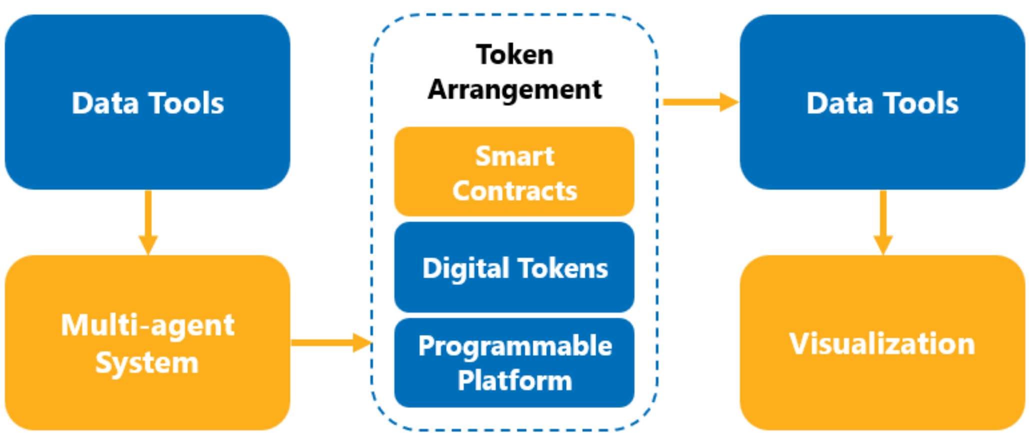
- The Project Pine system includes a smart contract toolkit prototype that is housed in a programmable platform, with tokens representing money and securities.
- In addition to smart contracts that pay interest on reserve tokens, there is a "factory" that creates different tools, calibrated to a central bank's requirements. These tools can interact with other smart contracts and tokens to create differently configured toolkits.
- To create hypothetical scenarios for testing the toolkit prototype, the project developed a multi-agent system to play through and visualize how different economies and toolkit configurations could be used.

For Project Pine to understand whether central banks could use smart contracts as tools, it was insufficient to just build the toolkit. The toolkit also had to be tested. That required the development of two interacting arrangements: a token arrangement, consisting of a programmable platform, assets, and the toolkit itself; and a testing arrangement, comprising a multi-agent system, data tools, and a visualization. Together the two arrangements were used to test a range of hypothetical scenarios.

3.1 Architecture Overview

The token arrangement sits at the center of the system. It includes a programmable platform that houses the smart contracts making up the central bank toolkit and the tokens with which they interact (Figure 1).

Figure 1. Project Pine System Overview



The testing arrangement had three components that carried out different functions: first, a multi-agent system allowed scenarios to be simulated through housing multiple agents that can take individual actions in a dynamic environment; second, a visualization tool was built to display the activity taking place in the token arrangement for each scenario; and to set up different scenarios and allow information to flow between the multi-agent system, token arrangement, and visualization, data tools were required.

Technology choices were made for each system component (Table 1). Except for the smart contracts, standard, popular, and "off-the-shelf" open-source options were chosen to better focus on the toolkit development.

Table 1. Token and Testing Arrangement Components

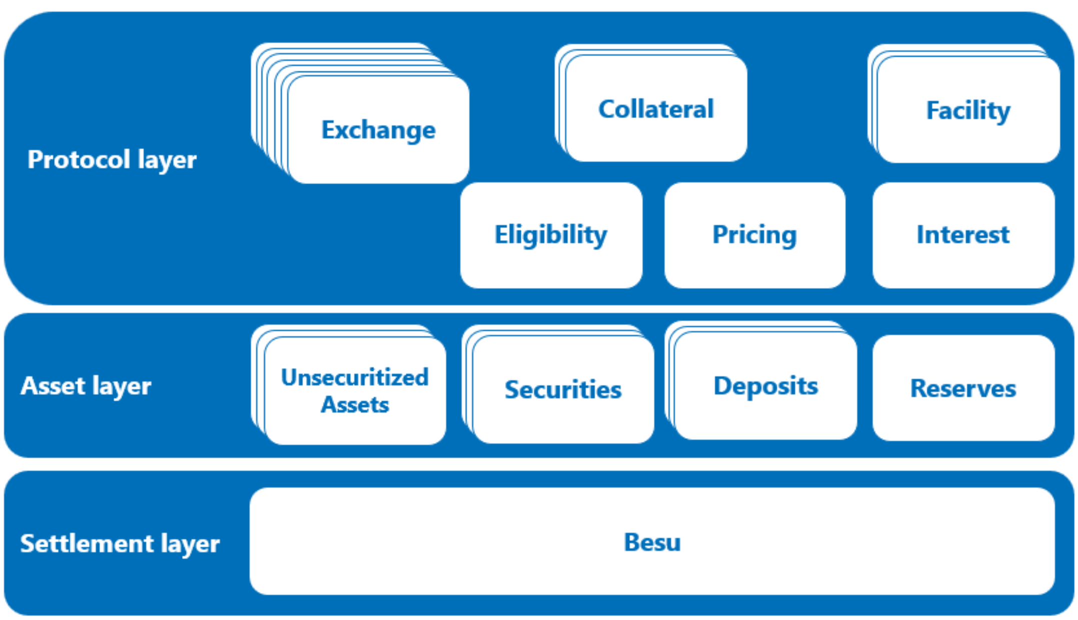
	Component	Role	Technology choice	Reason
Token arrangement	Programmable platform	Housing tokenized money, securities, and smart contracts	Besu	Besu is a benchmark and widely used open-source implementation of a permissioned Ethereum virtual machine (EVM) blockchain.
	Tokenized money and securities	Interact with smart contracts in testing scenarios	Token derived from ERC-20	The ERC-20 token standard is a robust standard for EVM blockchains.
	Smart contracts	To function as a central bank toolkit prototype	Smart contracts coded in Solidity	Solidity is the smart contract language used in EVM blockchains and the most widely used smart contract language.
Testing arrangement	Multi-agent system	Used to simulate scenarios for testing	Typescript / Node.js	Typescript allows for the easy creation of different agent types and behaviors.
	Data tools	Used to generate data and simulate scenarios for testing	Python and multiple databases	Data requirements across the architecture varied and so multiple tools and databases were used.
	Visualization	Allowed testing to be viewed and engage advisers	Svelte	Visualizing smart contracts was novel and required.

3.2 Token Arrangement

Token arrangements are composed of several hierarchical "layers" (Schär 2021). The token arrangement in Project Pine has three (Figure 2).

- The first layer is the programmable platform or "settlement layer." Besu, an implementation of an Ethereum virtual machine (EVM), was chosen because it is open-source and widely used.[7]
- Above the settlement layer is the "asset layer," consisting of the wholesale money and securities issued. In Project Pine's case, these were all ERC-20 tokens, a popular token standard for EVM networks.[8] These tokens represented the reserves, commercial bank deposits, securities, and unsecuritized assets that would be used in testing scenarios.
- Finally, there is the "protocol layer," which holds the smart contracts. The toolkit has six different types of smart contracts. The "interest smart contract" interacts with the reserves token. The other smart contracts collectively manage central bank open market operations, including collateral management.

Figure 2. Project Pine Token Arrangement



7 See Private networks | Besu documentation.

8 See ERC-20 Token Standard | ethereum.org.

3.2.1 Interest smart contract.

Reserves are tokens that can be transferred and can interact with any of the smart contracts in the token arrangement. To meet the requirements, they need to have access restrictions, be fungible, and pay interest that might differ between holders. Two developments were necessary to achieve this: one simple and one complex. The first was to embed access requirements into a "base token contract." The second was to develop the base contract further with an additional smart contract that could calculate and accrue interest every second.

The interest contract interacts with the reserves contract. The reserves contract already contains a link between the wallet address and the balance (that is, it is possible to see the reserve balance for every holder). Yet an additional link was needed to record the accrued interest and the time at which the last interest calculation was made. With these additions, the reserves smart contract can calculate, accrue, and pay interest.[9] Every second, the smart contract notes the reserve balance held by each participant and calculates the interest that should be accrued to that holder. Interest is accrued (by the second) and is visible to the reserve holders. The central bank can then settle that interest whenever it wishes. Accrual and settlement functionality were separated to reduce the amount of computation required by the system (that is, to avoid sending a payment to every holder every second). There is also no incentive for holders to ask for very frequent settlements, since they can see the accrued interest the central bank owes them. However, because interest is only accrued on balances, not on the unsettled accrued interest, a frequent schedule of interest might be necessary.

This holder-specific calculation means that different interest rates can be applied while the reserves are still fungible and can be used for payments. (for example, one holder could receive 5 percent and another could receive 4.5 percent). By knowing the balance, the smart contract can also pay tiered interest (for example, a holder might receive 5 percent only for the first $1 million of their balance).

3.2.2 Open market operations smart contracts

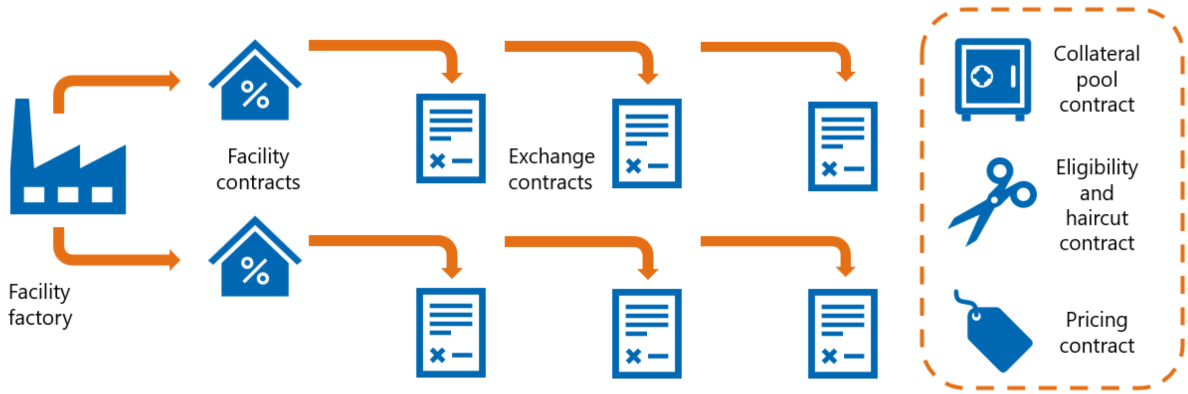
Smart contracts that create and run open market operations and manage collateral need to interact with one another. The number of smart contracts and the tasks they need to perform make them more complex than those for reserves. There is a hierarchy of contracts, starting with a *factory* that creates *facility contracts*, which validate requests to exchange tokens and create counterparty and operation-specific *exchange contracts*. These contracts are supported by *collateral pool contracts*, *collateral eligibility and haircut contracts,* and *pricing contracts* (Figure 3).

To create facilities in the toolkit prototype, there is a smart contract *facility factory*. This is not a smart contract but a program within the multi-agent system that creates *facility contracts.* To create a *facility contract*, the central bank decides which assets are being exchanged, the borrowing rate, the term, the collateral arrangements, and who has access. To determine the collateral arrangements, the factory specifies which other smart contracts the new facility should trust to determine collateral eligibility,

[9] Smart contracts in the toolkit prototype can also pay simple interest and negative interest.

haircuts, and pricing. A central bank can subsequently change any of these parameters and create multiple facilities.

Figure 3. Project Pine Open Market Operations Smart Contracts



A *facility contract*, once it is deployed by the factory, creates *exchange contracts*. *Exchange contracts* exist for every counterparty (for example, if a single facility was used by 50 counterparties, there would be 50 separate exchange contracts) and every exchange (for example, if the facility was a daily exchange, assuming all counterparties participated, every day another 50 contracts would be created). *Facility contracts* create *exchange contracts* only if they successfully validate a counterparty's request to use the facility.

Using a facility involves three steps and requires interaction with *collateral*, *pricing,* and *eligibility and haircut contracts*. First, a counterparty requests an amount of whatever the facility offers and submits a *collateral pool contract* to the *facility contract*. Second, the facility contract validates that: (i) the requesting counterparty has access; and (ii) that the collateral pool contract "references" the central bank's preferred *pricing* and *eligibility and haircut contracts*. If it does, then the facility contract checks that the value of the post-haircut eligible collateral is sufficient. If it is, then the final step is the creation of an *exchange contract* between the central bank and the counterparty that reflects the exchange terms. The pledging of the *collateral pool contract* to the *exchange contract* represents the counterparty's acceptance of the terms.

The collateral in *collateral pool contracts* is not static. The *pricing contract* updates the market value of any assets pledged (in Project Pine, this was every second). And the *eligibility and haircut contract* can also update the value if the central bank makes any changes during the life of the *exchange contract*. Relatedly, because the *collateral pool contract* can accept multiple types of assets, counterparties can switch out their assets during the life of an *exchange contract* if there is sufficient value. If the value of collateral falls (due to a price decrease, an increased haircut, or ineligibility), the contract issues a collateral call.[10]

Since collateral conventions differ between jurisdictions, two types of *collateral pool contracts* were developed. The first was specific to an *exchange contract*, so that if a counterparty was pledging collateral to three different facilities, it would need three *collateral pool contracts*. The second was a single *collateral pool contract* that could be linked to multiple *exchange contracts*, potentially allowing easier management for counterparties.

Not all central bank open market operations require collateral for a temporary exchange; some require an outright purchase or sale of an asset. For these operations, the *facility factory* can also create *asset purchase facility contracts*. These contracts are simple and do not create the equivalent of *exchange contracts* or interact with collateral. Their only tasks are to record the assets bought and sold using the facility and to enable settlement.

3.3 Testing Arrangement

To test the toolkit prototype, Project Pine developed a system to create and manage agents, assets, and infrastructure. The testing arrangement has three components: a multi-agent system, data tools, and a visualization.

3.3.1 Multi-agent system

Using a multi-agent system enabled Project Pine to simulate multiple scenarios to test the smart contract toolkit. In the simulations run, agents were "simple-reflex." They operated autonomously, making decisions and taking actions based on their internal logic in response to a changing environment that they perceived. There was no independent learning or adaptation by agents.

Agents' internal logic depended on their role. Project Pine's scenarios included several (Figure 4). For example, there was always a central bank, which issued reserves, held high-quality assets, and used smart contracts to meet a target interest rate. There were different types of commercial banks, which issued deposits, held reserves and a variety of assets, and interacted with the central bank smart contracts. Governments or corporations that issued debt could also play a simpler role.

[10] The central bank also has the flexibility to determine a threshold for issuing collateral calls (that is, a collateral call could be issued earlier than the moment collateral values are under water, for example, at 3 percent or 5 percent).

Figure 4. Agent Balance Sheets in an Example Scenario

Note: This screenshot of the visualization tool shows a hypothetical scenario where multiple commercial banks hold reserves, government bonds and other securities, and loans, and have issued deposit tokens.

The agents' environment included the token arrangement and simulated financial markets. Every agent had a wallet for interacting with the token arrangement. The agents could see the tokens they held and the tokens they had issued (that is, they knew their own balance sheet).[11] They could also see the smart contracts offered by the central bank and the eligibility and other conditions. Consistent with Project Pine's assumptions, activity such as trading was outside the token arrangement. A separate "environment wrapper" managed access to data about the market price of assets, the cost of borrowing in money markets, and so forth. Exogenous events (for example, a fall in prices) could then be introduced to the scenario and drive agents' behavior.

3.3.2 Data tools

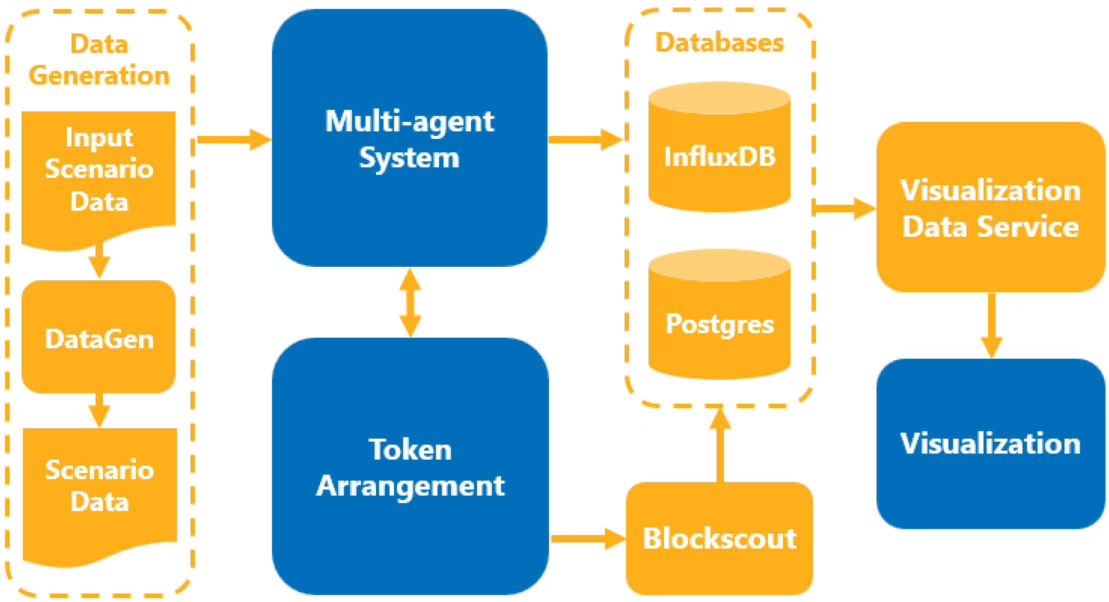
Running and recording a hypothetical testing scenario through Project Pine's token and testing arrangements required multiple data tools (Figure 5).

Before any test can be run, the scenario needs to be created. The first step is to create an *input scenario data* file. This file contains data relating to the scenario being tested (for example, the number, types, and behaviors of agents, events that take place, and so forth). A *DataGen* program, developed for the project, converts the input data into *Scenario data* files that are readable by the agents in the multi-

[11] "Wallets" in tokenization hold keys that enable access to transfer and interact with digital tokens. Unlike in a physical context, digital tokens do not exist inside the wallet; instead, a digital wallet holds the cryptographic keys that allow control of the tokens that exist in the token arrangement. Every agent in Project Pine had a wallet.

agent system. The multi-agent system creates all the agents and configures the token arrangement according to instructions (for example, creating assets and smart contracts).

Figure 5. Data Tools Used in Project Pine



Once a scenario has been created, data tools help manage the interaction between system components. Throughout a scenario, the multi-agent system and token arrangement interact through an EVM-compatible open-source application programming interface *(Hardhat)*, which was developed further to better interact with the toolkit prototype's smart contracts. Both the multi-agent system and the token arrangement store their activity in *Databases* (using a *Block explorer (Blockscout)* to analyze the activity on the token arrangement). A *Visualization data service* then aggregated data from the two databases (*InfluxDB and Postgres*) before the Visualization tool displayed the scenario being tested.

3.3.3 Visualization

Project Pine's testing needed to be understood by the central bank advisers who helped shape the requirements for the toolkit prototype. To that end, Project Pine constructed a visualization with four separate views:

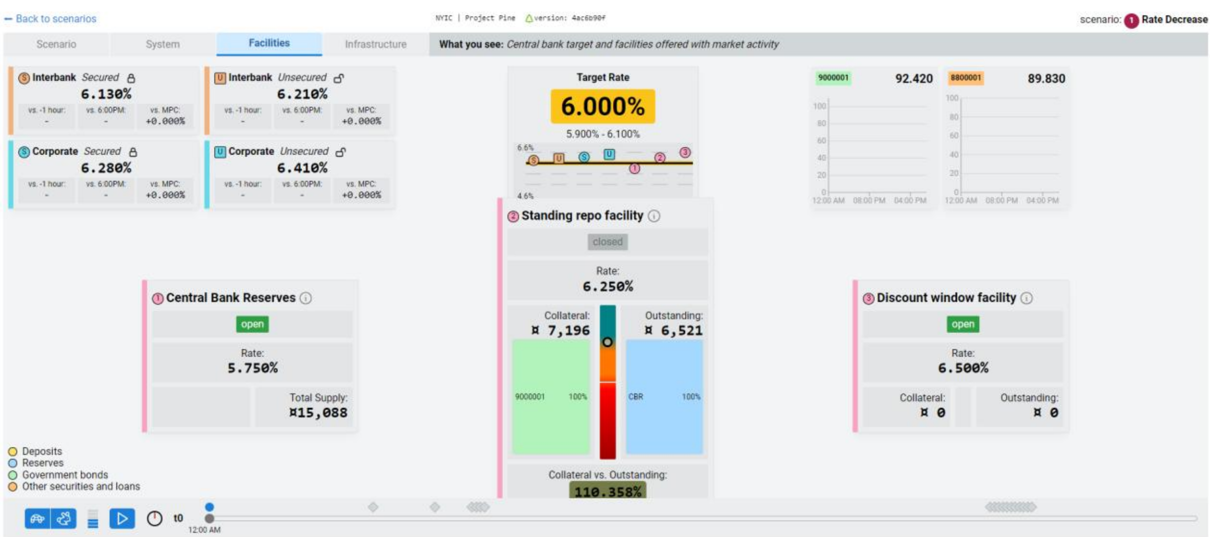
- First, a "scenario" view shows every event introduced in a scenario.
- Second, a "system" view shows all the agents in a scenario and their balance sheets (that is, the tokens they hold and have issued).

- Third, a "facilities" view shows the central bank's view. It includes the money market rates and asset prices that are not part of the token arrangement, the target rate, and all tools currently deployed (Figure 6).

- The final "infrastructure" view shows the smart contracts, assets, and agents in the token arrangement (Figure 7).

The time in each scenario was synchronized across all views, making it easier to show the links across agents' financial and technical activity. For example, in multiple scenarios agents pledged collateral to the central bank and borrowed reserves. The balance sheet effect could be seen (in the second view), together with an increase in activity relating to that facility (in the third view) and the movement of assets to a collateral contract and creation of reserves (in the fourth view). A timeline at the bottom of the visualization showed events. A complete example of a testing scenario with screenshots of the visualization is included in an Annex.

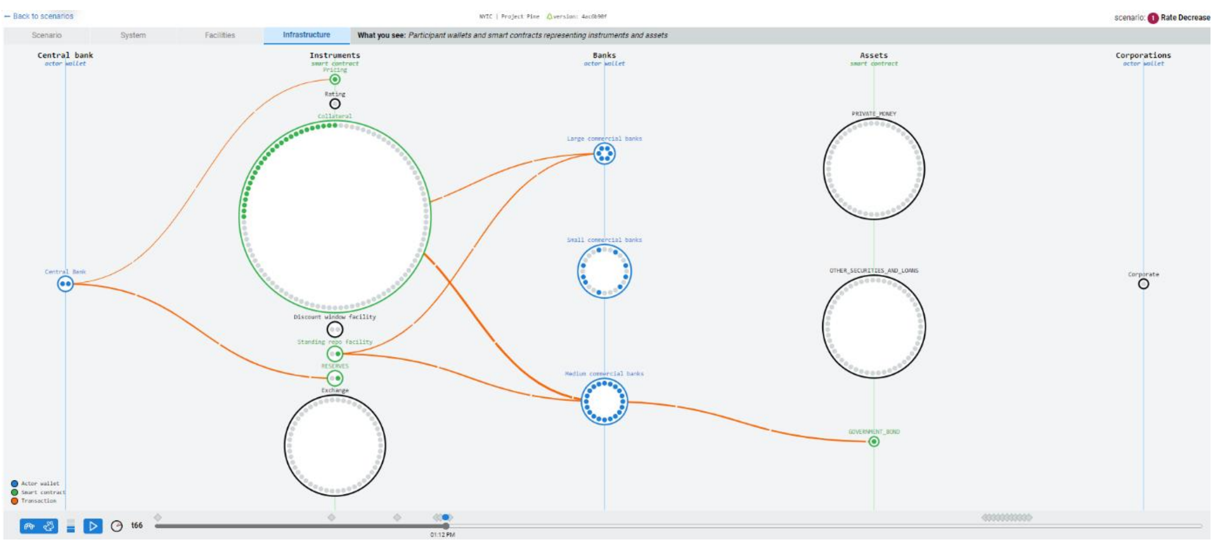
Figure 6. Project Pine Facilities Visualization Example



Note: This screenshot of the visualization tool shows a hypothetical scenario where commercial banks are pledging government bonds as collateral in exchange for reserves through a facility called the "standing repo facility."

Visualizing smart contracts was a novel challenge for the project but necessary to make the development and testing accessible for the central bank advisers. The visualization represented familiar context (eg system and facility views) with the novel (infrastructure view). Many user interfaces exist to interact with smart contracts, but this project required a visualization that made them understandable as they interacted with different agents and assets. This required a custom and iterative development using Svelte, an open-source framework of tools often used in website applications.

Figure 7. Project Pine Infrastructure Visualization Example



Note: This screenshot of the visualization tool shows a hypothetical scenario where commercial banks are pledging government bonds as collateral in exchange for reserves through a facility called the "standing repo facility."

3.4 Testing Approach

Having assembled the token and testing arrangements, testing was conducted to understand whether the toolkit prototype worked as designed. As is best practice for technology products, testing involved both unit and integration testing. Unit tests of all smart contracts isolated individual functions (for example, "transfer," "mint," "repayLoan") to ensure that the smart contracts carried them out as instructed. Integration testing, in Project Pine's case, involved developing and testing hypothetical scenarios where multiple agents interact in a simulation.

In early testing, all agent behavior was strictly scripted (that is, they were told what to do). This was to make activity more predictable to better assess smart contract performance. However, later in the project, simple models were included to create additional testing scenarios (for example, agents were assigned a simple reserve demand function based on Afonso et al. 2024).

Every scenario involves a series of events that occur at predetermined time steps in the scenario. After the multi-agent system and token arrangement are configured for the scenario to be tested, each scenario advances one step at a time. Every scenario involves 240 steps and takes 10 minutes to run (each step taking two and a half seconds).[12] A three-phase process is followed for every step. First, information is disclosed (this includes general and agent-specific event data and public market data).

[12] The block time for the programmable platform was set to one second per block, which enabled agents to perform multiple actions in a single step.

Second, agents have a chance to act (the actions depend on the agent but include making queries, submitting transactions, and deploying smart contracts). And third, time-stamped data are collected and indexed.

Since one of the key requirements for the toolkit prototype was flexibility, hypothetical scenarios included a range of different events and environments (Table 2). For example, the events that took place in a scenario included both the routine and the stressful. They might also take place over hours or months, depending on how the simulated time was mapped to the step time. Scarce and ample liquidity environments were also tested (and one testing scenario included moving from a scarce regime to an ample regime). In the various scenarios, the financial system was alternately large or small, with differing credit availability, which affected the number and size of different agents and the assets available in the token arrangement.

Table 2. Range of Parameters Used in Constructing Hypothetical Scenarios

Scenario parameter	Possible options	Examples in scenario
Events	Routine	Target interest rate rise
	Stress	Government debt collapse
Time lapse	Shorter	24 hours
	Longer	24 months
Liquidity	Scarce	Fewer unremunerated reserves
	Ample	More remunerated reserves
Financial system	Smaller	Six monetary policy counterparties
	Larger	Sixty monetary policy counterparties
Credit	Capital market-based	Corporate debt is eligible for backstop facilities
	Bank loan-based	Tokenized unsecuritized assets are eligible

Each scenario was based on inputs of historical data on past market events including interest rate tightening cycles, debt and currency crises, quantitative easing cycles. The central bank toolkit was always consistent with the liquidity environment. Each scenario was run until results were stable and consistent (an example scenario, with screenshots from the visualization tool, is included in an Appendix).

4. Findings and Considerations

- Testing was successful and the toolkit prototype met all the requirements set out by central bank advisers.
- The smart contract toolkit was fast and flexible. In hypothetical scenarios the central bank was able to add and change tools instantly.
- Based on these results, smart contracts could be useful for central banks if tokenization is adopted for money and securities

Project Pine was not a thought exercise. A smart contract toolkit for central banks did not exist and had to be developed. In addition to lessons learned during the project's development and testing, several considerations for central banks' use of smart contracts were identified.

4.1 Technical Findings

Testing showed that the prototype met all requirements. Multiple facilities operated simultaneously and interacted with reserves and other assets representing different kinds of securities. This was true even when additional complexity was included (for example, reserves with varying and tiered interest rates that changed over the scenario and increasing numbers of counterparties). Multiple jurisdictional collateral conventions were successfully tested. Some configurations also allowed for "pre-positioning" collateral, which many central banks encourage.

The team embraced an agile approach to software development that relied on tight integration of continuous integration and continuous delivery (CICD) validating rapid iterations of multiple component features through automated testing. Daily introduction of new code to the system required passing unit and integration tests in addition to format-checking and type-enabled documentation generation prior to peer code review. While obtaining a high percentage of test code coverage was not a focus of the project, automating any source of manual testing directly contributed to faster development.

Testing the flexibility in deploying and adjusting multiple facilities was also successful. The prototype's speed and consistency were also validated. For example, in one hypothetical 10-minute scenario with falling collateral values, the central bank: changed haircuts on eligible collateral, executed multiple collateral calls and exchanged liquid collateral for illiquid, deployed a new facility offering reserves, and changed the interest rate paid on reserves. All these actions were immediate (see the Appendix for more details).

Beyond learning that the prototype worked in testing, the project generated useful lessons during development. A basic lesson, obvious in hindsight, is that central banks' requirements for tokenization and smart contracts are novel. There was no "off-the-shelf" set of smart contracts available, and much of the prototype had to be developed from scratch. Nonetheless, where possible, "standards" were used.[13] For example, the reserve tokens use the ERC-20 standard combined with another standard for access control.[14] And although the interest contract had to be novel, the prototype used an open-source library of mathematical functions.[15]

The smart contracts in the toolkit prototype for creating facilities, exchanges, and collateral management are all novel. Although smart contracts in publicly available repositories and libraries exist for activities such as lending and pledging collateral, most have been built for decentralized finance (DeFi) or cryptocurrency lending, which are very different from traditional central bank arrangements (Auer et al. 2023). Central bank requirements therefore needed further development to supplement the functionality of existing standards.

Multiple benefits were identified from the trust the participants in the token arrangement were assumed to have in the central bank. By design, trust in the central bank allowed many contracts to be simpler and more efficient. For example, time is a question of consensus in trustless public networks. Every contract in the toolkit prototype that deals with interest (that is, the majority of them) requires a trusted timekeeping source to calculate interest and determine expiration. By giving the central bank (or a similarly trusted institution) the sole right to keep the time, Project Pine's contracts avoid the overhead of consensus-based arrangements in public networks (Box C).

4.2 Central Bank Considerations

Beyond the specific findings resulting from developing and testing the prototype, Project Pine raises several wider considerations for central banks. Many of these considerations are related to the potential usefulness and risks of using smart contracts to meet the technology challenges they face (or could face in the future if tokenization is adopted). Others are related to possible risks from this new technology.

Smart contracts and tokenization could help central banks better manage extraordinary events. The most significant benefit is that facilities can be created and deployed almost instantly with smart contracts. This speed, coupled with the ability to adjust any of the parameters at any time, gives central banks flexibility in responding to unforeseen events and fast-moving crises.[16] In practical terms, central banks also face analytical and legal hurdles when launching new facilities (for example, to work out how the facility should be calibrated and how it could be offered). Nonetheless, smart contracts could still represent high value to operations. Similarly, adding new counterparties and collateral that

---

13 A standard, in this context, refers to a technical guideline for tokens. With the standard acting as a common blueprint, tokens are then compatible with one another and with smart contracts.

14 Access Control - OpenZeppelin Docs

15 GitHub - abdk-consulting/abdk-libraries-solidity: Open-Source Libraries for Solidity by ABDK Consulting

16 This assumes that the parameter that requires changing is included in the equivalent of the smart contract factory. In the event that it is not, any addition is unlikely to be immediate.

participate or exist in a token arrangement is likely to be technically simple (albeit with the same analytical and legal hurdles as today).

Tokenization could benefit data collection and analysis. Smart contracts are unlikely to provide central banks with any additional data or analytical capacity. Yet data standardization and potential consolidation of participants' money and security holdings could be useful for monetary policy implementation analysis — if the data were available to a central bank.

Collateral management could benefit in small ways from smart contracts. Many central banks have already invested in their existing operations and risk management to make settlement and collateral management ("back-office") tasks fast, efficient, and automated. Smart contracts could automate many of the same tasks but offer no special possibilities beyond existing technologies (in this regard). However, in cases where smart contracts automate tasks, limits and conditions must be explicit, which could help make the boundary between automation and human judgment more transparent. Operating on a token arrangement might also add efficiencies not possible today, for example, by integrating collateral eligibility and haircut setting with execution, as Project Pine's contracts do.

Smart contracts might aid central banks in managing the increased complexity of transitioning from existing infrastructure to token arrangements. This change could be gradual and prolonged and could involve risks (Bech et al. 2020). Although smart contracts are unlikely to help manage interoperability between token and non-token systems, they could be useful if a central bank wanted to catalyze changes and ensure stability in any novel arrangements. Prototypes such as Project Pine could also be useful in modeling scenarios and analyzing new designs.

Relatedly, some potential risks from tokenization could also be mitigated with smart contracts. For example, their flexibility might help in managing volatile or changing demand for liquidity and give central banks additional options to meet this demand in cross-border token arrangements. If the adoption of tokenization changes policy transmission, smart contracts could quickly deploy new facilities that can then be easily adjusted to achieve their objectives. And if tokenization speeds up markets and settlement so that crises hit faster, having facilities without frictions (for example, telephone calls, emails, or other manual confirmations) allows a central bank's response to be implemented immediately.

Smart contracts could help central banks manage extended operating hours and any potential move to 24/7. Many central banks operate extended hours and have launched new facilities to accommodate overnight activity. The assumption in Project Pine is that the token arrangement operates 24/7 and interest on reserves is calculated continuously. Yet this choice is neither necessary nor necessarily optimal. Reserves and smart contract facilities could operate with defined opening hours just like today. And, as was tested, some facilities could be available 24/7 with some degree of automation while others operate on a schedule. For example, some actions could be automatic, others could be automatic within a threshold, and others could require human decision-making. As for other aspects, there is flexibility.

Finally, use of smart contracts might also bring new operational risks for central banks to manage (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024). For example, an error in an automated workflow within a smart contract could have an immediate and wide impact across a token arrangement. Connections between smart contracts and other systems (for example, the price feed used in Project Pine to value collateral) could be vulnerable to operational failure or cyber-attack. And ineffective privacy measures might not sufficiently protect central bank activity such as the use of backstop facilities, which could create a stigma for institutions that use them.

Box C: Smart Contracts in DeFi and Project Pine

Smart contracts are protocols or code operating on programmable platforms that execute when certain conditions are met. However, "smart contract" is a misnomer (Lim, Saw, and Sargeant 2016). They are not smart (they only execute as programmed) and are not contracts (in a legal sense). Nonetheless, because smart contracts are transparent to parties using them, there is a "coherence guarantee" of execution, as with a contract (Lee 2021).

Decentralized finance (DeFi) uses smart contracts on public blockchains to automate functions that are performed by intermediaries in traditional financial systems, for example, in "loan pools," where funds are automatically sent when collateral is verified, and in "automated market makers" that program trading of different assets (Aramonte, Huang, and Schrimpf 2021). Although DeFi smart contracts automate intermediary functions, there are some trade-offs. Public blockchains are decentralized and rely on consensus mechanisms, potentially resulting in high transaction costs that make small transactions uneconomical. And these barriers for smaller users can be compounded by the technical sophistication required for participation and the overcollateralization required in many loan pools.

DeFi smart contracts can also suffer from the "oracle problem" (Duley et al. 2023). When smart contracts execute on information from outside their programmable platform, they require an external data source (or "oracle") to provide it. The oracle problem is that smart contracts, not being smart, will execute on whatever information is provided, regardless of its accuracy. Different approaches are used to validate information from oracles, including using multiple parties, which can add complexity and reduce system performance.

Project Pine's smart contracts were not developed for DeFi and had a different purpose. Whereas DeFi protocols seek to automate intermediary functions, Project Pine's are used by the central bank. The only automation of the toolkit prototype is for collateral management, and unlike with a DeFi smart contract, there is no automated liquidation of collateral in a default (because a central bank would manage this with the counterparty). Relatedly, many of the smart contracts developed in Project Pine use the central bank as an oracle (for example, to price collateral), but there is no issue because the central bank is trusted by counterparties to perform the task. Finally, fixing mistakes or making changes to smart contracts in DeFi can be complex and require consensus. Conversely, a central bank can immediately change any smart contract in the toolkit prototype for maximum flexibility.

5. Conclusion

Project Pine is a first step in showing that monetary policy implementation is possible in a tokenized world. It also begins to explore the possibility that smart contracts could make implementation more nimble and more efficient and therefore potentially even more effective if tokenization is adopted. Yet there are significant caveats to this possibility. First, every central bank is different, and any benefits will be relative to existing operations. Second, any benefits will only materialize if the token arrangements that are adopted meet a central bank's requirements.

By developing a toolkit prototype, Project Pine showed that central banks will likely play a very different role than other participants in future token arrangements. In addition to deploying smart contracts, they might also require privileged access to institutional data and higher standards of privacy and security. Outlining requirements for a jurisdiction is a task that each central bank will perform alone. However, the experimentation in Project Pine showed that tokenization is flexible enough to accommodate many different central bank choices on toolkit design.

Tokenization research by central banks is still at an early stage. There are more areas for collaboration that were beyond the scope of Project Pine. For example, adding multiple currencies to the prototype might be valuable for central banks that implicitly or explicitly target exchange rates as part of their monetary policy implementation and for those that operate facilities in foreign currencies.

Glossary

Project Pine used terms as they are defined in Bank for International Settlements and Committee on Payments and Markets Infrastructures (2024)

Ledger: a recording information technology. Traditional ledgers rely on two segregated components: the database layer stores records of assets, while the application layer incorporates centralized logic and governance rules into the system and manages the recording, updating, and deleting of assets on the ledger.

Programmable platform: the technologies that allow eligible participants to develop and execute applications that update a common ledger.

Smart contract: protocol or code that self-executes when certain conditions are met.

Token: a representation of something else. In the context of money and other financial assets, digital tokens are entries in a database that are recorded digitally and that can contain information and functionality within the token themselves.

Tokenization: the process of generating and recording a digital representation of traditional assets on a programmable platform.

Token arrangement: the programmable platforms and/or participating entities that enable financial market functions by utilizing digital tokens.

References

Afonso, G., D. Giannone, G. La Spada, and J. C. Williams. 2024. "Scarce, Abundant, or Ample? A Time-Varying Model of the Reserve Demand Curve." Federal Reserve Bank of New York *Staff Reports* no. 1019 (April).

Aldasoro, I., S. Doerr, L. Gambacorta, R. Garratt, and P. K. Wilkens. 2023. "The Tokenisation continuum." *BIS Bulletin* no. 72 (April).

Aramonte, S., W. Huang, and A. Schrimpf. 2021. "DeFi Risks and the Decentralisation Illusion." *BIS Quarterly Review* (December).

Auer, R., B. Haslhofer, S. Kitzler, P. Saggese, and F. Victor. 2023. "The Technology of Decentralized Finance (DeFi)." BIS Working Paper no. 1066 (January).

Bank for International Settlements. 2023. "Blueprint for the future monetary system: improving the old, enabling the new", *Annual Economic Report* (June).

Bank for International Settlements and Committee on Payments and Market Infrastructures (2024): "Tokenisation in the context of money and other assets: concepts and implications for central banks." Joint Report (October).

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

Benos, E., R. Garratt, and P. Gurrola-Perez. 2017. "The Economics of Distributed Ledger Technology for Securities Settlement." Bank of England Working Paper no. 670 (August).

Bindseil, U. 2016. "Evaluating Monetary Policy Operational Frameworks." Paper presented at the 2016 Economic Symposium, Jackson Hole, Wyoming.

Cantú, C., P. Cavallino, F. De Fiore, and J. Yetman. 2021. "A Global Database on Central Banks' Monetary Responses to Covid-19." BIS Working Paper no. 934 (March).

Cap, A., M. Drehmann, and A. Schrimpf. 2020. "Changes in Monetary Policy Operating Procedures over the Last Decade: Insights from a New Database." *BIS Quarterly Review* (December).

Cullen, J. 2023. "Central Banks and Climate Change: Mission Impossible?" *Journal of Financial Regulation*, 9(2): 174–209.

Desch, C., and H. Holden. 2024. "Tokenization: Another Giant Leap for Securities?" *TheTeller Window* (September).

Duley, C., L. Gambacorta, R. Garratt, and P. K. Wilkens. 2023. "The Oracle Problem and the Future of DeFi." *BIS Bulletin* no. 76 (September).

Federal Reserve Bank of New York and Monetary Authority of Singapore. 2023. "Project Cedar Phase II x Ubin+ - Improving Wholesale Cross-Border Multi-currency Payments and Settlements." (May).

Gerosa, R., O. Gloede, and P. Müller. 2024. "Piloting Monetary Policy Implementation on a DLT-Based Infrastructure - Issuance of Digital SNB Bill." Swiss National Bank, *Economic Note* no. 04/2024 (November).

Hauser, A. 2023. "'Less Is More' or 'Less Is a Bore'? Re-calibrating the Role of Central Bank Reserves." Speech given at Kings College London's Bank of England Watchers' Conference, Institution of Engineering and Technology, London, November.

Lee, A. 2023. "What Is Programmable Money?" Federal Reserve Board of Governors, *FEDS Notes* (June).

Lim, C., T. J. Saw, and C. Sargeant. 2016. "Smart Contracts: Bridging the Gap Between Expectation and Reality." *Oxford Business Law Blog* (July).

Post-Trade Task Force. 2022. "Charting the Future of Post-Trade - Findings from the Post-Trade Task Force." (April).

Schär, F. 2021. "Decentralized Finance: On Blockchain- and Smart Contract-Based Financial Markets." Federal Reserve Bank of St. Louis, *Review* (April).

Contributors

Advisers from the Reserve Bank of Australia (RBA), Bank of Canada (BoC), Bank of England (BoE), European Central Bank (ECB), Bank of Mexico (BoM), Swiss National Bank (SNB), Board of Governors of the Federal Reserve System (FRB), Federal Reserve Bank of New York (New York Fed), and the Bank for International Settlements (BIS) attended workshops in 2023 and 2024 to set requirements and evaluate the project.

Central bank advisers

David Dolan	RBA	Antoine Martin	New York Fed
Matt McNeely	BoC	Jacqueline McInerney	New York Fed
Daniel Beale	BoE	Linsey Molloy	New York Fed
Julia Hodgson	BoE	Ari Morse	New York Fed
Stefania Spiga	BoE	Fabiola Ravazzolo	New York Fed
Ricardo Amaral Vieira	ECB	William Riordan	New York Fed
Daniel Hernansanz	ECB	Leslie Conner Warren	New York Fed
Guido della Valle	ECB	Jim Yu	New York Fed
Andrea Perez de Celis	BoM	Mike Zaporoshan	New York Fed
Carlos Vélez	BoM	Per von Zelowitz	New York Fed
Rebecca Gerosa	SNB	Mike Alonso	BIS
David Lowe	FRB	Morten Bech	BIS
Jesse Maniff	FRB	Codruta Boar	BIS
Mary-Frances Styczynski	FRB	Daniel Eidan	BIS
Nicole Trachman	FRB	Wenqian Huang	BIS
Alex Sproveri	FRB	Priscilla Koo Wilkens	BIS
Andrew Danzig	New York Fed	Robert Oleschak	BIS
Julia Gouny	New York Fed	Andreas Schrimpf	BIS
Brian Greene	New York Fed	Takeshi Shirakami	BIS

Project team

Guillermo Andres Marquez Musso	BIS (*ECB)	Henry Holden	New York Fed (*BIS)
Johannes Rogowsky	New York Fed (*Deutsche Bundesbank)	Donna Santoro	New York Fed
Jack Becker	New York Fed	Mark Vandergon	New York Fed
Christopher Desch	New York Fed	Kate Nguyen	San Francisco Fed

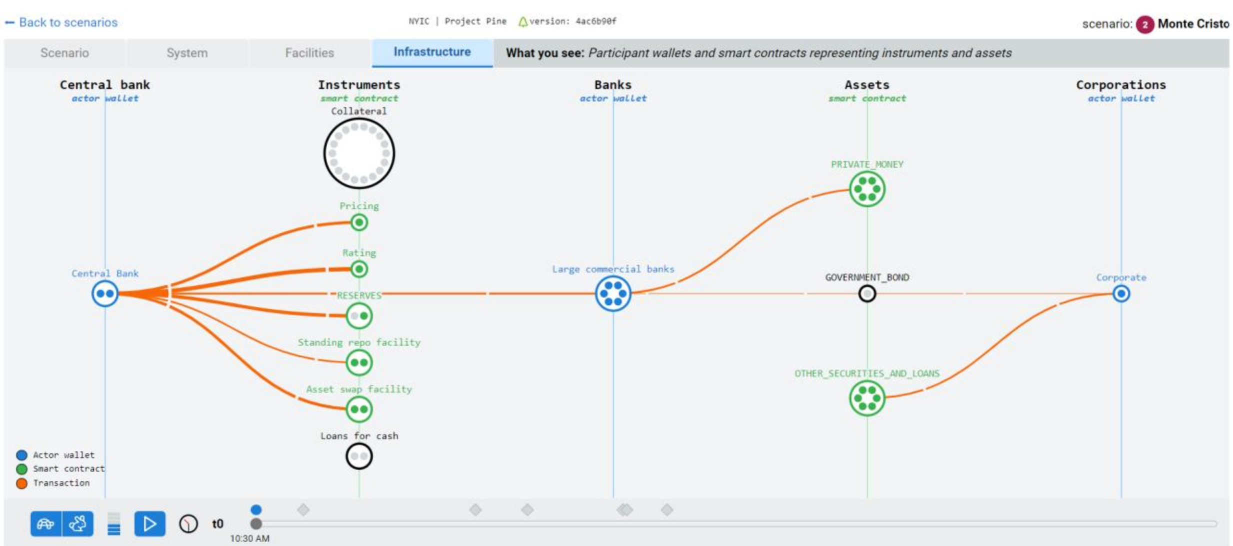
* *Seconded from*

Annex: Example Testing Scenario

Many scenarios were used to test the prototype toolkit. An early scenario involved a collapse in government bond prices and a central bank whose existing facilities needed to be adjusted to stabilize the market reaction. This appendix uses screenshots from the interactive visualization tool developed as part of the prototype to walk the reader through the scenario. This early scenario was entirely scripted from a data set that was created by combining simplified versions of historical data.

In the scenario, the hypothetical economy has a central bank and six commercial banks. Credit in the economy is based on bank loans. Commercial banks' balance sheets are composed of central bank money (reserves), government securities, their loan portfolios, and the claims of their customers (deposits). As with all Project Pine's scenarios, all money and securities are tokens and the bank uses smart contracts (Figure A1).

Figure A1. Testing Scenario, Starting Smart Contract Visualization



At the start of the scenario, the central bank's balance sheet has government securities and central bank money (Figure A2, left-hand panel). The central bank has a target rate of 6 percent, and the interbank market rate is slightly above this (Figure A2, middle panel). The central bank operates a scarce reserves regime. It does not pay interest and offers a daily standing repo facility that lends reserves for 24 hours at 6.25 percent collateralized by government securities. It also has an asset swap facility whereby the commercial banks can borrow government securities in exchange for a claim on their loan portfolios (Figure A2, right-hand panel). The indexed price of government securities is around 92.

At 1 pm each day, the central bank offers a daily auction for its repo facility, from which all six commercial banks borrow. The government bonds they pledge as collateral adequately cover the reserves they have borrowed for 24 hours. The rest of the day passes without significant event.

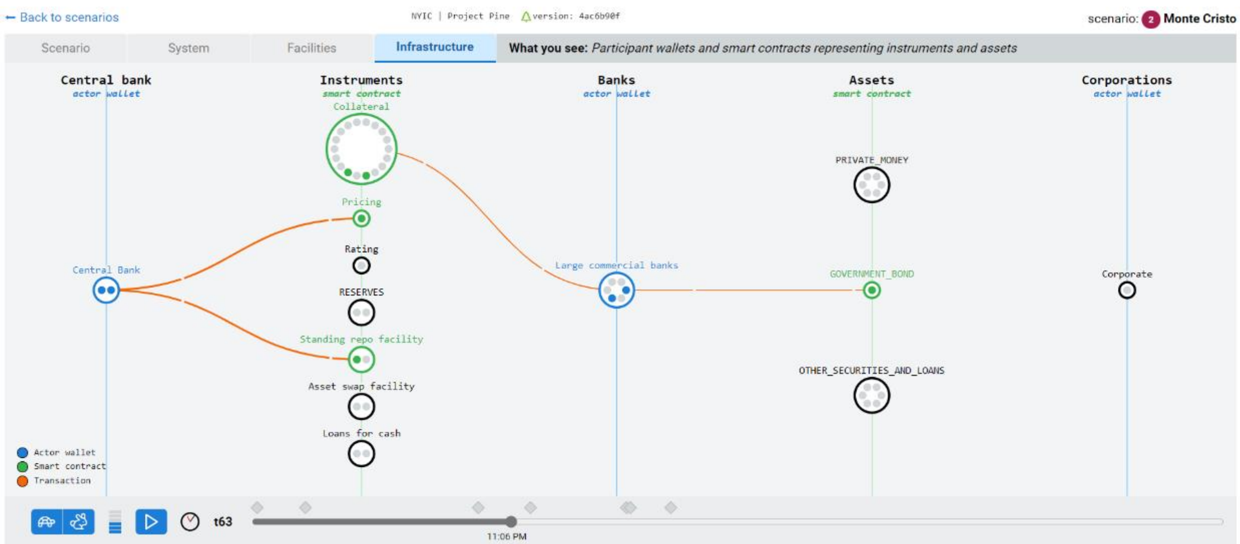
Figure A2. Testing Scenario, Screenshots at 1 pm, Day 1

Agents' balance sheets	Market rates	Central bank facilities

That evening, terrible news starts to circulate (for example, war, political unrest) that causes the price of government bonds to fall. By 7 pm they have fallen from 92 to 80. This fall in values means that the central bank starts automatically making collateral calls for the standing repo facility. The commercial banks meet these calls (Figure A3) but prices continue to fall, and by 9 pm the government debt index is at about 72. Reserve demand also rises because of the uncertainty surrounding events, and interbank market rates also climb past 10 percent (well above the 6 percent target). Some commercial banks are starting to struggle to meet their collateral calls.

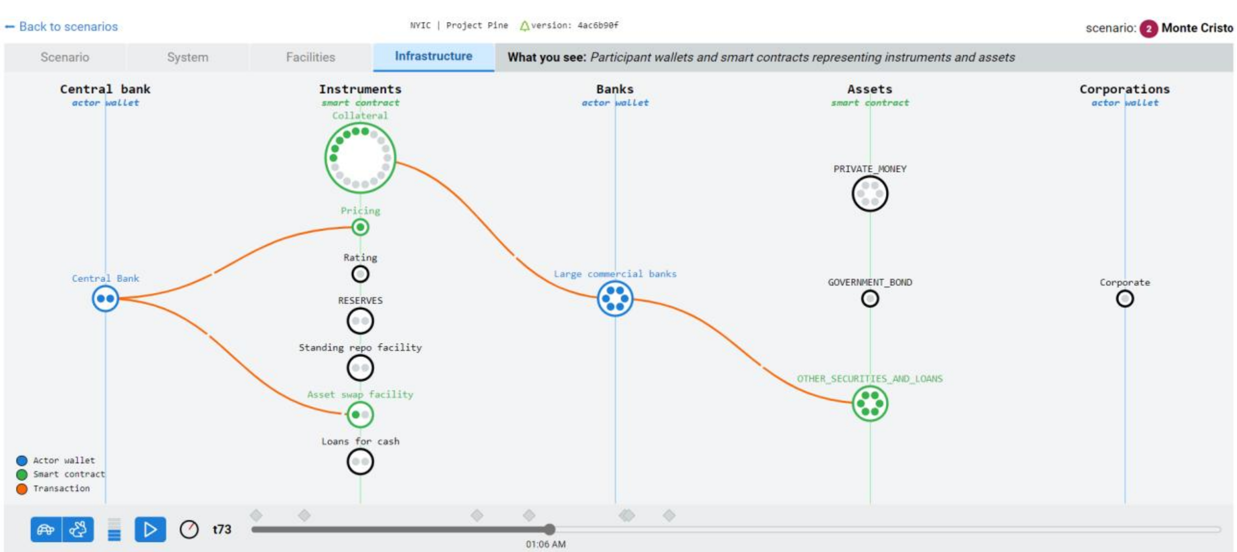
Between 9:30 pm and midnight, the central bank tries to arrest the pressure on money markets by removing the haircut on government debt (it was previously 0.5 percent) and reducing the rate charged by repo and asset facilities to 6 percent. However, none of these actions has a significant impact. By midnight, the government debt index is at 68, and money market rates also continue to climb.

Figure A3. Testing Scenario, Collateral Call Smart Contract Visualization



At 1 am, unable to meet collateral calls, the commercial banks pledge their unsecuritized assets in exchange for government bonds in the asset swap facility (Figure A4). The commercial banks use these bonds to meet their collateral calls and to borrow funds from the interbank market. This does not arrest the fall in government debt or the increase in interbank rates. By 4:30 am, government bonds have sunk to 66 and interbank rates are over 11 percent.

Figure A4. Testing Scenario, Pledging Loan Portfolios Smart Contract Visualization



At 5 am, the central bank launches a new facility: loans for cash. This facility offers reserves for 6 percent in exchange for unsecuritized assets. The commercial banks borrow heavily from the new facility and exit the other two, causing the central bank's balance sheet (and supply of reserves) to expand enormously (Figure A5). By 9 am, interbank rates have fallen to 9 percent, and government debt prices have slightly recovered to 73. Over the course of the next day, the recovery steadily continues. The only additional action the central bank takes is to begin paying interest on reserves at 5.5 percent. By 5:30 pm the day after the shock, interbank rates have normalized at just over 6 percent and government debt is 76.

Figure A5. Testing Scenario, Screenshots at 5:30 pm, Day 2

Agents' balance sheets	Market rates	Central bank facilities