Design of a Collaborative Payment System

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Abstract

For centuries, financial institutions have responded to liquidity challenges by forming closed clearing clubs with strict rules and membership that allow them to collaborate on using the least liquidity to discharge the most debt. As closed clubs, much of the general public has been excluded from participation. But the vast majority of private sector actors consists of micro or small firms that are vulnerable to late payments, generally ineligible for bank loans, and not privy to any clearing clubs. This low liquidity environment results in gridlock and leads to insolvency, and it disproportionately impacts small enterprises and communities.

We propose a payment system designed as an open clearing club. The design allows firms to overcome payment inefficiencies, to reduce their working capital needs, to clear more debt with less money and with minimal legal complexity, and to leverage diverse assets and liquidity sources, including lending and issuance protocols. The design is made uniquely possible by fault-tolerant, privacy-preserving execution of atomic multi-lateral settlement operations defined by a graph optimization algorithm under international obligation law. The design is based on a core insight: a significant amount of 'internal' liquidity resides within cycles in the obligation network's structure and can be accessed via set-off notices – mutual reductions in debt.

The paper extends present payment systems by introducing obligations as a fundamental primitive, by making clearing as a risk-reduction mechanism accessible to the general public, by focusing on the network structure of the liabilities rather than the aggregate structure of the assets, by prioritizing liquidity-saving over liquidity-provisioning, and by enabling new forms of distributed issuance. The trust-based collaborative finance instruments we describe allow for the optimized use of liquid assets and the compression of balance sheets, reducing leverage and risk, and enabling sustainable growth in an increasingly interconnected and crisis-prone world.

Contents

1 Introduction

We live in a world of increasing financial inequality among firms, aggravated by growing requirements for collateral when accessing formal financing sources [16]. The vast majority of corporate actors consists of micro and small firms with zero or modest collateral, which reduces their eligibility for bank loans [21, 5, 9]. This aggravates the late payment problem [31, 7, 48, 39, 20], leading to gridlock [32] and often even insolvency [10]. Firms are forced to seek informal liquidity sources – or in the worst case loan sharks – to access the working capital they need for their normal operations and growth. The Great Financial Crisis (GFC), the recent Covid public health crisis, and on-going environmental degradation are making their situation even harder. The rapid development of alternative monetary and financial systems such as complementary currencies and cryptocurrencies over the past 15 years can be seen as a direct response to this situation.

It has always been known that sharing financial information can produce better outcomes. Clearing systems are a primary example. For centuries, banks and payment providers have improved their profitability and stability by forming closed clearing clubs with strict rules to make collaboration possible [12, 8]. Clearing allows them to extinguish large amounts of debt using minimal amounts of money or liquidity in a coordinated and certain manner. Clearing institutions have therefore come to serve as a linchpin of risk management in financial systems, even though they, somewhat paradoxically, typically introduce new central counter parties to whom significant risk is transferred. However, most of the public is excluded from accessing these clearing systems. The general public and small firms cannot collaborate on clearing since there are no rules to protect them from the harm of exposing their financial data to their competitors and partners, and membership in clearing house clubs generally involves high-overhead financial contracts that put them out of reach.

Recent advances in privacy-preserving technology, distributed systems, and graph algorithms allow us to overcome these challenges. With privacy technology, debts can be securely and inexpensively collected from a large number of participants. With distributed systems, debts can be cleared by the fault-tolerant execution of atomic multi-lateral operations, allowing for the simultaneous discharge of a large number of debts. And with graph algorithms, debts can be cleared in a risk-reducing manner without transferring risk to central counter parties. In other words, we can now develop payment systems that optimize to clear the most debt by performing a large number of set-offs and settlements in a single operation, benefiting a wide number of participants, without the introduction of intermediaries or financial complexity. This opens further use cases for lending and issuance protocols, and allows firms and communities to greatly improve their liquidity position and reduce risk.

Here, we describe a common language for the design of payment systems. The language exposes the structure of the payment system as a network of obligations combined with one or more liquidity sources. From this, we propose a payment system design based on a graph optimization algorithm which allows a large number of participants (debtors, creditors, and liquidity providers) to benefit from clearing the most debt with the least money. The design is motivated by a core insight: a significant amount of 'internal' liquidity resides within the network structure of debts and can be accessed via set-off notices, which allow mutual reductions in debt. By surfacing the graph structure of the network in a privacy-preserving manner, operating on it atomically with multi-lateral set-off notices, and integrating diverse sources of liquidity, major benefits can accrue which are not otherwise accessible to individual companies, to trade networks, and to whole economies.

With our design, firms can connect their internal accounting system to a global network that optimizes the clearing of credits and debts using the available sources of liquidity. Firms select which of their debts they want to submit to the clearing system, and what kinds of assets (amounts, exchange rates, etc.) they want to use to pay them. Our initial focus is on the trade-credit economy, and its network of accounts payable. These are typically 30, 60, or 90-day credits extended by suppliers to their customers (i.e. invoices), that only bear interest once they are overdue. They are a major source of the cash flows (and stresses) that dominate the operations of a business. In some sense they are the financial foundation of a commercial economy. Our design presents a practical solution that optimizes the clearing of this debt via simple legal patterns, improving cash flow, and reducing dependence on expensive sources of credit like factoring and bank loans. While trade credit is the initial focus, the design presented here is more widely applicable to payments in general. It offers a new way to implement robust payment systems and a new foundation for reasoning about finance.

In this paper we focus on the language of payments and the core design problem of graph optimization over a network of obligations and liquidity sources. We leave the details of a fault-tolerant and privacy-preserving implementation and its economics to future work.

1.1 Payment Systems

We define a payment system to consist of a set of obligations (the debts to pay), and at least one liquidity source (typically, some asset) that can be used to discharge them. The obligations, together with offers to use and accept different sources of liquidity, form a network graph. Many of today's payment services (banks, fintech, blockchains) focus primarily on transfer and exchange of assets, with limited support for obligations, and with a limited view of the network graph. But these existing systems become much more powerful when they are integrated into an obligation graph of the kind we propose. As we will see, first class representation of obligations and the ability to operate atomically on the obligation graph unlock powerful new capabilities for the collaborative discharge of debt.

Our design is motivated by a critique of existing payment systems, which we summarize briefly here. Our aim with this critique is to offer a direction forward for enhancing and complementing existing systems, rather than replacing them.

First, the modern banking system was not derived from anything approaching a coherent theory of finance and economics, and has become quite fragile in its relationship to debt [13]. By contrast, we seek to ground our proposed payment system on *first principles*, by asking the question: "How do we design a payment system to reduce the most debt with the least money for everyone?"

Second, much of the risk management in modern systems is focused around central banks as lenders and dealers of last resort [36]. While useful for backstopping certain kinds of liquidity crises, this structure has led central banks to be captured by systemic risk [38] and to compound moral hazard [30, 14]. Instead, our design focuses on risk-reduction mechanisms accessible to the general public by enabling them to use a wider variety of assets and clearing protocols to make payments.

Third, much payments innovation is focused on the transfer and exchange of assets by individuals. However, the payment system has a *network structure* arising out of the web of obligations formed in the course of trade and finance. Our proposed payment system allows this network structure to be surfaced and optimized over with the tools of graph theory. We focus on the network structure of the liabilities, rather than the aggregate structure of the assets.

Fourth, modern payment systems often invoke intermediaries, new financial contracts, and novation, which are associated with a higher regulatory burden and transmutation of risk. By contrast, we can reduce the need for intermediaries and financial complexity by focusing instead on the existing network of liabilities (especially trade credit obligations) and leveraging the more permissible legal structure of set-off notices under *international private obligation law* [45]. This approach honours the network of relationships in the obligation graph and allows the focus to remain on network-level risk reduction. It allows debts to be reduced by formal set-off transactions that reduce debts for multiple parties at once.

Fifth, liquidity in modern banking and blockchain systems is organized around a system of market-making dealer intermediaries focused on their own enrichment through *liquidity provisioning* [2]. In contrast, our proposed payment system is designed without such intermediaries, and is focused on *liquidity saving* via set-off notices. Liquidity provisioning is a short volatility position associated with systemic risk.[1] Liquidity saving is a way to reduce that systemic risk [22].

Finally, payment systems must ultimately reckon with the problem of *issuance*, which arises when there is not enough liquidity in the system. There is much to lament about modern issuance through commercial and central banks [4, 37, 47]. Our proposed design leverages the obligation network – credit and debt relationships within the non-financial sector – as endogenous network liquidity to enable new forms of distributed issuance that improve the system's overall liquidity. We thus present a platform for new kinds of credit and issuance protocols that are more "network-aware".

1.2 Collaborative Finance

Our design emerges from a synthesis of traditions which are at their core efforts to implement robust and sustainable payment systems.[2] This synthesis is driven by the observation that a great deal of financial value in support of the real economy is not visible to selfish rational agents reasoning about their own assets, and can only be accessed through collaborative processes that allow us to operate over the network of liabilities, which we share an interest in discharging. We seek to harness these collaborative processes to reduce the constant liquidity pressure currently bearing down on the global economy.

Thus, without rejecting competition – or capital markets more generally – we uncover a new source of resilience and sustainability for networks of real economy actors, especially small and medium-sized enterprises (SMEs), and new ways to leverage internal and external liquidity for mutual benefit. In so doing, we offer a new path to empower communities to manage their own payment systems and to issue their own money in a sustainable fashion. In turn, new possibilities emerge for existing pools of capital to support a more sustainable finance.

The collaborative financial instruments we describe allow for optimized use of liquid assets and the compression of balance sheets, reducing leverage and risk and thereby improving credit scores. For micro and small enterprises, this signifies a paradigm shift. It improves their access to bank credit, reduces the time between payables and receivables, and ultimately enhances their relationships with suppliers and customers. Medium and large enterprises also find significant advantages in our system, as it offers enhanced treasury liquidity management and greater control over the use of a wide range of assets. Improved cash flow and reduced funding costs become more attainable, and risk management reaches a new level of sophistication. The surplus of liquidity opens doors to an expanded realm of investment opportunities, promising both growth and stability.

By eradicating payment gridlocks and reducing the systemic risk of payment defaults, communities can flourish. Collaborative projects within communities can boost liquidity, opening doors to the issuance of community currencies and enhancing the utility of various alternative currencies, including foreign national currencies and cryptocurrencies. Our design better enables currencies and other assets to be used more easily as part of day-to-day payments, and provides a platform for the development of new lending and issuance protocols. It enables communities to tune the provision of liquidity to their needs, and even to leverage DeFi protocols to benefit commerce more generally.

Banks and lenders also experience benefits from participation in collaborative finance. Through the improved credit ratings enabled by the efficient functioning of our system they can access a broader market, expanding their reach and influence. In addition, the clearing of the obligation network embedded within our system becomes a valuable tool for recovering non-performing loans (NPL).

On the macroeconomic scale, our system promises to facilitate better use of existing liquidity. Risk

[1] Also known as 'picking up pennies in front of the steamroller' [30]. In essence, betting on stable prices.

[2] See prior work on obligation-clearing for liquidity-saving [42, 19, 23] with mutual credit [44, 28, 33, 40, 34, 18] and the simultaneous use of multiple liquidity sources to discharge debt.

reduction and minimized spillover effects mitigate the effects of financial crises. Importantly, the same volume of liquidity can support a higher volume of economic activity, promoting growth and productivity. The system encourages the productive use of trust-based financial instruments, starting from bilateral IOUs and extending to traditional fiat legal tender, and beyond. It transforms the way society views and manages financial resources.

Thus, the benefits our proposed payment system offers are manifold, spanning from individual companies to the community and regional economies and from small enterprises to large financial institutions. Through efficient collaboration, optimizing asset utility, and enhancing liquidity management, we envisage a financial ecosystem that empowers, revitalizes, and ultimately enables sustainable growth in an increasingly interconnected world.

2 Design

We introduce some terminology and a graphical schema that can be used to describe a wide variety of payment and currency systems. This language and schema further motivate the formulation of a graph optimization problem whose solution can be executed as a single multi-lateral operation, allowing a large number of debts for a large number of firms to be cleared with a minimal amount of money all at once. The language is based on a system of intents that define a graph over which we can settle obligations in multiple ways. Intents allow participants to express their indebtedness and their preferences over the use of different liquidity sources. Debts can then be settled by three primary means: through set-off, through transferring assets, or through drawing on credit.

2.1 System of Intents

We recognize three basic types of intents, which we call Obligations, Tenders, and Acceptances. Generally speaking, any payment transaction can be decomposed into these three components. We assume intents are programmable, allowing a wide variety of payment, currency, and credit protocols to be defined.

Obligations. An obligation is the core of any payment – it is the debt the payment settles. If Alice owes Bob $30, that's an obligaiton. More generally an obligation is a tuple of (debtor, creditor, amount). It typically also involves a due date. Obligations originate from the debtor as a declaration of their liability to the creditor. An obligation is an intent to pay. It must be *ascertained* by its debtor, which is to say signed or accepted, but it requires no acceptance from the creditor. If Alice declares she owes Bob, who is Bob to stop her?

We say obligations are *discharged* when the amount owing on them is decreased. Obligations can be fully or partially discharged. Full discharge is usually referred to as settlement. Much of the benefit of the design we propose comes from the ability to *partially* discharge obligations.

To date, most settlement systems, blockchains included, have focused primarily on asset transfer, with limited support for obligations. However, without loss of generality, we might say that every asset transfer between parties executes the discharge of some current or future obligation, even if the obligation is not recorded in the same medium as the asset transfer, and even if the obligation and the asset transfer are coincident or almost coincident in time. That our payment systems have not supported these obligations as a base primitive is a major deficiency, and has greatly inhibited the ability of the public to access the benefits of clearing.

Tenders. A tender defines how someone wants to pay an obligation. If Alice says, "Will you accept this gold coin to settle my $30 debt?", that is a tender. More generally, a tender is an intent to use up to some maximum amount of a particular source of liquidity to discharge obligations you owe. Tenders are issued by debtors, and can draw on any source of liquidity available to the debtor. If Alice has gold, dollars, and Bitcoin, she might tender any one of them, or all three, to try and pay her debts. For a non-stable liquidity source like Bitcoin to settle a debt in dollars, the tender must specify an acceptable price for Bitcoin in dollars. This price could come from an oracle, or it could be specified directly by Alice. Note the Bitcoin are not actually exchanged for dollars, but they are used to pay a dollar debt.

Liquidity sources for tenders come in two flavours: positive and negative balances. Consistent with our ways to settle (see below), we call these Assignment and Overdraft, respectively. You pay your debts either by assigning your own assets (positive balances), or by drawing an overdraft (negative balances).

Acceptances. An acceptance defines how someone wants to be paid. If Alice says, "I'll only accept Bitcoin to settle the debt you owe me", that is an acceptance. More generally, an acceptance is an intent to accept up to some maximum amount of a particular type of liquidity in the discharge of obligations owed to you. Acceptances are issued by creditors – they are the complement of tenders.

Acceptances also come in two flavours, relating to positive and negative balance. We call an acceptance into a positive balance a deposit, and one into a negative balance a repayment. A successful deposit acceptance will increase your positive balance, or, if you have a negative balance, a successful repayment acceptance will reduce it towards 0.

By describing payments in terms of obligations, tenders, and acceptances, we can optimize across them to find a set of operations that discharge the most debt with the least (and most preferred) money. The presence of cycles and chains of obligations allows the network to discharge more debt than would be possible otherwise, thanks to the power of set-off and the different ways to settle.

2.2 Four Ways to Settle

Broadly speaking, there are four ways to discharge obligations: Set-off, Assignment, Overdraft, and Novation.[3] Set-off allows obligations to be offset against one another – if I owe you and you owe me, we can do set-off. Assignment allows a debtor to use their own assets to discharge an obligation – how we normally think about paying a debt. Overdraft allows a debtor to draw on new credit to discharge an obligation – borrowing to pay. And novation allows the participants in an obligation to change.

Much of modern finance today revolves around novation (securitization, factoring, clearing houses, etc.), which implies a change in the obligation contract (usually a change in counterparties and hence the structure of the graph). Changing contracts is expensive, slows down business, and mutates risk. We propose a system that limits the need for novation by instead making maximal use of set-off, assignment, and overdraft. This has the added legal benefit of moving from the complex world of financial regulation to the simpler world of private obligation law, which is more accessible and better able to adapt to different contexts. This framing allows us to also pursue novel use cases for lending and issuance protocols, empowering communities to make better use of these monetary powers in a more distributed and sustainable fashion.

In what follows, we use balance sheets and graph representations to review the different ways to settle. This framing will allow us to more completely define the graph optimization problem at the heart of our payment system design.

Set-off. Set-off is the discharge of obligations without money. This is done by balancing obligations across balance sheets so they offset each other – hence, set-off. If Alice owes Bob and Bob owes Alice, they can do set off. Set-off can also happen in cycles – if Alice owes Bob and Bob owes Carol and

[3] We are building on the formulation in [15], which is focused on describing accounts from the perspective of the payment system. Here we are more interested in the perspective of the users and communities, so our terminology differs slightly. What is called Issuance in [15], we call Overdraft, which in our formulation includes Issuance as a special case.

Carol owes Alice, they can all set off the lowest amount, as shown in Fig. 1.

Set-off reduces the size of each party's balance sheet. We define a *set-off notice* as a formal and legally binding communication about the result of a set-off process. For any agent to execute a set-off, at least two obligations must be reduced, one where they are debtor, and one where they are creditor. Set-off thus functions as a multilateral payment.

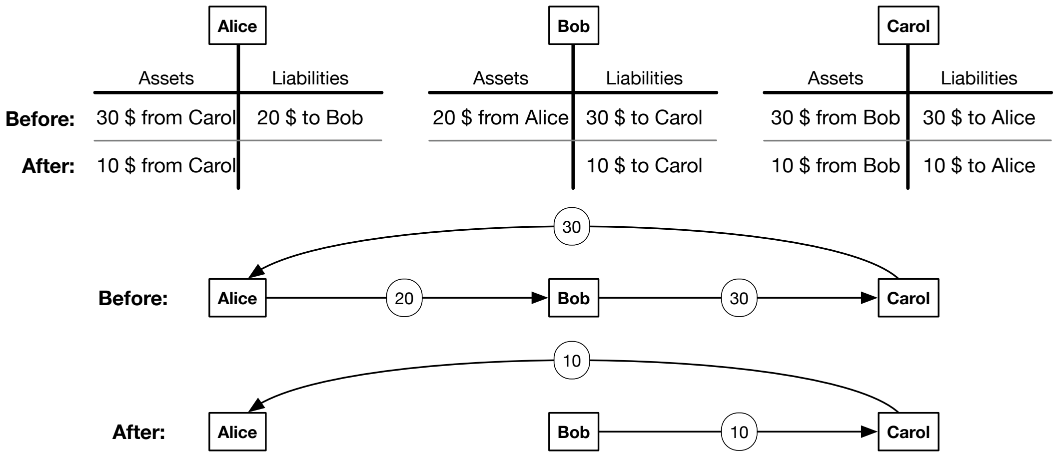

Figure 1: **3-cycle set-off**. Alice owes Bob 20, who owes Carol 30, who also owes Alice 30. With set-off, each obligation can be reduced by 20, fully discharging Alice's debt to Bob, and partially discharging the others. Total debt in the system drops from 80 to 20.

Assignment. Assignment is the discharge of an obligation by the transfer of some amount of an asset from one party to another. Unlike set-off, which is multilateral, assignment can be initiated unilaterally by the debtor of an obligation. Multiple consecutive assignments allow the same money to be used to discharge a chain of multiple obligations. Fig. 2 shows a chain of assignments involving three parties transferring \$20 to clear \$40 of debt. Assignment only reduces the balance sheet of the debtor. In a chain of obligations, it reduces the balance sheet of all parties except the last one in the chain.

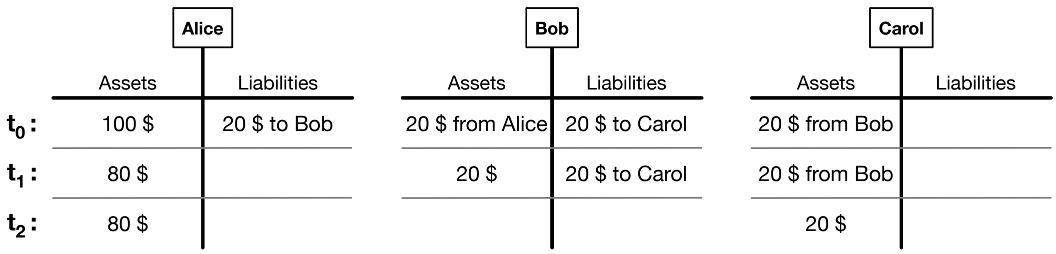

Figure 2: **Assignment chain**. Alice has \$100, and owes \$20 to Bob, who owes \$20 to Carol. Alice uses some money to pay Bob, who then pays Carol.

Assignment and set-off can be combined atomically so that assignment (the asset transfer) only occurs between the first and last agents in a chain of obligations, while all other obligations in the chain are set off. This avoids multiple independent assignments down the chain, achieving the same result but in a single multi-lateral operation. This is important because it allows for optimizations over the graph.

It is useful to think of liquidity more formally as a node in the graph, which can be connected to debtor and creditor nodes via tenders and acceptances, respectively, as shown in Fig. 3. We can still interpret these edges as a kind of obligation, only between the liquidity source and agents with access to it. The liquidity source, in the case of assignment, is the keeper of positive balances. It could be a bank, a blockchain, or a mutual credit system.

Fig. 3 shows a visualization where Alice owes Bob, who owes Bill, who owes Ben, who owes Carol. Bob's, Bill's, and Ben's debts are cleared by the transfer of 20 units of liquidity directly from Alice to

Carol, atomically and with set-off notices received by all of them. In a single operation all the debts are discharged and Alice's 20 is transferred directly to Carol, without Alice or Carol ever knowing about each other. Bob, Bill, and Ben never handle any money, and all their debt is cleared by set-off.

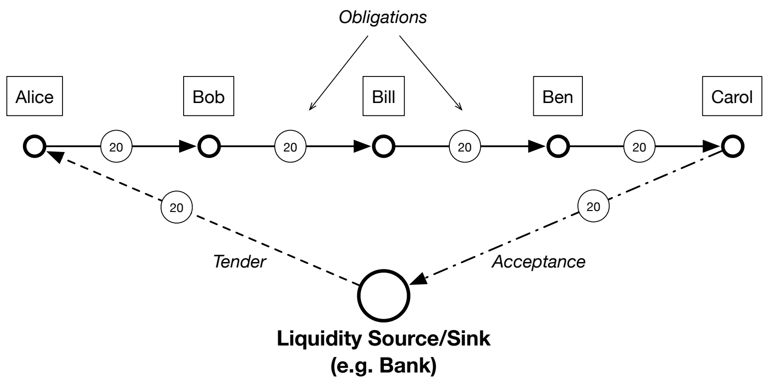

Figure 3: **Visualization of liquidity source**. Many debts can be cleared by a single assignment. Alice's money gets assigned to Carol, and all debts are set off.

Overdraft. Overdraft is discharge of one obligation by the creation of a new one – borrowing to pay. If assignment is interpreted as a positive balance that can be drawn on to pay, overdraft is a negative balance – it can be drawn past 0, but must in some way be paid back. The dynamics of the negative balance can be defined by a lending protocol for some liquidity source that determines how negative the balance can go and how it is paid back. For a given type of liquidity, there can be many different overdraft facilities opened, each defined by its own lending protocol.

Fig. 4 shows a simple case of overdraft.[4] A Lender opens an overdraft facility for Alice to draw on. Alice can draw on this facility, running up a negative balance, which appears as an asset to the Lender and a new liability to Alice. The Lender's assets are used to pay Bob, thus discharging Alice's obligation to Bob. In the end, Bob is paid, and Alice owes the Lender. Unlike set-off and assignment, overdraft alone does not reduce the size of any balance sheets – they all stay the same size.

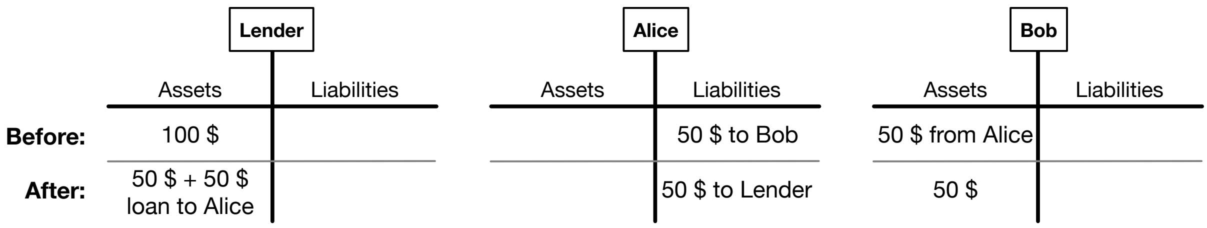

Figure 4: **Overdraft**. Alice draws on an overdraft facility (a line of credit with the Lender). All balance sheets stay the same size.

Note that Alice is not first taking out a loan, and then using the asset she acquired in the loan to pay Bob via assignment – taking on the new debt and paying the old debt comprise a single action. This is the meaning of an overdraft facility as used for payments (i.e. a debt used to reduce other debt), in contrast to a loan (i.e. a debt used to acquire an asset).

Overdraft can also be combined with assignment and set-off, and can be conceptualized as a node in the graph the same way as assignment in Fig. 3. An overdraft facility is a negative balance node that can be tendered from and accepted to (repayment). It's distinguished from an assignment node by the rules that govern repayment (it's a credit line).

Notably, overdraft also permits the possibility of *issuance*, which amounts to the creation of new monetary units. This allows us to think about issuance as a kind of credit, a negative balance expected

[4] We assume for simplicity we are dealing with assets that can be self-custodied by the participants (e.g. cash or a stablecoin), so we do not need to also show a bank that holds dollars as deposits on behalf of the participants.

to be paid back. While set-off and assignment reduced balance sheets, and overdraft kept them the same, overdraft with issuance results in balance sheet expansion. Most money issuance today is done by expanding the balance sheets of commercial banks, using central banks as a backstop. But the network structure surfaced by our design makes new opportunities for issuance possible. Use cases for overdraft and issuance are covered further in Section 3.

Novation. In all three of Set-off, Assignment, and Overdraft, the structure of the network, in terms of the counterparties and the direction of obligations, is preserved. Debts can be reduced, even to zero, and new debts can be created, but the counterparties of a given obligation cannot change. Novation is different in that it does mutate the structure of the obligation graph. With novation, the counterparties in an obligation, and the direction of an obligation, can change.

A common form of novation in trade credit markets is factoring, where the creditor of an obligation is changed – the original creditor sells the debt to someone else, usually at a discount. It's important to understand how our solution is distinct from factoring. We achieve a similar result as factoring, but without novation, by using an overdraft up the obligation chain.

Suppose Alice owes Bob, who owes Carol, as shown in Fig. 5a. In invoice factoring (Fig. 5b), Bob would factor ("sell") his receivable from Alice to Frank for cash to pay Carol. In this case a liquidity provider, Frank, is buying the receivable from Bob, seeing it as an asset he can purchase at a discount and later collect on from Alice. This changes the graph, since instead of owing Bob, Alice now owes Frank, whom she doesn't even know. But Frank could just as well offer an overdraft facility to Alice (Fig. 5c), that she might draw on to pay her debt to Bob, who can then pay Carol. The difference is that, rather than letting Bob break the structure of the obligation graph for Alice (forcing her to owe Frank), Alice can choose to draw on the source most appropriate for her (maybe it's not Frank, but Fiona) to discharge her obligation to Bob.

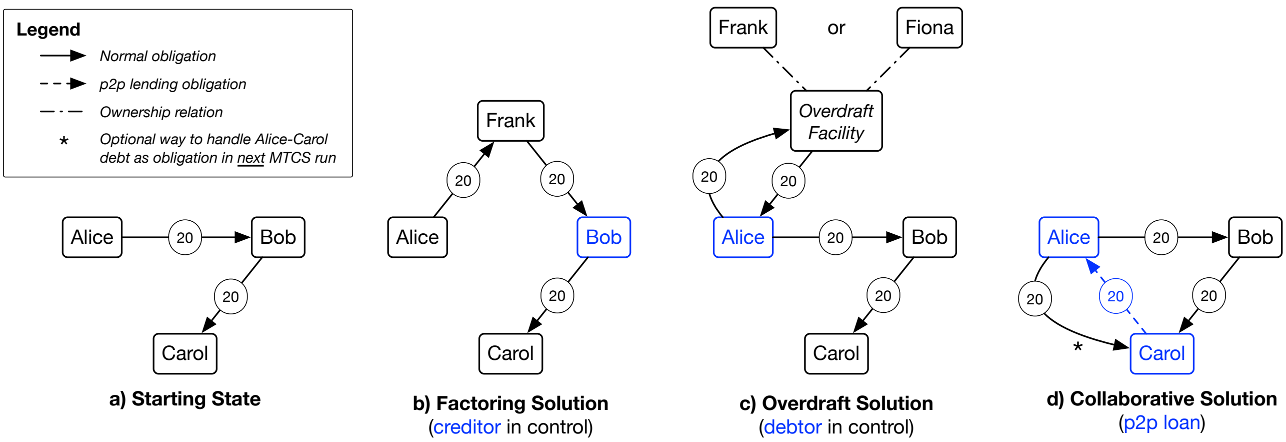

Figure 5: **Comparison of factoring, overdraft, and p2p lending solutions (amounts shown nominal)**

This requires us to frame the availability of liquidity in terms of the structure of the debts, rather than factoring or securitizing the assets. By doing so we can unlock new sources of liquidity within the network and empower debtors to draw from sources of credit most appropriate for them. A powerful example of this is a 'p2p loan', as shown in Fig. 5d. Instead of borrowing assets from Frank or Fiona (outside the network), Alice borrows in the form of a "good-faith" obligation from Carol, a kind of p2p loan that allows the whole network to be cleared. By borrowing in this way from Carol, even without transferring any assets, a cycle is created that can be discharged via set-off, leaving only a single debt from Alice to Carol to be paid in the future.

The point is, liquidity is in the graph! Starting with the obligation network, the addition of liquidity sources (assignment and overdraft), including p2p loans, extends the graph to make it more dense and cyclical. We can do clearing without novation because liquidity is hidden in the cycles. The key to our design then is an algorithm that finds cycles.

2.3 MTCS

The graph algorithm at the core of our design is called Multilateral Trade Credit Set-off (MTCS) [23, 22]. MTCS solves for the maximum amount of debt that can be discharged in a network defined by a set of obligations, tenders, and acceptances. The result of an MTCS run is a list of set-off notices to be applied to obligations and liquidity sources. Set-offs are executed atomically by a fault-tolerant multi-lateral state machine. In a single operation, debts are reduced and payments are made for many parties at once.

Liquidity sources, lending protocols, and issuance protocols can be incorporated into the system as nodes within the graph being optimized over by MTCS. Sources of liquidity can range from own assets, to the assets of external lenders, to mutual credit, DeFi protocols, currency issuers, and to p2p loans that generalize the issuance of obligations themselves. By exposing the graph and enabling collaborative action by stakeholders, new forms of internal liquidity become possible.

The MTCS algorithm finds a so-called cyclic structure in the obligation graph. The existence of the cyclic structure implies that the amount of liquidity required to discharge all the debt is less than the total amount of debt. We call this amount of liquidity the Net Internal Debt (NID). MTCS proceeds by finding the minimum cost flow of this amount of liquidity (the NID). Subtracting that flow from the full obligation graph yields the cyclic structure.

The mathematical details of MTCS are described in [22]. As shown in Fig. 6, the algorithm defines a fictitious liquidity source v_0 as a node external to the obligation network and connects it to each node v_i, where i spans from 1 to the number of firms n, with a new set of directed edges. For each firm, the weight of the new edge corresponds to the firm's net position (*total credits* − *total debts*). The direction is from v_0 to the node if its net position is negative (it needs to draw on the liquidity source) and vice versa if it is positive (it has excess liquidity to deposit back to the source). The NID is the sum of the negative net positions. The figure shows how the fictitious liquidity source can be split for greater clarity into two auxiliary nodes, one that acts as a source and the other as a sink.

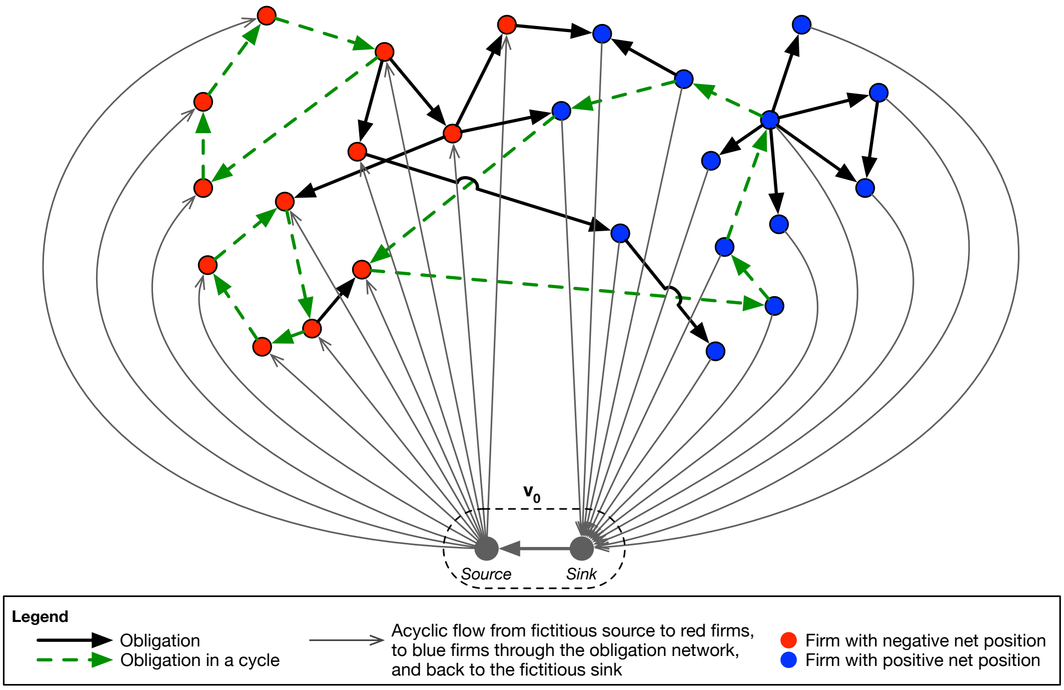

Figure 6: **Flow from a fictitious liquidity source.** The red nodes (net debtors) draw from the fictitious source, and the blue nodes (net creditors) deposit to the fictitious source. Subtracting the min-cost max-flow leaves the cyclic structure (green).

No actual liquidity is used here because subtracting the cyclic structure from the original graph does not change the net positions. The weight of each edge belonging to the cyclic structure constitutes the set-off notice, or decrease in obligation amount, that needs to be sent to the two companies defining that edge. This is the amount of liquidity saved or cleared, i.e. which does not have to be paid by the debtor.

The optimal solution of the min-cost max-flow MTCS algorithm is not unique. There are in general many optimal paths satisfying the problem. While randomness could be used to pick between solutions, it would be better to enable other solutions to be expressed, for instance through direct governance, some kind of preference system, or other possible parameters.

Without a source of liquidity, only obligations in cycles can be cleared by MTCS, and they can only be partially discharged (up to the smallest debt in the cycle). But even small amounts of liquidity can result in a much greater amount of debt being cleared, and with benefits for a larger number of participants. By adding enough liquidity (at least the NID), 100% discharge of *all* the obligations can be achieved. The optimal solution found by MTCS implies that the amount of liquidity required is much smaller than the total debt, due to the simultaneous set-off of chains of obligations.

Fig. 7 shows an example of this 'multiplier' effect by plotting the percentage of debt cleared against the amount of liquidity injected as a fraction of the total debt. The debt cleared rises steeply at first with slope greater than 1 (corresponding to chains of obligations), then grows with slope = 1 (corresponding to the clearing of isolated obligations), before levelling off at a fraction of injected liquidity that is significantly smaller than the total debt. The figure also shows how the average fraction of accounts payable (AP) cleared for each firm grows with injected liquidity. The first plateau corresponds to the clearing of large companies after the chains have been exhausted.

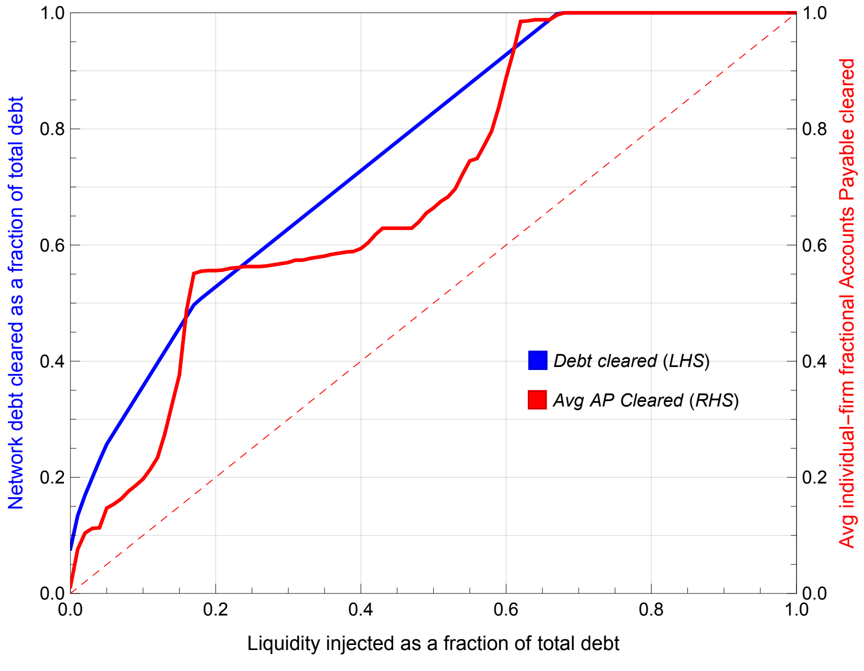

Figure 7: **Variation of debt set-off expressed as a fraction of total debt.** With no liquidity, nearly 10% of the debt is in cycles and can still be cleared. With small amounts of liquidity, much more debt can be cleared. The graph is based on anonymized Italian data: 1,280,000 invoices, 760,000 companies, December 2020.

2.4 Liquidity

We can now introduce liquidity to the MTCS algorithm. Recall Fig. 3, where we introduced a node in the graph to represent a single source of liquidity, with outgoing and incoming edges (tenders and acceptances). Like the fictitious liquidity node in Fig. 6, a real liquidity node can connect to and from every other node in the network, and can be decomposed into auxiliary nodes: a source and a sink. However, in line with our ways to settle, there are two kinds of sources (Assignment and Overdraft), and thus two kinds of sink (which we call Deposit and Repayment). In other words, you can tender from your positive (assignment) and negative (overdraft) balances, and you can accept into your positive (deposit) and your negative (repayment) balances.

As shown in Fig. 8, we decompose the liquidity source node into four auxiliary nodes: Assignment, Overdraft, Repayment, and Deposit. Tenders are made from Assignment and Overdraft nodes, while acceptances are made to Repayment and Deposit nodes. After the MTCS run, set-off notices involving firms that declared tenders and acceptances are sent also to the liquidity source, which performs the necessary transfer of funds. The sum of flow from Assignment and Overdraft nodes must equal the sum of flow to Repayment and Deposit nodes. As per Fig. 7, the presence of obligation chains means even a small amount of liquidity can significantly increase the amount of debt discharged.

Consider the obligation chains in Fig. 8. Intermediate nodes in the chain such as I, D, and G (i.e. those without any tenders from or acceptances to the liquidity source) still benefit from the existence of the liquidity source without having any direct relation to it. So long as Firms A and B are willing to pay with and accept, respectively, the particular asset of this liquidity source, the intermediate firms in the chain benefit, without ever having to use or engage that asset at all, and without firms A and B having to know each other. This opens profound new possibilities for different currencies and assets to be used in real world payments: so long as a small number of people are willing to use a currency, a much larger group stands to benefit. This is the power of Collaborative Finance.

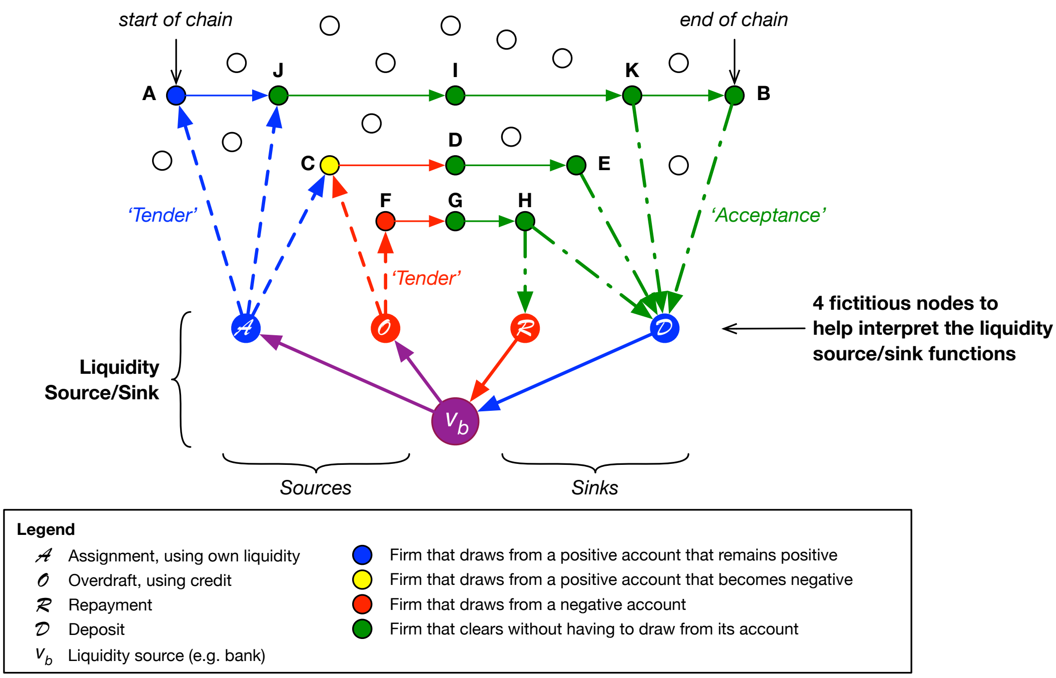

Figure 8: **Generalized CoFi Liquidity Schematic.** Liquidity node v_b is decomposed into 4 auxiliary nodes: $\mathcal{A}$, $\mathcal{O}$, $\mathcal{R}$, $\mathcal{D}$. All other nodes are firms. Firms at the start of obligation chains (like Firm A, C, or F) tender from $\mathcal{A}$ and/or $\mathcal{O}$. Notice firm C tenders from both – it doesn't have enough of its own assets (from $\mathcal{A}$), so it also needs to draw some credit (from $\mathcal{O}$). Inner nodes in the chain can also tender, like firm J, who owes I more than it's owed by A, and so tenders the difference. Firms at the end of obligation chains (like Firm B, E and H) accept into $\mathcal{R}$ and/or $\mathcal{D}$. Notice firm H repays some of its existing credit line (into $\mathcal{R}$), and deposits the remainder (into $\mathcal{D}$). Inner nodes in the chain can also accept, like firm K, who is owed more by firm I than it owes to B, and so accepts the difference as a deposit. The other inner nodes in obligation chains (e.g. firms I, D, and G) here interact only with set-off notices and not with the liquidity source.

While a single liquidity source already provides significant benefits, we can introduce multiple sources of liquidity for the same network, compounding the opportunities for, and the overall volume of, set-offs, and greatly enhancing the network effect. Crucially, each currency "circuit" operates separately, so no currency exchange service is needed for settlement.

Consider the case of two uncoupled liquidity sources, shown in Fig. 9. We can see that Firm B is at the intersection of two separate cycles, one based on tenders/acceptances in fiat, and another based in crypto. B will benefit from the set-off in each cycle separately, with no interaction between them, and without having to actually use either fiat or crypto. In this case, B only engages with set-off notices. Furthermore, the transfers of funds from A to C and from D to E will take place in fiat and crypto, respectively, again without any interaction or need for a currency exchange service.

In this example of Fig. 9 we have two chains where in each chain the first and last firm agreed on the same currency. In the A-B-C chain, both A and C want to use fiat, and in D-B-E, both D and E want to use crypto. But in Fig. 10 we break this symmetry. Now we have A-B-E, where A wants to pay in fiat and E wants to accept crypto, and we have D-C, where D wants to pay in crypto and C wants to accept fiat. With MTCS, we can still solve this case, by forming a *single* cycle across *two* liquidity sources. A's fiat can be used to pay C, and D's crypto can be used to pay E. As long as an oracle is available to transform everything to the same unit of account for the purposes of running the MTCS algorithm, after the run the set-off amounts are converted back to their original currencies and are sent to the relevant firms and liquidity sources. Thus, the only movement of money takes place *within* each liquidity source and independently of the others.

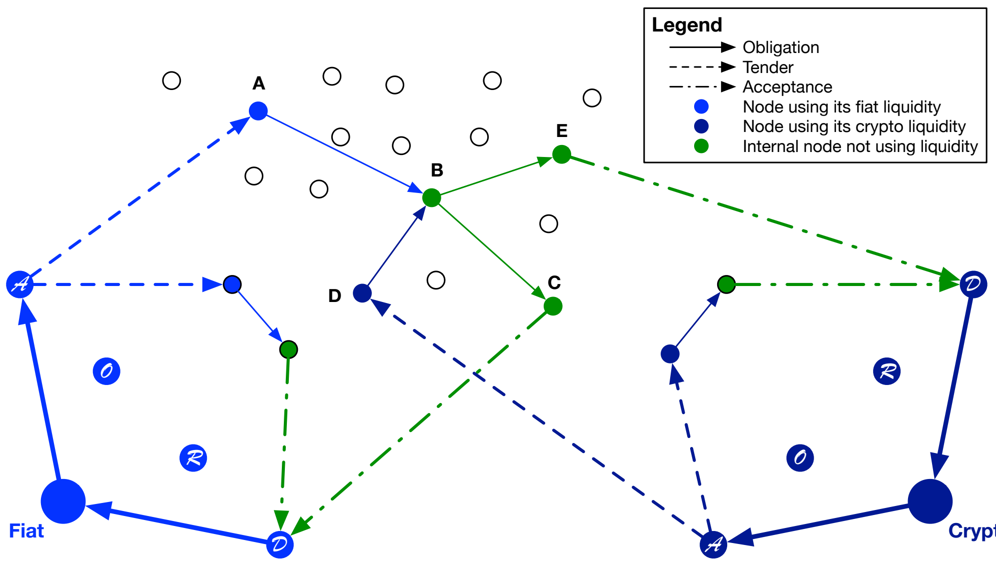

Figure 9: **Two uncoupled liquidity sources**. B benefits from both without having to handle either.

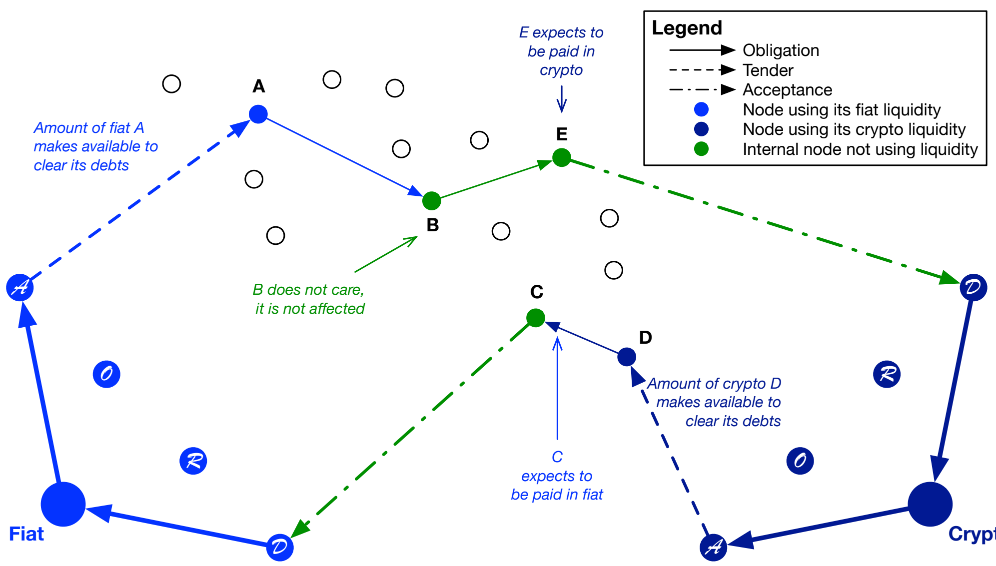

Figure 10: **Two liquidity sources in the same cycle.** The use of multiple currencies can greatly improve the ability to discharge debt in the network.

Our design thus enables a large number of currencies and liquidity sources to be utilized in the collaborative discharge of debt, greatly reducing working capital needs and various interest, exchange, and transfer fees. It promotes an open platform for participation of diverse actors and liquidity sources, and encourages development of new currency and credit protocols within a larger common framework for collective debt discharge, which yields numerous benefits. We turn to some of those use cases, and their benefits, next.

3 Use Cases

As a payment system with native support for obligations and credit protocols, the use cases of our design are endless. Our hope is that the language of Section 2 and the collective graph optimization problem we outlined can serve as a new foundation for finance and monetary economics that takes a network view of the liability graph instead of an aggregate view of the assets. Meanwhile, our design has tremendous practical implications. We covered many of the benefits in Section 1.2. Here we take a closer look at some use cases, including a diverse array of lending and issuance protocols, which benefit within the wider context of improved cash flow management and risk reduction provided by MTCS.

3.1 Cash Flow and Treasury Management

Cash flow and treasury management are critical challenges for SMEs, who struggle with payment inefficiencies and often have to resort to costly solutions [1]. Limited liquidity options and the need to rely on bank deposits aggravate late payments that can potentially escalate into solvency problems, particularly for smaller enterprises. The implications extend beyond individual businesses, impacting the broader community. By providing an easy-to-integrate and privacy-preserving clearing network, CoFi addresses these core cash-flow management issues, allowing businesses to connect their books and various sources of liquidity seamlessly, improving cash flow, and reducing working capital requirements and costs.

Our design builds on a tradition of existing production MTCS systems, like the obligation-clearing done in Slovenia [41, 23], Romania [25], and Bosnia-Herzegovina [11]. None of these systems, to our knowledge, incorporates liquidity beyond obligations. Going beyond the existing systems, our design opens avenues for using multiple currencies as liquidity sources, including community currencies, foreign currencies, and cryptocurrencies in addition to fiat, all without incurring forex costs, as long as there are enough users in the network who accept them. As we've shown, the willingness of some firms to use a different currency can potentially benefit a much wider number of others, even those that do not wish to use or be exposed to that currency. Our design thus provides a means for cryptocurrencies and other kinds of alternative and community currencies to become much more useful in real world payments.

The CoFi MTCS service can be presented to SMEs as a treasury dashboard with an overview of the firm's assets, overdraft facilities, and payment obligations. This creates an opportunity to make better-informed decisions about the use of available resources or to even automate the relevant tasks, to improve working capital conditions, reduce costs, and reduce risks. Such treasury functionality – normally reserved to large financial institutions – will be made available to all.

3.2 Risk Reduction

MTCS contributes towards risk reduction across diverse dimensions. Individual enterprises reap the benefits of diminished risk due to regular balance sheet contraction, reducing leverage and supporting credit scores. By eradicating gridlocks within the payments graph using set-off, MTCS reduces the payment risk, improves the days payable, and consequently reduces the late payment issue. This influence extends to loan repayments, as the system becomes a valuable tool for using circuit laws to recover non-performing loans (NPL) by extending new credit. Unlike central clearing houses, MTCS achieves this derisking without introducing central counter parties to whom significant risk is transferred. Furthermore, MTCS presents an opportunity for more sophisticated credit risk assessment based on the knowledge of the payment network. These risk reduction benefits apply in general, in the environment created by MTCS, across a diversity of lending and issuance protocols.

3.3 Lending Protocols

Access to credit is one of the most difficult and problematic aspects of running a small company, and increasingly so in the wake of increasing bank competition and consolidation, restricting access to financial services to urban centres and well established firms [6, 17, 43]. To begin to address these challenges, our design includes overdraft facilities as an explicit source of liquidity in the risk-reduced environment of MTCS, opening up a platform for development of diverse lending protocols.

The simplest lending protocol involves a lender putting up assets into an overdraft facility and approving a particular firm to draw from it. More advanced protocols can allow multiple liquidity providers to pool their assets and open credit lines to different firms, based on various criteria. Collateral requirements and terms can vary. There are numerous examples of these kinds of lending protocols already existing in the world of Decentralized Finance. Our design can integrate such protocols, enabling them to connect to a shared obligation graph, thereby enhancing their potential utility, reducing risk, and increasing the likelihood of repayment. This opens the door to larger markets, greater numbers of borrowers, reduced risk for lenders, and overall greater efficacy.

A major source of risk reduction is integration of loan repayment obligations into the obligation network. This comes in the form of standing programmable acceptances, which can give loan repayments automatic priority, reducing the moral hazard associated with firms deciding whether or not to pay. In addition, the repayment of loans inside the obligation network creates an opportunity for active management of NPLs. Lenders can prioritize the new loans' approval in a way that reduces or even fully resolves the NPLs.

In addition to being a platform for the development of diverse protocols for lending existing assets, our design also serves as a platform for protocols that issue new assets. In Section 2.2 we called this *overdraft with issuance*. It is a type of overdraft where the assets being lent did not already exist, but were created as part of the operation of lending. Our design provides a new framework for reasoning about issuance in the context of the larger obligation graph, and makes possible a diversity of use cases. The remainder of our examples below are of this type: overdraft with issuance.

3.4 Bank Lending

A dominant form of overdraft with issuance is lending by commercial banks. These overdraft facilities provide people and businesses with working capital to pay their debts, but the ability to extend them to SMEs is heavily restricted by the Basel accords [21, 5]. Therefore, banks too can benefit from our payment system design because the lower credit risk associated with firms in an MTCS network effectively increases the number of firms eligible for a loan, and therefore the market for bank loans.

In general, when a bank lends money, it is actually *creating new money* and its balance sheet expands [35, 49], as shown in Fig. 11. When this money is used directly for payment, it is overdraft with issuance.

While banks have largely dominated the ability to issue new money as liabilities, this power need not be limited to them. Arbitrary community networks can establish their own balance sheets, representing a mutual accounting of monetary flows within the community. This is the idea behind a diverse array of alternative issuance systems, from stablecoins and mutual credit to trust networks and p2p loans.

	Bank		Alice		Bob	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
Before:	100 $			50 $ to Bob	50 $ from Alice	
After:	100 $ + 50 $ loan to Alice	50 $ (Bob's deposit)		50 $ to Bank	50 $	

Figure 11: **Overdraft with money creation.** The bank's balance sheet expands

3.5 Stablecoin Protocols and Central Bank Digital Currencies

One of the perceived challenges in the adoption of cryptocurrencies in the real economy is their price volatility, leading to the rise in stablecoins [29, 24, 3]. Similarly, central banks are increasingly interested in developing their own digital currencies (the 'CBDCs'). While stablecoins are seeing increasing adoption in 'DeFi' use-cases, they have yet to really penetrate the world of trade finance. Similarly, the many CBDC proposals maintain much of the status quo of existing financial and payment systems, and can thus be subjected to our critique from Section 1.1. That said, CBDCs are likely to be easier to integrate than traditional bank deposits into new payment system designs like ours [26]. In any case, all of these stabelcoin and CBDC issuance protocols can be understood in our design as overdraft with issuance, allowing them to connect to the risk-reduced environment of MTCS and inherit the associated benefits. This can enable new opportunities for stablecoins and CBDCs to be used to support real-world commerce.

While the most popular stablecoins are custodial (i.e. USD stablecoins can be redeemed directly for USD bank deposits), an emerging class of non-custodial, over-collateralized lending systems allows stablecoins to be issued as debt against some underlying collateral. Our design also opens the possibility for new kinds of stablecoin design, where issuance terms are based on the ability to discharge more debt for more people. This in a sense is the approach of mutual credit, a kind of stablecoin issuance protocol backed not by liquid assets, but by future productivity.

3.6 Mutual Credit

Mutual credit tends to emerge spontaneously in times of crisis [27, 44], to offset the lack of a medium of exchange in general and working capital for small firms without cash reserves in particular. Mutual credit monetizes the trust between the members of a closed network, allowing them to issue 'credits' based on their future productivity [18].

From an accounting perspective, mutual credit functions in the same way as a bank with money creation, but is differentiated by the kind of entity the balance sheet represents. For the bank, the balance sheet represents the ownership structure of the bank. But mutual credit has no such concept of ownership over the balance sheet. In a mutual credit system, Alice doesn't have to pay the mutual credit system "back". Instead, she reduces her negative balance by accepting the mutual credit currency in the future as payment for obligations due to her (e.g. when Bob pays her for her products and services). As a condition of drawing on the currency's overdraft facility, Alice must commit to a standing acceptance for the currency in future MTCS runs. Repayment takes place as Acceptance.

Another related form of issuance that is also based on future productivity is vouchers. Whereas anyone in a mutual credit circuit can issue the mutual credit currency (up to a limit) by taking on a negative balance, in a company-specific voucher system only a specific company can issue and move into negative balance. For example, the 'egg vouchers' introduced by Grassroots Economics can be spent only to buy eggs from a specific vendor [46]. Therefore, they have a strong local character and can be redeemed only locally, with the companies that issued them. Such vouchers can still have a value in a given unit of account and can therefore also act as a medium of exchange in each restricted community where the issuer is known.

3.7 Trust Networks

Trust networks attempt to scale voucher systems by establishing formalized trust relationships between users in terms of acceptance of their respective currencies. Payments between users who do not trust each other, therefore, require a trust path through one or more additional users who do. A good example is Circles UBI.[5] In the language of Section 2, each user in Circles has their own liquidity source (their token), for which they are the only ones with access to the overdraft facility with issuance, and they issue themselves a fixed amount of their token each day (the UBI). Users have standing tenders for the currencies they hold, and they extend trust to each other by issuing standing acceptances for the currencies of users they trust. Paying an obligation through the trust graph can then be seen as the solution of an MTCS run which finds a cycle across some number of these liquidity sources. Circles thus generally attempts to find cycles with a single obligation and multiple liquidity sources, and to do it in real-time. This can be seen as a specific instance of the more general design we have described, motivating a number of directions of innovation for Trust Networks like Circles.

3.8 P2P Lending

Last but not least, we revisit the p2p lending introduced in Section 2.2 and depicted in Fig. 5d. In that scenario, Alice owes Bob, who owes Carol. The p2p loan can be motivated by considering if Carol were to open an overdraft facility for Alice, allowing Alice to borrow assets from Carol in an MTCS run. Alice's debt to Bob would be cleared by set-off, while Bob's debt to Carol would be cleared by Carol receiving back the asset she lent to Alice in the first place! So Carol doesn't need any actual asset to make this kind of loan to Alice, since she will get paid back immediately.[6] In fact, this loan is indistinguishable from a normal obligation from Carol to Alice, and hence we referred to it as a 'good faith' obligation that creates a return obligation from Alice back to Carol in the future.

Notice the power of the obligation as a primitive here. It allows us to achieve the same effect as an overdraft facility with real assets, without the assets at all. This kind of lending achieves a significant quantitative effect by allowing new obligations to be created specifically for the purpose of turning chains in the obligation graph into cycles, thereby increasing the amount of debt that can be discharged through set-off. The impact of the p2p loan is most notable in the changed network topology and decreased total debt in the obligation network. The benefit for the community is the reduced risk and increased transparency in the network of mutual indebtedness.

We should point out that in a privacy-preserving setting, Alice and Carol in Fig. 5d have no way of knowing ahead of time whether or not the p2p obligation will be part of a cycle. If it isn't, the obligation will not be offset, and it can be automatically cancelled. Alternatively, a few days before the algorithm is due to run, and if the privacy constraints permit it, an MTCS service provider could analyse the network and notify any pairs of companies that could close one or more cycles about this topological fact, and suggest to them that they could issue p2p obligations to each other. On the other hand, many firms can take their own initiative. If a firm is net-positive and wants to increase the chance of clearing its accounts receivables and by so doing decrease its collection costs, it can ask firms it trusts or, even better, firms it might want to have business with in the future if by any chance they are in need of a p2p loan. If the firms asked are net-negative – and that is easy for them to establish – they might accept such a loan offer to reduce their debt towards key suppliers or just to save more liquidity, thereby gaining more flexibility to manage payments between MTCS runs.

[5] See https://joincircles.net/. See also https://circlesentropy.github.io/blackpaper/ for a privacy-preserving version of the protocol.

[6] This is reminiscent of "flashloans" in DeFi, where assets are borrowed and payed back within a single transaction

Whether through a service or by individual initiative, this is a prime example of collaborative issuance – in this case obligation issuance – that, by redistributing debt to individual firms that are better able to pay it, could be very beneficial and empowering for the whole network.

4 Conclusion

In this paper we explored the transformative potential of a collaborative payment system, designed to discharge debt efficiently with the least amount of liquidity. Our approach combines a system of intents, (obligations, tenders, and acceptances) with distinct means of settlement (set-off, assignment, and overdraft). This web of financial tools, supported by graph theory, is encapsulated in the MTCS algorithm, and soon to be realized via a privacy-preserving Byzantine Fault-Tolerant replicated state machine network.

The implications of our research extend beyond the confines of traditional finance and payment systems. We have uncovered several key insights that are poised to reshape the financial landscape:

1. **Empowering Individuals**: Our design offers individuals greater control over sourcing liquidity, effectively opening doors to peer-to-peer lending and reinforcing the notion that liquidity fundamentally resides within the network itself.
2. **Community Sovereignty**: By extending the concept of inside money to communities, we enhance their sovereignty and equip them to withstand external credit shocks more effectively.
3. **Clarity in Language**: We have consciously chosen to communicate in obligation language rather than the jargon of traditional finance. This deliberate shift aims to eliminate misunderstandings, operate in the more flexible regulatory regime of obligation law, and emphasize the collaborative nature of the financial tools we have introduced.
4. **Inclusivity of All Currencies**: Our algorithm, with its introduction of multiple liquidity sources, accommodates all currencies accepted by the community members. This inclusivity dramatically enhances the ability to clear debt effectively.
5. **Blockchains**: The case for implementing this functionality on a blockchain is due to the fact that blockchains are virtually unique in enabling us to achieve secure atomic execution of multilateral set-off notices and asset-transfers in a privacy-preserving way across a diversity of liquidity sources. With such a platform for atomic execution, one can run optimizations across a much more dense and diverse graph, leading to much greater and more widely distributed benefits.

This paper has not only presented a compelling conceptual framework but has also provided practical insights into what Collaborative Finance means in tangible terms. The empirical and simulated data vividly illustrate the untapped potential within our proposed system. Through the combination of a collaborative approach and an understanding of network topology, significant sources of value can be unlocked.

Our vision extends beyond this paper. In particular, we leave details of a privacy-preserving and fault-tolerant implementation architecture, as well as all relevant economics, to future work. We invite all stakeholders, from individuals and communities to financial institutions, to join us on the Collaborative Finance journey.

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References

[1] Godfred A Afrifa and Ishmael Tingbani. Working Capital Management, Cash Flow and SMEs' Performance. *International Journal of Banking, Accounting and Finance*, 9(1):19–43, 2018.

[2] Massimo Amato and Luca Fantacci. *The End of Finance*. Polity, Cambridge, 2012.

[3] Douglas W Arner, Raphael Auer, and Jon Frost. Stablecoins: risks, potential and regulation, 2020. BIS Working Paper no. 905. URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3979495.

[4] Walter Bagehot. *Lombard Street: A description of the money market*. HS King&Company, 1873.

[5] European Central Bank. Survey on the access to finance of enterprises in the euro area, 2023. URL: https://www.ecb.europa.eu/stats/ecb_surveys/safe/html/ecb.safe202306~58c0da48d6.en.html.

[6] Anne Beck and Sebastian Doerr. The financial origins of regional inequality, 2023. BIS Working Paper No 1151. URL: https://www.bis.org/publ/work1151.pdf.

[7] Claudia Berloco, Gianmarco De Francisci Morales, Daniele Frassineti, Greta Greco, Hashani Kumarasinghe, Marco Lamieri, Emanuele Massaro, Arianna Miola, and Shuyi Yang. Predicting corporate credit risk: Network contagion via trade credit. *PLoS One*, 16(4):e0250115, 2021. URL: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0250115.

[8] Nils Bertschinger, Martin Hoefer, and Daniel Schmand. Strategic payments in financial networks, 2019. arXiv preprint 1908.01714. URL: https://arxiv.org/pdf/1908.01714.pdf.

[9] Bruno Biais and Christian Gollier. Trade Credit and Credit Rationing. *The Review of Financial Studies*, 10(4):903–937, 1997. URL: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=72ee9c4a526142780b45c5f65f8f6fb425fbf366.

[10] Frédéric Boissay. Credit chains and the propagation of financial distress, 2006. ECB Working Paper No. 573, European Central Bank. URL: https://www.econstor.eu/bitstream/10419/153007/1/ecbwp0573.pdf.

[11] Milan Božić and Jurica Zrnc. The Trade Credit Clearinghouse: Liquidity and Coordination. *Available at SSRN 3924908*, pages 1–77, 2022. URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3924908.

[12] Marie-Thérèse Boyer-Xambeu, Ghislain Deleplace, and Lucien Gillard. *Private Money & Public Currencies: The 16th Century Challenge*. Routledge, London, 1994.

[13] Charles W Calomiris and Stephen Haber. *Fragile by design: The political origins of banking crises and scarce credit*. Princeton University Press, 2015.

[14] Edward Chancellor. *The price of time: the real story of interest*. Grove Press, 2022.

[15] Borja Clavero. Money and Hierarchy: Four Ways to Discharge a Payment Obligation. Technical report, Local First CIC, De Monfort University, 2022. URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4032398.

[16] Filippo De Marco, Christiane Kneer, and Tomasz Wieladek. The real effects of capital requirements and monetary policy: Evidence from the united kingdom. *Journal of Banking and Finance*, 133:106237, 2021.

[17] Asli Demirgüç-Kunt and Ross Levine. Finance and inequality: Theory and evidence. *Annual Review of Financial Economics*, 1:287–318, 2009.

[18] Paolo Dini and Alexandros Kioupkiolis. The alter-politics of complementary currencies: The case of Sardex. *Cogent Social Sciences*, 5(1):1–21, 2019. https://www.tandfonline.com/doi/full/10.1080/23311886.2019.1646625.

[19] Larry Eisenberg and Thomas H Noe. Systemic Risk in Financial Systems. *Management Science*, 47(2):236–249, 2001. URL: http://www.jstor.org/stable/2661572.

[20] Daniela Fabbri and Leora F Klapper. Bargaining power and trade credit. *Journal of corporate finance*, pages 66–80, 2016. URL: https://openaccess.city.ac.uk/id/eprint/17179/1/.

[21] Maria Finnegan and Supriya Kapoor. ECB unconventional monetary policy and SME access to finance. *Small Business Economics*, 2023. URL: https://doi.org/10.1007/s11187-023-00730-0.

[22] Tomaž Fleischman and Paolo Dini. Mathematical Foundations for Balancing the Payment System in the Trade Credit Market. *Journal of Risk and Financial Management*, 14(9):452, 2021. Available online: https://www.mdpi.com/1911-8074/14/9/452.

[23] Tomaž Fleischman, Paolo Dini, and Giuseppe Littera. Liquidity-Saving through Obligation-Clearing and Mutual Credit: An Effective Monetary Innovation for SMEs in Times of Crisis. *Journal of Risk and Financial Management*, 13(12):295, 2020. Available online: https://www.mdpi.com/1911-8074/13/12/295.

[24] Jon Frost, Hyung Song Shin, and Peter Wierts. An early stablecoin? The Bank of Amsterdam and the governance of money, 2020. DNB Working Paper 696. URL: https://www.moneylaundering.com/wp-content/uploads/2020/11/Netherlands.Paper_.Crypto.111020.pdf.

[25] Lucian-Ionut Gavrila and Alexandru Popa. A novel algorithm for clearing financial obligations between companies-an application within the romanian ministry of economy. *Algorithmic Finance*, 9(1-2):49–60, 2021.

[26] George Giaglis et al. Central Bank Digital Currencies and a Euro for the Future, 2021. EU Blockchain Observatory and Forum Thematic Report. URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3891861.

[27] Georgina Gómez and Paolo Dini. Making sense of a crank case: monetary diversity in Argentina (1999–2003). *Cambridge Journal of Economics*, 40(5):1421–1437, 2016. URL: https://eprints.lse.ac.uk/67120/.

[28] Thomas Greco. *The End of Money and the Future of Civilization.* Chelsea Green Publishing, 2009.

[29] Anneke Kosse, Marc Glowka, Mattei Ilaria, and Tara Rice. Will the real stablecoin please stand up?, 2023. BIS Papers, No. 141. URL: https://www.bis.org/publ/bppdf/bispap141.pdf.

[30] Tim Lee, Jamie Lee, and Kevin Coldiron. *The Rise of Carry.* McGraw-Hill, New York, 2020.

[31] Vivien Lefebvre. Trade credit, payment duration, and smes' growth in the european union. *International Entrepreneurship and Management Journal*, 19:1313–1340, 2023. URL: https://link.springer.com/article/10.1007/s11365-023-00871-4.

[32] Harry Leinonen. Liquidity, risk and speed in payment and settlement systems – a simulation approach. Technical report, Bank of Finland, 2005. URL: https://publications.bof.fi/bitstream/handle/10024/45674/118263.pdf?sequence=1.

[33] Bernard Lietaer and Jacqui Dunne. *Rethinking Money: How New Currencies Turn Scarcity into Prosperity.* Berrett-Koehler, San Francisco, 2013.

[34] Giuseppe Littera, Laura Sartori, Paolo Dini, and Panayotis Antoniadis. From an Idea to a Scalable Working Model: Merging Economic Benefits with Social Value in Sardex. *International Journal of Community Currency Research*, 21:6–21, 2017. https://ijccr.files.wordpress.com/2017/02/littera-et-al.pdf.

[35] Michael McLeay, Amar Radia, and Ryland Thomas. Money creation in the modern economy, 2014. Bank of England Quarterly Bulletin, Q1.

[36] Perry Mehrling. *The new Lombard Street: how the fed became the dealer of last resort.* Princeton University Press, 2011.

[37] Hyman P Minsky and Henry Kaufman. *Stabilizing an unstable economy*, volume 1. McGraw-Hill New York, 2008.

[38] Onur Özgöde. The emergence of systemic risk: The federal reserve, bailouts, and monetary government at the limits. *Socio-Economic Review*, 20(4):2041–2071, 2022.

[39] Mitchell A Petersen and Raghuram G Rajan. The benefits of lending relationships: Evidence from small business data. *The journal of Finance*, 49(1):3–37, 1994. URL: https://onlinelibrary.wiley.com/doi/10.1111/j.1540-6261.1994.tb04418.x.

[40] Laura Sartori and Paolo Dini. Sardex, from complementary currency to institution. A micro-macro case study. *Stato e Mercato*, 107:273–304, 2016.

[41] Tomaž Schara and Rudi Bric. Deleveraging of Indebtedness in an Economy through Non-Monetary Intervention, 2018. Working Paper. URL: https://www.researchgate.net/publication/322235409_Deleveraging_of_Indebtedness_in_an_Economy_through_Non-Monetary_Intervention, doi:10.13140/RG.2.2.26019.96805/1.

[42] Slobodan Simić and Vladan Milanović. Some Remarks on the Problem of Multilateral Compensation. *Publikacije Elektrotehničkog fakulteta. Serija Matematika*, pages 27–33, 1992. Available online: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.100.8429&rep=rep1&type=pdf (accessed on 23 June 2021).

[43] Richard Simmons, Paolo Dini, Nigel Culkin, and Giuseppe Littera. Crisis and the Role of Money in the Real and Financial Economies—An Innovative Approach to Monetary Stimulus. *Journal of Risk and Financial Management*, 14(3):129, 2021. Available online: https://www.mdpi.com/1911-8074/14/3/129.

[44] Tobias Studer. *WIR and the Swiss National Economy*. WIR Bank, Basel, 1998.

[45] UNIDROIT. Principles of International Commercial Contracts, Art. 1.6(2), 2016. International Institute for the Unification of Private Law.

[46] Leanne Ussher, Laura Ebert, Georgina M Gómez, and William O Ruddick. Complementary Currencies for Humanitarian Aid. *Journal of Risk and Financial Management*, 14(11):557, 2021. URL: https://www.mdpi.com/1911-8074/14/11/557.

[47] Ludwig Von Mises. *The theory of money and credit*. Skyhorse Publishing, Inc., 2013.

[48] Adam Walker. A Hoard of Unpaid Invoices: Dissecting Economies & Private Market Forces To Solve B2B Late Payments, 2017. MS Thesis, Rocherster Institute of Technology. URL: https://scholarworks.rit.edu/cgi/viewcontent.cgi?article=10760&context=theses.

[49] Richard A Werner. Can banks individually create money out of nothing? The theories and the empirical evidence. *International Review of Financial Analysis*, 36:1–19, 2014.