CBDCs, Open Finance and tokenization as tools to improve financial intermediation: application to a SMEs' credit platform

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Abstract

Innovative resources provided by central banks, like CBDCs and Open Finance, combined with data management technologies, such as algorithms and DLT, bring promising perspectives to the financial intermediation activity. They enable the adoption of multiple strategies to deal with typical frictions of financial markets, including informational asymmetries, limited commitment and transaction costs. This paper discusses how these innovations improve financial intermediation with a practical example: a financial intermediation platform, which manages trade credit to small and medium enterprises (SMEs) from providers interested in Accounts Receivable (AR) within SMEs' invoices. CBDC is a convenient instrument for the funding of such anticipations. The evaluation of these credit operations would be based on market information obtained from multiple sources, like *Open Finance*, publicly available information and questionnaires, which would be classified using Artificial Intelligence techniques. Additionally, borrowers could obtain endorsement and collateral from guarantors, using CBDCs and smart contracts. This feature would play an important role in enabling new entrants to have access to those credits. Securitized shares in loans would be traded through secondary markets on Digital Loan Funds, which provide liquidity for investors and enable the trading of such loans as their history improves or deteriorates. A secondary market, based on Financial NFTs, would also be available for individual (or specific) loans, mainly when such loans deviate from their expected performance. An agent-based simulation tool was designed to simulate the behavior of the platform. Illustrative simulation examples suggest that the system is relatively stable and is capable of generating reasonable returns for investors. They also indicate that guarantors play an important role in improving financial intermediation through the platform.

Keywords: Credit Market Frictions, Small and Medium Enterprises, Tokenization, Financial NFTs, CBDC, Smart Contracts, Open Finance, DeFi, Artificial Intelligence (AI), Real Digital, Agent-based simulation.

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1. Introduction

Financial intermediation is key for the development of economies and the welfare of individuals. It enables the efficient use of resources, channeling funds from savers to investors with promising projects. It also protects economic agents - households and firms - from adverse shocks, which improves welfare and facilitates entrepreneurial activity. However, it is a well-known fact that market frictions, such as fixed costs of access, informational asymmetries and limited commitment by contracting parties create important challenges for the intermediation markets to properly fulfill their roles. Confronting these frictions has shaped contracts and entities (both formal and informal) involved in financial intermediation activities, and multiple strategies have been employed to mitigate their damage. But these strategies are still not capable of completely overcoming the effects of these frictions. Some economic agents - especially poor households and small businesses with little capacity to provide collateral and about which there is little public information - have significant difficulty in accessing financial instruments. The combination of public policies and innovations from the private sector contribute to expand access to these services and improve their quality over time.

Government organizations have been providing resources to address financial frictions. The Central Bank of Brazil has introduced several innovative solutions to tackle this issue, with Open Banking and Real Digital (the forthcoming Brazilian CBDC) standing out as highly promising initiatives. These resources, combined with the increasing use of algorithms and Distributed Ledger Technologies (DLTs), offer a wealth of opportunities to the intermediation industry. This paper explores how these innovations improve financial intermediation, using a concrete example: a Decentralized Finance (DeFi) platform designed for the provision of trade credit that relies on CBDCs, Open Banking and DLT. A platform following these lines is actually being considered for implementation by DeLend, a Brazilian DeFi startup. This example provides a clear understanding of how these instruments help address the challenges faced by financial intermediation activities, improving collective welfare.

The focus of this paper will be on a system that enables trade credit providers to use their resources for anticipating customer payments through tokenized Account Receivables (AR). Such project would not only extend loans to companies that currently do not have access to credit (especially small and medium enterprises) and improve contractual conditions for companies that already can borrow, but, also, generate alternatives for small and large investors. These are complementary tasks. Companies seeking loans benefit from an expanded base of lenders. Opportunities for borrowers and investors are enhanced by innovative management of a large volume of information from new sources and a convenient platform connecting borrowers, lenders, and other investors. Most of the liquid assets to be transferred among the agents connected to the platform - from lenders to borrowers, initially, and then from borrowers to investors after repayment - would be CBDCs, which have significant advantages over conventional crypto currencies, as we discuss in the next section of this paper.

Open finance would also be a key facilitator for this intermediation system. The main information sources to be used by the platform would be: (i) *Open Finance* data about these agents, (ii) public information certifying the identity and characteristics of final borrowers and their providers; (iii) privately provided data from other online platforms (such as social networks and collaborative economy); and (iv) endorsement from peers or acquaintances.

The data arising from these sources would be processed through big data and utilizing Artificial Intelligence techniques. Ratings of customers and loans are generated, and are presented through reports to guide investor's decisions. This kind of information will act as a Blockchain Oracle[3].

The platform implements a market design strategy aimed at managing risk and liquidity, and pricing loans by matching supply and demand for resources. It also embeds a secondary market, which improves the efficiency of loan management and provides liquidity to lenders. Agreements between borrowers and lenders would be performed by Smart Contracts – digital contracts enforced by code, executed by the platform, informed by the data sets provided by borrowers, guarantors and third parties (including, possibly, the regulators), following parameters defined by investors.

The possibility of delinquency, due to the lag between the time of the anticipation and the time of the final payment, is a key risk to be managed. In order to minimize the situations that contribute to the non-fulfillment of the full cycle, the use of guaranties could be of great value. For instance, some of the resources in the platform may be allocated as collateral in order to protect the interests of the investors. The use of Smart Contracts are enabled by Distributed Ledger Transactions (DLTs) through optimized processes of delivery versus payment (DvP), including multi-party transactions. For example, they allow an immutable commitment that future income flows be sequestered as collateral, especially through the inclusion of remunerated guarantors.

Additionally to CBDCs, the platform employs blockchain technology to certify and manage loans and other assets (such as shares on loans and certificates). Each loan is embedded in the platform as a Financial NFT[4] (F-NFT), which allows information updates to generate new loan exchanges over time, optimizing loan allocation. Digital liquid assets, such as cryptocurrencies and CBDCs are managed and distributed across agents through the platform.

The remainder of this paper is organized as follows. Section 2 deals with the opportunities for improved financial intermediation raised by the innovative use of CBDCs, open finance and DLT; Section 3 describes the proposed market design; Section 4 presents a summary of some simulations generated on an agent-based design for the described model; Section 5 presents a synthesis of the main ideas contained in the text.

2. DLT, CBDC and Open Finance as innovations with promising disruptive potential

DLT is a decentralized database that uses a network of computers to store, share and synchronize information across multiple locations. It provides security for transactions and storage of information without, necessarily, a (ideally) reliable central authority.

CBDCs are digital versions of a country's fiat currency issued and backed by their central banks. They can be used for peer-to-peer transactions, as well as commercial transactions. They also may include novel functionalities, such as smart contract features.

An oracle, a computer science term used to denote a function or node which knows the answer, is used to verify known facts that represent states of a contract.

[3] Blockchain Oracles connect blockchain Smart Contracts to inputs and outputs in the real world.
[4] Digital representation of debts in the Blockchain as financial non-fungible tokens.

DLT, CBDCs and oracles are powerful tools for the management of contracts. A contract may be entered by multiple parties, which are nodes that can be associated with accounts publicly or anonymously. DLTs and/or CBDCs may allow both cases depending on what the regulation (such as GDPR) requires. Each node may have specific permissions to access and/or write into the contracts. DLT could reduce the reliance on a central ledger and enhance market transparency. A smart contract is a code which is validated as it is instantiated, eliminating the need of additional verifications. It either works or not (thwarting potential collusions, for example). The agreement of such a contract occurs via public and private keys. Once validated, it becomes immutable. Therefore, there is no need for trust on these particular conditions. Additionally, it specifies states at points in time, such as current ownership or other conditions.

Despite the mentioned advantages, considered alone, according to the Bank for International Settlements, "*DLT presents some risks for payments, which include the potential uncertainty about operational and security issues arising from the technology; the lack of interoperability with existing processes and infrastructures; ambiguity relating to settlement finality; questions regarding the soundness of the legal underpinning for the implementations; the absence of an effective and robust governance framework; and issues related to data integrity, immutability, and privacy*" (BIS 2017a, Townsend, Killian, 2019). The Committee on Payments and Market Infrastructures (CPMI) chair, Benoît Cœuré, writes, "*Central banks have traditionally played an important catalyst role in payments and settlements.*" (BIS 2017b, Townsend, Killian, 2019). Therefore, a CBDC is important to minimize (potentially, solve) some of these risks, in particular those associated with legal aspects, finality and governance framework.

Open finance refers to the use of open APIs and other technologies to share financial data between different institutions and stakeholders, with the consent of the parties disclosing information.

All these ingredients, individually or combined, enable the creation of new strategies for credit provision. The mere fact that new players engage in financial intermediation is beneficial, since it enhances competition, and thus, lower tariffs for borrowers and investors. Also, new products with novel features are made available.

The intermediation platform described in this paper, for instance, enables credit access to companies that are currently unassisted. This stems from the fact that one of the pillars of the project is information management. It is a well-established fact in the economic literature that information asymmetry frictions (some agents are misinformed about ingredients that are crucial for contractual arrangements) restrict access to credit and compromise the efficiency of contracts. Specifically, for credit agreements, lenders have incomplete information about the risks to which borrowers are subject (*adverse selection*, as in Stiglitz and Weiss, 1981) and the actions taken by borrowers to make the repayment of loans feasible (*moral hazard* as in Aghion and Bolton, 1996)[5].

Availability of information is crucial to minimize these informational frictions. However, the amount of information available about new businesses or small and medium enterprises is limited, which restricts their access to credit. An innovative platform could overcome this limitation by combining multiple sources of information that have become available recently and endorsement by peers and acquaintances. Advanced big data and Artificial Intelligence techniques can be applied to these pieces of information, to generate ratings of loans and

[5] Examples of the empirical relevance of these well-documented frictions are in Paulson, Karaivanov and Townsend, 2006; Karaivanov and Townsend, 2014; and Karlan and Zinman, 2009.

companies (minimizing *adverse selection*) and indicators on their evolution over time (minimizing *moral hazard*).

The timing is appropriate for the development of this strategy. The Central Bank of Brazil (and of other countries) is currently implementing the *Open Finance* initiative, making financial information of potential borrowers widely available upon data owner request and consent. This allows entrants not only to compete with established banks and fintechs with large datasets, but also to develop innovative products and strategies that are currently not pursued by such institutions, which may follow more conventional business strategies. Additionally, official sources have been increasingly providing access to datasets that certify the identity and characteristics of borrowers and their guaranties. Finally, datasets produced by online platforms such as social networks and online marketplaces are a potential source of valuable information.

Ideally, the platform should achieve a large base of borrowers, including small and medium enterprises. This goal is feasible with the application of numerical algorithms to manage rich datasets available about each client. Such algorithms generate ratings about potential borrowers with a low cost, especially when compared to the assessments made by professional analysts. But the intermediation platform is designed to make participation easily accessible to investors as well.

The creation of investment opportunities is an important contribution of this type of innovation. Financial inclusion comprises not only expanding access to credit, but also offering savings alternatives. Both are complementary tasks that contribute to the development of economies and social mobility[6]. However, the engagement of investors is often limited by access and transaction costs. These barriers can be minimized with the use of the new instruments discussed in this paper. The platform should have a convenient and easy-to-use interface that allows the participation of many investors in multiple regions with low transaction costs. The monetary values managed by the platform are digital assets, mainly CBDCs, but also, possibly, other cryptocurrencies. This feature allows easy transfers among agents and fast conversion into local currencies, either to anticipate cash for borrowers or to be withdrawn by investors.

Connecting a large set of users (borrowers and investors) and transferring assets among them requires a reliable technology for storing data and transferring values. This feature is provided by DLTs. So, in principle, even the transfers of monetary values could be made in cryptocurrencies. However, CBDCs have important advantages over other cryptocurrencies. First, the monetary value of CBDCs are fixed over time. Even when DLTs provide safe means to transfer cryptocurrencies among users, the value of such currencies are often subject to strong nominal value fluctuations. Some strategies have been pursued by DLT developers to create cryptocurrencies with fixed nominal value - the stablecoins - but CBDCs are more reliable, since they are guaranteed by local monetary authorities (they are, in fact, money). Second, CBDCs are easily converted into other forms of local money, and are even directly usable in commercial transactions. Indeed, a key property of CDBCs is their interoperability with other payment means and bank accounts. In this sense, CDBCs are perfectly liquid. Finally, CBDCs are very convenient for supervision and regulation , since they are managed and guaranteed by central banks.

The platform would employ DLT combined with CBDC. While most of the liquid assets would be CBDCs, DLT would be used to register information on loans, on internal assets (such as shares on loans and internal certificates) and to manage transfers of such assets,

[6] See, for instance, Greenwood and Jovanovic, 1990.

using smart contracts. Investors would hold shares on a securitized loan fund and would receive payments in CBDCs based on these shares, following the rules on smart contracts.

This model is convenient for the efficient use of information. For instance, investors would be able to obtain information about characteristics of the borrowings backing their loans. Since all borrowings are managed by the platform, it is easy to keep track of the payments expected, characteristics and ratings of the borrowers, the evolution of default patterns and other information that are relevant to the decision making by investors. This wealth of information is also convenient for the regulators, which, in principle, could have access to the main risk indicators of investments made through the platform. Indeed, the model is based on the real economy and has clearly traceable fundamentals

Note, however, that not all data should be revealed by the platform to every investor and borrower. Information must be disclosed in such a way as to not compromise secrecy and privacy. The pieces of information and statistics disclosed to borrowers might not be the same as those revealed to investors and regulators. Indeed, an important feature of smart contracts is that they are capable of using information that is not disclosed to contracting parts. This feature improves the capacity of contracts to deal with asymmetric information. For instance, contracts may use information that agents are reluctant to reveal publicly.

One characteristic of the assets held by investors in the platform is that they are not completely liquid. These assets are not like bank deposits, instantly available for withdrawal at any moment. This is positive from the point of view of prudential concerns, since there is no duration mismatch between the borrowers' and investors' points of view. So, the system is immune to liquidity runs (similar to bank runs), where financial institutions are not able to fulfill their obligations with investors (depositors), given the lack of liquidity. However it has an undesirable feature from the perspective of investors: liquid assets might not be available in events of cash need due to unpredicted contingencies. This limitation can be minimized by a secondary market hosted on the platform itself, operating using smart contracts.

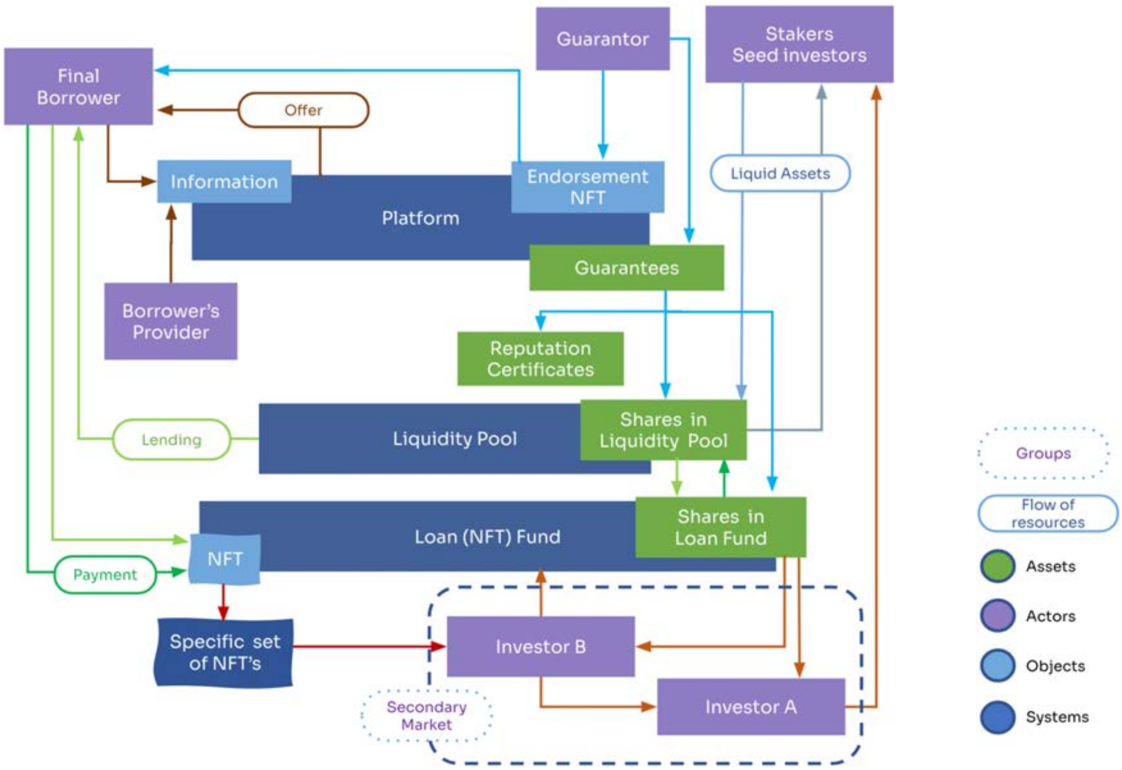
The secondary market provides liquidity (and thus additional safety) for lenders. The platform also minimizes risks to lenders through securitization. The counterpart of lending are shares in funds containing multiple loans. These shares are the assets traded in the secondary market. Even though there is a secondary market, the receivables that back each share are easily traceable by the platform. Therefore, there is transparency about the risks to which investors are subject.

Another feature of the platform that would be powered by smart contracts and CBDCs is the possibility of using guarantors to endorse loans. These guarantors could be either peers or acquaintances of borrowers, or professional analysts. The presence of these guarantors is important for financial inclusion, since small and medium enterprises often have short or no bank and credit history. The platform remunerates the endorsement of loans, so incentives must be given for guarantors to endorse lower risk loans. Therefore, incentive constraints, which are managed with the support of smart contracts, must be imposed on guarantors. Guarantors can also provide collateral, and the use of CBDCs as collateral is convenient given their reliability, liquidity and programmability.

3. Market Design

This section provides details about a possible market design to be implemented by such a Platform. The diagram in Figure 1 illustrates the main steps of the operation. The platform connects three classes of agents: *borrowers*, *guarantors* and *investors* (*lenders*). These actors exchange assets through the platform. Such assets are CBDCs/other digital instruments for storing value that exist outside the platform or assets generated inside the system. The intermediation by the platform takes place in four main stages: *the fund origination*, the *lending,* the *peer endorsement* and the *secondary market*. Each of these steps is described below.

Figure 1 - Market Design (DeLend schema illustration)

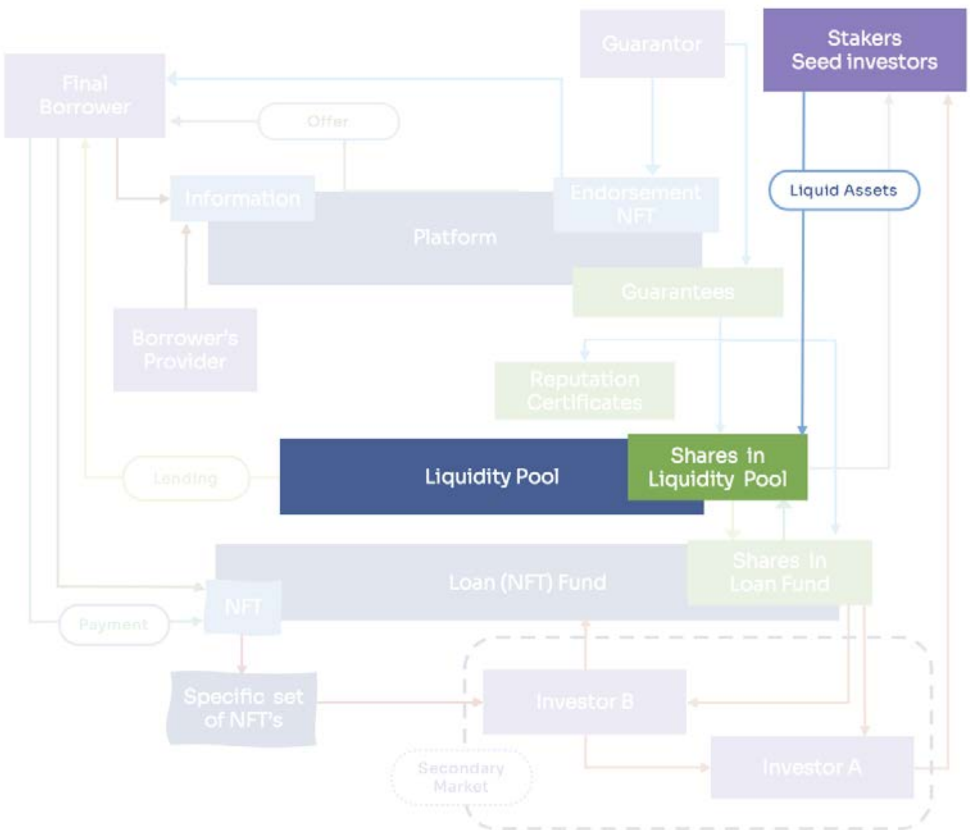


3.1 Fund Provision

Fund provision is the step in which liquid resources are brought into the platform. Those are the resources to be advanced to borrowers in exchange for Accounts Receivable (AR). *Stakers* or *Seed Investors* provide liquid assets to be placed in the platform. Such assets could be CBDCs or other cryptocurrencies (which would be convenient for investors positioned in any of those options). The staker-provided assets generate a *liquidity pool*. As a counterpart to their investment, these *stakers* receive shares in the *liquidity pool*.

Stakers can choose which liquid asset (among a class of available options) to make available to the *liquidity pool*. The risks related to this choice are incurred by the own investor. CBDCs have the advantage (for the investor) of having no value fluctuation in nominal terms. Another advantage is that, as part of the central bank reserve system, they can be remunerated by the basic interest rate (if it is made available, at the time of the investment). The investors' shares in the liquidity pool are denominated in the asset provided: if a staker brings some CDBC or cryptocurrency to the liquidity pool, the shares obtained are measured by that particular asset. When CDBCs are remunerated by the basic interest rate, an investor that contributed to the liquidity pool with an amount in CBDC is rewarded with the interest on this amount, as extra shares in the liquidity pool. Smart contracts manage the conversion of liquid assets deposited in the liquidity pool into shares. The platform may provide information to help the staker to choose which asset to keep in the liquidity pool (e.g. volatility, exchange rate risks). This step is illustrated in Figure 2 below:

Figure 2 - Fund Provision



3.2 Loan Request and Lending

Once the platform is operating, with assets in the liquidity pool, potential borrowers can request loans. In order to request a loan, the borrowers should provide information about the final borrower, its provider (merchant) and the receivables to be anticipated. This information includes *Open Finance* data and official data that certify the identity of each borrower. It might also include endorsement by other agents (to be discussed below).

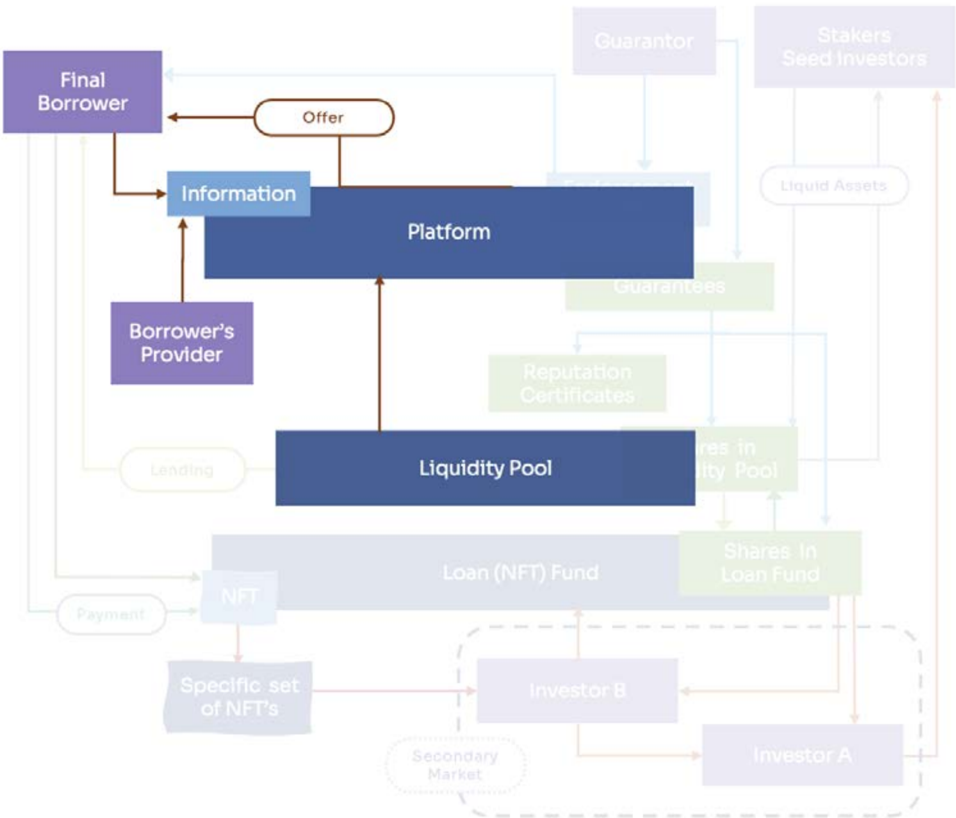
Based on the information provided, the platform either refuses to give credit or makes a loan offer, by establishing an amount to be anticipated, which implicitly determines an interest rate. This pricing procedure follows standard pricing models, informed by open finance data, public data and data from the platform.

A dynamic pricing algorithm may be used to manage the amount of CBDC and other liquid assets in the platform: if liquidity is following an increasing path, the platform decreases interest rates to increase the demand for liquidity (by borrowers) and decrease the supply of liquidity by investors. If, on the other hand, liquidity is decreasing over time, interest rates increase in order to attract more investment and decrease the demand for liquid resources .

The pricing mechanism may depend on parameters chosen by stakers. Such parameters are subject to some collective decision mechanism such as voting or choice by an elected manager.

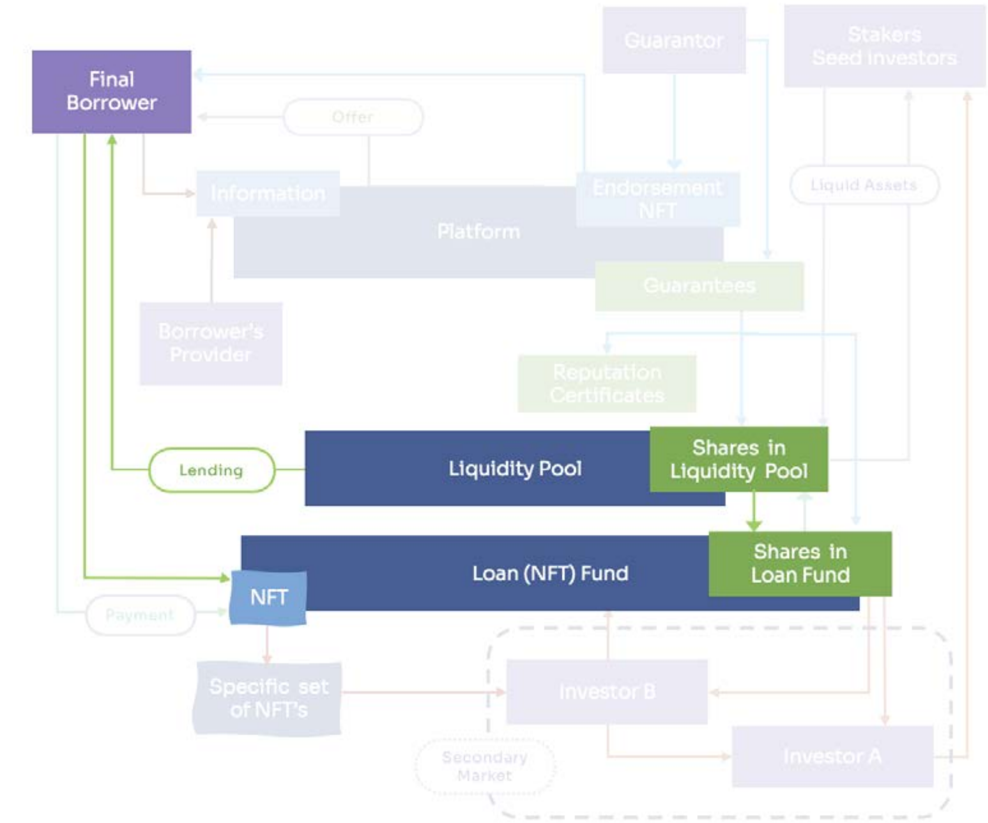
The loan request procedure and corresponding offer is described in Figure 3:

Figure 3 - Loan Request



If a loan offer is accepted by the borrower, resources are removed from the liquidity pool and transferred to the borrower as CBDC. Then, a F-NFT containing information about the borrower, the provider and the particular receivables backing the loan is issued by the platform. This F-NFT is placed in a *loan (or NFT) fund*, containing F-NFTs from multiple loans. Each shareholder in the liquidity pool contributes for the amounts anticipated to borrowers proportionally to their participation in the liquidity pool (given the exchange rate prevailing at the time of withdrawal by the borrower, if there are investors with other liquid assets additionally to CBDC). Then, their shares in the *liquidity pool* corresponding to the amount advanced to the borrower are converted into shares in the *loan fund*. This process is depicted in figure 4:

Figure 4 - Offer accepted and lending provided



When the loan performs, payments in CBDC (or immediately converted to CBDC) by the borrower (corresponding to the receivables) are transferred to all shareholders in the *loan fund*. Note that the *loan fund* provides securitization of its loans, so all shareholders receive resources from each payment, proportionally to their share in the *loan fund*. Such CBDC payments may be available for withdrawal by investors, conversion into other cryptocurrencies or reinvestment in the liquidity pool, depending on rules collectively determined by *stakers*. For instance, the platform could give the investor the option to either automatically reinvest the upcoming payments to the *Loan Fund* or, alternatively, make them immediately available for withdrawal. The withdrawal policy may be managed by smart contracts associated with the CBDC.

Such steps are depicted in figures 5 and 6:

Figure 5 -Payments are made

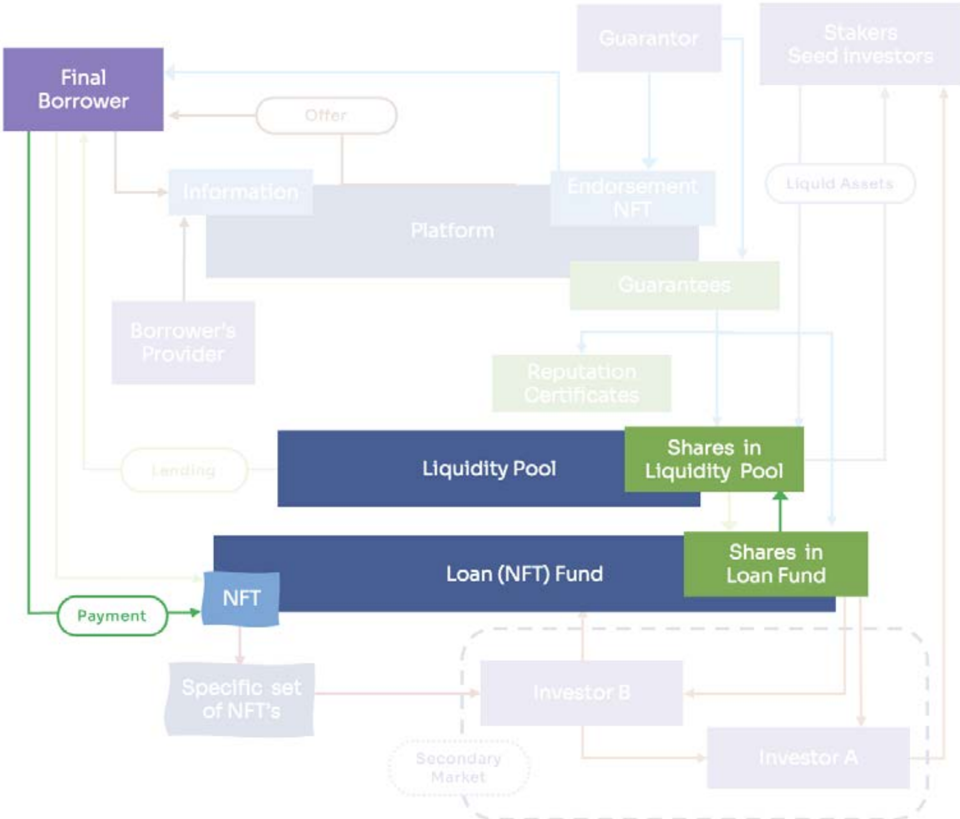
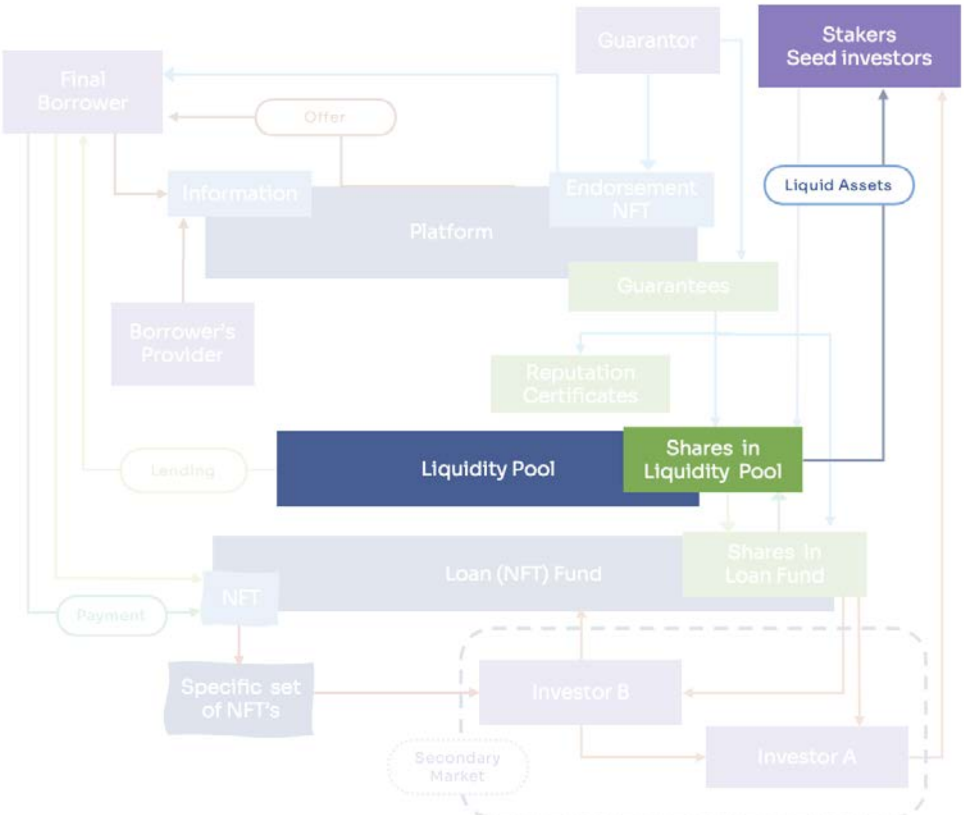


Figure 6 - Withdrawal requested



3.3 Currency Exchange Rate Risk and Hedge

A promising feature of the system discussed in this paper is that, in principle, it allows investments across borders. Investors in one country can provide resources for borrowers in another country. Some liquid assets, such as cryptocurrencies, can move across borders and enable these transactions. However, more efficient procedures would be available if international protocols were defined for the integration of different CBDCs. First, authorities would be able to keep track of international exchanges of values (without violating privacy), which is convenient for supervision and regulation. Also, the integration of CBDCs would facilitate the hedge against exchange rate risks.

As mentioned in section 3.1, when other liquid assets, additionally to a single CBDC, are placed in the liquidity pool, the exchange rate risk related to all such assets is incurred by the investors. When a given asset is removed from the liquidity pool, it purchases the asset to be anticipated to the borrower, which is typically the CBDC at the country where the borrower's business is located – e.g. United States Dollar (USD), if the borrower is located in the USA or Real Digital (BRL, as the Brazilian CBDC), if the borrower is located in Brazil. The repayment amount is also denominated in the local currency. Once a repayment is made, the amount owed to a given investor is converted (by the current exchange rate) into the currency preferred by this investor and placed in the liquidity pool for withdrawal or reinvestment.

This system protects the borrowers from exchange rate risks if their business's revenues are also in their local currency. However, it exposes investors willing to keep their assets in some other currency to some exchange rate risks. For instance, if an investor wants to keep their liquid resources in US dollars (or some currency attached to USD), she will incur some dollar loss if the local currency of the borrower (e.g. BRL) devalues (relatively to the USD) in the period between the lending and the repayment.

In principle, given the high interest rates paid by borrowers in developing economies such as Brazil, investors may be interested in providing funds for lending even if they are subject to these exchange rate risks. However, there are strategies that can be adopted to minimize such risks.

In order to give investors some protection against exchange rate fluctuations, the platform may provide access to derivatives on currencies. If the currencies used are CBDCs, their nominal values are paired with their countries' currencies, and several derivatives are already available for such currencies. For instance, an investor who expects to receive a given amount of USD at a certain moment for loans denominated in BRL, can purchase call options of USD to exercise at the time when their receipts in BRL are expected.

The platform may also provide a hedge directly to investors, negotiating derivatives that allow payments denominated in the currency preferred by investors. The costs of such hedge strategies would be paid by the investors themselves, as an extra fee. Exchange rate hedge can also be offered, as an additional product, for borrowers who are willing to denominate their installments in some currency that is different from their local currency. For instance, exporters in Brazil, which have most of their revenues in USD, may prefer to have their installments also denominated in USD.

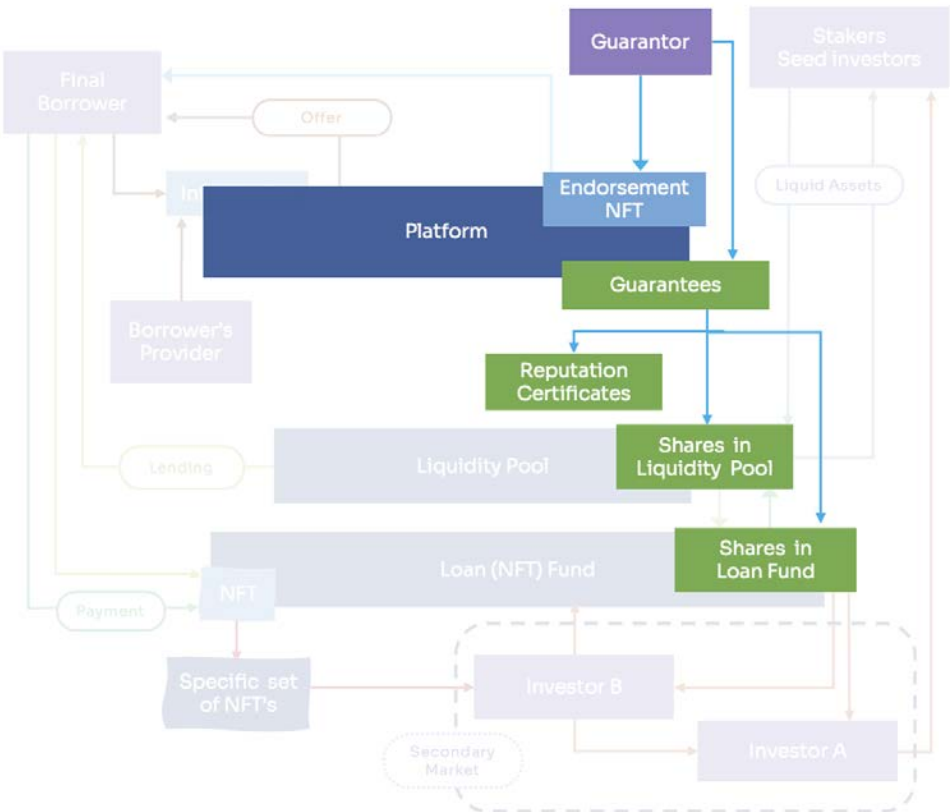
The hedging alternatives to be offered to investors, as well as their terms and the degree of protection against exchange rate risks, will depend on the availability and design of derivatives existing in the market at each moment.

3.4 Endorsement by Peers, Acquaintances or Experts

The platform offers individuals the opportunity to endorse lendings from investors to borrowers they are well informed about. This feature exploits mutual knowledge between peers and acquaintances to expand credit access and improve credit conditions. Indeed, the economic literature provides evidence that informational links among individuals can help to mitigate informational frictions that curb intermediation markets. Strategies exploiting these links have been employed for instance, for group lending arrangements, joint liability contracts or informal lending agreements (e.g. Besley and Coate, 1995; Ghatak, 1999; and Ghatak and Guinnane, 1999). This resource also provides opportunities for guarantors willing to profit from evaluating the risk of borrowers or prospecting promising loans. The purpose is that professional evaluation by experts or well informed agents complements the rating generated by the platform algorithm.

As a first step, guarantors have to provide guarantees, that can be either assets or *reputation certificates* attesting to their reliability. The assets presented can be either liquid assets such as CDBCs or shares in the *loan fund*. *Reputation certificates* are issued by the platform at the request of guarantors, and comprise information regarding their past activity in the platform, as borrower, investor or guarantor. When a potential guarantor presents guarantees to the platform, the platform issues an *Endorsement NFT* (as a soulbound[7] token) that can be employed to endorse loans to third parties. This step is presented in figure 7:

Figure 7 - Endorsement NFT



[7] SoulBound is a new non-transferable, public-verifiable digital token project which can serve as a representative of the social status of an individual on web3.

Guarantors can make their *Endorsement NFTs* available to back loans for potential borrowers. Then, the borrowers present *Endorsement NFTs* and the other requested information to the platform at the time of the credit request. Endorsement NFTs can improve the chance of credit approval and increase the amount to be anticipated. On the other hand, guarantors are remunerated by their endorsement when loans perform. Once information and an Endorsement NFT are presented to the platform with a loan request, the platform makes an offer that comprises: (i) an amount to be anticipated to the borrower in exchange for the receivables; and (ii) a fraction of the repayments by the borrower to be transferred to the guarantor. Such steps are illustrated in figures 8 to 10:

Figure 8 - Presentation of the Endorsement NFT by the Borrower

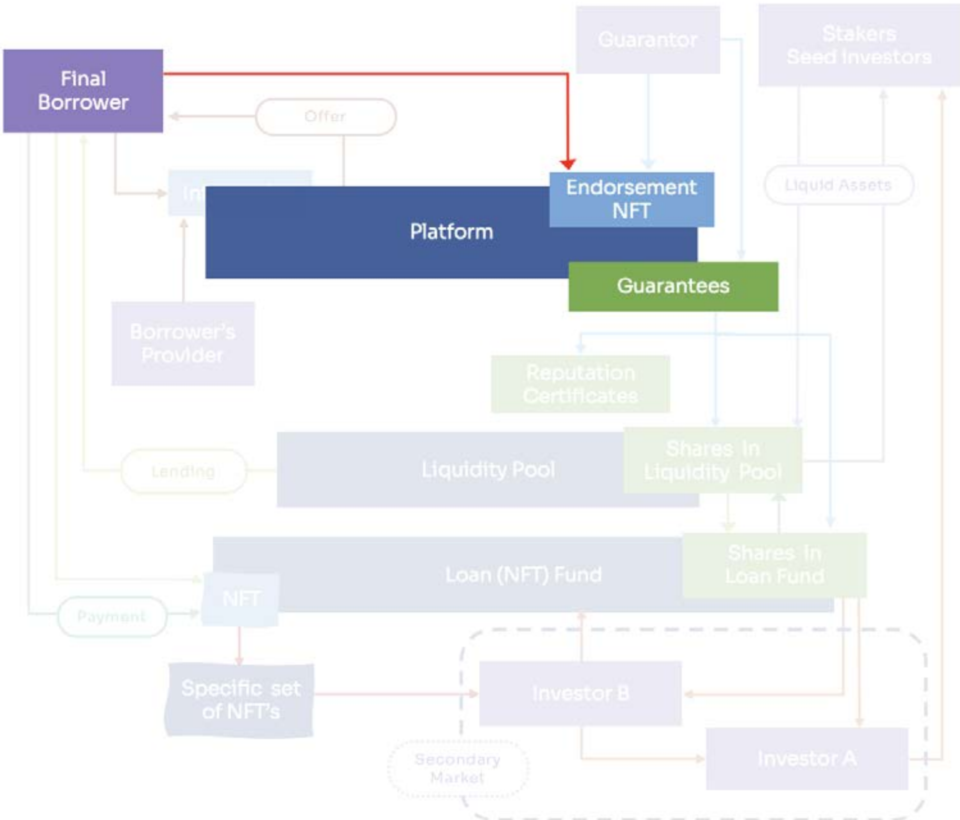


Figure 9 - Offer made to the borrower and the guarantor

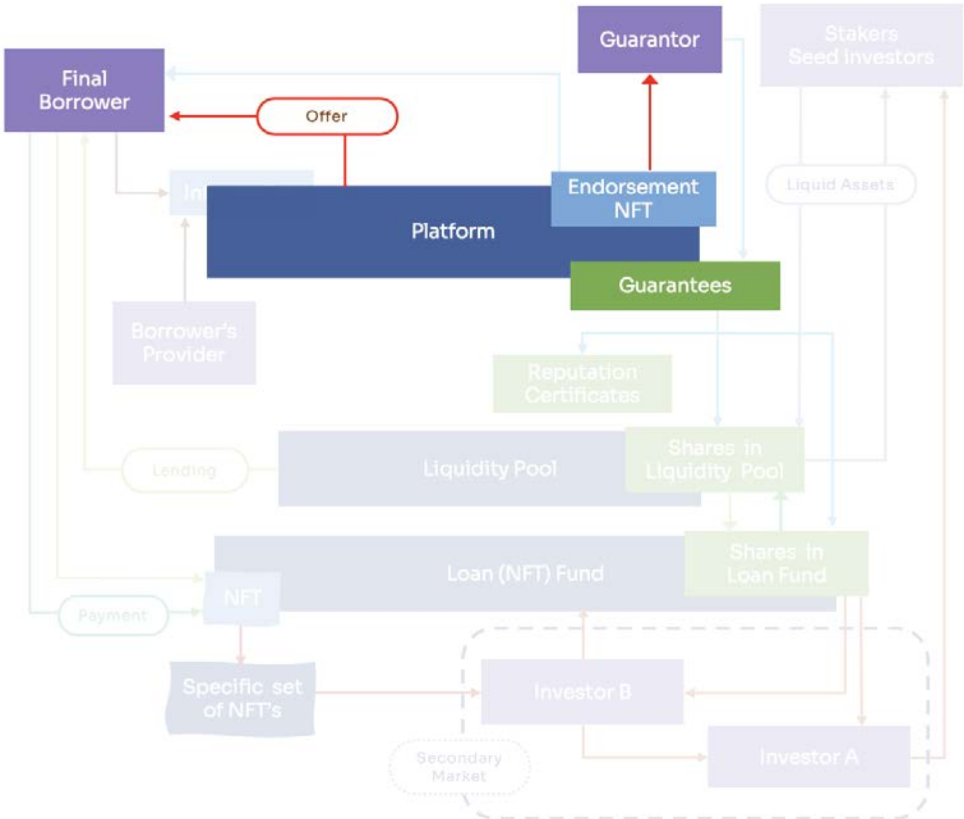
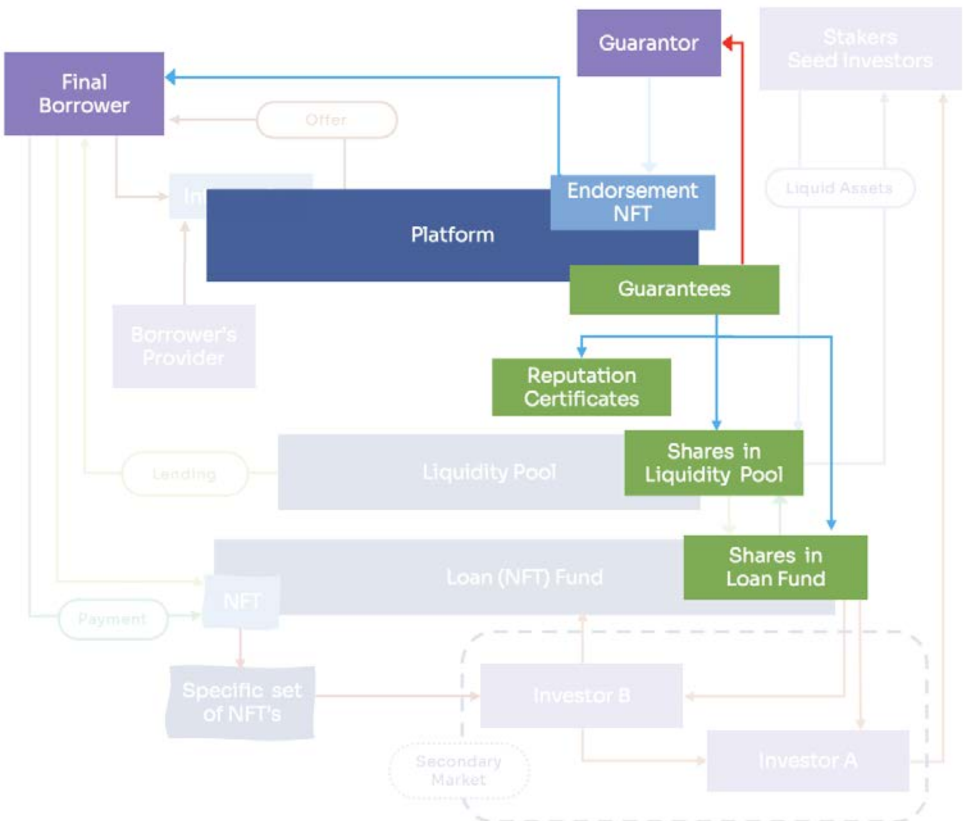


Figure 10 - Completion of the loan agreement



If a loan performs, part of the payments are transferred to the guarantor, in accordance with the initial offer. The remaining amount is transferred to shareholders in the corresponding *Loan Fund*. If a loan does not perform, the assets placed as guarantees are transferred to shareholders in the *Liquidity Pool* or *Loan Fund*. Also, the reputation certificates by the guarantor are downgraded (or canceled), unless the guarantor provides the full payment of the loan. The transferring of collateral may be managed by smart contracts, which contributes for enforcement and credibility of contracts (especially if the asset placed as collateral is trustable, as, for instance, a retained CBDC amount).

The endorsement mechanism is designed to discourage guarantors from endorsing high risk loans. Guarantors are punished if a loan they endorse does not perform. Not only do they have to deliver part (or all) of their assets placed as collateral but, also, they may be downgraded in their reputation certificate. They may also lose part of their claims on other loans they have endorsed. The amount of punishment for guarantors follows an incentive compatibility condition[8], which ensures that a high probability of success (which may be a decision parameter for *stakers*) is necessary for the endorsement of any given loan to be worthwhile.

Before reputation certificates have a strong endorsement power, guarantors are expected to build reputation, either with past performance as borrower or with past history of endorsement backed on assets (liquid assets or Loan Fund shares). Therefore, guarantors typically start their endorsement activity placing assets as collateral. Once reputation has been obtained (high grades), certificates have significant endorsement value and the amount of collateral assets needed to endorse each loan diminishes. The impact of endorsement NFTs on the rating of loans, and thus, on the likelihood of acceptance and the amounts to be anticipated, are determined by the rating algorithm, which learns about the value of endorsement. Therefore, the endorsement mechanism is likely to become more accurate over time.

This endorsement system can be adapted to design multiple borrowing arrangements. For instance, reputation certificates can be employed to enable group or joint liability loans: if a group of borrowers jointly requests loans, each member of the group receives a reputation certificate which depends on the information and characteristics of all the group members. The offer they receive then depends on this information set, and the evolution of their reputation depends on the performance of the whole group[9].

3.5 Secondary Markets

The loans in the *Loan Fund* can be traded in a *secondary market*. Secondary markets provide liquidity to lenders and opportunities for investors. They also contribute to efficient allocation of investments. Two classes of secondary markets will be available in the DeLend system (i) Secondary markets for shares in the Loan Fund; and (ii) Secondary markets on specific loans (or F-NFTs).

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[8] Incentive compatibility constraints will follow standard models in Contract Theory. Exemples and clarifications are provided in Salanie, 2005; and Townsend, 2020.

[9] In principle, even the installments paid by each individual borrower may depend on the performance of their peers. This can be easily implemented with each borrower having claims on the payments of other borrowers in the group.

3.5.1 Secondary Markets on shares in the Loan Fund

After stakers acquire shares in the Loan Fund, they can trade these shares with other investors. A secondary market allows an investor (say investor A, as in figure 11 below) to transfer money (or other liquid assets) to stakers and other shareholders and, in exchange, earn shares in the *Loan Fund*. Once this acquisition is made, the investor receives part of the payments to the Loan Fund and can also sell its participation to other investors (say, investor B, as in figure 12 below).

Figure 11 - Market for shares in the loan fund

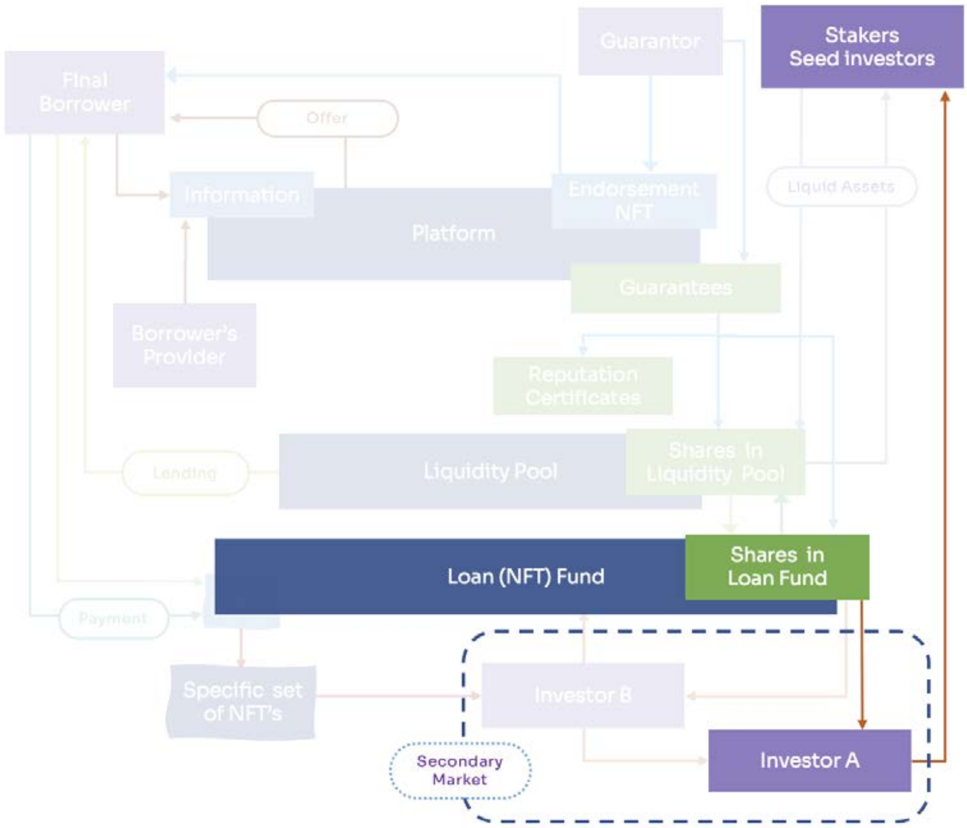
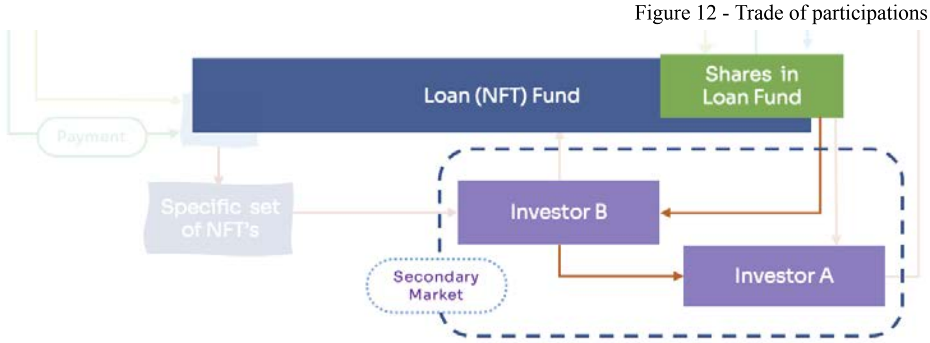


Figure 12 - Trade of participations in the loan fund



The pricing of shares in the *Loan Fund*, which matches supply and demand (market clearing), follows a bidding mechanism. Shareholders in the Loan Fund inform the platform with two parameters: a minimum price to sell assets and a maximum amount to be sold. Investors willing to acquire shares in the *Loan Fund* inform the platform with the following parameters: a desired quantity of shares to purchase, and the maximum price they are willing to pay. These pieces of information are kept private to bidders. Periodic (e.g. daily) auctions determine a price that matches supply and demand. The price (***p***) is chosen so that the amount of shares supplied (i.e., the amount of shares offered by shareholders willing to sell shares for a price equal or higher than ***p***) equals the amount of loans demanded (i.e., the amount of loans demanded by investors willing to pay a price ***p*** or less per loan). The operation of this auction mechanism is enabled by smart contracts, which collects and uses private information without disclosure to other agents.

Note that, according to this mechanism, suppliers often sell their shares for a price that is higher than the minimum they are willing to take, and demanders often purchase shares for a price that is lower than the maximum they are willing to make. That is, both parties typically obtain an economic surplus with this class of deals. The mechanism is designed such that, when the number of bidders is large, investors have no incentive to understate the maximum amount they are willing to pay for a share, and shareholders have no incentive to overstate the minimum amount they are willing to receive for each share. Or, in game theory terminology, bidding with the true value assigned to a stake is a *dominant strategy* for suppliers and demanders of shares in the Loan Fund[10].

The secondary market for shares in the loan fund is an important piece of the DeLend system, since it brings liquidity to lenders (stakers) and other investors. The possibility to cash shares in the loan fund, when needed, improve safety for investors and, thus, contribute to raise funds for lending. It also provides an opportunity for investors that are willing to acquire loans at lower risk than those incurred by stakers. Borrowers also benefit from this resource, since the resulting increase in funds for the acquisition of loans contributes to lower their prices (which means larger amounts anticipated to borrowers). This secondary market also helps to mark prices in the primary market. Indeed, the equilibrium price in the secondary market is valuable information for the price setting in the primary lending stage.

3.5.2 F-NFT (Specific Loans) Market

The shares in the Loan Fund are a securitized asset, that is, packs with pieces of multiple loans. However, the whole set of agents connected to the platform can benefit from investments on specific loans. Information on loans evolve, and loans can become riskier or safer over time, acquiring a different profile than the one prevailing at the time of acquisition. If a given loan deviates over time from the profile originally targeted by stakers, it may be efficient to sell it for other investors. For instance, if a given loan becomes riskier before maturity, it may be more efficiently managed by investors specialized in distressed assets. Also, investors interested in particular classes of assets (such as loans for some specific sector) may be interested in targeting specific loans. It might be efficient (and profitable) that such loans be sold from stakers in the Loan Fund to these investors.

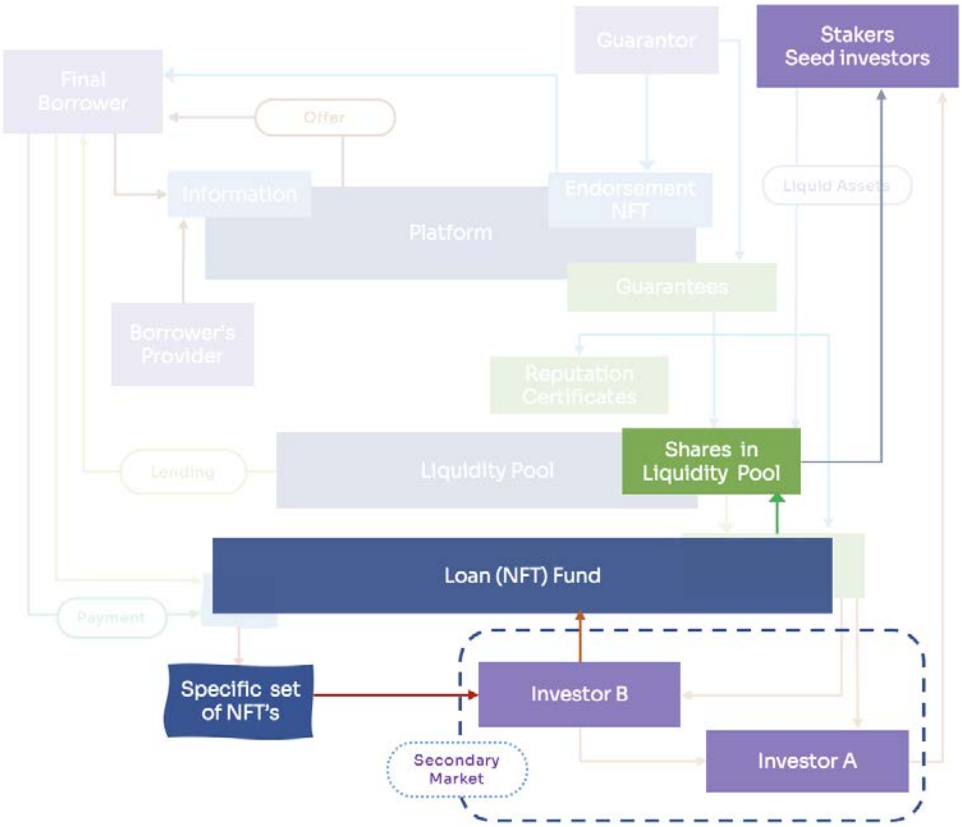
The market for specific F-NFTs can take two formats. First, the Loan Fund selects a set of F-NFTs (possibly through the algorithm, subject to parameters set by stakers) to be auctioned. Selection of F-NFTs to be auctioned and threshold prices may be determined by algorithm or collective decision (voting or possibly assigned manager). Second, investors can bid on specific F-NFTs. In this case, since purchases of specific F-NFTs impact the

[10] In Game Theory, a strategy is called *dominant* for a given agent if, regardless of how other agents act, there is no other strategy that brings better outcome for this agent. In the current case, if the number of bidders is high, the bid of a single agent is very unlikely to affect the final price of shares, since it is very unlikely that the equilibrium price determined by the platform is exactly equal to his particular bid. If a demander understates the maximum price he is willing to pay, he has the risk of not purchasing a share by a price that is actually worthwhile. Similarly, if a supplier overstates the minimum price he is willing to accept, he has the risk of losing the chance of selling shares by a worthwhile price. A comprehensive presentation of Game Theory and the concept of dominant strategy is presented in Tadelis, 2013.

portfolio of all shareholders in the Loan fund, the threshold price for acceptance must be subject to a collective decision (vote, manager or algorithm subject to parameters). Smart contracts could be used to aggregate preferences, collecting information from agents and determining the relevant transaction parameters (such as prices and amounts traded), conditional on relevant constraints. For instance, the minimal price for specific assets should be higher than the price of a corresponding share in the Loan Fund, since bidders tend to make *cream skimming*[11].

The structure of the F-NFT (or Specific Loans) market is illustrated in figure 13.

Figure 13 - Set of NFT's placed on auction



3.6 Secondary Funds

Purchases of specific F-NFTs or subsets of F-NFTs can originate new funds, (denominated secondary funds since they were not involved in the generation of loans). Each secondary fund will be characterized by the profile of loans targeted, the governance rules and the management parameters provided to the platform. Such funds will contribute to raising funds to the whole system and to improve the efficiency of loan allocation. Importantly, despite the fact that these funds contain only loans purchased from other funds, the informational link to the original borrowing and the corresponding receivables is kept strong. Indeed, one key (and desirable) property of investments at the platform is that the real receivables backing each loan is easily trackable.

[11] *Cream skimming* is an economic concept that refers to the selection, in a pool, of individuals (loans, in the current case) that have higher quality than the average.

The system can potentially evolve to have competition also among primary origination funds. Each of these funds would have different management parameters, governance rules and criteria for targeting loans. At this stage, a bidding mechanism, managed by smart contracts, would determine which fund would provide original lending for each borrower.

4. Numerical simulations as a means to test the ecosystem stability

In order to gain insights on the stability of the proposed ecosystem, we have developed a simulation tool that allows us to perform numerical simulations considering different scenarios. By adjusting parameters and input data, we can analyze the system's response to different stressors and it also allows us to evaluate the effectiveness of various management strategies. The simulations also contribute to the understanding of how different resources would be employed by the system. For instance, resources in the liquidity pool, quantified in simulations, would mostly be kept as CBDC, while resources in the loans fund would be managed by DLT. Impacts of guarantors on the system reveal the importance of collateral (stored as CBDC, mainly) and incentive constraints governed by smart contracts.

In the following sections, we present a summarized version of our simulation method and results. More details are provided by Novaes et. al.(2023).

4.1 Agent-based simulations

Complex collective behaviors can, sometimes, be modeled by decomposing systems into a set of agents that interact between themselves following relatively simple rules/interactions. Simulations built on such modeled agents are called agent-based simulations. An agent-based simulation tool was designed to simulate the behavior of the above described platform, and provide illustrative examples of such simulations.

The platform connects different sets of agents: borrowers, investors and guarantors. The parameters governing the platform must be set so that there is coherency among the actions of such actors. Resources anticipated for borrowers should be similar to the amount provided by investors. Guarantors must have incentives to truly facilitate the borrowing process. Simulations can be used to verify if such properties are achievable with the platform design proposed. Additionally, they provide an estimate of the gains obtained by each agent connected to the platform. Finally, simulations reveal impacts on amounts lent, prices and return to investors of different parameters under multiple scenarios, thus guiding the choices of operational parameters and policies.

We start by briefly introducing the agents and their interactions, including a discussion on the important topic of (loan) demand modeling. Next, we simulate somewhat realistic examples, where all classes of agents are presented, and obtain the optimal spreads on different scenarios, as an example usage of the tool. The results indicate that the system is capable of channeling the resources from investors to borrowers with a reasonable return for investors and relative stability of the liquidity pool. They also suggest that a good engine for rating loans is crucial, and that guarantors are an important tool to improve the performance of the system whenever the rating engine is not sufficiently accurate.

Agent-based simulations require a characterization of the behavior of agents and rules of interaction amongst such agents. The set of agents and their interaction rules are described below.

4.2 Agents

Three classes of agents drive the simulations: investors, borrowers and guarantors. Those are the agents that will connect through the platform. Two classes of investors are modeled: (i) seed investors, which provide liquid assets to the platform initially; and (ii) regular investors, which provide liquid assets for lending over time. The number of those agents usually varies over time – agents can enter and leave the system. The behavior of agents depends on preference parameters and information available to them.

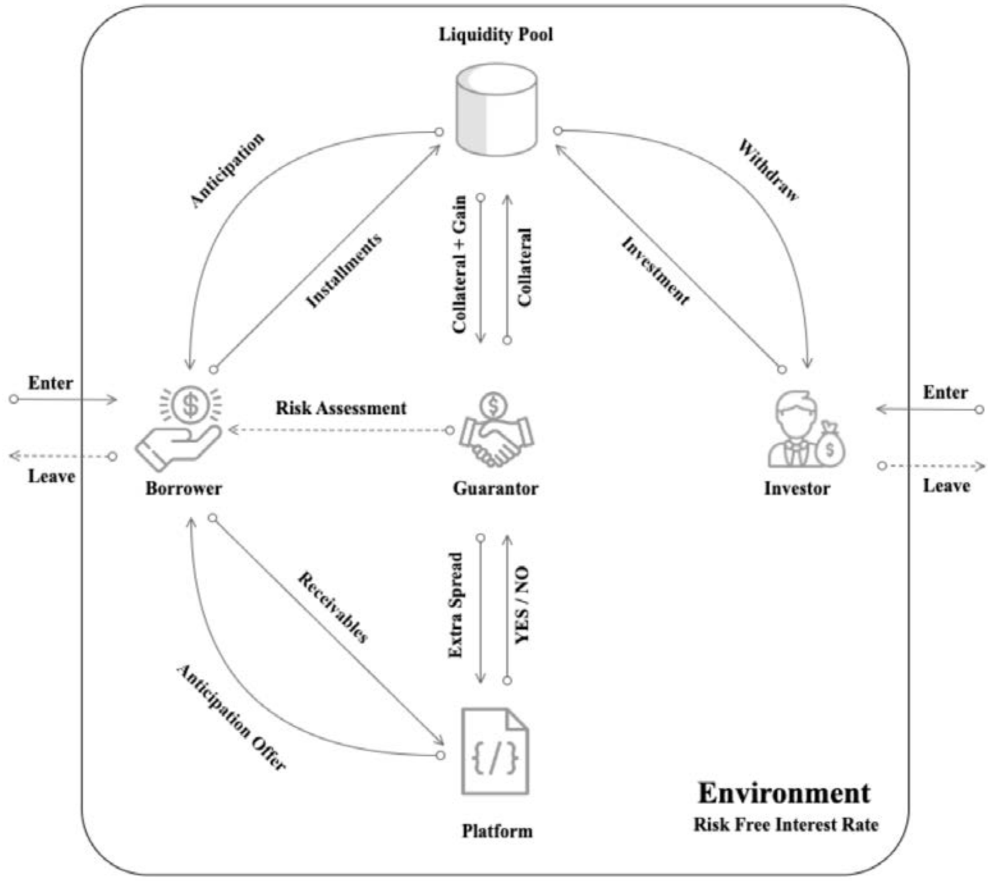
The Platform is the engine that computes the anticipation offers for each potential borrower – it may also refuse to offer an anticipation, if it considers the borrower to be too risky. The anticipation is computed considering four main parameters: (i) a risk evaluation (quantified as a default probability); (ii) the environment's risk free interest rate; (iii) a spread, which stipulates extra returns per loan (when compared to the risk-free rate) (iv) guarantors contributions.

The Liquidity Pool manages the cash flow, by transferring and receiving resources from borrowers and investors. Given the dynamical nature of the system, there may be periods where there are not enough resources to anticipate or to fully pay an investor (in which case, the investor will only partially withdraw, since we have not implemented a secondary market in the simulation yet). Thus, the management of the liquidity pool is a key piece of the platform.

Figure 14 depicts the agents and their interactions. Since the interactions between borrowers and guarantors with the liquidity pool are simple, being simply a cash transfer, we will only focus on simulating the interactions between borrowers and the platform - with and without guarantors - and between investors and the liquidity pool.

Investors and guarantors provide funds, while borrowers absorb such resources.

Figure 14: Agents and their interactions. We also include environmental parameters, so far we have considered only a risk free interest rate, that acts as a base rate.



The interactions presented are a subset of the possible options given the structure of the platform.

4.2.1. Anticipation without guarantor

Borrowers may trade a set of receivables for an anticipation. The platform's job is to make an anticipation offer based on the set of receivables (amount and number of installments) and its risk evaluation. If the borrower accepts the anticipation offer, the anticipation value is transferred from the liquidity pool to the borrower, in return for the installments. Over time, the liquidity pool then receives the installments, except for the event of a default.

Given a set of N receivables (e.g. installments of a sale), a merchant may want to trade these receivables for cash anticipation. Here, we consider a scenario without guarantors, where, in order to make an anticipation offer, the platform considers two main factors that impact the anticipation discount: (i) the default risk discount (that depends on the estimated default probability we refer as p); and (ii) the present value discount (a combination of the risk free interest rate r, the platform's spread s, and the number of installments N).

The challenge for the platform is to compute the amount A to anticipate, and the loan's return will be directly related to the discount offered: the bigger the discounts, the higher the returns for investors. However, if discounts are too greedy, lower volumes will be captured, since borrowers are more likely to reject anticipation offers, resulting in sub-optimal allocation of the liquidity pool. Also, if risk discounts are not properly computed, returns may become negative and/or lead to adverse selection.

4.2.2. Anticipation with guarantor

Guarantors can contribute in different ways to the dynamics of the system. In particular, when they are able to provide more accurate risk assessments regarding particular borrowers, their role can be beneficial to all players: it enables lending by improving anticipation offers (as we'll discuss below) while also being potentially profitable to the guarantor.

As shown in Figure 14, guarantors participate in the trade between a borrower and a platform: they have their own risk assessment and they ask for an extra spread in return for their investment (collateral). The platform then decides if it is worth involving the guarantor.

The dynamics works as follows. Guarantors must first deposit a collateral Vc. If the borrower defaults, the guarantor loses the collateral, being an investment with higher risks than for standard investors. Thus, the loan's fund return alone, usually, would not be enough as an incentive to attract guarantors, and the platform must also offer an extra gain, characterized by the guarantor's spread s_g. Guarantors also have an estimate for the borrower's default probability, in order to compute expected losses. The following elements characterize a guarantor: (i) s_g the guarantor's extra spread; (ii) V_c the guarantor's collateral amount; and (iii) p_g the guarantor's default probability estimate (its risk assessment).

From the platform's perspective, since we have not (yet) included a (extra) financial reward coming from the partnership with the guarantor, the advantage comes from being able to offer better anticipation deals to the borrowers, increasing the acceptance probability. From the guarantor's perspective the reward is profitability.

As already mentioned, the type of guarantor we are discussing here becomes more relevant the bigger the asymmetry between the default probability estimates: the platform assigns a high default probability to a borrower, while the guarantor estimates a (much) lower value.

Such situations, where guarantors are better at estimating risks, may occur, for example, in new markets, where data may not be available or of poor quality. In any case, whenever a guarantor is willing to stake and asks for a reasonable extra gain, even if they happen to be wrong on their risk assessment, it will harm the platform less, given the collateral.

4.2.3. Investors providing resources to the Liquidity pool

Investors provide liquid resources (mostly in CDBC, but also, possibly on other crypto currencies) for the loans/anticipations, expecting an extra spread in return (with respect to the base rate r). The greater this spread, the better for investors, as long as there is still demand to efficiently allocate the liquidity pool resources. This balance, in order to attract both, investors and borrowers, is adjusted by the platform via its spread rate s. Default rates also impact returns. Even with a perfect rating engine, returns would be as expected only on average, with a certain level of variance. Different investors may have quite different strategies/criteria when making investment decisions (both, to invest and to withdraw). Since this influx of investments is an important component of the simulations, we have to include it.

In our simulations, investors decide when to invest/withdraw only by considering the funds historical performance, which is a simplified version of the complex reality of investment decision policies. These are the main parameters that describe each investor: (i) investment amount; (ii) (annualized) expected performance over a certain number of periods; (iii) loss and profit withdrawal rate, where, with a certain withdrawal probability, investors decide to withdraw their investments; (iv) minimum holding period.

Given the stochastic nature of the simulations, even when all input parameters are held fixed, outcomes will vary.

The parameters we have just described specify the investors population, and how this population will behave during the time evolution of the system – even if it is a stochastic behavior.

4.2.4. Borrowers' anticipation demand modeling

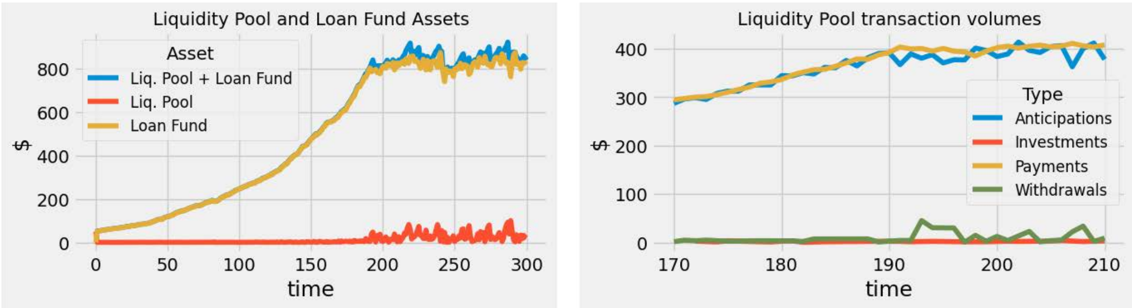
From the platform's perspective, the main pricing mechanism is setting its spread s. From the borrowers' side (the demand side), however, the anticipation price is probably the main factor they are sensitive to – here, by price, we mean the discount with respect to the sum of the receivables in negotiation. Also, we'll consider that the borrowers' response to a particular offer is probabilistic, let's call it $f(A)$, where $f(A)$ is a number between 0 and 1, representing the acceptance probability for that particular offer.
Given that the anticipation offer depends on a number of factors, such as the number of installments N and the base rate r, this price sensitivity curve f must also depend on these factors.

An advantage of this approach is that these curves can be constructed in two ways: (i) by tuning their parameters in order to represent different market conditions, e.g. more/less elastic demand; (ii) by fitting them to data. For now, we'll consider only the first approach, as we have not obtained data to fit yet.

4.3. Simulations

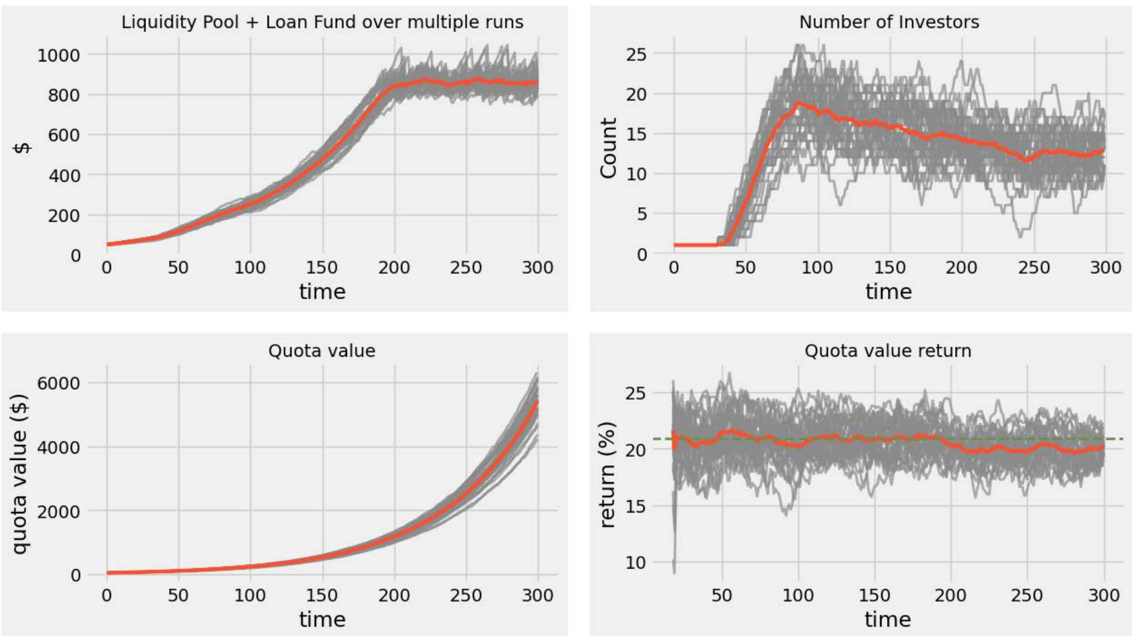
Figure 15 (left plot) shows the time evolution of the liquidity pool (mostly held as CBDC) and of the loan fund (held as other assets managed by DLT). The sum of them compose the total assets resulting from the investments and the loans. Note that a relatively small stock of CBDC is held at the end of each period, when compared with the total stock of assets (Figure 15, left plot). However, the value of the flow of transactions in CBDC taking place in each period is considerably higher than this stock (Figure 15, right plot). In this simulation we have kept the total number of borrowers constant. As a consequence, after a certain number of periods (~ 190), the market saturates, when loan demand is fully fulfilled. As already mentioned, whenever the allocation of the liquidity pool is sub-optimal, the overall performance is also sub-optimal (lower than expected return rates), and investors start to withdraw (from the liquidity pool, see Figure 15 right plot). This re-balances the overall performance. However, this mechanism is not perfectly stable and there are periods with lower allocation of the liquidity pool.

Figure 15: Time evolution of the assets, loan fund and liquidity pool (left). On the right we show the liquidity pool transaction volumes per type of transaction (a subset of the time window, for clarity).



An important outcome from the simulations is to evaluate variances. Even when input parameters are kept constant, each simulation run will result, in general, in different outcomes. Different metrics can be computed after each simulation, like the number of investors, the quota value and the historical returns over a certain number of periods (see Figure 16). Each metric will have its own average behavior and variance.

Figure 16: Time evolution of a set of metrics that can be computed for each simulation. The green dashed line at the returns plot is the target return and returns were computed using an 8 period moving window (bottom right plot).

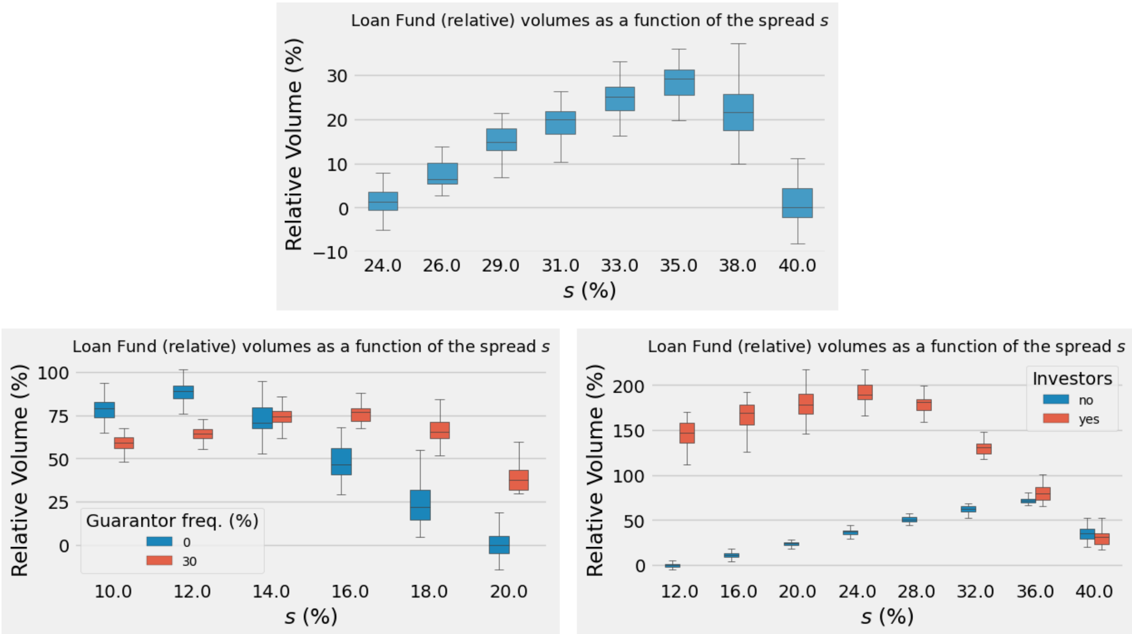


Finally, we can leverage simulations to estimate optimal operational parameters, like the platform's spread s. As an example, let's assume we wanted to maximize the loan's fund volume over a period of 36 months, considering different scenarios. The first scenario considers a situation with just one seed investor, and where the spread is kept constant during the time evolution of the system (Figure 17 top plot). In this case, the optimal spread would be s ~ 35% (annualized value).

Considering the same scenario (input parameters), but now simulating a biased risk assessment engine, one that overestimates the default probabilities, with and without guarantors. The consequence of overestimating the default probability is to overcharge for the loans/anticipations. In order to compensate, the platform's spread must be lowered to obtain optimal results (Figure 17 bottom left plot).

To conclude, instead of having a biased risk assessment engine, we introduce investors to the system (Figure 17 bottom right plot). As expected, investors can significantly improve loan volumes, especially for cheaper spreads.

Figure 17: Optimization of the platform's spread rate for different scenarios.
Here we use relative volumes, considering the lowest volume at each scenario as the reference value.
The results are represented using boxplots to express the variance too.



The numerical results suggest that the system is capable of governing the channeling of resources from investors to borrowers with a reasonable return for investors and relative stability of the liquidity pool. They also reveal that a good engine for rating loans is essential, and that guarantors are an important tool to improve the performance of the system.

Further simulations of additional guarantee schemes (with corresponding incentives for guarantors) should reveal new opportunities to optimize the platform and expand the access and quality of products provided.

5. Final remarks

We have described a potential financial intermediation platform that would intensively explore CBDCs, Open banking and DLT to increase access and improve quality of financial products. We also discussed how these innovations are crucial for the functioning of the system. The platform directs liquid resources, which typically take the form of CBDC, from trade credit providers to anticipate customers payments. The system not only extends loans to companies that currently do not have access to credit (especially SMEs) and improves contractual conditions for companies that already can borrow, but also generates alternatives for investors.

This system aims to provide a convenient and easy-to-use interface that allows the participation of many investors in multiple regions with low transaction costs. The monetary values managed by the platform are digital assets such as cryptocurrencies and CBDCs. This feature allows easy transfers among agents and fast conversion into local currencies, either to anticipate cash for borrowers or to be withdrawn by investors. It may be convenient also for investors utilizing cryptocurrencies.

Blockchain applications contain elements from three main areas of knowledge: Economics (especially Game Theory), Software Engineering and Cryptography. We have explored the elements associated with Economics (including incentives and Game Theory, like loan allocation and fund profitability) and Software Engineering (through artificial intelligence and data structures, such as the F-NFT). The cryptography element will be expanded in future work, when we will discuss aspects related to sensitive information (such as the borrower's history and the necessary secrecy in terms of legal aspects) and governance (the evolution of the platform and the necessary roles considering a decentralized platform and their associated challenges when deciding what is best for the collective welfare).

This paper describes the key ingredients of the market design of this projected platform and presents numerical simulations representing its operation, highlighting the importance of CBDCs, Open Banking and DLT for multiple components of the system: fund origination, lending, loan endorsement by peers or experts, secondary markets and secondary funds. The presented case study illustrates how the use of these instruments contribute to minimize access and transaction costs, optimize management of information and privacy, support the use of sophisticated contracts and provide safety and credibility to intermediation agreements.

References

Aghion, Philippe, and Patrick Bolton. "A theory of trickle-down growth and development." *The review of economic studies* 64.2 (1997): 151-172.

Bank for International Settlements. “Distributed ledger technology in payment, clearing and settlement: An analytical framework.” Committee on Payments and Market Infrastructures Papers No. 157, In: BIS, 2017a.

Bank for International Settlements. “Distributed Ledgers In Payment, Clearing And Settlement Carry Promise As Well As Risks.”, In: BIS, 2017b[12].

Besley, Timothy, and Stephen Coate. "Group lending, repayment incentives and social collateral." *Journal of development economics* 46.1 (1995): 1-18.

Ghatak, Maitreesh. "Group lending, local information and peer selection." *Journal of development economics* 60.1 (1999): 27-50.

Ghatak, Maitreesh, and Timothy W. Guinnane. "The economics of lending with joint liability: theory and practice." *Journal of development economics* 60.1 (1999): 195-228.

Greenwood, Jeremy, and Boyan Jovanovic. "Financial development, growth, and the distribution of income." *Journal of political Economy* 98.5, Part 1 (1990): 1076-1107.

Karaivanov, Alexander, and Robert M. Townsend. *"*Dynamic financial constraints: Distinguishing mechanism design from exogenously incomplete regimes*." Econometrica 82.3 (2014): 887-959.*

Karlan, Dean, and Jonathan Zinman. "Observing unobservables: Identifying information asymmetries with a consumer credit field experiment." *Econometrica* 77.6 (2009): 1993-2008.

Novaes, Frederico Dutilh, and Madeira, Gabriel et.al., "The Economics of the DeLend Project - Agent-based Simulations" In: arXiv, 2023[13].

Paulson, Anna L., Robert M. Townsend, and Alexander Karaivanov. "Distinguishing limited liability from moral hazard in a model of entrepreneurship." *Journal of political Economy* 114.1 (2006): 100-144.

Salanié, Bernard. *The economics of contracts: a primer*. MIT press, 2005.

Steler, Fernando, and Cerqueira, Aurimar. "Blockchain: todos os negócios serão impactados", *Computer World Brasil, março de 2017*.

Stiglitz, Joseph E., and Andrew Weiss. "Credit rationing in markets with imperfect information." *The American economic review* 71.3 (1981): 393-410.

Tadelis, Steven. *Game theory: an introduction*. Princeton university press, 2013.

Townsend, Robert M. *Distributed Ledgers: Design and Regulation of Financial Infrastructure and Payment Systems*. MIT Press, 2020.

Townsend, Robert M. and Killian, Elizabeth & James: *Distributed Ledgers: Innovation and Regulation in Financial Infrastructure and Payment Systems*. In: MIT, 2019[14].

[12] https://www.bis.org/cpmi/publ/d157.pdf

[13] https://arxiv.org/abs/2303.03214

[14] https://economics.mit.edu/sites/default/files/2022-09/Distributed%20Ledgers-first%20circulation-041819.pdf (accessed March 2023)